Title

Comparability of published cut-points for the assessment of physical activity: Implications for data harmonization

Running head:

Effect of cut-points on physical activity

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Abstract

This study aimed to compare estimations of sedentary time (SED) and time spent in physical activity (PA) intensities in children with overweight/obesity across different age-appropriate cut-points based on different body-worn attachment sites and acceleration metrics. A total of 104 overweight/obese children (10.1±1.1 years old, 43 girls) concurrently wore ActiGraph GT3X+ accelerometers on their right hip and non-dominant wrist for 7 days (24 hours). Euclidean Norm Minus One *g* (ENMO) and activity counts from both vertical axis (VACounts) and vector magnitude (VMCounts) were derived. We calculated estimates of SED and light, moderate, vigorous, and moderate-to-vigorous (MVPA) intensity PA using different published cut-points for children. The prevalence of children meeting the recommended 60 min/day of MVPA was calculated. The time spent in SED and the different PA intensities largely differed across cut-points based on different attachment sites and acceleration metrics (i.e., SED = 11-252 min/day; light PA = 10-217 min/day; moderate PA = 1-48 min/day; vigorous PA = 1-35 min/day; MVPA = 4-66 min/day). Consequently, the prevalence of children meeting the recommended 60 min/day of MVPA varied from 8% to 96% of the study sample. The present study provides a comprehensive comparison between available cut-points for different attachment and acceleration metrics in children. Furthermore, our data clearly show that it is not possible (and probably will never be) to know the prevalence of meeting the PA guidelines based on accelerometer data since apparent differences range from almost zero to nearly everyone meeting the guidelines.

Keywords (3-8): Activity monitor; exercise; sedentary lifestyle; lifestyle behaviors; adolescent; youth.

1. Introduction

Accurate and objective estimations of daily sedentary time (SED) and physical activity (PA) are important to estimate the prevalence of populations meeting the current PA guidelines, to assess the success of interventions aiming to increase PA in specific populations, to explore population activity trends, and to quantify the dose-response impact of SED and PA on health [1]. Accelerometers are feasible tools to objectively assess SED and PA in large-scale studies, but their utilization requires standardized data collection (e.g., attachment site) and processing criteria (e.g., how to filter the raw accelerations), both demonstrating a high potential to affect the estimation of PA [2]. Additionally, protocols and methods vary largely across studies which aims to develop cut-points (e.g., differences in the exercise protocols or the measurement of energy expenditure), resulting in differences in the identification and application of cut-points, i.e., intensity thresholds for SED and PA intensity classification. Since SED refers to any waking behavior in a reclining posture with requires low related energy expenditure [3], it is important to note that SED estimations based on cut-points are limited because they are not able to detect changes in posture. Many authors have called for a harmonization of data collection, processing criteria, and selection of cut-points to assess SED and PA in order to gain comparability between studies [2,4,5]. This harmonization would be of special interest to compare data across studies, especially when the populations assessed are similar. To date, such harmonization and consensus is not available.

Data collection decisions include selecting a device, the body attachment site (i.e., hip or wrist in the majority of studies) and the sampling frequency for the recording (usually between 30-100 Hz) [2]. The traditional hip attachment site is being replaced with a wrist location by some consumer-grade manufacturers (e.g., FitBit, Polar, Garmin, or Up) and by large-scale studies, such as the US National Health and Nutrition Examination Survey (NHANES) and the UK Biobank. This strategy was undertaken as an effort to obtain a higher wear compliance [2,6,7]. Both hip and wrist attachment sites have been validated for classifying PA intensities [2,8–10], and are potentially able to assess energy expenditure during free-living conditions in different populations [11,12], yet due to differences in the protocols used in cut-point validation studies it is unknown how well measures from the hip and wrist compare to each other.

The main purpose of processing criteria is to get a clean estimate of body accelerations by removing gravity acceleration and noise from the acceleration signal. The first commercially available accelerometers coerced researchers into using the manufacturer's activity counts (i.e., accelerations due to body movement) from the vertical axis (VACounts) or vector magnitude (VMCounts) derived from proprietary algorithms. These activity counts were hardly comparable between devices, or even between different models from the same manufacturer [13,14]. However, contemporary accelerometers are capable of storing high-frequency raw accelerations, which are highly comparable between frequently used research-grade devices (i.e., ActiGraph, GENEActiv, and Axivity) [15]. In the last five years, researchers have published open source methods to process raw accelerations in order to obtain alternative acceleration metrics to activity counts [16,17]. Euclidean Norm of raw accelerations Minus One *g* (ENMO) is now widely used and has shown a high agreement between brands [15,18], facilitating data harmonization across studies.

