Author(s): Leppänen, M. H.; Migueles, J. H.; Cadenas-Sanchez, C.; Henriksson, P.; Mora-Gonzalez, J.; Henriksson, H.; Labayen, I.; Löf, M.; Esteban-Cornejo, I.; Ortega, F. B.

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

Year: 2020

Version: Accepted version (Final draft)

Please cite the original version:

Leppänen, M. H., Migueles, J. H., Cadenas-Sanchez, C., Henriksson, P., Mora-Gonzalez, J., Henriksson, H., Labayen, I., Löf, M., Esteban-Cornejo, I., & Ortega, F. B. (2020). Hip and wrist accelerometers showed consistent associations with fitness and fatness in children aged 8-12 years. Acta Paediatrica, 109(5), 995-1003. https://doi.org/10.1111/apa.15043

DR. MARJA H LEPPÄNEN (Orcid ID : 0000-0001-6933-8809)

Article type : Regular Article

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

MH Leppänen[1,2], JH Migueles[3], C Cadenas-Sanchez[3], P Henriksson[2,4], J Mora-Gonzalez[3], H Henriksson[4], I Labayen[5], M Löf[2,4], I Esteban-Cornejo[3,6], FB Ortega[3]

[1]Faculty of Sport and Health Sciences, University of Jyväskylä, FI-40014 University of Jyväskylä, Finland
[2]Department of Biosciences and Nutrition, Karolinska Institutet, SE-141 83 Huddinge, Sweden
[3]PROmoting FITness and Health through physical activity research group (PROFITH), Department of Physical and Sports Education, Faculty of Sport Sciences, University of Granada, 18071 Spain
[4]Department of Medicine and Health, Linköping University, Linköping SE-581 83, Sweden
[5]Institute for Innovation & Sustainable Development in Food Chain (IS-FOOD), Public University of Navarra, 31006 Pamplona, Navarra, Spain
[6]Center for Cognitive and Brain Health, Department of Psychology, Northeastern University, Boston, MA, USA

Short title: Comparing hip and wrist accelerometers

Corresponding author: MH Leppänen, University of Jyvaskyla, P.O. Box 35, FI-40014 University of Jyvaskyla, Finland, Tel: +358447881067, Email: marja.leppanen@folkhalsan.fi

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/APA.15043

ABBREVIATIONS

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

ABSTRACT

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

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

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

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

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

KEY NOTES

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

INTRODUCTION

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

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

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

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

METHODS

Study design and participants

This study used cross-sectional data collected between 2014-2016 for the ActiveBrains project by the University of Granada, Spain. It was a randomised controlled trial that aimed to examine the effects of a physical exercise programme on the brain, cognition and physical and mental health. The details of the project have previously been described by Cadenas-Sanchez et al (17). Briefly, the project focused on 109 overweight and obese Spanish children (65% boys) aged 8-12 years. It compared 57 children who underwent a 20-week programme of three to five extra after-school sessions lasting 90 minutes and 52 controls. The current study comprised 103 children (62% boys) aged 8-12 years with complete baseline data on sedentary time, PA, fatness and cardiorespiratory fitness (CRF). Their parents provided written, informed consent for them to participate in the study. The trial was approved by the Ethics Committee on Human Research at the University of Granada (number 848, February 2014) and registered at ClinicalTrials.gov (NCT02295072).

Data collection

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

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

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

Body weight in kilograms was measured with a SECA 861 electronic scale (SECA GmbH, Hamburg, Germany) and height in centimetres was assessed using a SECA 225 precision stadiometer (SECA GmbH). The children's body mass index (BMI) was calculated as body weight in kilograms divided by height squared in metres and overweight was defined using sex and age specific international BMI standards (25). Waist circumference was measured twice at the mid-distance between the bottom of the rib cage and the top of the iliac crest and the mean of the two values was used in the analyses. Fat mass in kilograms was measured by dual-energy X-ray absorptiometry using a Discovery (Horizon® DXA system) densitometer (Hologic Canada ULC, Ontario Canada), as previously described (26). The fat mass index was calculated as fat mass in kilograms divided by height in square metres. Because two different dual-energy X-ray machines were used in the measurements, z-scores were calculated for the fat mass indexes. The fat mass index and waist circumference were used as estimates of total and central adiposity, respectively.

