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Hurter, L, Rowlands, AV, Fairclough, SJ, Gibbon, KC, Knowles, ZR, Porcellato, LA, Cooper-Ryan, AM and Boddy, LM

 Validating the Sedentary Sphere method in children: does wrist or accelerometer brand matter?

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Article

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1   **Full title: Validating the Sedentary Sphere method in children: does wrist or**

2   **accelerometer brand matter?**

3   **Running title: Validating the Sedentary Sphere method in children**

4   **Keywords: wearable technology, activity classification, sedentary behaviour**

5   **Word count: 4518**

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Abstract

This study aimed to validate the Sedentary Sphere posture classification method from wrist-worn accelerometers in children. Twenty-seven 9-10-year-old children wore ActiGraph GT9X (AG) and GENEActiv (GA) accelerometers on both wrists, and activPAL on the thigh while completing prescribed activities: five sedentary activities, standing with phone, walking (criterion for all 7: observation) and ten minutes free-living play (criterion: activPAL). In an independent sample, 21 children wore AG and GA accelerometers on the non-dominant wrist and activPAL for two days of free-living. Percent accuracy, pairwise 95% equivalence tests ($\pm$10% equivalence zone) and intra-class correlation coefficients (ICC) analyses were completed. Accuracy was similar, for prescribed activities irrespective of brand (non-dominant wrist: 77%-78%; dominant wrist: 79%). Posture estimates were equivalent between wrists within brand ($\pm$6%, ICC>0.81, lower 95% CI$\geq$0.75), between brands worn on the same wrist ($\pm$5%, ICC$\geq$0.84, lower 95% CI$\geq$0.80) and between brands worn on opposing wrists ($\pm$6%, ICC$\geq$0.78, lower 95% CI$\geq$0.72). Agreement with activPAL during free-living was 77%, but sedentary time was underestimated by 7% (GA) and 10% (AG). The Sedentary Sphere can be used to classify posture from wrist-worn AG and GA accelerometers for group-level estimates in children, but future work is needed to improve the algorithm for better individual-level results.

Keywords: wearable technology, activity classification, sedentary behaviour

Introduction

In recent years sedentary behaviour in children has emerged as an independent risk factor for adverse health outcomes (Saunders, Chaput, & Tremblay, 2014) and has consequently become a target for future interventions (Lewis, Napolitano, Buman, Williams, & Nigg, 2017). Sedentary behaviour is defined as any waking *sitting, reclining* or *lying* behaviour with low energy expenditure (≤ 1.5 METs in adults (Tremblay et al., 2017), ≤ 2.0 METs in children (Saint-Maurice, Kim, Welk, & Gaesser, 2016)). Growing trends of children's sedentary behaviour are reason for concern (Carson et al., 2016), especially amidst the fast-paced advances of screen-based technologies occupying children's out-of-school hours, increasing their total sedentary time (Kiatrungrit and Hongsanguansri, 2014; Lane, Harrison, & Murphy, 2014; Olafsdottir et al., 2014). Despite this, research into children's sedentary behaviour is still in its infancy and requires valid and reliable measures (Carson, et al., 2016) for the field to advance towards effective epidemiological and intervention studies. Accurately measuring sedentary behaviour is vital to such research; however, it remains difficult to quantify sedentary behaviour due to the multiple contexts in which it occurs, the varied types of sedentary behaviour people engage in and the postural characteristics of the behaviour (Hardy et al., 2013).

Wrist- and hip-worn accelerometers are the most widely used objective measurement tools in children's physical activity research (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013). Although accelerometers have also been regularly used to quantify sedentary time, as characterised by an absence of or low levels of dynamic acceleration, this approach does not take into account the postural element of sedentary behaviour. Posture classification is vital in the measurement of sedentary behaviour and is central to its definition (Tremblay, et al., 2017). The ability to accurately classify sedentary behaviour and physical activity using one

75   accelerometer would be advantageous to the discipline, as it would remove the requirement for

76   additional devices that classify posture such as the activPAL. In turn, this would reduce

77   participant burden, researcher processing time, and financial costs involved with running a

78   study. Researchers have been calling for such a solution, i.e. a feasible method that would allow

79   the use of one accelerometer able to classify posture as well as providing raw acceleration data

80   (Boddy et al., 2018; Hildebrand, Hansen, van Hees, & Ekelund, 2016). In children, such a

81   device should preferably be a wrist-worn monitor, as compliance is highest with wrist-worn

82   devices (Fairclough et al., 2016) and children view it as more socially desirable than other

83   devices or placements (McCann, Knowles, Fairclough, & Graves, 2016). Additionally,

84   compliance with activPAL is low in adolescents, who reported the 7 days of wear time to be

85   too long and would prefer not to wear it again (Shi et al., 2019).

86

87   Rowlands and colleagues first introduced the concept of the Sedentary Sphere in 2014 as a new

88   method of analysing, identifying and visually presenting data from the wrist-worn GENEActiv

89   accelerometer. The Sedentary Sphere uses arm elevation to classify the most likely posture in

90   adult populations (Rowlands et al., 2014), thus providing a pragmatic solution to the lack of

91   postural classification using the magnitude of acceleration intensity alone. During periods of

92   inactivity, gravity provides the primary signal to the accelerometer and the Sedentary Sphere

93   uses this gravitational component of the acceleration signal to determine the orientation of the

94   monitor and therefore, the position of the wrist (Rowlands, et al., 2014). In a subsequent study,

95   Rowlands and colleagues further validated this approach for posture classification using data

96   from the widely used ActiGraph accelerometer worn on the wrist (Rowlands et al., 2016). The

97   Sedentary Sphere represents a promising and feasible approach to measuring sedentary time

98   that can be applied to the many large observational datasets using wrist-worn GENEActiv or

99   ActiGraph accelerometers to assess children's physical behaviours (e.g. the Pelotas Birth

100   Cohort (da Silva et al., 2014), the Melbourne Child Health Checkpoint (Wake M et al., 2014),

101   the Cork Children's Lifestyle Study (Li, Kearney, Keane, Harrington, & Fitzgerald, 2017), the

102   National Health and Nutrition Examination Survey 2011-2014 (Troiano, McClain, Brychta, &

103   Chen, 2014)). To date, application of the Sedentary Sphere concept has not been validated in

104   children; therefore, this study aims to investigate whether the Sedentary Sphere method of

105   classifying posture using GENEActiv and ActiGraph GT9X wrist-worn accelerometers, can be

106   used in its current state in child populations.