As the process of harmonizing data collection and processing criteria proceeds, it is important to study how different body attachment sites, acceleration metrics, and cut-points affect the final estimations of SED and PA intensities. Rowlands et al. reported a moderate agreement between moderate-to-vigorous PA (MVPA) estimates derived using different cut-points based on ENMO from wrist accelerations and classical activity counts thresholds based on hip-worn devices [19]. In contrast, other studies comparing cut-points developed independently for different attachment sites and acceleration metrics have reported large differences across MVPA estimates in adolescents [4] and adults [5]. Although there is an increasing interest in the study of SED and light intensity PA [20], previous studies have only focused on MVPA.

Therefore, there is a need to better understand how data collection, processing criteria, and cut-points influence estimations of SED and PA in different populations, including children and those classified as overweight/obese. Thus, this study aimed to examine how cut-points relative to different attachment sites and acceleration metrics affect the final estimations of SED and PA in children with overweight/obesity.

2. Methods

The present cross-sectional study analyzed data from the baseline assessment of the ActiveBrains Project (http://profith.ugr.es/activebrains). A detailed description of the study design and methods has been published elsewhere [21]. Briefly, ActiveBrains is a randomized controlled trial intended to examine the effect of a 20-week PA intervention on brain structure, function, cognitive performance, academic achievement, and physical and mental health outcomes in overweight/obese children [21]. A total of 110 overweight/obese children (classified based on the World Obesity Federation cut-points [22,23]) were recruited from Granada (Spain). A final sample of 104 children (10.1 ± 1.1 years of age, 41% girls) met the accelerometry inclusion criteria (more details below). The data were collected between November 2014 and February 2016. We informed the parents or legal guardians about the purpose of the study, and we obtained written informed parental consent. The ActiveBrains project was approved by the Human Research Ethics Committee of the University of Granada, and was registered as a clinical trial (NCT02295072, http://clinicaltrials.gov).

The participants' anthropometry, SED, and PA were assessed as part of the protocol of the ActiveBrains project [21]. Briefly, we measured the body weight and height to the nearest 0.1 kg and 0.1 cm using an electronic scale (SECA 861, Hamburg, Germany) and a precision stadiometer (SECA 225, Hamburg, Germany), respectively. Body mass index (BMI) was calculated as kg/m^2. The participants were also required to concurrently wear two accelerometers (ActiGraph GT3X+, Pensacola, FL, USA) for 7 complete days (24 hours): one on the right hip and the other on the non-dominant wrist. The participants were instructed to wear the accelerometers as many hours as possible and to remove them only for water activities (i.e., shower or swimming), and both at the same time. Concomitantly, the participants reported the time they went to bed and woke-up in a diary log throughout the study.

ActiGraph GT3X+ is a triaxial accelerometer with a dynamic range of +/- 6 G. Both hip- and wrist-worn accelerometers were initialized to capture and store accelerations at 100 Hz. The raw accelerations were then downloaded and converted to ".csv" format using ActiLife v.6.13.3 (ActiGraph, Pensacola, FL, USA). Raw ".csv" files were imported to R software (v. 3.1.2, https://www.cran.r-project.org/) and processed using the GGIR package (v. 1.5-12, https://cran.r-project.org/web/packages/GGIR/). They were also imported and processed in the ActiLife software (ActiGraph, Pensacola, FL, USA) to obtain VMCounts and VACounts using the normal filter developed by ActiGraph. The processing methods involved: 1) Auto-calibration of the data according to the local gravity [24]. 2) Detection of the non-wear time based on the raw acceleration of the three axes [16]. Briefly, each 15-min block was classified as non-wear time if the standard deviation of 2 out of the 3 axes was lower than 13 m*g* during the surrounding 60-min moving window, or if the value range for 2 out of the 3 axes was lower than 50 m*g*. 3) Detection of sustained abnormal high accelerations, i.e., higher than 5.5 g. 4) Calculation of the Euclidean Norm Minus One (ENMO) as (~ 9.8 m/s^2) with negative values rounded to zero. 5) Importation of the VMCounts and VACounts ".csv" files to R to follow the same processing criteria than ENMO. 6) Imputation of detected non-wear time and abnormal high accelerations by means of the acceleration for the rest of the recording period during the same time interval than the affected periods. 7) Identification of waking and sleeping hours using an automatized algorithm guided by the times reported by the participants [25]. Waking and sleeping hours were detected using data from the non-dominant wrist and detected times were then matched to the right hip data for each participant. And, 8) Estimation of SED and PA intensities using different age-appropriate cut-points for ENMO, VMCounts, and VACounts as detailed in **Table 1**.

Mean daily SED and PA intensity levels were then calculated as: (mean of available weekdays*5 + mean of available weekend days*2) / 7. The participants were excluded from the analyses if they recorded less than 4 valid days (i.e., ≥ 16 hours/day), including at least 1 weekend day. Out of the 110 participants, 4 children recorded less than 4 days of valid wearing time, 1 accelerometer attached to the non-dominant wrist malfunctioned, and 1 participant was excluded for having mean acceleration values during nights between 6-9 standard deviations above the group mean. Thus, a final sample of 104 participants was included in the present study.

