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8 **Hip and wrist accelerometers showed consistent associations with fitness and fatness in**
9 **children aged 8-12 years**

10

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32 **ABBREVIATIONS**

33

34 BMI, body mass index; CRF, cardiorespiratory fitness; ENMO, Euclidean norm minus one; PA,
35 physical activity; SD, standard deviation.

Accepted Article

36 **ABSTRACT**

37

38 **Aim:** Physical activity (PA) has traditionally been measured wearing accelerometers on the hip,
39 but they are increasingly being worn on the wrist. We compared hip and wrist accelerometers
40 with regard to their acceptability and any associations between PA and fatness and fitness.

41 **Methods:** This cross-sectional study comprised 103 children aged 8-12 years (62% boys) who
42 participated in the ActiveBrains trial by the University of Granada, Spain, in 2014-2016. The
43 children wore both ActiGraph GT3X+ hip and wrist accelerometers round the clock for seven
44 days. The acceptability of both placements was evaluated by a questionnaire, while the children's
45 fat mass index, waist circumference, and cardiorespiratory fitness (CRF) were assessed.

46 **Results:** Wearing wrist accelerometers caused less disturbance, mainly because hip
47 accelerometers caused more issues during the night. The measurements from both placements
48 showed that lower PA levels were associated with fatness and that increased PA was associated
49 with CRF.

50 **Conclusion:** Both placements showed consistent results with regard to measuring associations
51 between PA levels and fatness and fitness. However, wearing them on the wrist caused less
52 discomfort at night. Future studies are needed to confirm the best placement for accelerometers
53 during PA studies.

54 **KEY WORDS** adiposity, exercise, hip accelerometers, physical fitness, waist accelerometers

55 **KEY NOTES**

- 56 - There has been no clear consensus about how different accelerometer placement
57 measure associations between PA and fatness and fitness.
- 58 - Hip and wrist accelerometers were equally effective in measuring negative associations
59 with fatness and positive associations with fitness in 103 subjects aged 8-12 years.
- 60 - Wrist accelerometers were more comfortable at night, but further research is still needed
61 to confirm the best placement for accelerometers during PA studies.

62 INTRODUCTION

63

64 Physical activity (PA) has been connected to numerous health benefits, such as a reduced risk of
65 becoming overweight and maintained or improved physical fitness (1). At the same time,
66 sedentary time has been identified as the fourth leading risk factor for noncommunicable
67 diseases by the World Health Organization (2). There has been increasing public concern about
68 insufficient PA, particularly because of the high worldwide prevalence of people who are
69 overweight and obese. This excess weight has been associated with a large number of physical
70 and psychological health consequences (3). In contrast, physical fitness has been associated
71 with reduced all-cause mortality and a lower risk of developing a wide range of noncommunicable
72 diseases (4). However, it is important to understand how data collection can affect the results
73 when investigating associations between accelerometer-based PA and sedentary time with
74 regard to health outcomes, such as adiposity or physical fitness. This involves looking at where
75 the accelerometers are attached to the subject and how the data are processed in terms of PA
76 metrics or selected cut-off points (5). PA metrics are algorithms that aggregate the raw
77 acceleration signals acquired by the accelerometer and correlate them with the intensity of the PA
78 that the person engages in.

79 Accelerometers are currently the most widely used objective method of assessing
80 PA in research (6). Wearing the devices has been found to modulate total PA (7) and this means
81 that it is essential to understand any associations between PA and health outcomes. Better
82 compliance improves the monitoring of daily PA due to the association between the duration of
83 monitoring and the reliability of the PA data (8). Compliance has been reported to show large
84 variations in intervention studies, from 25% to 99%, and studies with higher compliance during
85 follow-up periods have tended to report larger effects (7). On the other hand, intervention results
86 that have demonstrated PA improvements may not have been meaningful when compliance was
87 low (7). The factors that could have an effect on compliance include whether the device is
88 attached to the hip or wrist (9), and whether the accelerometers are acceptable in terms of
89 comfort and appearance (10). They include the time spent wearing the device, such as waking
90 hours versus round the clock, and how well people remember the instructions about when to
91 wear them (11). However, there have not been any previous studies that have investigated how
92 acceptable children find wearing the accelerometers on their hips or wrists during research
93 studies. It would be helpful to know this, as it could increase how well children comply with
94 wearing the device and improve the representativeness of the PA data. In addition, the placement
95 has been reported to influence measured PA levels in children (9). For instance, a study of 129
96 children aged 9-10 years found that mean levels of moderate-to-vigorous PA varied from 47.55

97 ± 1.69 minutes per week with an ActiGraph accelerometer (ActiGraph Corp, Pensacola, Florida,
98 USA) worn on the hip to 86.63 ± 2.90 minutes per week when a GENEActiv accelerometer
99 (Activeinsights Ltd, Cambridgeshire, UK) was worn on the wrist (9). In addition to the different
100 placements, various brands have been reported to detect somewhat different PA levels (9) and
101 these could also lead to variations in the associations between PA and health outcomes. That is
102 why it is so hard to compare the results of different studies.