107

108   **Methods**

109   This is a secondary data analysis, and the methods have been published previously (Hurter et

110   al., 2018). The first part of the analysis was taken from a calibration study, conducted in a

111   school gymnasium while the second part came from a subsequent study to provide added free-

112   living data. After obtaining ethical approval from the Research Ethics Committee of Liverpool

113   John Moores University (16/SPS/056), 27 children (17 girls, 10 boys), aged 9-10 years old,

114   were recruited from one primary school in Liverpool. Signed informed parental/carer consent

115   and child assent forms were obtained from all participants prior to data collection. Data

116   collection took place in January 2017.

117

118   Body mass was measured in light clothing without shoes, to the nearest 0.1 kg using an

119   electronic scale (Seca, Birmingham, UK). Stature and sitting height were measured to the

120   nearest 0.1 cm using a stadiometer (Leicester Height measure; Seca, Birmingham, UK). Waist

121   circumference was measured at the midpoint between the bottom rib and the iliac crest, to the

122   nearest 0.1 cm using a plastic non-elastic measuring tape (Seca, Birmingham, UK). Participants

123   self-reported their dominant hand, and researchers confirmed this while participants were

124   writing during the homework station of the calibration circuit.

125

Each participant wore five accelerometers: one ActiGraph GT9X (AG) and GENEActiv (GA)

monitor on each of the dominant and non-dominant wrists (using the manufacturers' straps)

and an activPAL monitor (attached with activPAL stickies) to the right anterior thigh.

ActiGraph and GENEActiv monitors were placed next to each other on the wrist, but in no

consistent or specific order. All monitors were worn throughout the testing protocol, which

involved seven different 'stations' typically representative of sedentary behaviour and light

physical activity. These were resting, television viewing, playing with a tablet, playing with

lego, doing homework, standing while playing with mobile phone, and walking (see Table 1

for detailed description of the stations), with three participants per session rotating between the

seven stations. The stations were designed to simulate, as accurately as possible, children's

typical real life sedentary behaviours. Television viewing was always performed first, with the

three participants watching together, in an effort to prevent the television from distracting

participants during the other activities. The rest of the activities were completed individually,

in no particular order. All activities were performed for five minutes, with each participant's

start and end times observed with a Garmin Forerunner235 wristwatch and recorded onto a

participant data collection sheet. The first author and two trained research assistants were

present at each data collection session, observing the three participants completing the stations

to confirm the posture was as described in Table 1. The first and last 30 seconds of data from

each activity were excluded from the analysis, to remove any data from potential transitional

movements. After each session in the school gymnasium, the participants continued to wear

the monitors for at least 10 minutes outside, during school recess. Participants were instructed

to play as they normally would during this time. Direct observation was used as the criterion

for posture allocation for the seven sedentary and light activities. However, direct observation

was not possible during recess due to the playground being very busy and not all

150 movements/postures were visible to the researchers. Therefor the activPAL monitor was used

151 as the criterion reference for posture allocation during school recess. Validation studies have

152 shown almost perfect correlation between activPAL and direct observation ($r = 0.99$) in both

153 adults (Lyden, Kozey Keadle, Staudenmayer, & Freedson, 2012) and children (Aminian and

154 Hinckson, 2012). While these studies used the older, uni-axial activPAL, its agreement with

155 the tri-axial activPAL3 for characterising posture has proved to be high (>95%) (Sellers, Dall,

156 Grant, & Stansfield, 2016).

157

158 In a subsequent study (ethical approval reference number: 17/SPS/034), an independent sample

159 of 21 children (13 girls, 8 boys, 9-10 years old) was recruited from two primary schools to

160 provide additional free-living data. Anthropometric measurements were taken as described

161 above. The children wore three monitors in total for this part of the study: GENEActiv and

162 ActiGraph accelerometers on their non-dominant wrist (AG distal to GA) and activPALs

163 attached to their thigh. They wore the monitors for two consecutive days, and were requested

164 to wear the thigh devices continually and only remove the wrist-worn devices for water-based

165 activities. The activPAL monitors were waterproofed with small, flexible sleeves and attached

166 with 10-15 cm Tegaderm adhesive. Participants were supplied with log sheets to record times

167 when they removed the monitors.

168

169 [INSERT TABLE 1 NEAR HERE]

170

171 *Accelerometers and data processing*

172 The GENEActiv is a small, lightweight tri-axial accelerometer with a dynamic range of $\pm8g$

173 (Activinsights Ltd., Cambridgeshire, UK). The monitors were initialised to collect data at a

174 sampling frequency of 100 Hz. All GENEActiv data were downloaded using GENEActiv PC

175   software version 3.1, saved in raw format as binary files before being converted to 15 s epoch

176   .csv files, matching the format required for Sedentary Sphere analysis. The 15 s epoch files

177   were then imported into custom-built Microsoft Excel spreadsheets (available from the authors

178   on request), to facilitate computation of the most likely posture.

179

180   The ActiGraph GT9X is also a small, lightweight tri-axial accelerometer, with a dynamic range

181   of ±8g (ActiGraph LLC, Pensacola, FL). Data were collected at a sampling frequency of 100

182   Hz, downloaded with ActiLife version 6.13.3, saved in raw format as .gt3x files, then converted

183   to time-stamped .csv files containing *x, y* and *z* vectors. These 100 Hz .csv files were

184   subsequently converted with a custom-built programme (GT9X-to-SedSphere) written in

185   MATLAB (R2017b, The MathWorks Inc., Natick, MA, USA) to 15 s epochs with the

186   orientation of each axis matched to those of the GENEActiv. Thus, this matched the format

187   required for the analysis in the custom-built Excel spreadsheets. The resultant 15 s epoch files

188   contained *x, y* and *z* vectors (mean acceleration over the epoch, retaining the gravity vector)

189   and vector magnitude (VM) values (summed over each epoch and corrected for gravity).