CRF was measured using a maximal incremental treadmill test with the h/p/cosmos ergometer (h/p/cosmos sports and medical GmbH, Munich, Germany) using a modified protocol for children (27). It was performed using a COSMED gas analyser (COSMED, Rome, Italy). Participants walked on a treadmill at a constant speed of 4.8 kilometres per hour with a 6% slope with grade increments of 1% every minute until volitional exhaustion. They were encouraged to walk as long as they could. The test was carried out by clinicians from the Andalusian Centre of Sport Medicine. Maximal oxygen consumption in mL/kg/min, heart rate and the respiratory exchange ratio were measured every 10 seconds. The maximal oxygen consumption was confirmed when three out of four criteria were met. These were: volitional fatigue, defined as more than eight points in the OMNI scale, a plateau in maximal oxygen consumption during the last two exercise work rates (<2.0 mL·kg^{-1}·min^{-1}), achieving more than 85% of the age-predicted maximum heart rate, and a respiratory exchange ratio of ≥1.10 (28).

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

Statistical methods

Descriptive information is given as arithmetic means and standard deviations (SD) or frequencies and percentages. Linear regression analysis was used to assess the associations of intensity-specific PA, based on both the ENMO measurements and vector magnitude counts with fatness and fitness. Fatness was fat mass index and waist circumference and fitness was defined as CRF. Each model was adjusted for the child's sex, the continuous variable of peak height velocity and the categorical variables of the wave of the measurements and parental educational level due to their potential effect on the study outcomes. The paired samples t-test was used to assess the differences between the characteristics of hip and wrist accelerometers. In addition, we used the J test (30) to examine whether the associations between PA and fatness and fitness differed statistically between the hip and wrist accelerometers. PA measurements have been commonly taken from hip-based accelerometers (5) using the vertical axis based on Evenson's cut-off points (23). Our supplementary analyses examined whether the associations of sedentary time and PA differed from the associations based on the vertical axis counts, when we used the ENMO measurements and vector magnitude counts with fat mass index, waist circumference and CRF. We also investigated if the associations differed by sex by adding an interaction term into the regression models. As sex had no significant interaction effects on the analyses, the results for both sexes are presented together. Although we are presenting cross-sectional analyses, it is worth noting that an alpha error of 5%, a sample size of 103 and a statistical power of 95% identified a medium effect size. G*power software, version 3.0.1 (Heinrich Heine University, Dusseldorf, Germany) was used for the calculations. All the statistical tests were conducted using the two-sided 5% level of significance and performed using SPSS Statistics 24 (IBM Corp, New York, USA), except the J tests, which were conducted using Stata Statistical Software version 15.0 (StataCorp LLC, Texas, USA).

RESULTS

The 103 children who took part in the study had an average BMI of 26.8 kg/m^2, fat mass index of 11.8 kg/m^2, waist circumference 90.3cm, and CRF of 37.3 mL/kg/min (Table 1). Their mean age was 10.1 ±1.1 years (range 7.9 to 12.0 years).