Descriptive statistics were calculated as means and standard deviations. The time estimates of SED, light, moderate, vigorous intensity PA, and MVPA were compared between each pair of estimations (i.e., estimations from each pair of cut-points) using repeated measures analysis of variance (ANOVA). Additionally, we inspected the distributions of the time spent in MVPA and the prevalence of the study sample meeting the PA guidelines (i.e., at least 60 min/day of MVPA) [26] using different cut-points. All analyses were performed in R. Overall, the significance level was set at $p<0.05$ for all the analyses; however, in order to account for multiple comparisons, significant differences at $p<0.01$ were interpreted as statistically meaningful.

3. Results

The anthropometric characteristics, the time spent in SED, and the various PA intensities (calculated using the different cut-points) are reported in **Table 2**.

The comparisons between SED and PA intensities estimated from the different cut-points are graphically presented in **Figure 1**. The differences expressed in min/day between different cut-point estimates are shown in **Table 3**. Nearly every pairwise comparison was significantly different (all $p < 0.05$) (exceptions are shown in Table 3). Overall, the various mean daily estimations differed between 11-252 min/day for SED, 10-217 min/day for light intensity PA, 1-48 min/day for moderate intensity PA, 1-35 min/day for vigorous intensity PA, and 4-66 min/day for MVPA.

Figure 2 presents the time distributions spent in MVPA for the different cut-points examined. Overall, this figure shows that cut-points based on VMCounts produced higher MVPA time compared to those estimations based on ENMO or VACounts, independently of the attachment site (as reported in Table 3).

Figure 3 shows that the sample prevalence meeting the recommended 60 min/day of MVPA per day ranged from 8% to 96% depending on the cut-points applied to the data. Overall, the prevalence of meeting the PA guidelines was higher for boys than for girls using all cut-points except for the Chandler et al. [9] cut-points (i.e., 90% of the boys versus 95% of the girls met the PA guidelines, accordingly).

4. Discussion

The primary purpose of this study was to provide a clear picture of which cut-points are more and less comparable in free-living conditions in children with overweight/obesity, including traditional (e.g., Evenson cut-points based on VACounts [27]) and recently developed (e.g., Hildebrand cut-points based on ENMO [8,28], Romanzini [10] and Chandler [9] cut-points based on VMCounts) cut-points, and when the accelerometer was attached to the hip and wrist. Contrary to what could have been expected, all cut-points based on VMCounts produced significantly higher estimations of time spent in MVPA than ENMO and VACounts cut-points, regardless of the attachment site. To our knowledge, this is the first study investigating differences across accelerometer-based estimations of SED and PA intensities using a complete set of available cut-points, running from the most traditionally used cut-points for VACounts detected from a hip attachment, i.e., the Evenson et al. [27] cut-points, to the newly developed cut-points for ENMO [8,28] and VMCounts [9,10,29] from both hip and non-dominant wrist attachments.

Since the selection of the different data collection and processing criteria are known to affect SED and PA intensity estimations [2], we applied cut-points specifically developed for the two different attachment sites for use in children. We also followed the same processing criteria (i.e., same acceleration metric and epoch length) as originally used in validation studies. In agreement with recent studies [5,30], our results confirm non-comparable estimates of the time spent in MVPA when using different data collection and processing criteria. However, the present study expands upon this knowledge by additionally comparing estimates of SED and a complete range of PA intensities in a sample of overweight/obese children. Each of these metrics also displayed non-comparable estimates with large differences between cut-points (see Table 3 and Figure 1). Hildebrand et al. [8,28] developed two sets of cut-points in the same sample to get similar estimations of SED and PA intensities from the hip and the non-dominant wrist. In contrast, herein the estimations for SED and PA for all intensities varied greatly when using the Hildebrand et al. cut-points [8,28] for hip and wrist. This inconsistent result agrees with the Smith et al. findings [4], who reported different estimations derived from two sets of cut-points developed in the same sample and differing only in the acceleration metrics (i.e., VACounts and VMCounts). Our results, together with those from Smith et al. [4], confirm that cut-points from different attachment sites or different acceleration metrics that are comparable in a certain sample could largely differ in others as a result of population-specific features, which may contribute to these differences in SED and PA estimations.

Rowlands et al. [19] looked for ENMO-based cut-points from the non-dominant wrist which could replicate the traditional PA estimations from the Evenson et al. [27] cut-points (applied to VACounts from the hip). Specifically, they reported moderate agreement (intraclass correlation coefficient -ICC- of 0.76) and 2 min/day more of MVPA when applying a cut-point of 250 m*g* for ENMO from wrist compared to the Evenson et al. [27] cut-point. Accordingly, we used a lower cut-point for MVPA for ENMO wrist (i.e., 200 m*g* – validated by Hildebrand et al. [8]) and detected 15 min/day more of MVPA from ENMO wrist compared with the Evenson et al. [27] cut-point on hip. Thus, higher values of MVPA can be expected when using the cut-point by Hildebrand et al. [8] for ENMO wrist compared to the MVPA threshold by Evenson et al. [27] for VACounts hip. A more comparable threshold to identify MVPA from ENMO wrist could be 250 m*g* [19].