190

191   The activPAL3c is a small, single-site lightweight, tri-axial activity monitor that uses

192   proprietary algorithms to classify an individual's activity into periods spent sitting, standing

193   and walking (PAL Technologies Ltd., Glasgow, UK). Default settings were used during

194   initialization, thus collecting data at 20 Hz. Data were downloaded using activPAL3

195   Professional Research Edition version 7.2.32, saved as .datx files and converted to 15 s epoch

196   .csv files.

197

198   ***Sedentary Sphere***

199   A detailed explanation of the use of the Sedentary Sphere for posture classification can be

200   viewed elsewhere (Rowlands, et al., 2014). In short, the Sedentary Sphere calculates the most

201   likely posture (sitting/reclining or upright) based on arm elevation and acceleration intensity.

202   An arm elevation higher than 15º below the horizontal coupled with low intensity (<489 g·15

203   s (value is specific to data collected at 100 Hz over a 15 s epoch), or 326 mg (value is sampling

204   frequency and epoch independent)) is indicative of a seated/reclining position (Rowlands, et

205   al., 2016), thus classified as "sedentary". If the arm is hanging more vertically (lower than 15º

206   below the horizontal), an "upright" (standing) posture is classified (Rowlands, et al., 2016).

207   Moderate to vigorous physical activity intensities (>489g·15 s, or 326 mg) results in an

208   "upright" classification, irrespective of wrist elevation (Rowlands, et al., 2016). During a free-

209   living sample of 34 adults, agreement between GENEActiv (sedentary sphere) and activPAL

210   was 85% (Rowlands, et al., 2014). Another free-living study in adults (Pavey, Gomersall,

211   Clark, & Brown, 2016) found a strong, significant correlation (Pearson's r = 0.81 (95% CI

212   0.69-0.88)) between estimated sedentary time as measured by activPAL and GENEActiv

213   (sedentary sphere).

214

215   *Data analysis*

216   After applying the Sedentary Sphere method to both GENEActiv and ActiGraph data, the

217   percentage of epochs correctly coded as sedentary and upright during the gymnasium protocol

218   (criterion: direct observation) and school recess (criterion: activPAL) were calculated for both

219   the dominant and the non-dominant wrists. Percentages (i.e. accuracy) were summarized and

220   presented as means (95% CI) for each individual activity. Pairwise 95% equivalence tests

221   (±10%) and intra-class correlation coefficients (ICC, single measures, absolute agreement)

222   were used to evaluate agreement of posture estimates between wrists and between

223   accelerometer brands.

224

During the subsequent free-living study, the Sedentary Sphere method was applied to all valid hours collected from GENEActiv and ActiGraph monitors between 07:00 and 21:00 on the second day of data collection and in the same way, compared to results from activPAL. Hours were deemed invalid if the monitors were removed for any number of minutes during that hour, according to the log sheets. Visual inspection of data files in GENEActiv, ActiGraph and activPAL software verified the recorded log sheet wear times (Rowlands, et al., 2016). Thirty-one hours were excluded due to non-wear, while two participants' activPALs fell off resulting in another 18 hours being excluded. A total of 245 free-living hours across the whole sample were included in the analysis. Intra-individual classification agreement across 15 s epochs was reported as percentage agreement, sensitivity and specificity, and limits of agreement were examined using Bland-Altman analysis. Due to the presence of heteroscedasticity, Bland-Altman analysis were re-run using logarithmic transformation (Bland and Altman, 1999). Equivalency analysis was performed to assess average group level equivalence between AG and GA sedentary estimates according to the sedentary sphere method with the criterion being sedentary time according to activPAL. An equivalence test was completed to establish whether the 90% confidence intervals for AG and GA sedentary time fell within the zone of equivalence, defined as ±10% of the activPAL mean (Dixon et al., 2018). Mean percent error (MPE) and Mean absolute percent error (MAPE) were calculated as described by DeShaw et al. (2018). In addition, for comparison we also applied a cut-point approach to classifying sedentary behaviour. All free-living seconds with a corresponding accelerometer output of less than 50 mg were coded as sedentary, with all other seconds coded as non-sedentary. The resultant sedentary times estimated by the 50 mg threshold for both GA and AG were compared with activPAL in the same way as the Sedentary Sphere results.

248

249 **Results**

250 *Sedentary stations and free-play during recess*

251 Descriptive data for all participants are presented in Table 2. Twenty-seven participants (17

252 girls, 10 boys; 3 left-handed) completed all the stations in the school gymnasium, while 10

253 minutes of school recess data for 25 participants were included in the analysis (two

254 participants' activPALs fell off during school recess). Table 3 shows the mean (95% CI)

255 percentage of 15 s epochs correctly coded as sedentary and upright for activities grouped by

256 type and classification category, for each measurement method. During the protocol in the

257 gymnasium, sedentary (lying and sitting) activities were correctly classified for the majority of

258 the time (87-100%), except for Television viewing that had a slightly lower accuracy (66-71%).

259

260 Classification of walking as upright was accurate the vast majority of the time (87-90%),

261 however 'standing while playing with a mobile phone' was misclassified as sitting for most of

262 the time (≤12% accuracy). Free-living data during recess showed high classification accuracy

263 (82-88%) relative to the activPAL. When the 'standing while playing with a mobile phone'

264 activity was excluded from the analysis, accuracy increased across the board: from 77% to 87%

265 for GENEActiv non-dominant wrist, 78% to 91% for GENEActiv dominant wrist, 78% to 90%

266 for ActiGraph non-dominant wrist and from 79% to 91% for ActiGraph dominant wrist data

267 (data not shown). During the observed activities, data from activPAL showed a 96.9% (SD =

268 4) agreement with direct observation.

269

270 Mean percent accuracy for the whole data collection period (observed and recess activities)

271 was similar, irrespective of accelerometer brand, at 77%-78% for the non-dominant wrist and

272 79% for the dominant wrist. Posture estimates could be considered equivalent (Figure 1)

273 between brands worn on the same wrist (±5%, ICC>0.84, lower 95% CI>0.80, top panel of

274 Figure 1), between wrists within brand (±6%, ICC>0.81, lower 95% CI≥0.75, middle panel of

275 Figure 1) and between brands worn on opposing wrists (±6%, ICC≥0.78, lower 95% CI≥0.72,

276 lower panel of Figure 1).

