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Validating the sedentary sphere method in children : does wrist or accelerometer brand matter?

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24 **Abstract**

25 This study aimed to validate the Sedentary Sphere posture classification method from wrist-
26 worn accelerometers in children. Twenty-seven 9-10-year-old children wore ActiGraph GT9X
27 (AG) and GENEActiv (GA) accelerometers on both wrists, and activPAL on the thigh while
28 completing prescribed activities: five sedentary activities, standing with phone, walking
29 (criterion for all 7: observation) and ten minutes free-living play (criterion: activPAL). In an
30 independent sample, 21 children wore AG and GA accelerometers on the non-dominant wrist
31 and activPAL for two days of free-living. Percent accuracy, pairwise 95% equivalence tests
32 ($\pm 10\%$ equivalence zone) and intra-class correlation coefficients (ICC) analyses were
33 completed. Accuracy was similar, for prescribed activities irrespective of brand (non-dominant
34 wrist: 77%-78%; dominant wrist: 79%). Posture estimates were equivalent between wrists
35 within brand ($\pm 6\%$, $ICC > 0.81$, lower 95% $CI \geq 0.75$), between brands worn on the same wrist
36 ($\pm 5\%$, $ICC \geq 0.84$, lower 95% $CI \geq 0.80$) and between brands worn on opposing wrists ($\pm 6\%$,
37 $ICC \geq 0.78$, lower 95% $CI \geq 0.72$). Agreement with activPAL during free-living was 77%, but
38 sedentary time was underestimated by 7% (GA) and 10% (AG). The Sedentary Sphere can be
39 used to classify posture from wrist-worn AG and GA accelerometers for group-level estimates
40 in children, but future work is needed to improve the algorithm for better individual-level
41 results.

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

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50 **Introduction**

51 In recent years sedentary behaviour in children has emerged as an independent risk factor for
52 adverse health outcomes (Saunders, Chaput, & Tremblay, 2014) and has consequently become
53 a target for future interventions (Lewis, Napolitano, Buman, Williams, & Nigg, 2017).
54 Sedentary behaviour is defined as any waking *sitting, reclining* or *lying* behaviour with low
55 energy expenditure (≤ 1.5 METs in adults (Tremblay et al., 2017), ≤ 2.0 METs in children
56 (Saint-Maurice, Kim, Welk, & Gaesser, 2016)). Growing trends of children's sedentary
57 behaviour are reason for concern (Carson et al., 2016), especially amidst the fast-paced
58 advances of screen-based technologies occupying children's out-of-school hours, increasing
59 their total sedentary time (Kiatrungrit and Hongsanguansri, 2014; Lane, Harrison, & Murphy,
60 2014; Olafsdottir et al., 2014). Despite this, research into children's sedentary behaviour is still
61 in its infancy and requires valid and reliable measures (Carson, et al., 2016) for the field to
62 advance towards effective epidemiological and intervention studies. Accurately measuring
63 sedentary behaviour is vital to such research; however, it remains difficult to quantify sedentary
64 behaviour due to the multiple contexts in which it occurs, the varied types of sedentary
65 behaviour people engage in and the postural characteristics of the behaviour (Hardy et al.,
66 2013).

67

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

126 Each participant wore five accelerometers: one ActiGraph GT9X (AG) and GENEActiv (GA)
127 monitor on each of the dominant and non-dominant wrists (using the manufacturers' straps)
128 and an activPAL monitor (attached with activPAL stickies) to the right anterior thigh.
129 ActiGraph and GENEActiv monitors were placed next to each other on the wrist, but in no
130 consistent or specific order. All monitors were worn throughout the testing protocol, which
131 involved seven different 'stations' typically representative of sedentary behaviour and light
132 physical activity. These were resting, television viewing, playing with a tablet, playing with
133 lego, doing homework, standing while playing with mobile phone, and walking (see Table 1
134 for detailed description of the stations), with three participants per session rotating between the
135 seven stations. The stations were designed to simulate, as accurately as possible, children's
136 typical real life sedentary behaviours. Television viewing was always performed first, with the
137 three participants watching together, in an effort to prevent the television from distracting
138 participants during the other activities. The rest of the activities were completed individually,
139 in no particular order. All activities were performed for five minutes, with each participant's
140 start and end times observed with a Garmin Forerunner235 wristwatch and recorded onto a
141 participant data collection sheet. The first author and two trained research assistants were
142 present at each data collection session, observing the three participants completing the stations
143 to confirm the posture was as described in Table 1. The first and last 30 seconds of data from
144 each activity were excluded from the analysis, to remove any data from potential transitional
145 movements. After each session in the school gymnasium, the participants continued to wear
146 the monitors for at least 10 minutes outside, during school recess. Participants were instructed
147 to play as they normally would during this time. Direct observation was used as the criterion
148 for posture allocation for the seven sedentary and light activities. However, direct observation
149 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 $\pm 8g$
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 $\pm 8g$ (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 15° 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 15°
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 ($\pm 10\%$) 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

