

1 **Title: Accuracy of posture allocation algorithms for thigh and waist-worn**  
2 **accelerometers**

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23

## 24 Abstract

25 **Purpose:** To compare the accuracy of the activPAL and ActiGraph GT3X+ (waist and thigh)  
26 proprietary postural allocation algorithms and an open source postural allocation algorithm  
27 applied to GENEActiv (thigh) and ActiGraph GT3X+ (thigh) data. **Methods:** 34 adults ( $\geq 18$   
28 years) wore the activPAL3, GENEActiv and ActiGraph GT3X+ on the right thigh and an  
29 ActiGraph on the right hip while performing four lying, seven sitting and five upright  
30 activities in the laboratory. Lying and sitting tasks incorporated a range of leg angles (e.g.,  
31 lying with legs bent, sitting with legs crossed). Each activity was performed for five minutes  
32 while being directly observed. Percent time correctly classified was calculated. **Results:**  
33 Participants consisted of 14 males and 20 females (mean age  $27.2 \pm 5.9$  years; mean body  
34 mass index of  $23.8 \pm 3.7 \text{ kg/m}^2$ ). All postural allocation algorithms applied to monitors worn on  
35 the thigh correctly classified  $\geq 93\%$  of the time lying,  $\geq 91\%$  of the time sitting and  $\geq 93\%$  of  
36 the time upright. The ActiGraph waist proprietary algorithm correctly classified 72% of the  
37 time lying, 58% of the time sitting and 74% of the time upright. Both the activPAL and  
38 ActiGraph thigh proprietary algorithms misclassified sitting on a chair with legs stretched out  
39 (58% and 5% classified incorrectly respectively). The ActiGraph thigh proprietary and open  
40 source algorithm applied to the thigh worn ActiGraph misclassified participants lying on their  
41 back with their legs bent 27% and 9% of the time, respectively. **Conclusion:** All postural  
42 allocation algorithms when applied to devices worn on the thigh were highly accurate in  
43 identifying lying, sitting and upright posture. Given the poor accuracy of the waist algorithm  
44 for detecting sitting, caution should be taken if inferring sitting time from a waist-worn  
45 device.

46 **Keywords:** Sitting, standing, sedentary behaviour, inclinometer, open source.

47

## 48 Introduction

49 Sedentary behaviour, defined as sitting or reclining with low energy expenditure during  
50 waking hours ([22+6](#)), has consistently been associated with morbidity and mortality ([42](#), [53](#),  
51 [106-128](#), [23+7](#), [27+1](#), [292](#)) in adults. However, the majority of epidemiological studies to date  
52 have employed either self-reported sedentary behaviour measures or objective measures that  
53 infer sedentary behaviour through lack of movement ([53](#), [292](#)). Self-report questionnaires to  
54 assess sedentary behaviour have consistently demonstrated poor validity and underestimate  
55 sedentary behaviour (1). Objective measures that infer sedentary behaviour through lack of  
56 movement may overestimate sedentary behaviour (i.e., due to upright activities with very  
57 limited ambulation being recorded as sedentary) (18). A key factor in furthering our  
58 knowledge on sedentary behaviour and health, levels, patterns and determinants of sedentary  
59 behaviour and the effectiveness of sedentary behaviour interventions is to use objective  
60 devices that directly measure the posture of sitting and distinguish between sitting and  
61 upright postures with limited movement (e.g., standing). This is important given that recent  
62 experimental research has demonstrated that even light activity such as standing still can have  
63 a positive effect on markers of health ([64](#), [16](#), [260](#)).

64 Three devices that are capable of postural classification are the activPAL (all models), the  
65 thigh worn GENEActiv and the ActiGraph (when worn on the waist or thigh). The activPAL  
66 and ActiGraph are small tri-axial accelerometers that provide information on body posture  
67 (i.e., lying, sitting and upright postures such as standing and stepping) using proprietary  
68 software algorithms created by the manufacturers. Alternatively an open source algorithm is  
69 available, based on relative values of the x, y, z vectors, which can be applied to raw  
70 acceleration data from a thigh-worn tri-axial accelerometer to provide lying, sitting and  
71 standing information ([20+4](#)). A key recommendation from the 2009 Objective Measurement

72 | of Physical Activity Meeting, co-sponsored by the National Institute of Health and American  
73 | College of Sports Medicine, was that monitor data should be collected and saved as raw  
74 | signals, with data transformation carried out post processing to facilitate comparisons  
75 | between output regardless of which monitor is used (2, 7, 9, 28). This is only possible if open  
76 | source algorithms are available for data processing. The open source algorithm for classifying  
77 | posture from a thigh-worn monitor was ~~method was initially~~ developed by ActivInsights  
78 | (Activinsights Ltd., Cambridgeshire, UK) for the GENEActiv; to date it has ~~and been~~  
79 | validated using GENEActiv data, ~~but not with data from other devices~~ (2014).