Taking these findings into consideration, the selection of cut-points to estimate PA intensities with accelerometers is a major obstacle to overcome in objective monitoring since different cut-points could lead to wildly discrepant conclusions. For example, in our sample, the prevalence of boys meeting the 60 min/day of MVPA was higher than that for girls for all the cut-points except for the Chandler et al. [9] cut-points, for which the prevalence was higher in girls than in boys, i.e. 95% vs. 90%. Likewise, Figure 3 shows large differences in the prevalence of our sample meeting the PA guidelines (i.e., from 8% to 96%), so the fundamental query regarding the prevalence of the population achieving healthful levels of PA is still unresolved. In this regard, Leinonen et al.[31] found moderate-to-high agreement between different methods to classify adults meeting the PA guidelines. It is important to consider that PA guidelines have been developed predominantly using self-reported data, thus, these estimations should be considered with caution. Several authors have proposed reporting PA using a full range of different accelerometer data collection and processing criteria until a consensus is reached [4,5]. However, this is not practical since reporting different and multifactor methodologies could require long explanations and high technical expertise from readers to understand these nuanced inconsistencies. Data pooling and reanalyzing raw accelerometer data may be a solution to overcome processing criteria inconsistencies and have been successfully applied (http://www.mrc-epid.cam.ac.uk/research/studies/icad/).

Although estimations of SED and PA intensities are easily understandable for the general population, we suggest that all studies using accelerometers should also report other PA indicators which are not influenced by cut-points, e.g., mean of the acceleration metric per day. As a first step to achieve this, we suggest using research-derived metrics, such as ENMO, which provides a valid estimate of free-living PA from hip and wrist attachments [8,16,28]. Furthermore, in contrast to traditional activity counts, such metrics enable comparability between devices [15,32] and they may be easier to interpret since the acceleration is expressed using a SI unit (i.e., m*g*). In fact, ENMO can be easily implemented in epidemiological studies using the GGIR software implemented in R (https://cran.r-project.org/web/packages/GGIR/). Studies providing normative values for these acceleration metrics will ease the interpretation of findings in the PA measurement field. Furthermore, these normative values could help to identify acceleration values corresponding to meeting the PA guidelines, which could help to obtain a direct measure unaffected by the limitations shown by the cut-points.

Some limitations with this study should be acknowledged: 1) the sample analyzed herein was composed of overweight/obese children, and the results may not be generalizable to other populations; 2) the current study did not have a criterion measure for comparison that would allow us to assess the accuracy of each set of cut-points; and, 3) we used 90 accelerometers randomly placed in either hip or wrist. It could be hypothesized that the use of different accelerometer units is a source of error for the measurement. However, ActiGraph GT3X devices have shown to provide reliable estimations [33], so we assume this source of error is likely to be very small in this study. Furthermore, all the estimates are derived from the same recordings, in case there is a device-related error, this error would be constant in all the estimates presented, and so, it is unlikely this will affect the findings. In contrast, this study's advantages are 1) the use of consistent data processing techniques with all the acceleration metrics (i.e., same calculation of non-wear time, waking and sleeping hours, which allow for a direct comparison between attachment sites, and acceleration metrics); and, 2) that the participants achieved high wearing time compliance, enabling the collection of a complete range of daily living accelerations.

In conclusion, this study shows large discrepancies in the time spent in SED and PA intensities across cut-points relative to different body attachment sites and acceleration metrics in overweight/obese children. Furthermore, we provide a comprehensive comparison between available cut-points in order to better understand which cut-points provide comparable results and which ones not. Also, our data clearly showed that it is not currently possible to know the prevalence of a population meeting the PA guidelines based on accelerometer data, with differences from nearly none to nearly everyone meeting the guidelines. Although currently elusive, data harmonization and consensus are essential to comparatively measure and communicate objectively monitored time in SED and various PA intensities across different studies.

5. Perspectives

In the present study, we provide a comprehensive overview on the comparability of available cut-points for the classification of SED, light, moderate, vigorous PA and MVPA from different accelerometer attachment sites and acceleration metrics in children. This overview allows researchers to know how comparable are their findings with other published studies, for example, it can be expected that SED derived from Hänggi et al.[29] and Romanzini et al.[10] cut-points is comparable, but large differences can also be expected for light PA classified using the same cut-points. The general belief that PA estimations from wrist-worn accelerometers provide higher values than those from hip-worn accelerometers is not supported by the current study. Other factors such as the acceleration metric used, and the cut-points themselves seem to have a higher influence in the final estimations than the accelerometer attachment site. Therefore, our results confirm previous studies and extend their findings to a different sample (overweight/obese children) and by using a complete set of published cut-points for this population. Data pooling and harmonization should be performed, as well as meta-analyses using data from cut-points validation studies to propose a consensual set of cut-points to be used in different settings/projects.