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

The ENMO measurements during sedentary time showed positive associations with the fat mass index and waist circumference for both the hip and wrist accelerometer, but the wrist accelerometer produced slightly stronger associations ($p<0.05$) as shown in Table 3. When we used vector magnitude counts, both the placements showed similar significant associations with fat mass index and waist circumference ($p<0.01$). The ENMO measurements showed that higher moderate PA, vigorous PA and moderate-to-vigorous PA were significantly associated with lower fat mass index with the hip accelerometer (all $p\leq0.01$) and wrist accelerometer (all $p<0.001$). The same was true for waist circumference (both $p<0.05$), although the wrist accelerometer led to slightly stronger associations overall (Table 3). When we used the vector magnitude counts, both placements showed that higher vigorous PA or moderate-to-vigorous PA were associated with a lower fat mass index. However, the wrist accelerometer produced stronger associations ($p<0.001$) than the hip accelerometer ($p<0.05$). Only the wrist accelerometer led to significant associations between moderate PA, vigorous PA, or moderate-to-vigorous PA and waist circumference (all $p<0.001$) (Table 3). Furthermore, light PA with the hip accelerometer was significantly associated with the fat mass index and waist circumference (both $p<0.01$). The J test results showed that the wrist accelerometer contained the correct sets of regressors in most of the models when compared to the hip accelerometer ($p>0.05$). The latter contained the correct sets of regressors in fewer models (Table 3).

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

The supplementary analyses compared the associations of sedentary time and PA with fat mass index, waist circumference and CRF. These were based on the ENMO measurements and vector magnitude counts for both accelerometer positions, with Evenson's vertical axis cut-off points being used for the hip (23). The time spent in sedentary time and PA, in accordance with Evenson et al (23), are presented in Table S2**.** According to the findings (Table 3 and Table S3), the vertical axis counts produced similar results between sedentary time and the fat mass index than the vector magnitude counts and the ENMO measurements ($p<0.05$). Furthermore, when it came to sedentary time and waist circumferences, the vertical axis counts were comparable with all the measurements, except the hip accelerometer based on the ENMO measurements ($p<0.01$ and $p<0.05$, respectively). The association between sedentary time and CRF was stronger for the hip accelerometer using vertical axis counts rather than the ENMO measurements ($p=0.022$ versus $p=0.057$). However, the associations were weaker when they were compared to the others (all $p \leq 0.004$), as shown in Table 3 and Table S3.

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

DISCUSSION

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

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

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

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

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

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

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

Strengths and limitations

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

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

The ActiveBrains project only targeted overweight and obese children, as Spain has one of the highest percentages of such children aged 7-11 years in Europe. Therefore, our results cannot be generalised to normal weight children. Future studies should confirm these findings using larger samples sizes and by including different age and weight groups. In addition, because different accelerometers lead to somewhat different PA levels (9), comparing our results to studies that have used other brands than the ActiGraph, such as the GENEActive, should be done with caution until our findings have been confirmed using other brands.

CONCLUSION

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

FUNDING

This study was conducted under the umbrella of the ActiveBrains and the SmarterMove projects supported by the MINECO/FEDER (DEP2013-47540, DEP2016-79512-R, RYC-2011-09011). Other study funders were: the University of Granada, Research and Knowledge Transfer Fund 2016; Excellence actions: Scientific Units of Excellence; the Unit of Excellence on Exercise and Health, the Andalusian Regional Government, Consejeria de Conocimiento, Investigacion y Universidades, the European Regional Development Fund (SOMM17/6107/UGR), the SAMID III network (RETICS); the ISCIII- Sub-Directorate General for Research Assessment and Promotion, the EXERNET Research Network on Exercise and Health in Special Populations (DEP2005-00046/ACTI) and the European Union's 2020 research and innovation programme (grant number) 667302. Further funding for individual authors came from the Spanish Ministry of Education, Culture and Sport (FPU15/02645), the Spanish Ministry of Economy and Competitiveness (BES-2014-068829), the Strategic Research Area Health Care Science, Karolinska Institutet and Umeå University and the Alicia Koplowitz Foundation.

CONFLICTS OF INTEREST

The authors declare no conflict of interests.

REFERENCES

1. 2018 Physical Activity Guidelines Advisory Committee. 2018 Physical Activity Guidelines Advisory Committee Scientific Report. Washington, DC: U.S. Department of Health and Human Services, 2018.