80 | The activPAL device has been extensively validated in both laboratory and free-living studies  
81 | ([149](#), [150](#), [174-193](#), [2145](#)), however very little research has been published on the validity of  
82 | the waist ([34](#), [85](#)) and thigh worn ([2448](#), [2549](#)) ActiGraph inclinometer ~~algorithm~~ and  
83 | the thigh worn GENEActiv ([2014](#)). Furthermore, the majority of validation studies, including  
84 | those with the activPAL, have usually involved lying and sitting activities that are not fully  
85 | representative of daily postures. For example, lying in daily life usually involves lying on the  
86 | back or side with legs sometimes straight and sometimes bent. Sitting usually involves  
87 | different leg positions such as crossed legs or tucked under a chair for example. Studies to  
88 | date have not considered these types of activities in their validation methods. One exception  
89 | is the recently published study by Steeves and colleagues ([2549](#)) where participants wore the  
90 | activPAL and the ActiGraph on the thigh whilst completing sitting activities with different  
91 | leg positions (e.g., sitting with legs crossed at the knee). They found that the activPAL and  
92 | ActiGraph were highly accurate for some (e.g., sitting with legs crossed), but not all (e.g.,  
93 | sitting on a laboratory stool), sitting activities, To expand our understanding of the accuracy  
94 | of the devices that are capable of posture classification it is important to include, in validation  
95 | studies, a wide range of activities that are as representative of daily life as possible.

96 Therefore, the purpose of this study was to investigate the accuracy of the activPAL, waist  
97 and thigh worn ActiGraph GT3X+ proprietary postural allocation algorithms and the open  
98 source thigh postural allocation algorithm (applied to GENEActiv and ActiGraph data).  
99 Accuracy for identifying a range of lying and sitting positions, representative of daily  
100 postures, and light intensity upright activities was examined in a laboratory-based setting.  
101 Application of the open source postural allocation algorithm to both the GENEActiv and  
102 ActiGraph data will enable the assessment of the generalizability of the open source  
103 algorithm and comparison of the accuracy of the open source and ActiGraph proprietary  
104 algorithm.

## 105 **Methods**

### 106 **Participants**

107 A convenience sample of 34 adults ( ~~$\geq 18$  years~~) was recruited from Loughborough University  
108 and University of Leicester (staff and students) via word of mouth and email. Participants  
109 needed to be  $\geq 18$  years, English speaking, and without mobility issues which would prevent  
110 full participation in the protocol of activities. Ethical approval was received from  
111 Loughborough University.

### 112 **Procedure**

113 Participants visited the research centre at Loughborough University between March 2014 and  
114 August 2014. Participants provided written informed consent and basic demographic  
115 information (date of birth, sex). Body weight (Tanita, West Drayton, UK) and height  
116 (Leicester portable height measure) were measured to the nearest 0.1 kg and 0.5 cm  
117 respectively. Participants were fitted with an activPAL3<sup>TM</sup>, GENEActiv and ActiGraph  
118 | GT3X+ on the mid-line anterior aspect of their right thigh and an ActiGraph GT3X+ on

119 | their right hip. Participants were directly observed continuously (criterion measure) whilst  
120 | completing a protocol consisting of 16 activities (Figure 1), each performed for five minutes  
121 | with a 30 second gap in between activities. Participants started with the lying activities and  
122 | each participant completed the activities in the same order. The start and stop time for each of  
123 | the activities was measured and recorded by the observer using the clock function on the  
124 | same computer used to initialize the devices.

### 125 | **Objective Sedentary and Activity Measures**

126 | The activPAL3<sup>TM</sup> is a small (35x53x7 millimeters), lightweight (15g) tri-axial accelerometer  
127 | and via proprietary algorithms (Intelligent Activity Classification), accelerometer-derived  
128 | information about thigh position and acceleration are used to determine body posture (i.e.,  
129 | sitting/lying and upright) and transition between these postures and stepping. Default settings  
130 | were used during initialisation (i.e, 20Hz, 10 second minimum sitting and upright period).  
131 | The activPAL was attached midline on the anterior aspect of the right thigh using Hypafix  
132 | medical dressing.