103 A few large epidemiological studies have assessed PA in both children and adults
104 using hip accelerometers (11-13). However, when the National Health and Nutrition Examination
105 Survey was carried out in the United States of America in 2011–2014, it used a wrist
106 accelerometer to collect the data instead of the hip accelerometer used in 2003-2006 survey (14).
107 In addition, wrist accelerometers were also used in the large Biobank study in the United
108 Kingdom, which has been collecting data on the respective contributions of genetic predisposition
109 and environmental exposure to the development of disease since 2006 (15). There is no clear
110 consensus about how the different placements are associated with fatness and fitness. To the
111 best of our knowledge, no previous studies have compared the hip and wrist placement outputs
112 with health outcomes in children. Having overweight or obesity and physical fitness are closely
113 connected to health (16) and their associations with sedentary time and PA have been widely
114 investigated. Therefore, we aimed to carry out further research into how these associations
115 depended on the placement of the accelerometer. The first aim of this study was to compare the
116 acceptability of wearing the accelerometers on the hip versus the wrist. The second aim was to
117 compare the associations between sedentary time and PA with fatness and fitness based on
118 accelerometer data recorded from the hips and wrists of children who were overweight and
119 obese.

120

121 **METHODS**

122

123 **Study design and participants**

124 This study used cross-sectional data collected between 2014-2016 for the
125 ActiveBrains project by the University of Granada, Spain. It was a randomised controlled trial that
126 aimed to examine the effects of a physical exercise programme on the brain, cognition and
127 physical and mental health. The details of the project have previously been described by
128 Cadenas-Sanchez et al (17). Briefly, the project focused on 109 overweight and obese Spanish
129 children (65% boys) aged 8-12 years. It compared 57 children who underwent a 20-week
130 programme of three to five extra after-school sessions lasting 90 minutes and 52 controls. The
131 current study comprised 103 children (62% boys) aged 8-12 years with complete baseline data

132 on sedentary time, PA, fatness and cardiorespiratory fitness (CRF). Their parents provided
133 written, informed consent for them to participate in the study. The trial was approved by the Ethics
134 Committee on Human Research at the University of Granada (number 848, February 2014) and
135 registered at ClinicalTrials.gov (NCT02295072).

136

137 **Data collection**

138 Sedentary time and PA were measured using the ActiGraph GT3X+, triaxial accelerometer
139 (ActiGraph), which was worn for 24 hours over seven consecutive days. The participants wore
140 the accelerometers at two different placements at the same time: on the right hip and on the non-
141 dominant wrist. The raw accelerations collected at a sampling frequency of 100 Hz were
142 processed to derive the Euclidean norm minus one (ENMO) metric in R version 3.1.2 (The R
143 Foundation, Vienna, Austria) using the GGIR package version 1.5-12 (The R Foundation) (18).
144 We followed the recommendations in a systematic review by Migueles et al (5) and included
145 children with at least four days of valid PA data in the analyses. These four days had to include
146 three weekdays and one weekend day. A valid day was defined as at least 16 hours in any 24-
147 hour period.

148 The accelerometer data was categorised as sedentary time, light PA, moderate PA,
149 vigorous PA and moderate-to-vigorous PA. Furthermore, we used two different metrics to analyse
150 sedentary time and PA. First, we calculated the minutes per day of sedentary time and PA levels
151 separately for the hip and wrist accelerometers, based on the ENMO measurements for each
152 child in accordance with Hildebrand et al (19,20). Secondly, we calculated the same minutes per
153 day based on vector magnitude counts, in accordance with Romanzini et al (21) for the hip
154 accelerometers, and with Chandler et al (22) for the wrist accelerometers. To calculate the cut-off
155 points, we used uniaxial PA measurements, namely vertical axis counts, measured on the hip
156 and based on Evenson's cut-off points (23) (Table S1). These have frequently been used to
157 assess PA using the vertical axis (5) and the cut-off points have also been cross-validated by
158 Trost et al (24).

159 The acceptability of wearing the accelerometers was measured using a
160 questionnaire at the eight-month follow-up visit. Three questions were posed. We asked whether
161 the hip or wrist accelerometer disturbed them most and, if they did, when each one disturbed
162 them: in the morning, afternoon, evening or at night. A two-point scale representing yes or no
163 was used and multiple answers were allowed.

164 Body weight in kilograms was measured with a SECA 861 electronic scale (SECA
165 GmbH, Hamburg, Germany) and height in centimetres was assessed using a SECA 225
166 precision stadiometer (SECA GmbH). The children's body mass index (BMI) was calculated as

167 body weight in kilograms divided by height squared in metres and overweight was defined using
168 sex and age specific international BMI standards (25). Waist circumference was measured twice
169 at the mid-distance between the bottom of the rib cage and the top of the iliac crest and the mean
170 of the two values was used in the analyses. Fat mass in kilograms was measured by dual-energy
171 X-ray absorptiometry using a Discovery (Horizon® DXA system) densitometer (Hologic Canada
172 ULC, Ontario Canada), as previously described (26). The fat mass index was calculated as fat
173 mass in kilograms divided by height in square metres. Because two different dual-energy X-ray
174 machines were used in the measurements, z-scores were calculated for the fat mass indexes.
175 The fat mass index and waist circumference were used as estimates of total and central
176 adiposity, respectively.