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Table 1. Children's age-appropriate cut-points for the estimation of sedentary time (SED) and physical activity (PA) intensities.

References	Attachment site	Acceleration metric	Epoch length	SED/LPA	LPA/MPA	MPA/VPA
Hildebrand et al.[7,27]	Hip	ENMO	5 sec	63 m*g*	143 m*g*	465 m*g*
Hildebrand et al.[7,27]	Wrist	ENMO	5 sec	36 m*g*	201 m*g*	707 m*g*
Hänggi et al.[28]	Hip	VMCounts	1 sec	3 c	56 c	-
Romanzini et al.[9]	Hip	VMCounts	15 sec	180 c	757 c	1112 c
Chandler et al.[8]	Wrist	VMCounts	5 sec	305 c	818 c	1969 c
Evenson et al.[26]	Hip	VACounts	15 sec	25 c	574 c	1003 c

ENMO: Euclidean norm minus 1 *g*; VMCounts: Vector magnitude counts; c: Activity counts; VACounts: Vertical axis counts; LPA: Light physical activity; MPA: moderate physical activity; VPA: Vigorous physical activity.

Table 2. Anthropometry, sedentary time (SED), and physical activity (PA) characteristics of participants.

	All (n=104)	Boys (n=61)	Girls (n=43)	P sex
Anthropometry				
Age (years)	10.1 ± 1.1	10.2 ± 1.2	9.9 ± 1.1	0.248
Weight (kg)	56.2 ± 10.8	56.8 ± 10.7	55.4 ± 11.1	0.533
Height (cm)	144.3 ± 8.3	144.9 ± 7.9	143.6 ± 8.9	0.443
BMI (kg/m^2)	26.8 ± 3.5	26.9 ± 3.6	26.7 ± 3.5	0.766
Wearing time during waking hours				
Hip device (hours/day)	15.0 ± 0.6	15.1 ± 0.6	15.0 ± 0.6	0.569
Wrist device (hours/day)	14.8 ± 0.6	14.8 ± 0.5	14.8 ± 0.6	0.926
SED (min/day)				
Hip ENMO $_{Hildebrand}$	817.4 ± 44.7	811.1 ± 42.9	826.3 ± 46.2	0.093
Wrist ENMO $_{Hildebrand}$	565.1 ± 56.4	560.5 ± 56.3	571.6 ± 56.5	0.327
Hip VMCounts $_{Hänggi}$	639.1 ± 64.8	634.4 ± 58.3	645.5 ± 73.1	0.412
Hip VMCounts $_{Romanzini}$	628.3 ± 68.2	623.9 ± 65.7	634.5 ± 71.8	0.445
Wrist VMCounts $_{Chandler}$	576.4 ± 53.9	577.4 ± 54.7	575.1 ± 53.3	0.828
Hip VACounts $_{Evenson}$	600.6 ± 70.1	593.0 ± 69.7	611.1 ± 69.9	0.198
LPA (min/day)				
Hip ENMO $_{Hildebrand}$	65.8 ± 15.8	68.4 ± 15.6	62.1 ± 15.5	**0.043**
Wrist ENMO $_{Hildebrand}$	282.7 ± 38.5	279.3 ± 37.1	287.4 ± 40.3	0.298
Hip VMCounts $_{Hänggi}$	176.9 ± 38.0	175.0 ± 33.3	179.5 ± 44.1	0.579
Hip VMCounts $_{Romanzini}$	198.2 ± 41.5	193.6 ± 39.4	204.5 ± 44.0	0.197
Wrist VMCounts $_{Chandler}$	239.0 ± 29.5	235.4 ± 29.2	244.0 ± 29.6	0.144
Hip VACounts $_{Evenson}$	273.1 ± 52.1	276.4 ± 52.0	268.5 ± 52.5	0.452
MPA (min/day)				
Hip ENMO $_{Hildebrand}$	32.9 ± 13.9	37.5 ± 14.7	26.5 ± 9.6	**<0.001**