133 | The ActiGraph GT3X+ (Actigraph LLC, Pensacola, FL, USA) is a small (45×33×15  
134 | millimeters), lightweight (19 g) tri-axial accelerometer that can be worn on various body  
135 | locations including waist, wrist, ankle and thigh. Through a proprietary postural algorithm  
136 | the ActiGraph, when worn on the waist, is capable of describing positional information  
137 | (lying, sitting, standing and non-wear) during periods of inactivity due to gravitational forces  
138 | acting on the orientation on the 3 axes. When the device is worn on the thigh, the lying and  
139 | sitting category is grouped together. ActiGraph devices were initialised to record at a  
140 | frequency of 100Hz and the low frequency extension filter was selected. Participants wore  
141 | two ActiGraph GT3X+ devices; one on an elastic belt around the waist on the right

142 midaxillary line of the hip and one on an elastic belt on the midline on the anterior aspect of  
143 the right thigh (below the activPAL3™).

144 The GENEActiv (Gravity Estimator of Normal Everyday Activity, Activinsights Ltd.,  
145 Cambridgeshire, UK) is a small (43x40x13 mm), lightweight (16 g) triaxial accelerometer  
146 that can be worn on various body locations including wrist, waist, ankle, upper arm and thigh.  
147 ~~that~~ When worn on the thigh the GENEActiv can assess posture based on the relative  
148 values of the x (mediolateral), y (vertical), and z (anteroposterior) vectors. The GENEActiv  
149 was initialised to record at a frequency of 100Hz. Participants wore the GENEActiv on the  
150 midline on the anterior aspect of the right thigh using an elastic belt.

151

## 152 **Data Reduction and Analysis**

### 153 **Proprietary algorithms**

154 ActivPAL data were downloaded using activPAL Professional Research Edition v7.2.29  
155 (PAL Technologies, Glasgow) and 15 second epoch csv files were created. ActiGraph data  
156 were downloaded using ActiLife v6.10.2 (ActiGraph, Pensacola, FL, USA) and converted  
157 into 15 second epoch csv files. Posture classification is determined proprietarily within the  
158 manufacturer's software for the thigh-worn activPAL, thigh-worn ActiGraph and waist-worn  
159 ActiGraph (APAL<sub>PROP</sub> and T\_AGRAPH<sub>PROP</sub>, and W\_AGRAPH<sub>PROP</sub>, respectively).

### 160 **Open source algorithms**

161 GENEActiv data were downloaded using GENActiv PC software v2.2 and the raw .bin files  
162 were converted into 15 second epoch csv files. The 15-s epoch files were imported into a  
163 custom-built template in Excel that computed the most likely posture based on the relative

164 values of the x, y, z vectors measured at the thigh (T\_GACTIV<sub>OPEN</sub>). This method was  
165 developed by ActivInsights for use with the GENEActiv when it is worn on the thigh and has  
166 been described previously (20). ~~The~~<sub>is</sub> method is open source and we have made the Excel  
167 template ~~is~~ available on the Leicester-Loughborough Diet, Lifestyle and Physical Activity  
168 Biomedical Research Unit website ([http://www.ll.dlpa.bru.nihr.ac.uk/Sedentary\\_Sphere-](http://www.ll.dlpa.bru.nihr.ac.uk/Sedentary_Sphere-5483.html)  
169 [5483.html](http://www.ll.dlpa.bru.nihr.ac.uk/)~~http://www.ll.dlpa.bru.nihr.ac.uk/~~) (~~Note: This will be made available at this~~  
170 ~~location on acceptance of this manuscript~~).

171 The 100 Hz GT3X<sub>±</sub> files from the thigh-worn ActiGraph were converted to 100 Hz csv files  
172 containing x, y and z vectors using Actilife version 6.10.2. In order to match the format to the  
173 GENEActiv and to that required for the open source algorithm, a purpose built Excel  
174 template was used to convert the raw 100 Hz files to 15 s epoch files containing x, y and z  
175 vectors (mean acceleration over the epoch). The 15 s epoch files were then imported into the  
176 custom-built Excel template for computation of the most likely posture (T\_AGRAPH<sub>OPEN</sub>).  
177 The first and last 30 seconds of each activity were excluded from the analyses to protect  
178 against the potential of imperfect time synchronization and transition between activities.