225 During the subsequent free-living study, the Sedentary Sphere method was applied to all valid
226 hours collected from GENEActiv and ActiGraph monitors between 07:00 and 21:00 on the
227 second day of data collection and in the same way, compared to results from activPAL. Hours
228 were deemed invalid if the monitors were removed for any number of minutes during that hour,
229 according to the log sheets. Visual inspection of data files in GENEActiv, ActiGraph and
230 activPAL software verified the recorded log sheet wear times (Rowlands, et al., 2016). Thirty-
231 one hours were excluded due to non-wear, while two participants' activPALs fell off resulting
232 in another 18 hours being excluded. A total of 245 free-living hours across the whole sample
233 were included in the analysis. Intra-individual classification agreement across 15 s epochs was
234 reported as percentage agreement, sensitivity and specificity, and limits of agreement were
235 examined using Bland-Altman analysis. Due to the presence of heteroscedasticity, Bland-
236 Altman analysis were re-run using logarithmic transformation (Bland and Altman, 1999).
237 Equivalency analysis was performed to assess average group level equivalence between AG
238 and GA sedentary estimates according to the sedentary sphere method with the criterion being
239 sedentary time according to activPAL. An equivalence test was completed to establish whether
240 the 90% confidence intervals for AG and GA sedentary time fell within the zone of
241 equivalence, defined as $\pm 10\%$ of the activPAL mean (Dixon et al., 2018). Mean percent error
242 (MPE) and Mean absolute percent error (MAPE) were calculated as described by DeShaw et
243 al. (2018). In addition, for comparison we also applied a cut-point approach to classifying
244 sedentary behaviour. All free-living seconds with a corresponding accelerometer output of less
245 than 50 mg were coded as sedentary, with all other seconds coded as non-sedentary. The
246 resultant sedentary times estimated by the 50 mg threshold for both GA and AG were compared
247 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 ($\leq 12\%$ 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 ($\pm 5\%$, ICC >0.84 , lower 95% CI >0.80 , top panel of

274 Figure 1), between wrists within brand ($\pm 6\%$, $ICC > 0.81$, lower 95% $CI \geq 0.75$, middle panel of
275 Figure 1) and between brands worn on opposing wrists ($\pm 6\%$, $ICC \geq 0.78$, lower 95% $CI \geq 0.72$,
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.

431

432 **Disclosure statement**

433

434 The authors declare no conflict of interests.

435

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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.