277

278 [INSERT TABLES 2 AND 3 NEAR HERE]

279

280 [INSERT FIGURE 1 NEAR HERE]

281

282 ***Free-living sample***

283 Free-living data from 21 participants (13 girls, 8 boys; 3 left-handed) were included in the

284 analysis (see Table 2 for descriptive data). Mean wear time was 700 ± 181 min (mean $\pm$ SD).

285 Results from the various statistical analyses are presented in Table 4. According to activPAL,

286 participants spent on average 67% of their time seated (468 ± 134 min). The corresponding

287 estimates of sedentary time according to the Sedentary Sphere were both lower (GA: 60%, 415

288 ± 138 min and AG: 58%, 407 ± 131 min). Mean (95% confidence interval) intraindividual

289 classification agreement between GA and activPAL across 15 s epochs was 77.3% (73.5, 81.1)

290 with sensitivity at 77.2% (71.9, 82.6) and specificity 76.4% (72.2, 80.6). Figure 2 shows the

291 log-transformed data: the mean bias of GA relative to activPAL was -0.06, with limits of

292 agreement between -0.2 and 0.09 (Figure 2A). Back-transformation (antilog) of the log-

293 transformed data revealed that the GA 95% limits of agreement were 37.4% lower to 22.5%

294 higher than AP.

295

296 Agreement between AG and activPAL across 15 s epochs was similar, at 76.7% (74.5, 79),

297 sensitivity 75.4% (71.8, 78.9) and specificity 78% (73.7, 82.4). Mean bias (Figure 2B) of log

298 transformed data was also -0.06, but with narrower limits of agreement (-0.16 – 0.03, or 30.6%

299   lower to 5.9% higher than AP). Results from the equivalence testing are displayed in Figure 3.

300   Estimates of sedentary time according to the Sedentary Sphere method applied to both GA and

301   AG data could not be considered statistically equivalent when compared with the activPAL, on

302   average at the group level. While both monitors underestimated time spent sedentary compared

303   with activPAL, GA came closer than AG to achieving equivalency with activPAL. This is

304   confirmed in the MPE indicating underestimations of -11.3% (GA) and -13.7% (AG) against

305   activPAL, and MAPE (GA = 13.5%, AG = 15.3%). Table 4 and Figure 3 also display results

306   from the comparison between activPAL and the 50mg threshold. Sedentary time according to

307   the threshold were significantly higher compared with activPAL (GA: 72%, 505 ± 114 min, p

308   = 0.001; AG: 72%, 504 ± 144 min, p = 0.002). Mean bias and limits of agreement of log-

309   transformed GA and AG 50mg data relative to activPAL were similar (both with mean bias of

310   0.03, 95% limits of agreement 10% lower and 29% higher than AP).

311

312   [INSERT TABLE 4 NEAR HERE]

313   [INSERT FIGURE 2 NEAR HERE]

314   [INSERT FIGURE 3 NEAR HERE]

315

316   **Discussion**

317   The aim of this study was to validate the Sedentary Sphere method of classifying posture using

318   GENEActiv and ActiGraph GT9X wrist-worn accelerometers in children. Posture

319   classification is vital to accurately measuring sedentary behaviour, though the majority of

320   studies classify sedentary time using low levels or an absence of acceleration using threshold

321   without considering posture. This study suggests that the Sedentary Sphere method can be used

322   to classify the most likely posture in children (from either wrist-worn GENEActiv or ActiGraph

323   accelerometers), but researchers should be cautious, knowing that the method is likely to

324 underestimate sedentary time. Wrist-worn accelerometers are increasingly being used to

325 measure children's physical activity and sedentary behaviour (e.g. Keane et al., 2017), due to

326 improved wear compliance in comparison to hip-worn devices (Fairclough, et al., 2016),

327 therefore the ability to classify posture using one wrist-mounted accelerometer is advantageous

328 to researchers and funders.

329

330 Posture classification accuracy was high for most observed activities, and during free-living

331 recess and the longer free-living period, irrespective of monitor brand or dominance (mean

332 around 78%). This is higher than the 69% agreement reported between the widely used

333 ActiGraph hip cut-point for sedentary time (100 vertical-axis counts·min^{-1}) compared with

334 activPAL sitting time during the school day (Ridgers et al., 2012). During free-living time, the

335 Sedentary Sphere applied to AG and GA data both underestimated sitting time compared with

336 activPAL, however, classification accuracy during this period was consistent with the observed

337 activities. The free-living results showed smaller mean bias and limits of agreement than those

338 reported by Hildebrand, et al. (2016) who compared sedentary cut-points with activPAL

339 (smallest mean bias +30, LoA -226 to +287 min). While the activPAL has proven to be a valid

340 tool to measure time spent sitting/lying, standing and walking (perfect correlation between

341 activPAL and observation, $r = 1.00$) in children (Aminian and Hinckson, 2012), the step count

342 become increasingly inaccurate as physical activity intensity increases ($r = 0.21$ to 0.34 for fast

343 walking and running respectively) (Aminian and Hinckson, 2012). It is established that wrist-

344 worn accelerometers can provide valid measures of physical activity in children (Chandler,

345 Brazendale, Beets, & Mealing, 2016; Phillips, Parfitt, & Rowlands, 2013). This study showed

346 that posture can also be classified using data from wrist-worn accelerometers during structured

347 low intensity activities, a period of recess and free-living time. Further, this study shows that a

348 wrist-worn GENEActiv or ActiGraph give equivalent estimates of sedentary time by using the

349 Sedentary Sphere method, irrespective of whether the monitor is worn on the dominant or non-

350 dominant wrist. While previous research has shown acceleration magnitude for ActiGraph to

351 be approximately 10% lower than that of GENEActiv (John, Sasaki, Staudenmayer, Mavilia,

352 & Freedson, 2013; Rowlands et al., 2015), our findings are consistent with previous work

353 suggesting that posture classification based on orientation of the gravitational component

354 compare well, irrespective of monitor brand (Rowlands, et al., 2016).