179 For each participant, the percentage of epochs that ~~were~~<sub>reas</sub> correctly coded as lying, sitting  
180 and upright against direct observation was calculated for each of the 16 activities for each  
181 method of measurement (APAL<sub>PROP</sub>, T\_AGRAPH<sub>PROP</sub>, W\_AGRAPH<sub>PROP</sub>, T\_GACTIV<sub>OPEN</sub>,  
182 T\_AGRAPH<sub>OPEN</sub>). Percentages were then summarised and presented as means and 95%  
183 confidence intervals for each individual activity and by activities grouped as lying, sitting and  
184 upright activity. Analyses were conducted in IBM SPSS Statistics v20.0.

## 185 **Results**

186 Participants consisted of 14 males and 20 females (mean age  $27.21 \pm 5.94$  years (range 20-40  
187 years); mean BMI  $23.82 \pm 3.68$  kg/m<sup>2</sup>; range 18.64-32.58kg/m<sup>2</sup>). Table 1 presents the mean  
188 percentage of time coded correctly, against direct observation, for each individual activity  
189 and activities grouped by type (i.e., lying, sitting and upright) by each measurement method.

190 The APAL<sub>PROP</sub> and T\_GACTIV<sub>OPEN</sub> classified all lying activities correctly 100% of the time.  
191 The T\_AGRAPH<sub>PROP</sub> and T\_AGRAPH<sub>OPEN</sub> classified three of the four lying activities 100%  
192 of the time, with lying on the back with legs bent classified correctly 73% of the time (93%  
193 correctly classified for all lying activities) and 91% of the time (98% correctly classified for  
194 all lying activities) respectively. The W\_AGRAPH<sub>PROP</sub> correctly classified lying activities  
195 between 67-77% of the time (72% overall for lying activities).

196 When examining sitting activities, the APAL<sub>PROP</sub> correctly classified six out of seven sitting  
197 activities  $\geq 97\%$  of the time, with sitting with legs stretched out classified correctly 42% of  
198 the time (91% overall for all sitting activities). The T\_GACTIV<sub>OPEN</sub> and T\_AGRAPH<sub>OPEN</sub>  
199 correctly classified all sitting activities 100% of the time. The T\_AGRAPH<sub>PROP</sub> correctly  
200 classified six out of seven sitting activities 100% of the time; sitting with legs stretched out  
201 was classified correctly 95% of the time (99% overall for all sitting activities). The  
202 W\_AGRAPH<sub>PROP</sub> correctly classified sitting activities between 46-70% of the time (58%  
203 overall for sitting activities).

204 Four out of five upright activities were correctly classified 100% of the time by the  
205 APAL<sub>PROP</sub>, with self-paced walking correctly classified 97% of the time (99% overall for all  
206 upright activities). The T\_GACTIV<sub>OPEN</sub>, T\_AGRAPH<sub>OPEN</sub> and the T\_AGRAPH<sub>PROP</sub>  
207 correctly classified upright activities  $\geq 88\%$  (93% overall for all upright activities),  $\geq 97\%$   
208 (98% overall for all upright activities) and  $\geq 91\%$  (96% overall for all upright activities) of the

209 time respectively. The W\_AGRAPH<sub>PROP</sub> correctly classified upright activities between 61-  
210 97% of the time (74% overall for upright activities).

## 211 **Discussion**

212 This study adds to the literature by comparing the accuracy of several accelerometers, with  
213 proprietary and/or open source postural allocation algorithms applied to the data, across a  
214 range of different postures and activities. This study demonstrated that all thigh-worn  
215 monitors were highly accurate in identifying lying, sitting and upright postures, irrespective  
216 of whether proprietary (activPAL and ActiGraph) or open source algorithms (GENEActiv  
217 and ActiGraph) were applied to the data. As noted recently by Steeves and colleagues ([2549](#))  
218 there is a need for improvements in algorithms to increase their ability to correctly classify a  
219 wider range of postures and activities. They further highlight that broader access to  
220 appropriate hardware and firmware to support postural and activity classification would be a  
221 major advancement for the research community. The open source algorithm applied in the  
222 current study demonstrated high accuracy across monitor brands and across the range of  
223 postures and activities typical during free-living; this is a significant step forward.