Wrist ENMO $_{Hildebrand}$	47.5	±	17.4	54.2	±	18.4	38.1	±	10.2	**<0.001**
Hip VMCounts $_{Romanzini}$	53.8	±	14.4	57.9	±	14.8	48.0	±	11.7	**<0.001**
Wrist VMCounts $_{Chandler}$	81.2	±	20.1	83.3	±	22.7	78.4	±	15.8	0.201
Hip VACounts $_{Evenson}$	33.8	±	11.5	37.9	±	12.2	28.2	±	7.4	**<0.001**
VPA (min/day)										
Hip ENMO $_{Hildebrand}$	3.0	±	2.0	3.7	±	2.1	2.1	±	1.4	**<0.001**
Wrist ENMO $_{Hildebrand}$	7.6	±	4.4	9.4	±	4.5	5.0	±	2.7	**<0.001**
Hip VMCounts $_{Romanzini}$	37.9	±	16.1	44.2	±	16.5	29.1	±	10.6	**<0.001**
Wrist VMCounts $_{Chandler}$	6.2	±	3.6	7.4	±	3.7	4.6	±	2.7	**<0.001**
Hip VACounts $_{Evenson}$	10.7	±	6.7	12.4	±	7.6	8.3	±	4.4	**0.001**
MVPA time (min/day)										
Hip ENMO $_{Hildebrand}$	36.0	±	15.3	41.2	±	16.1	28.6	±	10.6	**<0.001**
Wrist ENMO $_{Hildebrand}$	55.1	±	21.0	63.7	±	22.0	43.1	±	11.9	**<0.001**
Hip VMCounts $_{Hänggi}$	102.4	±	26.8	110.6	±	26.4	90.9	±	23.1	**<0.001**
Hip VMCounts $_{Romanzini}$	91.7	±	28.2	102.1	±	28.7	77.1	±	20.0	**<0.001**
Wrist VMCounts $_{Chandler}$	87.5	±	22.5	90.6	±	25.4	83.0	±	16.9	0.071
Hip VACounts $_{Evenson}$	44.5	±	16.7	50.2	±	18.1	36.6	±	10.3	**<0.001**

Data are presented as mean ± standard deviation. Statistically significant values are shown in bold.

Cut-points expressed with the body-worn attachment site, acceleration metric used and the first author of the validation study in subscripts, i.e., Hildebrand et al.[7,27], Hänggi et al.[28], Romanzini et al.[9], Chandler et al.[8] and Evenson et al.[26].

BMI: Body mass index; ENMO: Euclidean norm minus 1 *g*; VMCounts: Vector magnitude counts; VACounts: Vertical axis counts; LPA: Light physical activity; MPA: moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity.

Table 3. T-tests for the comparison between sedentary time (SED), light, moderate, vigorous, and moderate-to-vigorous (MVPA) intensity physical activity (PA) calculated from different cut-points.

	SED (min/day)	LPA (min/day)	MPA (min/day)
	Difference (95%CI)	Difference (95%CI)	Difference (95%CI)
Hip vs. hip			
$\text{ENMO}_{\text{Hildebrand}}$ - $\text{VMCounts}_{\text{Hänggi}}$	178 (163 to 194)**	-111 (-119 to -103)**	
$\text{ENMO}_{\text{Hildebrand}}$ - $\text{VMCounts}_{\text{Romanzini}}$	189 (173 to 204)**	-132 (-141 to -124)**	-21 (-25 to -17)**
$\text{ENMO}_{\text{Hildebrand}}$ - $\text{VACounts}_{\text{Evenson}}$	217 (201 to 233)**	-207 (-218 to -197)**	-1 (-4 to 3)
$\text{VMCounts}_{\text{Romanzini}}$ - $\text{VMCounts}_{\text{Hänggi}}$	-11 (-29 to 8)	21 (10 to 32)**	
$\text{VMCounts}_{\text{Romanzini}}$ - $\text{VACounts}_{\text{Evenson}}$	28 (9 to 46)*	-75 (-88 to -62)**	20 (16 to 23)**
$\text{VMCounts}_{\text{Hänggi}}$ - $\text{VACounts}_{\text{Evenson}}$	38 (20 to 57)**	-96 (-109 to -84)**	
Wrist vs. wrist			
$\text{VMCounts}_{\text{Chandler}}$ - $\text{ENMO}_{\text{Hildebrand}}$	11 (-4 to 26)	-44 (-53 to -34)**	34 (29 to 39)**
Hip vs. wrist			
$\text{ENMO}_{\text{Hildebrand}}$ - $\text{ENMO}_{\text{Hildebrand}}$	252 (238 to 266)**	-217 (-225 to -209)**	-15 (-19 to -10)**
$\text{VMCounts}_{\text{Hänggi}}$ - $\text{VMCounts}_{\text{Chandler}}$	63 (46 to 79)**	-62 (-71 to -53)**	
$\text{VMCounts}_{\text{Romanzini}}$ - $\text{VMCounts}_{\text{Chandler}}$	52 (35 to 69)**	-41 (-51 to -31)**	-27 (-32 to -23)**
$\text{ENMO}_{\text{Hildebrand}}$ - $\text{VMCounts}_{\text{Chandler}}$	-241 (-255 to -227)**	-173 (-180 to -167)**	-48 (-53 to -44)**
$\text{VMCounts}_{\text{Hänggi}}$ - $\text{ENMO}_{\text{Hildebrand}}$	74 (57 to 91)**	-106 (-116 to -95)**	
$\text{VMCounts}_{\text{Romanzini}}$ - $\text{ENMO}_{\text{Hildebrand}}$	63 (46 to 80)**	-85 (-95 to -74)**	6 (2 to 11)*
$\text{VACounts}_{\text{Evenson}}$ - $\text{ENMO}_{\text{Hildebrand}}$	35 (18 to 53)**	-10 (-22 to 3)	-14 (-18 to -10)**
$\text{VACounts}_{\text{Evenson}}$ - $\text{VMCounts}_{\text{Chandler}}$	24 (7 to 41)*	34 (22 to 46)**	-47 (-52 to -43)**

Data are presented as mean differences and 95% of confident interval.