177 CRF was measured using a maximal incremental treadmill test with the h/p/cosmos
178 ergometer (h/p/cosmos sports and medical GmbH, Munich, Germany) using a modified protocol
179 for children (27). It was performed using a COSMED gas analyser (COSMED, Rome, Italy).

180 Participants walked on a treadmill at a constant speed of 4.8 kilometres per hour with a 6% slope
181 with grade increments of 1% every minute until volitional exhaustion. They were encouraged to
182 walk as long as they could. The test was carried out by clinicians from the Andalusian Centre of
183 Sport Medicine. Maximal oxygen consumption in mL/kg/min, heart rate and the respiratory
184 exchange ratio were measured every 10 seconds. The maximal oxygen consumption was
185 confirmed when three out of four criteria were met. These were: volitional fatigue, defined as
186 more than eight points in the OMNI scale, a plateau in maximal oxygen consumption during the
187 last two exercise work rates ($<2.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), achieving more than 85% of the age-predicted
188 maximum heart rate, and a respiratory exchange ratio of ≥ 1.10 (28).

189 The children's sex was collected from the background questionnaire. Peak height
190 velocity was calculated separately for boys and girls using the equations provided by Moore et al
191 (29). The study was conducted in three waves. The first 17 children (16.3%) were enrolled in
192 2014-2015, with 42 (40.8%) at the start of 2015-2016 and the final 44 (42.7%) later in 2015-2016.
193 The parents' maximum educational level was assessed by whether neither, one or both of them
194 had a university degree.

195

196 **Statistical methods**

197 Descriptive information is given as arithmetic means and standard deviations (SD) or frequencies
198 and percentages. Linear regression analysis was used to assess the associations of intensity-
199 specific PA, based on both the ENMO measurements and vector magnitude counts with fatness
200 and fitness. Fatness was fat mass index and waist circumference and fitness was defined as
201 CRF. Each model was adjusted for the child's sex, the continuous variable of peak height velocity

202 and the categorical variables of the wave of the measurements and parental educational level
203 due to their potential effect on the study outcomes. The paired samples t-test was used to assess
204 the differences between the characteristics of hip and wrist accelerometers. In addition, we used
205 the J test (30) to examine whether the associations between PA and fatness and fitness differed
206 statistically between the hip and wrist accelerometers. PA measurements have been commonly
207 taken from hip-based accelerometers (5) using the vertical axis based on Evenson's cut-off points
208 (23). Our supplementary analyses examined whether the associations of sedentary time and PA
209 differed from the associations based on the vertical axis counts, when we used the ENMO
210 measurements and vector magnitude counts with fat mass index, waist circumference and CRF.
211 We also investigated if the associations differed by sex by adding an interaction term into the
212 regression models. As sex had no significant interaction effects on the analyses, the results for
213 both sexes are presented together. Although we are presenting cross-sectional analyses, it is
214 worth noting that an alpha error of 5%, a sample size of 103 and a statistical power of 95%
215 identified a medium effect size. G*power software, version 3.0.1 (Heinrich Heine University,
216 Dusseldorf, Germany) was used for the calculations. All the statistical tests were conducted using
217 the two-sided 5% level of significance and performed using SPSS Statistics 24 (IBM Corp, New
218 York, USA), except the J tests, which were conducted using Stata Statistical Software version
219 15.0 (StataCorp LLC, Texas, USA).

220

221 **RESULTS**

222

223 The 103 children who took part in the study had an average BMI of 26.8 kg/m², fat mass index of
224 11.8 kg/m², waist circumference 90.3cm, and CRF of 37.3 mL/kg/min (Table 1). Their mean age
225 was 10.1 ±1.1 years (range 7.9 to 12.0 years).

226 We found that 82 (79.6%) answered the question about the acceptability of wearing
227 the accelerometers and the results are illustrated in Figures 1a and 1b. Wearing a hip
228 accelerometer disturbed the subjects more than wearing a wrist accelerometer (45.1% versus
229 30.5%) (Figure 1a). Half of the children (50.0%) reported that the hip accelerometer disturbed
230 them during the night and 25.6% said it never disturbed them (Figure 1b). Furthermore, 31.7% of
231 the children reported that wearing a wrist accelerometer disturbed them in the morning and
232 45.1% said it never disturbed them. Table 2 shows sedentary time and PA, as measured by hip
233 and wrist accelerometers, and analysed using both the ENMO measurements and vector
234 magnitude counts metrics. The mean wearing time over the week-long 24-hour periods was
235 borderline significant between the placements (p=0.058). However, children were more likely to
236 wear the hip than wrist accelerometer when they were awake (p<0.001).