355

356 'Standing while playing with a mobile phone', was rarely correctly classified. The reason for

357 the misclassification lies in the nature of the activity itself. It is a known limitation of the

358 posture classification algorithm that any activity requiring the arms to be elevated while

359 standing will be misclassified as sitting (Rowlands, et al., 2016). This will have implications

360 in free-living studies, the extent of which will depend on the prevalence of standing with arms

361 raised. Similar findings were observed in adult studies, with activities like waitressing (Pavey,

362 et al., 2016) or washing-up (Rowlands, et al., 2014) misclassified as sitting. Participants

363 typically held the phone with both hands, resulting in the elevation of both arms, causing the

364 misclassification on both wrists. Standing still is notoriously difficult to classify from the

365 magnitude of acceleration alone, as noted by Lyden and colleagues (Lyden, Keadle,

366 Staudenmayer, & Freedson, 2014), irrespective of whether counts per second or raw

367 acceleration signals are examined, or whether laboratory or free-living settings are being

368 investigated. As little or no dynamic acceleration is recorded during sedentary behaviour,

369 devices cannot distinguish between sitting and standing still based on the magnitude of

370 acceleration signals alone. To overcome large misclassifications, previous studies have chosen

371 to group sitting and standing together (e.g. Ermes, Parkka, Mantyjarvi, & Korhonen, 2008;

372 Mathie MJ, Celler BG, NH, & ACF, 2004), however, doing so contradicts the consensus

373 definition of sedentary behaviour, that includes lying, reclining or sitting postures only

374 (Tremblay, et al., 2017). Notably, the Sedentary Sphere method accurately classifies standing

375 still in adults (mean percentage accuracy = 100% for GENEActiv data, 95% for ActiGraph

376 data) (Rowlands, et al., 2016), in structured conditions without the arms elevated.

377

378 During the recess period, where children did not have access to mobile phones, upright postures

379 were classified accurately most of the time, as is evident via the high percentage agreement

380 with activPAL ($\geq 82\%$). The use of handheld devices, such as mobile phones, is prevalent; in

381 a 2014 study, out of 8266 nine year old Irish children, 41% had their own mobile phones (Lane,

382 et al., 2014) and access to mobile phones has increased dramatically over relatively short time

383 periods (Kiatrungrit and Hongsanguansri, 2014). Potentially, mobile phone use could

384 detrimentally effect the accuracy of the posture estimation; the impact of this will depend on

385 whether children of this age spend a lot of time standing still with a mobile phone, or if they

386 prefer to sit down or walk.

387

388 However, epoch-by-epoch agreement between both GENEActiv and ActiGraph non-dominant

389 wrist data and activPAL during the subsequent free-living sample was the same (77%) as the

390 accuracy reported during the observed activities and recess period, superior to published results

391 from cut-points (Ridgers, et al., 2012). These are encouraging results, suggesting that the

392 method performed equally well in an ecologically valid setting and in the controlled

393 environment, where we aimed to mimic the typical range of activities children engage in during

394 and after school hours. Equivalence testing, MPE and mean bias values of free-living data,

395 however, showed that the method underestimated sedentary time compared with activPAL,

396 suggesting that while this method seems promising, the algorithms may require refinement for

397 use in children. While the Sedentary Sphere method underestimated sedentary time, the more

398 traditional thresholds method slightly overestimated sedentary time compared with activPAL.

399

400 Our study has several strengths. The protocol included five different sedentary activities, one

401 stationary activity and one light intensity physical activity as well as a recess period allowing

402 free-play, thus a wide range of behaviours were represented. The independent free-living

403 sample confirmed our observed activities had ecological validity, thus overcoming criticisms

404 of previous validation studies. The participants wore five different monitors each, enabling us

405 to validate the Sedentary Sphere method in both ActiGraph GT9X and GENEActiv monitors

406 and across both wrists. We used direct observation as criterion measure for the protocol in the

407 school gymnasium, with one trained researcher observing each participant. There were also

408 some limitations. The small homogeneous sample of 9-10 year old children should not be

409 considered representative of all ages, and further studies are needed for younger children and

410 older adults. The monitors were placed next to each other on the wrist, in no consistent or

411 specific order. Placing one brand consistently distal to the other might have resulted in slightly

412 higher acceleration from that brand; however, no formal randomisation techniques were used

413 and recent studies in adults suggest that results are consistent, regardless of placement

414 (Rowlands et al., 2018). Though the stations were not performed in the same order no formal

415 randomisation techniques were used, though unlike physical activity calibration studies, the

416 sedentary and stationary nature of the stations should have avoided issues related to fatigue.

417

418 **Conclusions**

419 This is the first study to apply the Sedentary Sphere classification algorithm to children's data.

420 The results suggest the method developed in adults can be applied to wrist-worn accelerometer

421 data to predict the *most likely* posture in children, but the algorithm needs refining for child

422 populations. Results found that the Sedentary Sphere was equally valid for GENEActiv and

423 ActiGraph GT9X accelerometers, whether the monitor was worn on the dominant or non-

424 dominant wrist, and agreement with activPAL was confirmed during the free-living sample.

425 However, the method underestimated free-living sedentary time and future work should ideally

426 use direct observation during free-living time, or simulated free living, to identify where

427 misclassification occurs. This will allow further work on improving the algorithm for child

428 populations in order to achieve better results on individual level estimates. Improvements might

429 include adding new features like patterns of movement within angles, patterns of changes in

430 angles or adding a frequency domain.

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432 **Disclosure statement**

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434 The authors declare no conflict of interests.

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436 **References**

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582   TABLE 1. Activities undertaken in the school gymnasium.

Posture		Activity
	Resting	Lying on a soft gym mat, in a supine position, asked to avoid bodily movements.
*Sedentary	TV	Sitting comfortably on a couch, watching TV.
	Tablet	Sitting comfortably on a couch, playing the Bike Race game on an iPad.
	Lego	Sitting at a table, playing with Lego.
	Homework	Sitting at a table, copying a piece of writing (mimicking homework).
*Upright	Phone	Standing while playing Subway Surf on a phone.
	Walking	Walking, at own pace, around a designated track.
†Free-living	Recess	10 min free-living during break time (recess) at school.