224

225 The high validity of the activPAL monitor has been demonstrated in numerous laboratory  
226 studies ([149,150](#)), however to our knowledge this is only the second study utilising the  
227 activPAL whilst including sitting postures with a variety of leg angles. Recently, Steeves and  
228 colleagues examined the accuracy of the activPAL for identifying different sitting postures  
229 (e.g., legs crossed at knee, legs crossed at ankle, legs crossed with ankle on opposite knee)  
230 and found that the activPAL was highly accurate for most sitting postures. In agreement with  
231 the current study they found that the activPAL misclassified (15% of the time) sitting with

232 | legs outstretched but not to the extent of the current study (58%). This sitting position  
233 | changes the angle of the thigh slightly (i.e., knee angle increases above 90° and front of thigh  
234 | dips) and tThe misclassification ~~during this particular activity~~ suggests that the activPAL  
235 | proprietary angular parameters for the classification of sitting require the thigh to be close to  
236 | parallel to the ground (2519). As the activPAL algorithm is proprietary it is not possible to  
237 | investigate whether accuracy can be improved by adjusting the parameters, as would be  
238 | possible with an open source algorithm. It is important to acknowledge that the extent to  
239 | which this would impact on misclassification of sitting time during a typical 7-day free-living  
240 | data collection would depend on the prevalence of this type of sitting posture.

241 | The use of the activPAL monitor in physical activity and sedentary behaviour research is  
242 | increasing rapidly (13) due to its ability to correct identify posture (14, 15,9-174). The high  
243 | accuracy of the ActiGraph thigh proprietary algorithm and open source algorithm applied to  
244 | both ActiGraph and GENEActiv data observed in the current study suggests that these could  
245 | also be an option for postural identification in research. This finding is consistent with a small  
246 | body of previous research (2418,2519) that has shown the ActiGraph thigh proprietary  
247 | algorithm to be highly accurate. Skotte et al (2418) under free-living conditions, compared  
248 | the hip and thigh worn ActiGraph postural allocation algorithms against a pressure logger to  
249 | detect sitting posture. They found that the thigh algorithm was more precise than hip  
250 | algorithm. Furthermore, in a recent study by Steeves et al (2519) the ActiGraph thigh  
251 | algorithm demonstrated 100% accuracy in detecting five different sitting postures, an  
252 | accurate ability to identify standing and light movement at a whiteboard and >95% accuracy  
253 | for stepping activities. The ActiGraph thigh algorithm did however misclassify 14% of the  
254 | time sitting on a laboratory stool as standing time (2519). Although we, and others, have  
255 | found the ActiGraph thigh algorithms to be highly accurate for the majority of activities, i  
256 | It is important to acknowledge ~~however,~~ the design limitations of ~~this e-ActiGraph~~ device. The

257 device, although small and lightweight, is considerably thicker than the activPAL for  
258 example, and has sharp edges where the elastic belt sits. This may make it visible under some  
259 clothing and uncomfortable on the thigh, possibly resulting in compliance issues when worn  
260 on the thigh. [Ideally a device needs to be both accurate and comfortable to wear. Before](#)  
261 [deciding upon a particular device pilot testing with the target population would be](#)  
262 [advantageous.](#)

263 In a small free living study, the accuracy and precision of the open source algorithm applied  
264 to GENEActiv data has been demonstrated against the activPAL monitor ([2014](#)), however the  
265 current study is the first to compare against direct observation. This is also the first study to  
266 apply a transparent open source algorithm to ActiGraph data and compare it to the  
267 manufacturer's proprietary algorithm. The open source algorithm applied to the ActiGraph  
268 thigh data performed slightly better than the ActiGraph proprietary algorithm for identifying  
269 lying and sitting activities, specifically on the individual activities of lying on the back with  
270 legs bent and sitting with legs stretched out, but had marginally lower accuracy for upright  
271 activities.

272 Few published studies have investigated the accuracy of the ActiGraph algorithm when worn  
273 on the waist ([34,85 2418](#)). All studies reported poor accuracy of the algorithm which  
274 corroborates the current findings. Given the poor accuracy of the waist algorithm for  
275 identifying lying, sitting and upright activities, caution should be taken when considering  
276 employing this device in research studies [especially those with a focus on time spent sitting.](#)

277 The strengths of this study include the comparison of five different postural identification  
278 measurement methods (including application of an open source algorithm), the range of  
279 lying, sitting and upright activities that were chosen to be more representative of daily  
280 postures, and the use of direct observation as the criterion measure for comparisons.