Cut-points expressed with the body-worn attachment site, acceleration metric used and the first author of the validation study in subscripts, i.e., Hildebrand et al.[7,27], Hänggi et al.[28], Romanzini et al.[9], Chandler et al.[8] and Evenson et al.[26].

CI: confident interval; ENMO: Euclidean norm minus 1 *g*; VMCounts: Vector magnitude counts; VACounts: Vertical axis counts; LPA: Light physical activity; MPA: moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity.

* $p < 0.05$

** $p < 0.01$

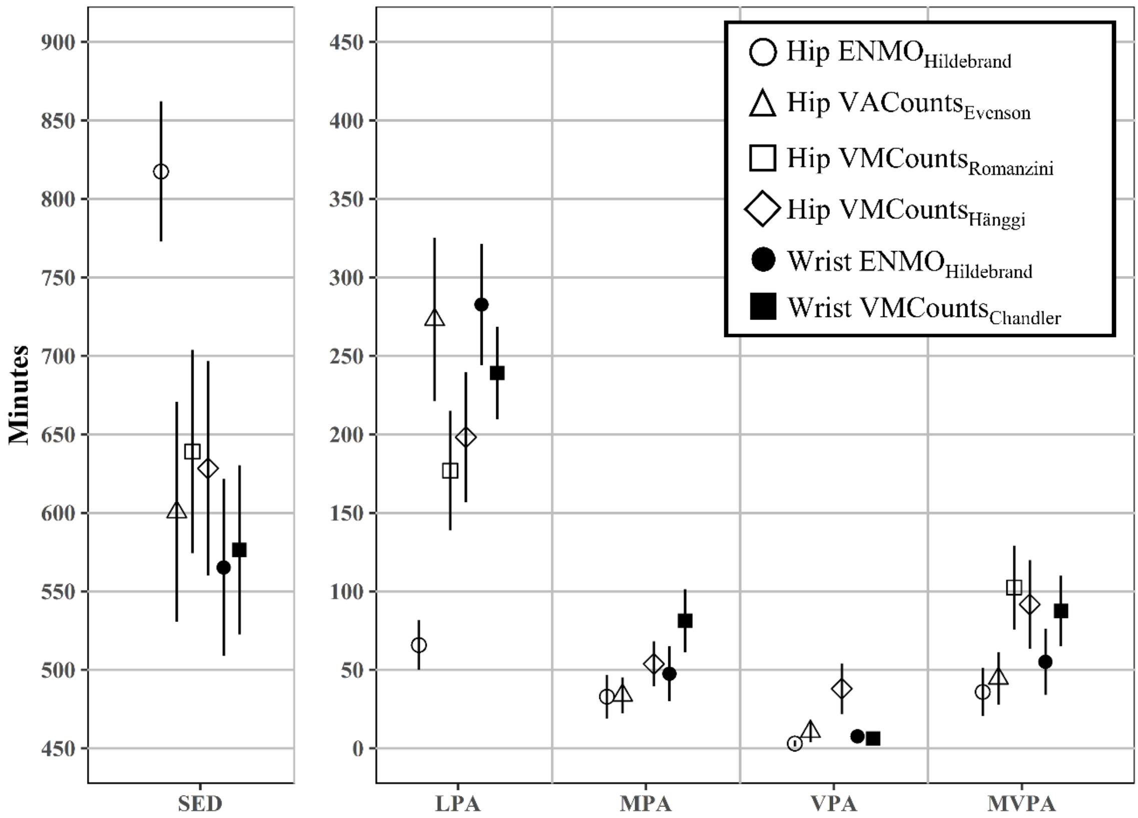

Figure 1. Mean daily time spent (min) and standard deviations (error bars) in sedentary time (SED) and physical activity (PA) considering different attachment sites and metrics.

Cut-points expressed in the legend with the body-worn attachment site, acceleration metric used and the first author of the validation study in subscripts, i.e., Hildebrand et al.[7,27], Hänggi et al.[28], Romanzini et al.[9], Chandler et al.[8] and Evenson et al.[26].

ENMO: Euclidean norm minus 1 *g*; VMCounts: Vector magnitude counts; VACounts: Vertical axis counts; LPA: Light physical activity; MPA: moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity.