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584   N.B. Each activity was performed for five minutes, in no particular order, but always starting
585   with TV viewing

586   *Participants were directly observed to ensure the posture was as described

587   †The activPAL was worn to provide a criterion measure of posture

588

589   TABLE 2: Descriptive characteristics of the participants [Mean (SD)].

	Gymnasium protocol (n=27)	Free-living data (n=21)
Age (years)	10.2 (0.3)	10.2 (0.3)
Stature (cm)	141.5 (6.9)	142.8 (7.4)
Sitting height (cm)	70.9 (3.9)	71.3 (3.3)
Waist circumference (cm)	66.7 (10.9)	70.3 (9.8)
Body mass (kg)	37.3 (11.4)	40.8 (10.6)
BMI (kg/m^2)	18.3 (3.9)	19.8 (4)

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591 TABLE 3. Mean (95% confidence interval) percentage of epochs correctly coded as sedentary (lying and sitting activities) and upright for each
592 activity and method.

Activity Type	Individual Activities	Sedentary Sphere: GENEActiv data		Sedentary Sphere: ActiGraph data	
		Non-dominant	Dominant	Non-dominant	Dominant
Sedentary*	Rest	92.8 (85.4,100.0)	88.0 (78.0,98.0)	90.2 (81.7,98.7)	86.9 (76.4,97.5)
	TV	66.2 (49.9,82.5)	68.8 (52.6,85.1)	71.4 (55.6,87.2)	71.4 (55.3,87.5)
	Tablet	96.3 (89.1,100.0)	99.8 (99.3,100)	100 (100,100)	99.8 (99.3,100.2)
	Lego	92.2 (82.5,100.0)	98.7 (96.5, 100)	99.6 (98.7,100.0)	100 (100,100)
	Homework	89.8 (80.5,99.0)	99.6 (98.7,100.4)	93.9 (86.3,101.5)	99.6 (98.7,100.0)
Upright*	Phone	12.2 (0.1,24.3)	0 (0,0)	1.5 (0.0,3.5)	1.5 (0.0,4.6)
	Walking	87.4 (77.4,97.4)	90.4 (82.9,97.9)	86.5 (77.1,95.9)	90.4 (84.7,96.1)
	All observed activities	**76.7 (71.2,82.2)**	**77.9 (72.3,83.5)**	**77.6 (72.1,83.1)**	**78.5 (73.0,84.0)**
Recess†	Recess	81.6 (73.1,90.1)	88.1 (83.3,92.9)	86.1 (80.5,91.6)	86.8 (81.3,92.3)
	Recess and observed activities	**77.3 (72.3,82.2)**	**79.1 (74.1,84.1)**	**78.6 (73.6,83.5)**	**79.5 (74.6,84.4)**

593 *Participants were directly observed to ensure the posture was as described

594 †The activPAL was worn to provide a criterion measure of posture

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598   TABLE 4: Sedentary time estimates according to the sedentary sphere applied to AG and GA free-living data compared with activPAL

	Comparison	Mean (SD) minutes	Intraindividual classification agreement across 15s epochs [mean(95%CI)]			MAPE* (%)	MPE† (%)	Limits of Agreement†		Equivalency Analysis (minutes)
			Agreement (%)	Sensitivity (%)	Specificity (%)			Lower	Upper	
activPAL (sit/lie)		468 (134)								Zone of Equivalence: 422 – 515
	GENEActiv (Sed Sphere)	415 (138)	77.3 (73.5, 81.1)	77.2 (71.9, 82.6)	76.4 (72.2, 80.6)	13.5 (11.3)	-11.3 (13.6)	37.4%	22.5%	90% CI 389 – 441
	ActiGraph (Sed Sphere)	407 (131)	76.7 (74.5 , 79)	75.4 (71.8, 78.9)	78 (73.7, 82.4)	15.3 (6.9)	-13.7 (9.7)	30.6%	5.9%	90% CI 389 – 424
	GENEActiv (<50mg)	505 (144)				9.6 (8.7)	8.1 (10.2)	10.2%	28.9%	90% CI 489 – 521
	ActiGraph (<50mg)	504 (144)				9.5 (8.9)	7.8 (10.5)	10.9%	29.4%	90% CI 488 – 520