237 The ENMO measurements during sedentary time showed positive associations with
238 the fat mass index and waist circumference for both the hip and wrist accelerometer, but the wrist
239 accelerometer produced slightly stronger associations ($p < 0.05$) as shown in Table 3. When we
240 used vector magnitude counts, both the placements showed similar significant associations with
241 fat mass index and waist circumference ($p < 0.01$). The ENMO measurements showed that higher
242 moderate PA, vigorous PA and moderate-to-vigorous PA were significantly associated with lower
243 fat mass index with the hip accelerometer (all $p \leq 0.01$) and wrist accelerometer (all $p < 0.001$). The
244 same was true for waist circumference (both $p < 0.05$), although the wrist accelerometer led to
245 slightly stronger associations overall (Table 3). When we used the vector magnitude counts, both
246 placements showed that higher vigorous PA or moderate-to-vigorous PA were associated with a
247 lower fat mass index. However, the wrist accelerometer produced stronger associations
248 ($p < 0.001$) than the hip accelerometer ($p < 0.05$). Only the wrist accelerometer led to significant
249 associations between moderate PA, vigorous PA, or moderate-to-vigorous PA and waist
250 circumference (all $p < 0.001$) (Table 3). Furthermore, light PA with the hip accelerometer was
251 significantly associated with the fat mass index and waist circumference (both $p < 0.01$). The J test
252 results showed that the wrist accelerometer contained the correct sets of regressors in most of
253 the models when compared to the hip accelerometer ($p > 0.05$). The latter contained the correct
254 sets of regressors in fewer models (Table 3).

255 With regard to sedentary time, both placements showed negative associations with
256 CRF when we used vector magnitude counts ($p < 0.01$) (Table 3). When we used the ENMO
257 measurements, there was a negative association with the wrist accelerometer ($p < 0.01$), while the
258 association with the hip accelerometer was borderline ($p = 0.057$). Furthermore, both placements
259 showed positive associations between all the specific intensities of PA and CRF when we used
260 the ENMO measurements or vector magnitude counts ($p < 0.05$) (Table 3). In accordance with the
261 J test, the wrist accelerometer data contained the correct sets of regressors more often than the
262 hip accelerometer data.

263 The supplementary analyses compared the associations of sedentary time and PA
264 with fat mass index, waist circumference and CRF. These were based on the ENMO
265 measurements and vector magnitude counts for both accelerometer positions, with Evenson's
266 vertical axis cut-off points being used for the hip (23). The time spent in sedentary time and PA, in
267 accordance with Evenson et al (23), are presented in Table S2. According to the findings (Table 3
268 and Table S3), the vertical axis counts produced similar results between sedentary time and the
269 fat mass index than the vector magnitude counts and the ENMO measurements ($p < 0.05$).
270 Furthermore, when it came to sedentary time and waist circumferences, the vertical axis counts
271 were comparable with all the measurements, except the hip accelerometer based on the ENMO

272 measurements ($p < 0.01$ and $p < 0.05$, respectively). The association between sedentary time and
273 CRF was stronger for the hip accelerometer using vertical axis counts rather than the ENMO
274 measurements ($p = 0.022$ versus $p = 0.057$). However, the associations were weaker when they
275 were compared to the others (all $p \leq 0.004$), as shown in Table 3 and Table S3.

276 The vertical axis counts were most comparable with the ENMO measurements
277 when it came to the PA levels and fat mass index for the hip accelerometer (Table 3 and Table
278 S3). When the vertical axis counts were used, the associations between PA levels and waist
279 circumference were only significant with regard to light PA and moderate-to-vigorous PA (both
280 $p < 0.05$), but there were borderline results for moderate PA and vigorous PA (both $p \leq 0.083$). The
281 associations between different PA levels and CRF were in line with all the other associations, but
282 stronger than the vector magnitude counts for the hip accelerometer (Table 3 and Table S3).

283

284 **DISCUSSION**

285

286 The main findings of this study were that wrist accelerometers caused less overall disturbance
287 than the hip accelerometers, but there were differences during the day and night. In addition, the
288 associations between sedentary time and PA with fatness and fitness were consistent between
289 the two accelerometer placements, although the wrist accelerometer produced slightly stronger
290 associations. Our findings demonstrate that the associations between sedentary time and PA with
291 fatness and fitness in children who were overweight or obese were similar between the hip and
292 wrist accelerometers, although the magnitude of the associations were different, partly due to the
293 metrics used. These results expand our knowledge about how differences in accelerometer
294 placements and data processing of raw signals from the accelerometer could affect the
295 relationships between PA and fatness and fitness.

296 To the best of our knowledge, there have not been any previous studies that have
297 examined the acceptability of children simultaneously wearing two accelerometers at the hip and
298 wrist. Such knowledge is important, as it can help researchers to improve how well children
299 comply with wearing monitors and this will, in turn, lead to more representative measurements of
300 daily sedentary time and PA. The findings of this study showed that wearing a wrist
301 accelerometer was less disturbing than wearing a hip accelerometer, yet the difference in overall
302 wearing time over the 24-hour periods did not reach statistical significance. However, the children
303 found that the wrist accelerometer disturbed them more during the day than at night, which was
304 reflected in the fact that wearing time was statistically higher for the hip than wrist accelerometers
305 during the day.