2. World Health Organization. Global status report on noncommunicable diseases 2014. Geneva: World Health Organization; 2015.

3. Pulgarón ER. Childhood obesity: A review of increased risk for physical and psychological comorbidities. *Clin Ther* 2013;35(1):A32.

4. Ross R, Blair S, Arena R, et al. Importance of assessing cardiorespiratory fitness in clinical practice: A case for fitness as a clinical vital sign: A scientific statement from the American Heart Association. *Circulation* 2016;134(24):e699.

5. Migueles J, Cadenas-Sanchez C, Ekelund U, et al. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. *Sports Med* 2017;47(9):1821-1845.

6. Strath S, Kaminsky L, Ainsworth B, et al. Guide to the assessment of physical activity: Clinical and research applications: A scientific statement from the American Heart Association. *Circulation* 2013;128(20):2259-2279.

7. Borde R, Smith JJ, Sutherland R, Nathan N, Lubans DR. Methodological considerations and impact of school-based interventions on objectively measured physical activity in adolescents: A systematic review and meta-analysis. *Obes Rev* 2017;18(4):476-490.

8. Levin S, Jacobs DR, Ainsworth BE, Richardson MT, Leon AS. Intra-individual variation and estimates of usual physical activity. *Ann Epidemiol* 1999;9(8):481-488.

9. Fairclough S, Noonan R, Rowlands A, Van Hees V, Knowles Z, Boddy L. Wear compliance and activity in children wearing wrist- and hip-mounted accelerometers. *Med Sci Sports Exerc* 2016;48(2):245-253.

10. Choi L, Ward SC, Schnelle JF, Buchowski MS. Assessment of wear/nonwear time classification algorithms for triaxial accelerometer. *Med Sci Sports Exerc* 2012;44(10):2009-2016.

11. Tudor-Locke C, Barreira TV, Schuna J, John M, et al. Improving wear time compliance with a 24-hour waist-worn accelerometer protocol in the international study of childhood obesity, lifestyle and the environment (ISCOLE). *Int J Behav Nutr Phys Act* 2015;12(1):11.

12. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the united states measured by accelerometer. *Med Sci Sports Exerc* 2008;40(1):181-188.

13. Sherar LB, Griew P, Esliger DW, et al. International children's accelerometry database (ICAD): Design and methods. *BMC Public Health* 2011;11(1):485.

14. Rosenberger ME, Haskell WL, Albinali F, Mota S, Nawyn J, Intille S. Estimating activity and sedentary behavior from an accelerometer on the hip or wrist. *Med Sci Sports Exerc* 2013;45(5):964.

15. Doherty A, Jackson D, Hammerla N, et al. Large scale population assessment of physical activity using wrist worn accelerometers: The UK biobank study. *PLoS One* 2017;12(2):e0169649.

16. Ortega FB, Cadenas-Sanchez C, Lee D, Ruiz JR, Blair SN, Sui X. Fitness and fatness as health markers through the lifespan: An overview of current knowledge. *Prog Prev Med* 2018; 3: e0013.

17. Cadenas-Sánchez C, Mora-González J, Migueles JH, et al. An exercise-based randomized controlled trial on brain, cognition, physical health and mental health in overweight/obese children (ActiveBrains project): Rationale, design and methods. *Contemp Clin Trials* 2016;47:315-324.

18. Migueles JH, Rowlands AV, Huber F, Sabia S, van Hees VT. GGIR: A Research Community–Driven Open Source R Package for Generating Physical Activity and Sleep Outcomes From Multi-Day Raw Accelerometer Data. *J Meas Phys Beh*av 2019;2(3):188–196.

19. Hildebrand M, Van Hees VT, Hansen BH, Ekelund U. Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Med Sci Sports Exerc* 2014;46(9):1816-1824.

20. Hildebrand M, Hansen BH, van Hees VT, Ekelund U. Evaluation of raw acceleration sedentary thresholds in children and adults. *Scand J Med Sci Sports* 2017;27(12):1814-1823.