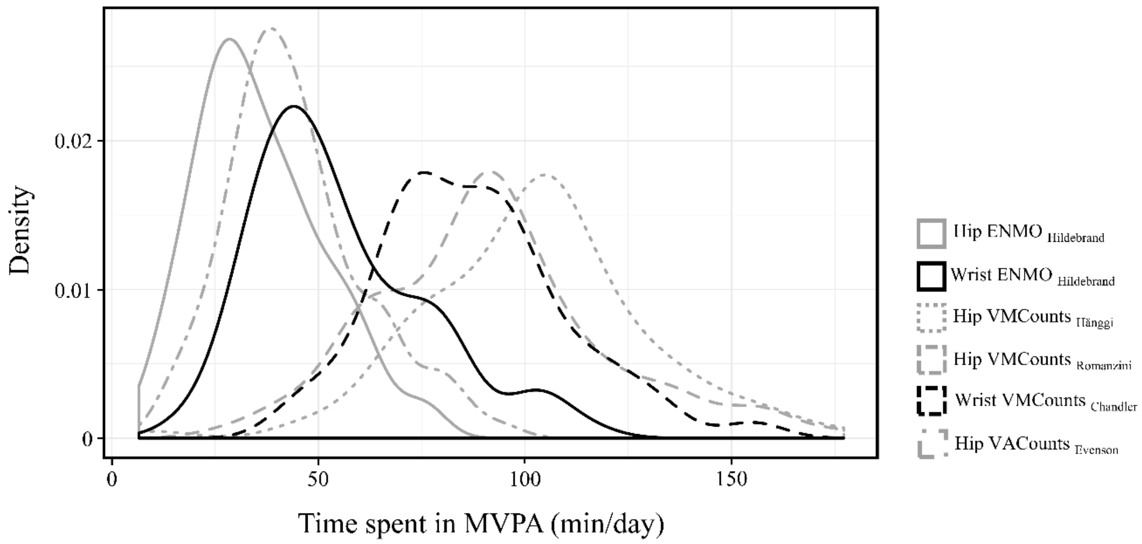

Figure 2. Distributions of the time spent in moderate-to-vigorous physical activity (MVPA) intensity (min/day) estimated with different cut-points.

Cut-points expressed in the legend with the body-worn attachment site, acceleration metric used and the first author of the validation study in subscripts, i.e., Hildebrand et al.[7,27], Hänggi et al.[28], Romanzini et al.[9], Chandler et al.[8] and Evenson et al.[26].

ENMO: Euclidean norm minus 1 *g*; VMCounts: Vector magnitude counts; VACounts: Vertical axis counts; MVPA: Moderate-to-vigorous physical activity.

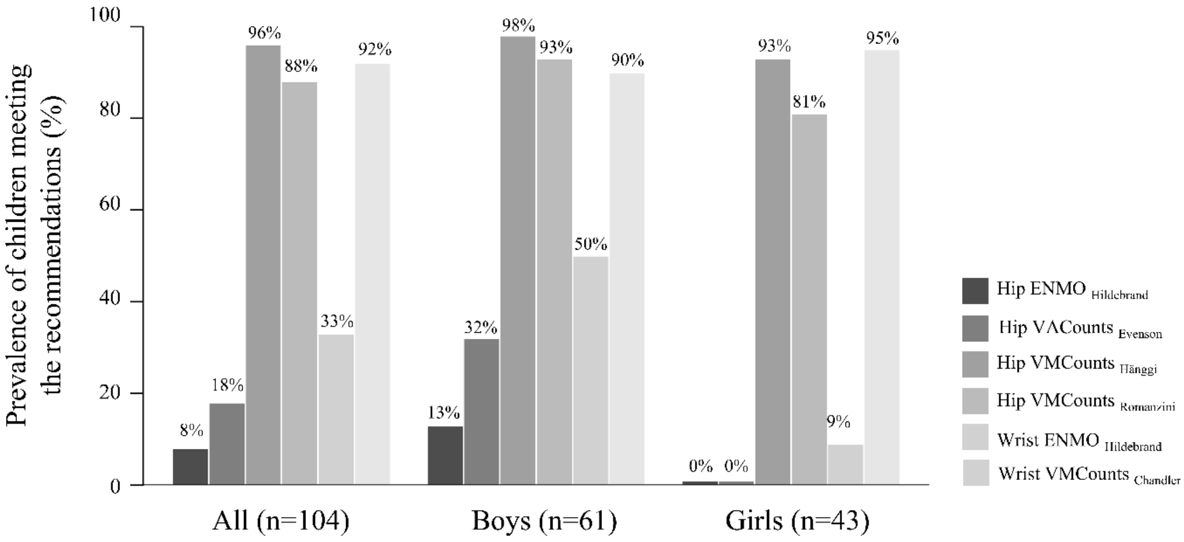

Figure 3. Prevalence of children meeting the physical activity (PA) guidelines (i.e., ≥60 min/day of moderate-to-vigorous physical activity -MVPA-) according to different cut-points.

Cut-points expressed in the legend with the body-worn attachment site, acceleration metric used and the first author of the validation study in subscripts, i.e., Hildebrand et al.[7,27], Hänggi et al.[28], Romanzini et al.[9], Chandler et al.[8] and Evenson et al.[26].

ENMO: Euclidean norm minus 1 *g*; VMCounts: Vector magnitude counts; VACounts: Vertical axis counts.