306 It is possible that the wrist accelerometer caused more disturbance during daily
307 living activities that required the subjects to use their hands, such as washing, dressing, eating
308 and studying. The differences in awake wearing time are interesting, since the children were
309 asked to always wear both the accelerometers at the same time and leave them attached for 24
310 hours for seven consecutive days. The hip accelerometer caused more disturbance at night and
311 that is probably why most studies tell participants to remove them at night. Wearing an
312 accelerometer that disturbs sleeping could also be reasonably expected to lead to lower
313 compliance. Yet, a previous study by Tudor-Locke et al (11) found that asking participants to
314 wear a hip accelerometer for 24 hours led to higher compliance during waking hours than only
315 asking them to wear them during waking hours and not at night. It is possible that compliance
316 was lower in the waking-hours protocol, because the participants forgot to put it on in the
317 morning. However, another study that used a waking-hours protocol found that compliance was
318 higher for wrist than hip accelerometers (9). Based on the current study, it is difficult to conclude
319 which one of the placements works better in terms of compliance. The conclusion that
320 researchers reach may be different depending on the research question. For example, if the aim
321 is to assess sedentary time and PA, the study's main interest may be in awake time and a hip
322 accelerometer may be the best option. But, if sleep time is one of the main interests, then a wrist
323 accelerometer may be more comfortable. This indicates that researchers should consider the
324 combined influences of the placement and the study protocol to maximise compliance.

325 In our study, the relationships between sedentary time and PA with fatness were
326 consistent with both the hip and wrist accelerometers. When we used the ENMO measurements,
327 the wrist accelerometer showed stronger associations between sedentary time and the fat mass
328 index and waist circumference than the hip accelerometer. However, when we used vector
329 magnitude counts, those associations showed greater similarities. In addition, the associations
330 were similar for the wrist accelerometers, regardless of whether they were gauged using the
331 ENMO measurements or the vector magnitude counts. The wrist placement showed a higher
332 consistency than the hip accelerometer in this regard. The inconsistency in our results may be
333 due to the different cut-off points or to differences in the methods used to process the
334 accelerometer data. It is also worth noting that the ENMO measurement cut-off points were
335 developed using the same protocol in the same study sample, namely asking the subjects to
336 simultaneously wear the wrist and hip accelerometers. This increased our ability to compare the
337 two accelerometer placements. When it came to the associations between the different intensities
338 of PA and the fat mass index and waist circumference, the ENMO measurements showed more
339 consistency than the vector magnitude counts. Moreover, the wrist accelerometer produced

340 consistently higher magnitudes than the hip unit, especially with regard to vector magnitude
341 counts. These findings were also supported by the J test.

342 These differences in the strength of the relationships between the measurements
343 obtained by the hip and wrist accelerometers may be explained by several factors. For example,
344 placements register the movement patterns of different body sites, but the filtering applied to the
345 raw accelerations to obtain the acceleration metrics data could work differently on the hip and
346 wrist. In addition, the cut-off points that we used came from different studies with different
347 samples and protocols and these could have produced different estimates. However, this was not
348 the case with the ENMO measurements.

349 Hip and wrist accelerometers led to similar associations between sedentary time
350 and CRF when using vector magnitude counts, while wrist accelerometer produced a somewhat
351 stronger association when using the ENMO measurement. This difference was also noted in the J
352 test results. PA was found to be associated with CRF in adolescents with overweight and obesity
353 and both the hip and wrist accelerometers reflected the association consistently.

354 There are number of studies that have used vertical or triaxial accelerometers and
355 there has also been growing interest in whether different placements provide similar information
356 about sedentary time and PA levels. Such knowledge could improve the ability of researchers to
357 compared the outcomes and conclusions of different studies. Therefore, we carried out
358 supplementary analyses to compare the associations between sedentary time and PA. These
359 were based on ENMO measurements and vector magnitude counts that were measured on the
360 hip and wrist. We also measured vertical axis counts on the hip and explored their associations
361 with fatness and fitness. We chose vertical axis counts based on Evenson's cut-off points (23),
362 since they have frequently been used to assess PA with accelerometers placed on the vertical
363 axis (5). According to our results, the overall associations were consistent between the different
364 metrics and placements. A potential explanation for the minor differences between vector
365 magnitude counts and vertical axis counts is that, because vector magnitude counts measure
366 movement in three planes, they are more sensitive to any kind of movement than vertical axis
367 counts. Thus, a horizontal movement could go unnoticed by vertical axis counts, but it would be
368 caught by vector magnitude counts. Because of that, vector magnitude counts may measure
369 higher sedentary time levels the associations may be stronger. However, with regard to
370 moderate-to-vigorous PA, the vertical axis is the main axis with regard to hip movement and the
371 movement in this plane is more important in terms of energy expenditure. This means that the
372 associations to moderate-to-vigorous PA will be stronger using vertical axis counts. That is why
373 any comparisons between different studies using vertical and triaxial accelerometers need to be
374 made with caution.