599   *Mean absolute percent error †Mean percent error †Log-transformed data back-transformed (antilog) and reported as percentages
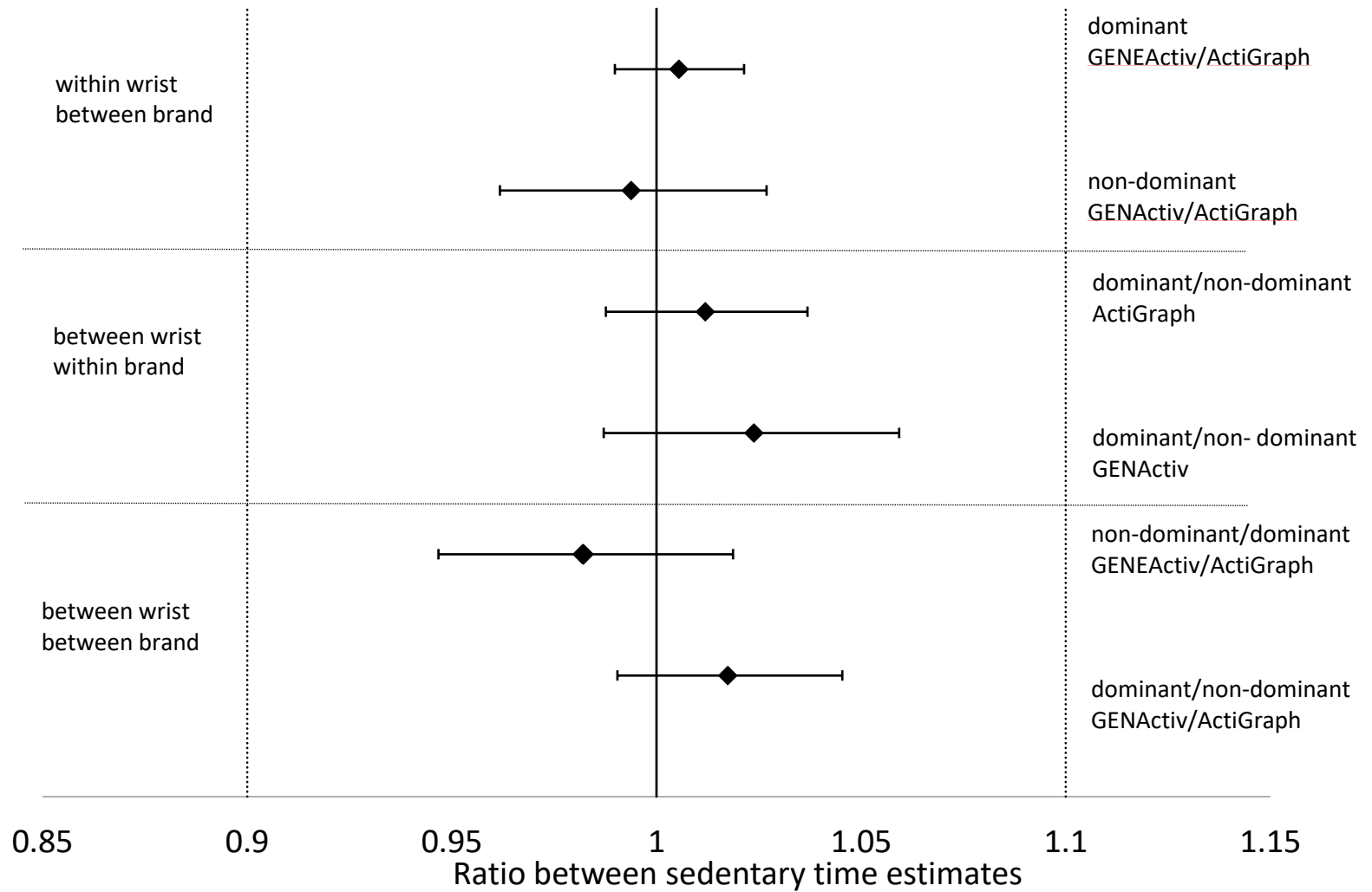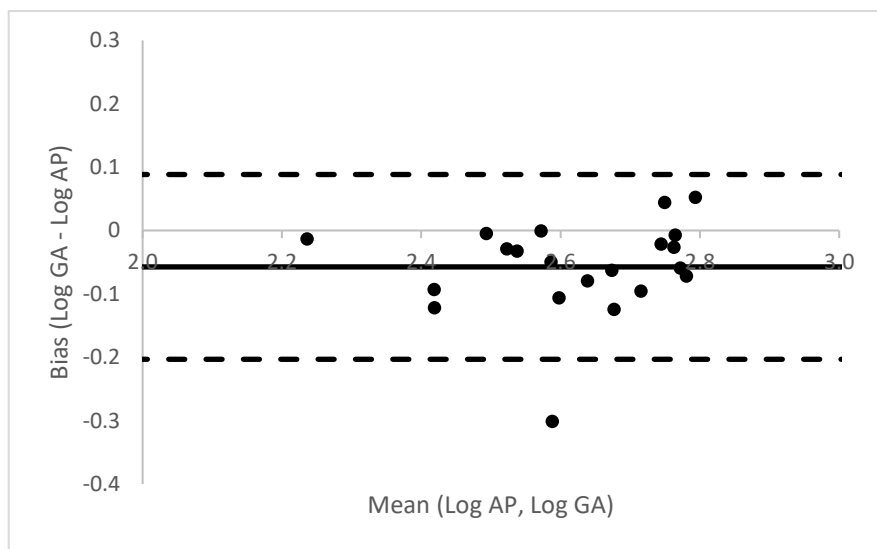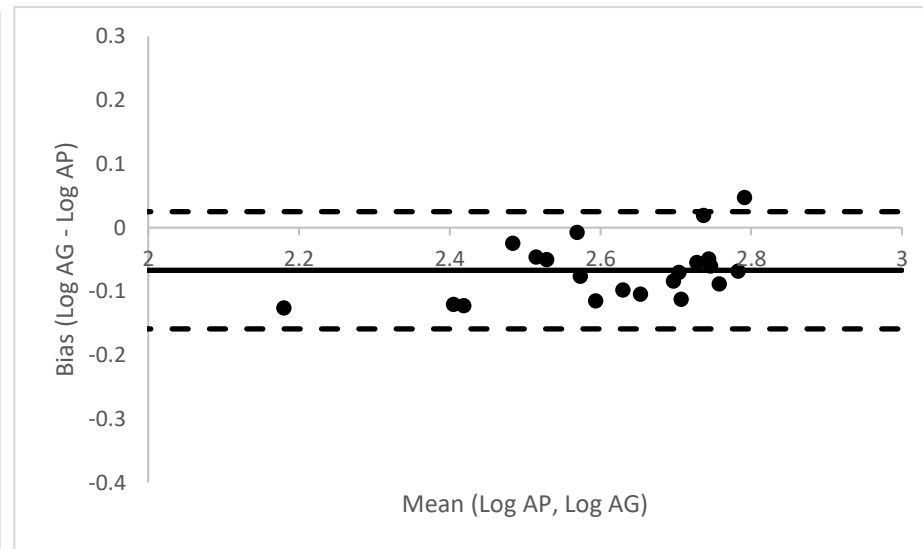
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within wrist
between brand

between wrist
within brand

between wrist
between brand

dominant
GENEActiv/ActiGraph

non-dominant
GENActiv/ActiGraph

dominant/non-dominant
ActiGraph

dominant/non- dominant
GENActiv

non-dominant/dominant
GENEActiv/ActiGraph

dominant/non-dominant
GENActiv/ActiGraph

0.85   0.9   0.95   1   1.05   1.1   1.15

Ratio between sedentary time estimates

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609   FIGURE 1: Equivalence between brands worn on the same wrist (top panel), between wrists within brand (middle panel) and between brands worn on
610   opposing wrists (lower panel). Dashed vertical lines represent equivalence zone of ±10% of the mean.
611