281 However, it is important to acknowledge that although activities and postures included were  
282 designed to mimic everyday behaviours, participants were instructed how to lie or sit and in a  
283 free-living environment may perform the same behaviours in a slightly different manner.  
284 Furthermore, our homogeneous sample of participants (i.e., narrow age range and 74% in the  
285 normal weight category) may limit generalizability of results.

286 In summary we demonstrated that all thigh worn monitors, irrespective of type (proprietary or  
287 open source) of algorithm, were highly accurate. It is important to note that it is not the  
288 device or the algorithm per se that is accurate, it is the combination of the two. A major  
289 limitation of any proprietary algorithm, in addition to the lack of transparency, is that it is  
290 limited to a single device. In contrast, open source methods are much more flexible for  
291 researchers to use (e.g., modifications can be made to angle thresholds for different  
292 population groups) and allow algorithms to be applied to different devices enabling  
293 assessments across devices to be made. The current study demonstrated accuracy of an open  
294 source algorithm across monitor brands and across a range of postures and activities.

#### 295 **Authors Contributions:**

296 CE, TY and AR conceived the study and TG, DE, MD and KK refined the study, CE wrote  
297 the first draft of the manuscript, SB and JS carried out data acquisition, SB, SOC and AR  
298 analysed the data. All authors reviewed/edited the manuscript and approved the final  
299 manuscript.

#### 300 **Conflict of Interest Statement:**

301 Alex Rowlands provides consultancy services to Activinsights, the manufacturer of the  
302 GENEActiv. The authors declare that there are no other conflicts of interests. The results of  
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312 **References**

313 [1. Atkin AJ, Gorely T, Clemes SA, et al. \(2012\). Methods of measuring sedentary behaviour  
314 in epidemiological research. \*Int J Epidemiol.\* 2012;41\(5\):1460-1471.](#)

315 [2. Basset DR, Rowlands AV, Trost SG. Calibration and validation of wearable monitors. \*Med  
316 Sci Sports Exerc.\* 2012;44:S32-S38.](#)

317 [34. Berendsen BA, Hendriks MR, Meijer K, Plasqui G, Schaper NC, Savelberg HH. Which  
318 activity monitor to use? Validity, reproducibility and user friendliness of three activity  
319 monitors. \*BMC Public Health.\* 2014;14:749.](#)

320 [42. Biswas A, Oh PI, Faulkner GE, et al. Sedentary time and its association with risk for  
321 disease incidence, mortality, and hospitalization in adults: A systematic review and meta-  
322 analysis. \*Ann Intern Med.\* 2015;162:123-132.](#)

323 [53. Brocklebank LA, Falconer CL, Page AS, Perry R, Cooper AR. Accelerometer-measured  
324 sedentary time and cardiometabolic biomarkers: A systematic review. \*Prev Med.\* 2015;76:92-  
325 102.](#)

326 | [64.](#)Buckley JP, Mellor DD, Morris M, Joseph F. Standing-based office work shows  
327 | encouraging signs of attenuating post-prandial glycaemic excursion. *Occup Environ Med.*  
328 | 2014;71:109-111.

329 | [7.](#)Butte NF, Ekelund U, Westerterp KR. Assessing Physical Activity Using Wearable  
330 | [Monitors: Measures of Physical Activity.](#) *Med Sci Sports Exerc.* 2012;44:S5–S12.

331 | [85.](#)Carr LJ, Mahar MT. Accuracy of intensity and inclinometer output of three activity  
332 | monitors for identification of sedentary behavior and light-intensity activity. *J Obes.*  
333 | 2012;2012:460271.

334 | [9.](#)Chen KY, Janz KF, Zhu W, Brychta RJ. Redefining the Roles of Sensors in Objective  
335 | [Physical Activity Monitoring.](#) *Med Sci Sports Exerc.* 2012;44:S13–S23.

336 | [106.](#)Cong YJ, Gan Y, Sun HL, et al. Association of sedentary behaviour with colon and rectal  
337 | cancer: a meta-analysis of observational studies. *Br J Cancer.* 2014;110:817-826.

338 | [117.](#)de Rezende LF, Rey-López JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and  
339 | health outcomes among older adults: a systematic review. *BMC Public Health.* 2014;14:333.