375

376 **Strengths and limitations**

377 A strength of the study was that we investigated the acceptability of wearing two accelerometers
378 simultaneously at different placements, the hip and wrist, while following a strict protocol. In
379 addition, we believe that this was the first study to compare the associations between sedentary
380 time and PA, based on accelerometer measurements on the hip and wrist, with fatness and
381 fitness. The accelerometer processes also allowed us to use two different metrics, the ENMO
382 measurements and vector magnitude counts. The cut-off points for the ENMO measurements
383 were developed using the same protocol with the same sample, which improves the validity of the
384 comparisons between the hip and wrist accelerometers. The measurements regarding fat mass
385 index and CRF were accurate and up-to-date, which improves the validity of the examined
386 associations.

387 The study had several limitations that should be recognised. The sample size in our
388 study was relatively small, but there has been a lack of studies that have investigated these
389 research questions. The questionnaire we used was created for the study and had not been
390 validated before use. Therefore, it is possible that the questions may have been somewhat
391 leading, for example in asking whether the participants had experienced any disturbance from
392 wearing the accelerometers. Furthermore, it was notable that the Romanzini's vector magnitude
393 counts that we used for the hip accelerometer were based on 15-second epochs (21), while
394 Chandler's vector magnitude counts for the wrist accelerometer were based on five-second
395 epoch lengths (22). Since the epoch length influences PA counts, it is possible that the different
396 lengths may have had minor effects on the findings. However, there are no valid cut-off points for
397 children using five-second epochs with a hip-worn accelerometer and that is why Romanzini's
398 cut-off points were the best choice for our study (21). In addition, since epochs of 1-15 seconds
399 have been recommended for use in children and adolescents (5), Romanzini and Chandler's cut-
400 off points are both in this range (21,22). Finally, due to the cross-sectional study design, any
401 conclusion about causality cannot be drawn from the association of sedentary time and PA with
402 fatness and fitness. However, the primary aim of the study was not to investigate the
403 associations, but to compare the associations between hip and wrist accelerometers and related
404 factors.

405 The ActiveBrains project only targeted overweight and obese children, as Spain has
406 one of the highest percentages of such children aged 7-11 years in Europe. Therefore, our results
407 cannot be generalised to normal weight children. Future studies should confirm these findings
408 using larger samples sizes and by including different age and weight groups. In addition, because
409 different accelerometers lead to somewhat different PA levels (9), comparing our results to

410 studies that have used other brands than the ActiGraph, such as the GENEActive, should be
411 done with caution until our findings have been confirmed using other brands.

412

413 **CONCLUSION**

414

415 Overall, wearing hip accelerometers disturbed the children more during the night than wearing
416 them on their wrists, but less during the day. They were asked to wear both accelerometers at the
417 same time and there was no statistically significant difference in wearing time, which suggests
418 that they complied with the instructions. Both accelerometers produced consistent associations
419 between sedentary time and PA with fatness and fitness, but the wrist accelerometer led to
420 somewhat stronger associations and these were supported by the additional analyses. There was
421 a difference between the hip and wrist accelerometers, particularly when using vector magnitude
422 counts rather than the ENMO measurements, and more differences in fatness indicators than in
423 CRF.

424

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439

440 **CONFLICTS OF INTEREST**

441 The authors declare no conflict of interests.

442

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518

Figure legends

Figure 1. The acceptability of wearing the accelerometers (n=82).

Accepted Article

Table 1. Descriptive characteristics of the study sample.

Characteristics	All (n=103)		Boys (n=60)		Girls (n=43)	
	Mean \pm SD	Min–max	Mean \pm SD	Min–max	Mean \pm SD	Min–max
Age (years)	10.1 \pm 1.1	7.9 – 12.0	10.2 \pm 1.2	7.9 – 11.9	9.9 \pm 1.1	8.0 – 12.0
Peak height velocity (years)	12.3 \pm 0.7	11.0 – 13.7	12.8 \pm 0.4	12.0 – 13.7	11.6 \pm 0.3	11.0 – 12.5
Height (cm)	144.3 \pm 8.3	123.1 – 166.0	144.9 \pm 7.9	127.9 – 166.0	143.6 \pm 8.9	123.1 – 161.0
Weight (kg)	56.2 \pm 10.8	29.9 – 78.9	56.8 \pm 10.7	36.7 – 78.5	55.4 \pm 11.1	29.9 – 78.9
Body mass index (kg/m ²)	26.8 \pm 3.5	19.7 – 36.5	26.9 \pm 3.6	20.8 – 36.5	26.7 \pm 3.5	19.7 – 33.6
Overweight ¹ (n, %)	26 (25.2)		15 (25.0)		11 (25.6)	
Obesity ¹ (n, %)	77 (74.8)		45 (75.0)		32 (74.4)	
Waist circumference (cm)	90.3 \pm 9.4	69.0 – 111.5	91.1 \pm 8.8	70.0 – 108.5	89.2 \pm 10.2	69.0 – 111.5
Fat mass (%)	44.1 \pm 5.3	33.9 – 59.4	42.8 \pm 4.8	33.9 – 59.4	45.8 \pm 5.6	34.6 – 57.8
Fat mass index (kg/m ²)	11.8 \pm 2.8	7.0 – 22.2	11.5 \pm 2.8	7.1 – 22.2	12.2 \pm 2.8	7.0 – 18.4
Fat mass index z-score	0.02 \pm 0.96	-2.46 – 2.46	-0.03 \pm 0.94	-1.89 – 2.10	0.09 \pm 0.99	-2.46 – 2.46
Cardiorespiratory fitness (VO ₂ max, mL/kg/min)	37.3 \pm 4.7	27.8 – 51.2	37.7 \pm 4.8	27.8 – 51.2	36.7 \pm 4.5	28.4 – 47.8
Parental educational level (n, %)						
Neither parents had a university degree	68 (66.0)		43 (71.7)		25 (58.1)	
One parent had a university degree	18 (17.5)		9 (15.0)		9 (20.9)	
Both parents had university degrees	17 (16.5)		8 (13.3)		9 (20.9)	

¹According to the World Obesity Federation cut-offs. (25). VO₂ max, maximal oxygen uptake.