612 A

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614 FIGURE 2: Mean bias (solid line) and 95% limits of agreement (dashed lines) for sedentary time estimated from the Sedentary Sphere posture

615 algorithm applied to free-living GENEActiv (A) and ActiGraph log transformed data (B), relative to activPAL.
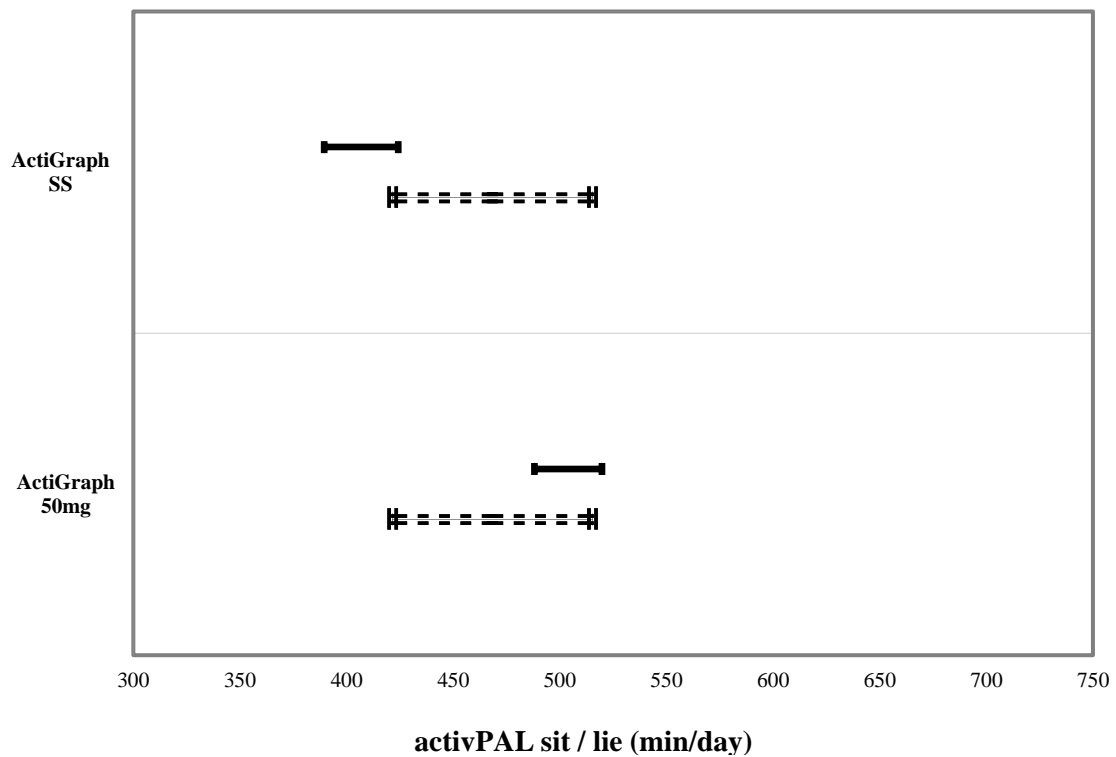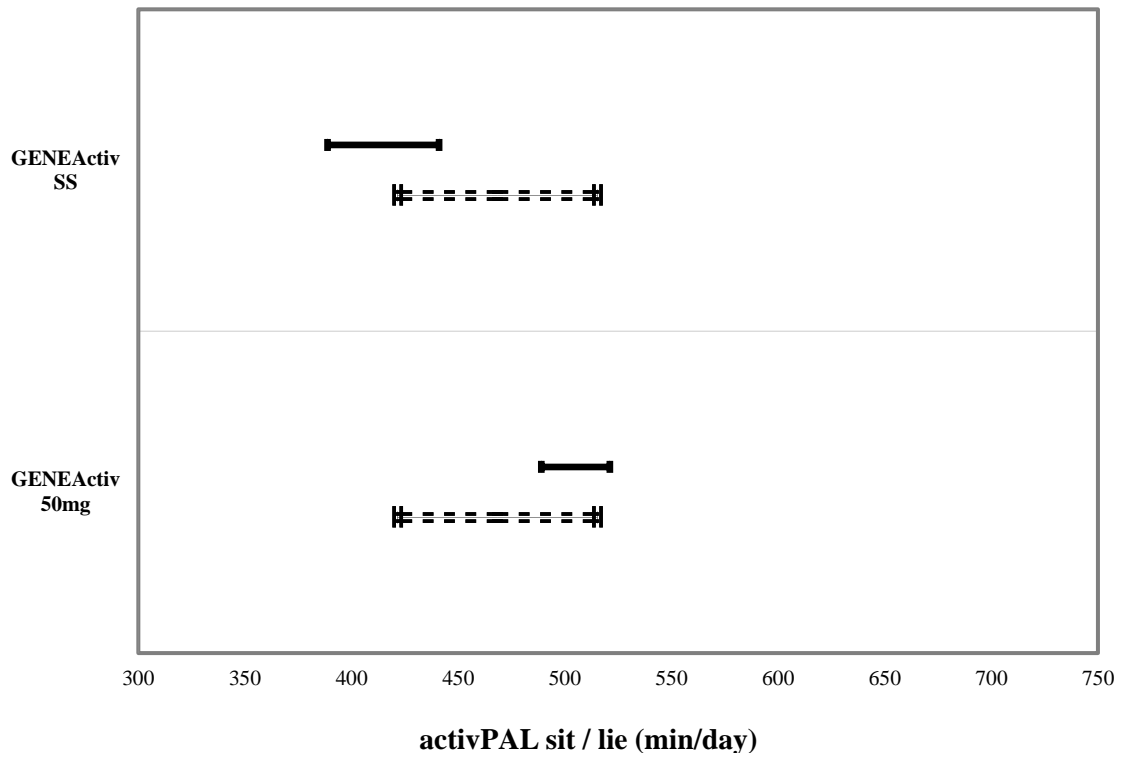
FIGURE 3: activPAL sedentary time zone of equivalence (dotted lines) and 90% confidence

intervals for the GENEActiv (top) and ActiGraph (bottom) sedentary time estimates

according to the sedentary sphere (SS) and threshold (50mg) methods.