583

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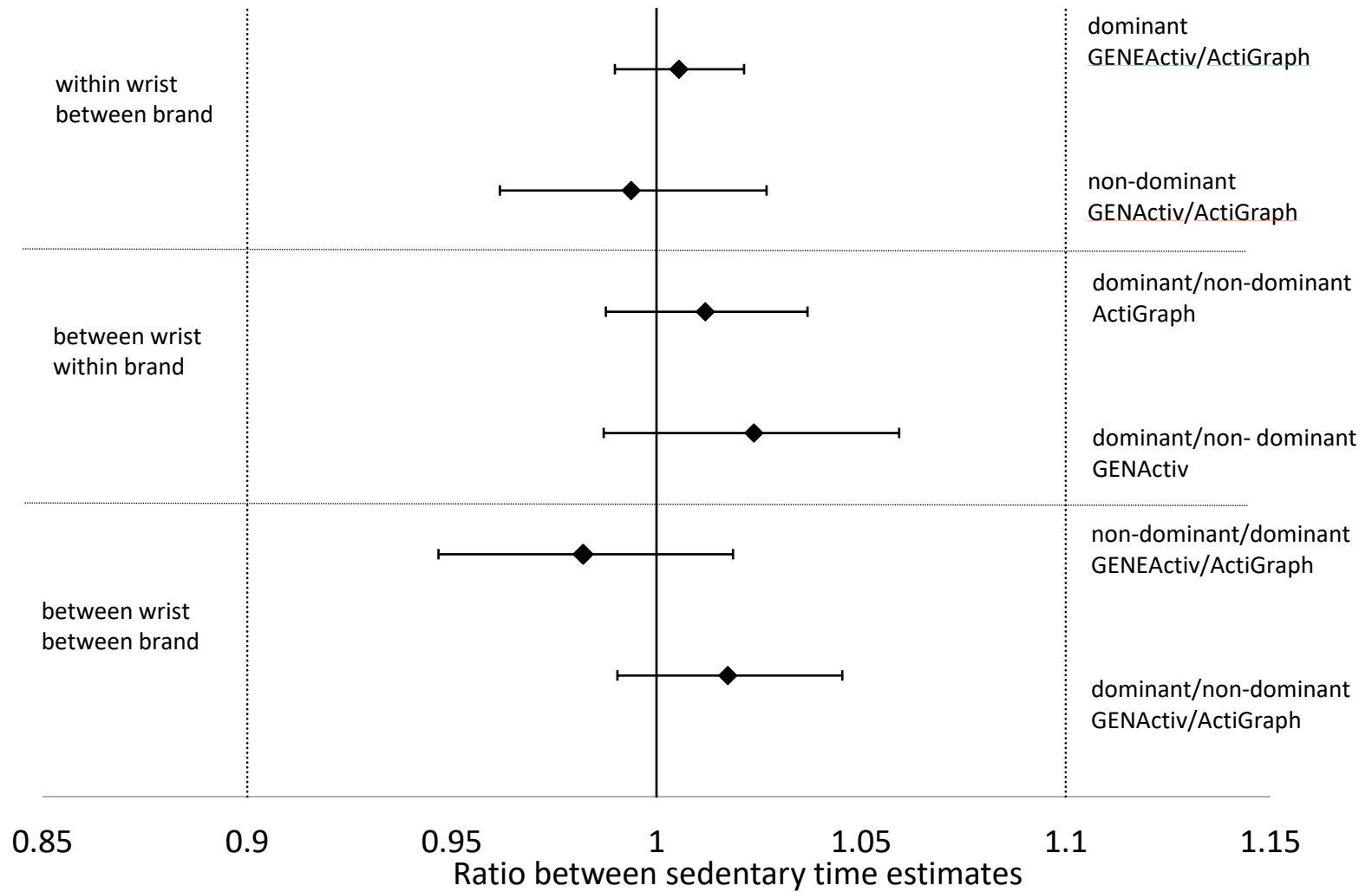
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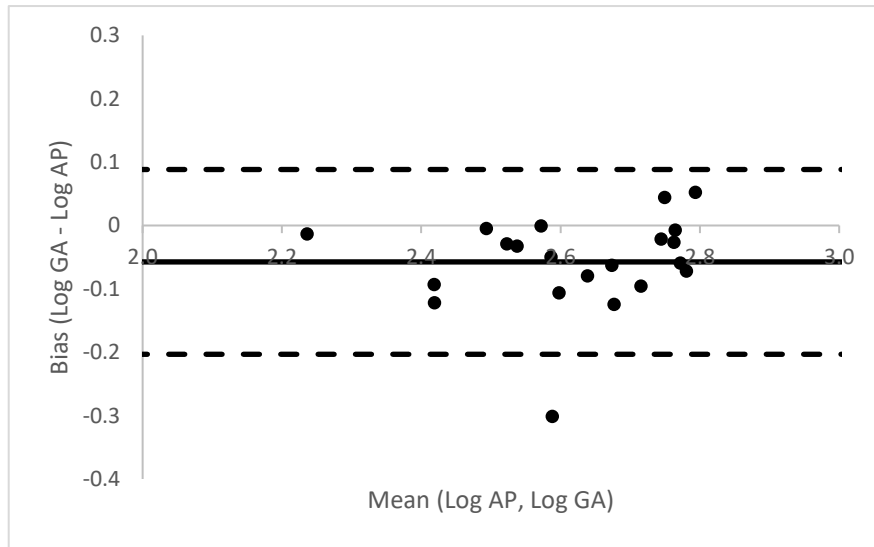
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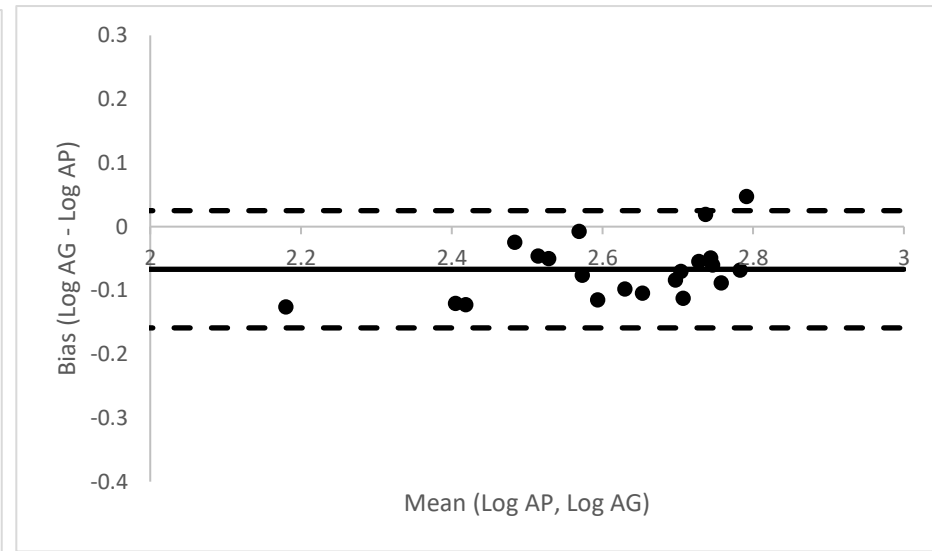
FIGURE 1: Equivalence between brands worn on the same wrist (top panel), between wrists within brand (middle panel) and between brands worn on opposing wrists (lower panel). Dashed vertical lines represent equivalence zone of $\pm 10\%$ of the mean.