Table 2. Total wear time, sedentary time and different PA intensities as measured by hip and wrist accelerometers in 103 subjects

Accelerometer characteristics	Hip		Wrist		p value for difference ¹
	Mean \pm SD	Min–max	Mean \pm SD	Min–max	
Valid days	6.8 \pm 0.5	4 – 7	6.9 \pm 0.5	4 - 7	0.26
Wearing time (over 24 hours) (hours/day)	23.6 \pm 0.3	22.4 – 24.1 ²	23.7 \pm 0.3	22.5 – 24.1 ²	0.058
Awake wearing time (min/day)	919.1 \pm 31.6	841.7 – 990.4	902.9 \pm 28.7	826.3 – 979.0	<0.001
Mean ENMO ³ (mg)	24.8 \pm 6.3	10.5 – 41.7	61.2 \pm 14.2	33.0 – 100.9	<0.001
Mean VM counts ⁴ (counts/5-15 sec)	77.4 \pm 17.4	39.7 – 123.2	300.6 \pm 46.1	188.2 – 433.2	<0.001
ENMO³ (min/day)					
Sedentary time	817.4 \pm 44.7	739.5 – 933.5	565.1 \pm 56.4	405.3 – 723.2	<0.001
Light PA	65.8 \pm 15.8	28.6 – 114.8	282.7 \pm 38.5	192.1 – 396.3	<0.001
Moderate PA	32.9 \pm 13.9	5.9 – 71.2	47.5 \pm 17.4	14.3 – 95.7	<0.001
Vigorous PA	3.0 \pm 2.0	0.2 – 10.0	7.6 \pm 4.4	1.0 – 20.5	<0.001
Moderate-to-vigorous PA	36.0 \pm 15.3	6.6 – 76.7	55.1 \pm 21.0	15.7 – 116.2	<0.001
VM counts⁴ (min/day)					
Sedentary time	628.3 \pm 68.2	454.2 – 794.4	576.4 \pm 53.9	425.8 – 747.4	<0.001
Light PA	198.2 \pm 41.5	106.1 – 306.8	239.0 \pm 29.5	160.1 – 323.9	<0.001
Moderate PA	53.8 \pm 14.4	18.5 – 99.1	81.2 \pm 20.1	40.8 – 139.1	<0.001
Vigorous PA	37.9 \pm 16.1	9.1 – 83.6	6.2 \pm 3.6	1.2 – 17.2	<0.001

Moderate-to-vigorous PA	91.7 ± 28.2	27.6 – 175.8	87.5 ± 22.5	42.9 – 155.6	0.027
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Abbreviations: ENMO, Euclidean norm minus one; VM, vector magnitude; PA, physical activity; SD, standard deviation.

¹ Paired samples t-test.

² Some participants were monitored on the day when the clocks went back and that means there was one 25-hour day in the measurements.

³ Classified according to Hildebrand et al (19,20).

⁴ Classified according to Romanzini et al (21) for the hip accelerometer and according to Chandler et al (22) for the wrist accelerometer.

Table 3. Linear regression analyses showing the associations between sedentary time and PA with fatness and fitness using two different attachment sites for the accelerometers (hip and wrist) and two different metrics (ENMO and VM counts) (n=103).

	Fat mass index				Waist circumference				Cardiorespiratory fitness			
	Hip ¹		Wrist ²		Hip ¹		Wrist ²		Hip ¹		Wrist ²	
	β	p value	β	p value	β	p value	β	p value	β	p value	β	p value
ENMO												
Sedentary time	0.24	0.013*	0.30	0.002*	0.20	0.037	0.31	0.001*	-0.19	0.057	-0.30	0.003*
Light PA	-0.25	0.012*	-0.19	0.052*	-0.19	0.055*	-0.19	0.056*	0.25	0.013*	0.26	0.011*
Moderate PA	-0.33	0.002	-0.42	<0.001*	-0.22	0.040	-0.43	<0.001*	0.31	0.004	0.42	<0.001*
Vigorous PA	-0.42	<0.001*	-0.42	<0.001	-0.36	0.001*	-0.43	<0.001*	0.40	<0.001*	0.31	0.009
MVPA	-0.36	0.001	-0.45	<0.001*	-0.25	0.020	-0.46	<0.001*	0.34	0.002	0.43	<0.001*
VM counts												
Sedentary time	0.31	0.001*	0.28	0.005*	0.32	0.001*	0.31	0.001*	-0.30	0.003*	-0.28	0.005*
Light PA	-0.31	0.002*	-0.15	0.15	-0.34	<0.001*	-0.17	0.091	0.32	0.001*	0.22	0.034
Moderate PA	-0.17	0.098	-0.37	<0.001*	-0.15	0.15	-0.37	<0.001*	0.21	0.041	0.40	<0.001*
Vigorous PA	-0.27	0.014	-0.42	<0.001*	-0.20	0.076	-0.40	<0.001*	0.33	0.004*	0.31	0.005*
MVPA	-0.25	0.024	-0.40	<0.001*	-0.20	0.071	-0.40	<0.001*	0.30	0.006	0.41	<0.001*