21. Romanzini M, Petroski EL, Ohara D, Dourado AC, Reichert FF. Calibration of ActiGraph GT3X, actical and RT3 accelerometers in adolescents. *Eur J Sport Sci* 2014;14(1):91-99.

22. Chandler JL, Brazendale K, Beets MW, Mealing BA. Classification of physical activity intensities using a wrist-worn accelerometer in 8–12-year-old children. *Pediatr Obes* 2016;11(2):120-127.

23. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci* 2008;26(14):1557-1565.

24. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc* 2011;43(7):1360-1368.

25. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatr Obes* 2012;7(4):284-294.

26. Gracia-Marco L, Ortega F, Jiménez-Pavón D, et al. Adiposity and bone health in spanish adolescents. the HELENA study. *Osteoporos Int* 2012;23(3):937-947.

27. Davis CL, Pollock NK, Waller JL, et al. Exercise dose and diabetes risk in overweight and obese children: A randomized controlled trial. *JAMA* 2012;308(11):1103-1112.

28. ACSM's guidelines for exercise testing and prescription. 9. ed. ed. Baltimore, MD: Wolters Kluwer, Lippincott Williams & Wilkins; 2014: 72-93.

29. Moore S, McKay H, MacDonald H, et al. Enhancing a somatic maturity prediction model. *Med Sci Sports Exerc* 2015;47(8):1755-1764.30. Greene WH. Econometric Analisys, 4. ed. Prentice Hall International Editions; 2000: 302-305.

Figure legends

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

Table 1. Descriptive characteristics of the study sample.

Characteristics	All (n=103)		Boys (n=60)		Girls (n=43)	
	Mean ± SD	**Min–max**	**Mean ± SD**	**Min–max**	**Mean ± SD**	**Min–max**
Age (years)	10.1 ± 1.1	7.9 – 12.0	10.2 ± 1.2	7.9 – 11.9	9.9 ± 1.1	8.0 – 12.0
Peak height velocity (years)	12.3 ± 0.7	11.0 – 13.7	12.8 ± 0.4	12.0 – 13.7	11.6 ± 0.3	11.0 – 12.5
Height (cm)	144.3 ± 8.3	123.1 – 166.0	144.9 ± 7.9	127.9 – 166.0	143.6 ± 8.9	123.1 – 161.0
Weight (kg)	56.2 ± 10.8	29.9 – 78.9	56.8 ± 10.7	36.7 – 78.5	55.4 ± 11.1	29.9 – 78.9
Body mass index (kg/m^2)	26.8 ± 3.5	19.7 – 36.5	26.9 ± 3.6	20.8 – 36.5	26.7 ± 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 ± 9.4	69.0 – 111.5	91.1 ± 8.8	70.0 – 108.5	89.2 ± 10.2	69.0 – 111.5
Fat mass (%)	44.1 ± 5.3	33.9 – 59.4	42.8 ± 4.8	33.9 – 59.4	45.8 ± 5.6	34.6 – 57.8
Fat mass index (kg/m^2)	11.8 ± 2.8	7.0 – 22.2	11.5 ± 2.8	7.1 – 22.2	12.2 ± 2.8	7.0 – 18.4
Fat mass index z-score	0.02 ± 0.96	-2.46 – 2.46	-0.03 ± 0.94	-1.89 – 2.10	0.09 ± 0.99	-2.46 – 2.46
Cardiorespiratory fitness (VO_2max, mL/kg/min)	37.3 ± 4.7	27.8 – 51.2	37.7 ± 4.8	27.8 – 51.2	36.7 ± 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)	