340 | [128.](#)Edwardson CL, Gorely T, Davies MJ, et al. Association of Sedentary Behaviour with  
341 | Metabolic Syndrome: A Meta-Analysis. *PLoS One.* 2012;7:e34916.

342 | [13.](#)Edwardson CL, Winkler EAH, Bodicoat DH, et al. Considerations when using the  
343 | [activPAL monitor in field based research with adult populations.](#) *J Sport Health Sci.* In Press.

344 | [149.](#)Grant PM, Ryan CG, Tigbe WW, Granat MH. The validation of a novel activity monitor  
345 | in the measurement of posture and motion during everyday activities. *Br J Sports Med.*  
346 | 2006;40:992-997.

347 | [150](#).Hart TL, McClain JJ, Tudor-Locke C. Controlled and free-living evaluation of objective  
348 | measures of sedentary and active behaviours. *J Phys Act Health*. 2011;8:848-857.

349 | [16](#).Henson J, Davies MJ, Bodicoat DH, et al. [Breaking up prolonged sitting with standing or](#)  
350 | [light activity reduces post-prandial markers of diabetes risk. \*Diabetes Care\*. 2015; Dec 1. pii:](#)  
351 | [dc151240. \[Epub ahead of print\].](#)

352 | [17](#).Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of  
353 | Wearable Monitors for Assessing Sedentary Behavior. *Med Sci Sports Exerc*. 2011;43:1561-  
354 | 1567.

355 | [18](#).Kozey-Keadle S, Libertine A, Staudenmayer J, Freedson P. The feasibility of reducing  
356 | and measuring sedentary time among overweight, non-exercising office workers. *J Obes*  
357 | 2012;2012:282-303.

358 | [19](#).Lyden K, Kozey-Keadle SL, Staudenmayer JW, Freedson PS. Validity of Two Wearable  
359 | Monitors to Estimate Breaks from Sedentary Time. *Med Sci Sports Exerc*. 2012;44:2243-52.

360 | [20](#).Rowlands AV, Olds TS, Hillsdon M, et al. Assessing sedentary behaviour with the  
361 | GENEActiv: Introducing the sedentary sphere. *Med Sci Sports Exerc*. 2014;46:1235-1247.

362 | [21](#).Ryan CG, Grant PM, Tigbe WW, Granat MH. The validity and reliability of a novel  
363 | activity monitor as a measure of walking. *Br J Sports Med*. 2006;40:779-784.

364 | [22](#).Sedentary Behaviour Research Network. Standardized use of the terms “sedentary” and  
365 | “sedentary behaviours”. *Appl Physiol Nutr Metab*. 2012;37:540-542.

366 | [23](#).Shen D, Mao W, Liu T, et al. Sedentary behavior and incident cancer: a meta-analysis  
367 | of prospective studies. *PLoS One*. 2014;9:e105709.

368 | [2418](#).Skotte J, Korshøj M, Kristiansen J, Hanisch C, Holtermann A. Detection of Physical  
369 | Activity Types Using Triaxial Accelerometers. *J Phys Act Health*. 2014;11(1):76-84.

370 | [2549](#).Steeves JA, Bowles HR, McClain JJ, et al. Ability of thigh-worn ActiGraph and  
371 | activPAL monitors to classify posture and motion. *Med Sci Sports Exerc*. 2015;47(5):952-9.

372 | [260](#).Thorp AA, Kingwell BA, Sethi P, Hammond L, Owen N, Dunstan DW. Alternating  
373 | bouts of sitting and standing attenuate postprandial glucose responses. *Med Sci Sports*  
374 | *Exerc*.2014;46:2053-2061.

375 | [274](#).Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent  
376 | health outcomes in adults a systematic review of longitudinal studies 1996-2011. *Am J Prev*  
377 | *Med*. 2011;41:207-215.

378 | [28](#).Welk G J, McClain J, Ainsworth BE. Protocols for Evaluating Equivalency of  
379 | accelerometry-Based activity Monitors. *Med Sci Sports Exerc*. 2012;44:S39–S49.

380 | [292](#).Wilmot EG, Edwardson CL, Achana FA, et al. Sedentary time in adults and the  
381 | association with diabetes, cardiovascular disease and death: systematic review and meta-  
382 | analysis. *Diabetologia*. 2012;55:2895-905.

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### 385 | **Figure Titles**

386 | Figure 1. Flow of 16 lying, sitting and upright activities.

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