612 A



613

B



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.

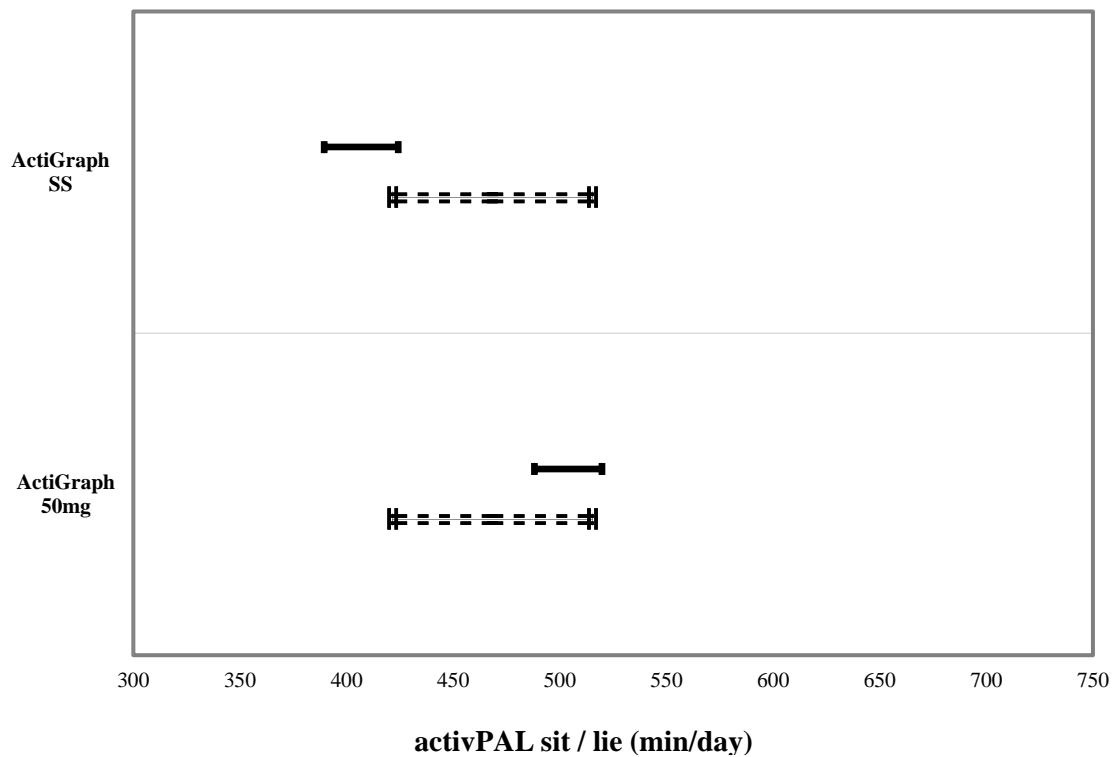
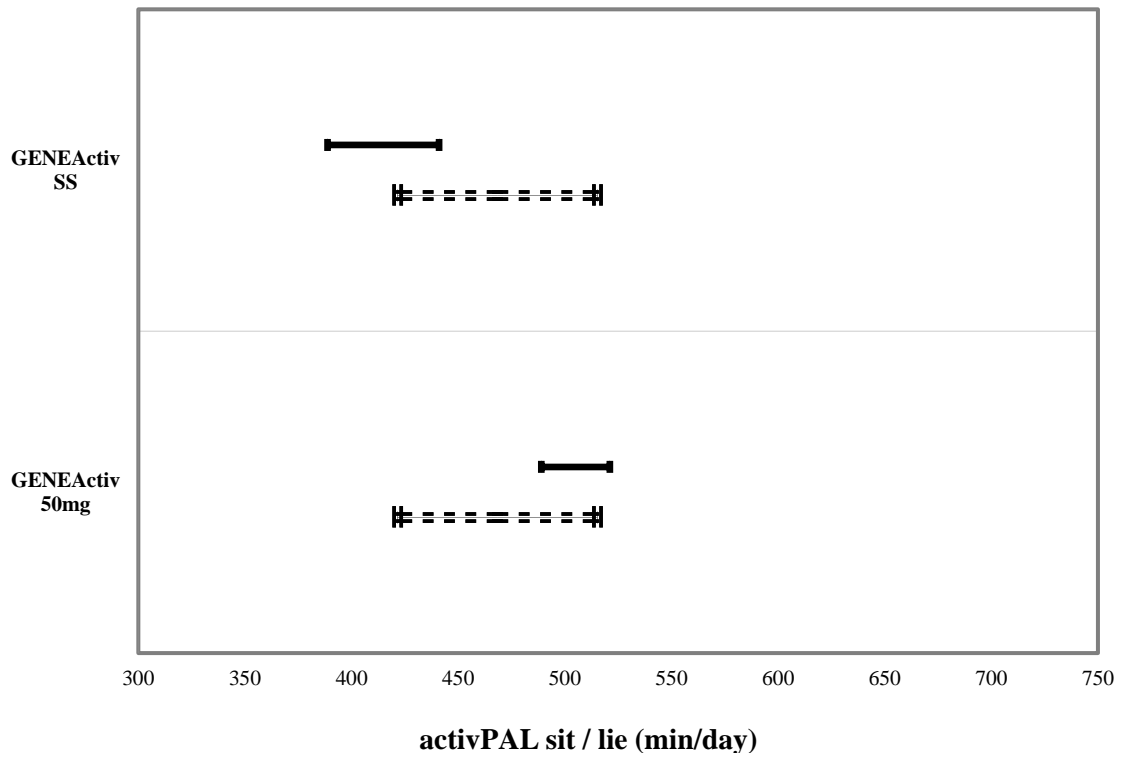


FIGURE 3: activPAL sedentary time zone of equivalence (dotted lines) and 90% confidence intervals for the GENEActiv (top) and ActiGraph (bottom) sedentary time estimates according to the sedentary sphere (SS) and threshold (50mg) methods.