Abbreviations: ENMO, Euclidean norm minus one; PA, physical activity; MVPA, moderate-to-vigorous-intensity PA; VM, vector magnitude; β , standardized regression coefficient.

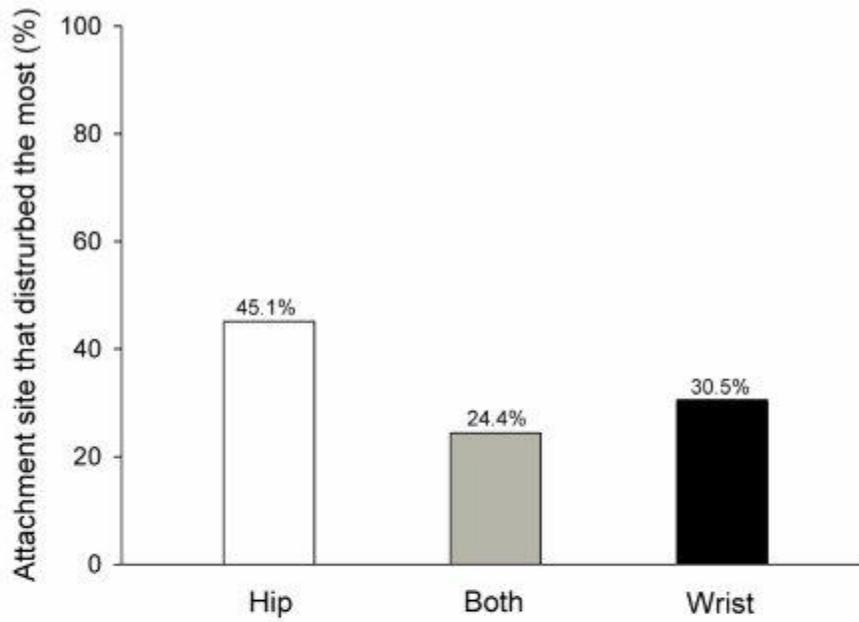
Adjusted for the child's sex, peak height velocity, wave of the measurements, and parental educational level.

¹ ENMO was classified according to Hildebrand et al (19,20), and VM counts were classified according to Romanzini et al (21).

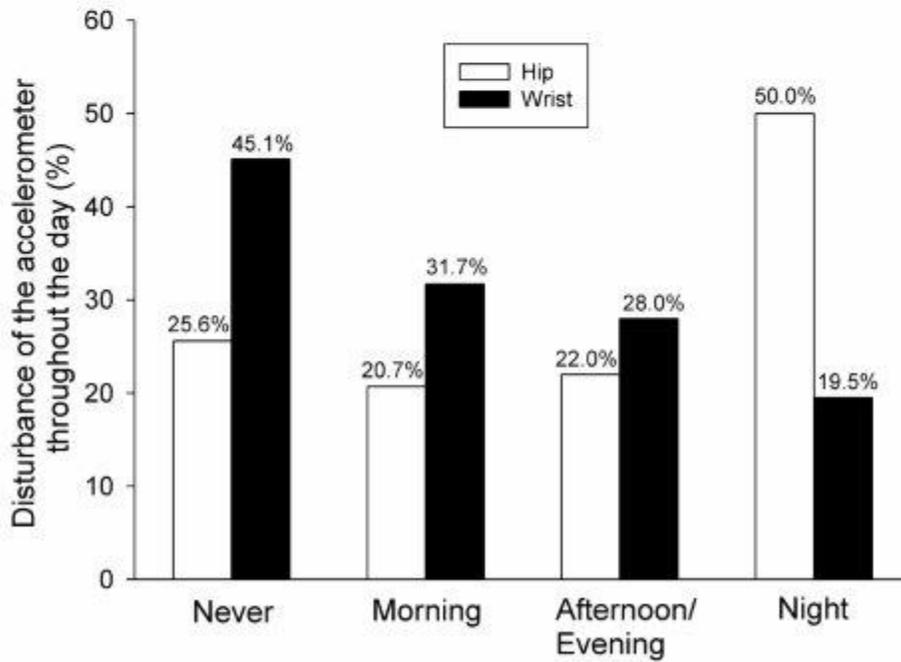
² ENMO was classified according to Hildebrand et al (19,20), and VM counts were classified according to Chandler et al (22).

The * shows which models contained the correct set of regressors in accordance with the J test ($p > 0.05$) (30).

A)



B)



apa_15043_f1.jpg