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

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***

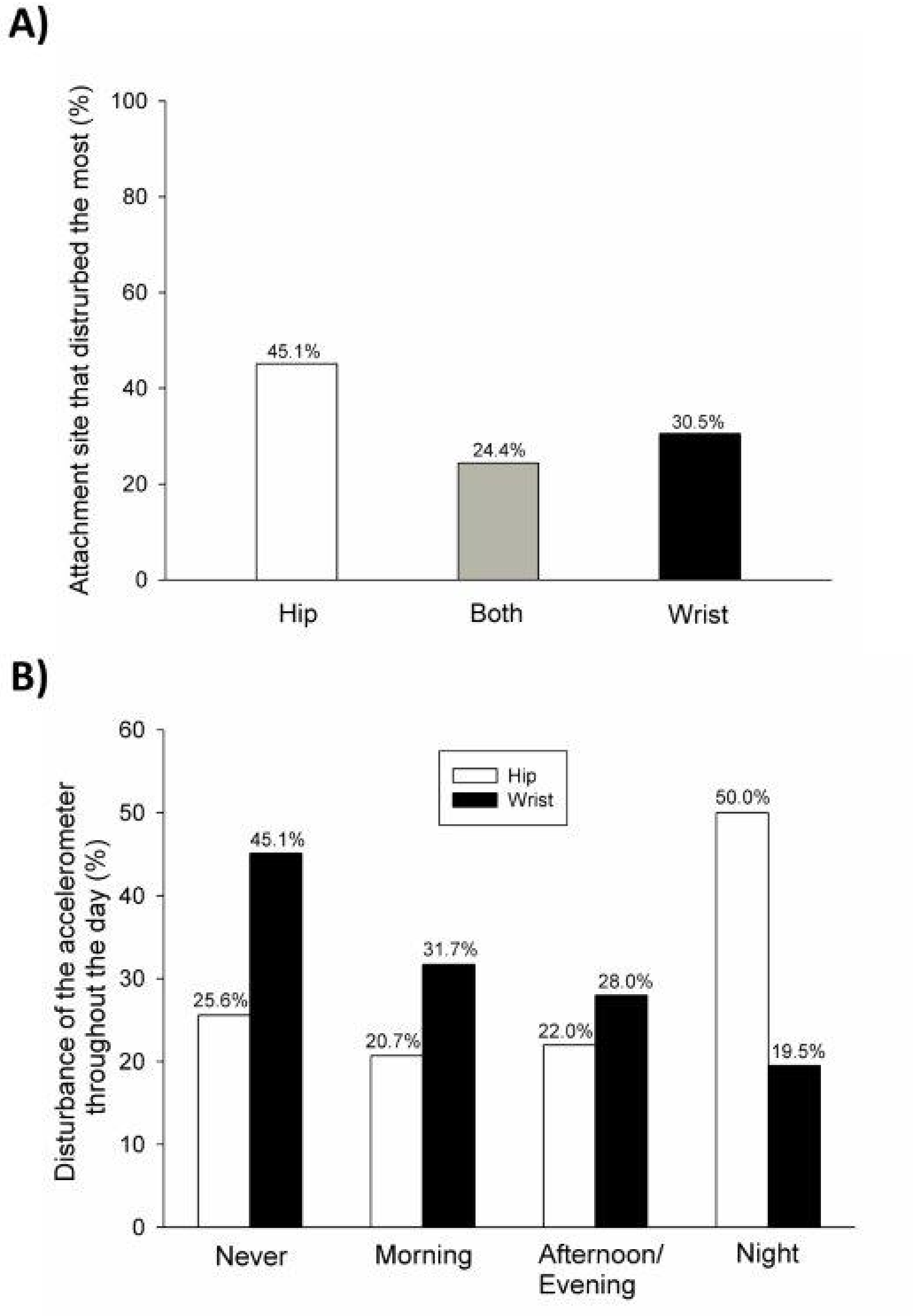
Abbreviations: ENMO, Euclidean norm minus one; PA, physical activity; MVPA, moderate-to-vigorous-intensity PA; VM, vector magnitude; β, standardized regression coefficient.

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).



apa_15043_f1.jpg