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Evaluation of Sedentary Behavior and Physical Activity Levels Using Different Accelerometry Protocols in Children from the GENOBOX study

Francisco Jesus Llorente-Cantarero
UCO
Jose Manuel Jurado-Castro
Instituto Maimónides de Investigación Biomédica de Córdoba https://orcid.org/0000-0002-0198-2793
Rosaura Leis
USC
Rocío Vázquez-Cobela
USC
Esther M González-Gil
Unizar
Concepción María Aguilera
UGR
Gloria Bueno (mgbuenol@unizar.es)
USC https://orcid.org/0000-0002-0902-387X
Luis A. Moreno
Unizar
Angel Gil
UGR
Mercedes Gil-Campos
UCO

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Abstract

Objectives. The present study aimed to examine the sedentary behavior (SB) and physical activity (PA) levels in children using six selected accelerometry protocols based on diverse cut-off points.

Methods. Clinical examination, anthropometric measurements, and PA evaluation by accelerometry were assessed in 543 selected children (10±2.4 years old) from the Spanish GENOBOX study. The ActiLife data scoring program was used to determine daily min spent in SB, and light, moderate, vigorous and moderate-vigorous PA using six validated accelerometry protocols differing in their cutt-off points.

Results. Very different estimations for SB and PA intensity levels were found in children, independently of the non-wear-time algorithm selected, and considering puberty stages, age and body mass index. The time spent in daily SB varied from 471 to 663.7 min, PA ranged from 141 to 301.6 min, and the moderate-vigorous PA was reported between 20.7 and 180.2 min.

Conclusion. The choice of a particular accelerometry protocol considering these factors is important to evaluate SB or PA intensities to suit the characteristics of the sample researched. It seems necessary to establish future lines of research that include different analytical approaches to measure SB and PA by accelerometry based on standardized and validated methodology.

Key Points

- Estimated sedentary behavior and physical activity in children using six accelerometry protocols with different cut-off points, could lead to substantially different results. There were large differences by puberty stages, age and BMI category,

- Thecut-off points proposed by Evenson et al. seems to be the most supported by the scientific community, due to the strict methodological and statistical procedures used in the validation of cut-off points

- It seems necessary to establish future lines of research that include different analytical approaches to measure sedentary behavior and physical activity by accelerometry.

1. Introduction

During the last decade, the term physical activity (PA) has acquired a significant relevance worldwide due to the health benefits associated with its practice [1–3]. The World Health Organization (WHO) recommends 60 min of moderate-vigorous physical activity (MVPA) per day in children [4]. However, a recent review revealed that globally, the practice of MVPA is below recommendations, being even lower in children with obesity (OB) than in their normal-weight (NW) peers [5].

In this way, valid, reliable, and feasible measures are needed to quantify the actual prevalence of PA practice. Traditionally, the most used methods to measure PA in children have been self-reported PA

questionnaires. Nevertheless, these methods present some limitations, such as their subjective character, the loss of information when children are not observed by their parents, such as the movement intensity or the real duration, or the difficulty of understanding the questions by scholars [6]. Consequently, researchers have looked for valid and reliable objective methods like accelerometry to assess PA in children despite this method has also some limitations [6,7].

Accelerometers are medical-grade biometric monitoring devices that capture and record high-resolution raw acceleration data. These values are converted into objective activity and sleep measures using publicly available validated algorithms [8,9]. Nowadays, these devices have a great quality of development, with a considerable number of data collection and processing capacity concerning specific criteria associated with SB and PA evaluations [10]. Notwithstanding, currently, there is no consensus on which cut-off points analytical approaches are the best to select [9,10]. These diversity of cut-off points used to define different PA intensities can interfere with interpreting the findings and comparing results between studies [11,12]. In children, different methods have been described without consensus, such as the accelerometer model, epoch length, non-wear-time (NWT), and cut-off points [7,9]. So, the consequence has been interpreting the prevalence of PA practice generally above the reality [11]. There is still a need to refine the analytical approaches in the accelerometry methodology to better understand the influence of PA, especially on health outcomes in children [10]. Therefore, the present work aimed to evaluate the sedentary behavior (SB) and PA levels in children of the Spanish GENOBOX study using selected accelerometry protocols based on diverse cut-off points and the relationship with puberty stage, age, and BMI status.

2. Materials And Methods

2.1. Study Design and Study Population

The present study was carried out under the framework of the cross-sectional case-control GENOBOX study [13].A subsample of children aged 6 to 14 years was selected for the present study using the following inclusion criteria: Children in good health and absence of endogenous OB, and having a minimal amount of useful accelerometer data as described below. Exclusion criteria were disease or malnutrition and the use of medications that altered physiological or biochemical parameters.

The study was conducted in accordance with the Declaration of Helsinki. The Ethics Committees approved all experiments and procedures (Code IDs: Córdoba 01/2017, Santiago de Compostela 1011/198, Zaragoza 10/2010). All parents or guardians provided written informed consent and the children gave their assent.

2.2. Clinical Examination and *Anthropometric Measurements*

A medical history and a physical exam, including the evaluation of sexual maturity according to Tanner's five-stages were assessed [14]. Anthropometric measurements and blood pressure were taken by a single examiner. Details have been previously reported [13].

2.3. Physical Activity Evaluation

PA was objectively evaluated using ActiGraph GT3 and GT3X+ accelerometers (ActiGraph; Pensacola, FL, USA). Two NWT validation were applied: 20 minutes of non-wear-time (NWT-20) [7] and 60 minutes of non-wear-time (NWT-60) [15]. Also was considered, but no applied 90 minutes of non-wear-time. More details about accelerometry data collection, data processing, cut-off points selection and scoring were provided as supplementary material 1 [16,17]. The cut-off points of six accelerometer validated protocols were employed [15,18–22].

2.4. Statistical Analysis

The sample size estimation was calculated for the GENOBOX study as reported elsewhere [13]. All continuous variables were tested for normality using the Shapiro–Wilk test. Heteroskedasticity between experimental groups was explored with the Levene test. A two-way ANOVA and Wilcoxon test, depending on variables following or not a normal distribution, with repeated measures were applied to compare mean SB and PA intensities among the different accelerometry protocols.

One-way ANOVA and the Kruskal–Wallis tests, depending on variables following or not a normal distribution, were employed to assess differences in SB and PA levels between OB, OW and NW, as well as prepubertal and pubertal stages and age quartiles. Pairwise analysis adjusted by BMI Z-score and age were applied conveniently as post-hoc analyses to determine which experimental groups differed from each other. Values in descriptive tables and results are expressed as means and standard deviations. A *p*-value <0.05 was considered significant.

Additionally, Bland-Altman plots were created to assess the level of agreement between the accelerometry protocol of Evenson et al. [18] compared with the others. Evenson et al. [18] was selected as a reference method for performing the Bland-Altman test, due to the strict methodological and statistical procedures used in the validation of cut-off points. The one-sample t-test was used to determine whether there were statistically significant differences between the mean of the scanning accelerometry protocols. All statistical procedures were conducted by using SPSS (IBM SPSS Statistics, Version 25.0. Armonk, NY, USA).

3. Results

3.1. *Demographic and anthropometric data*

A description of the participants' characteristics is shown in Table 1. Two hundred seventy-four participants were prepubertal (50.4%). Within the sample, 313 were OB (57.5%), 109 OW (20%) and 121 NW (22.5%).

Table 1. Descriptive characteristics of the selected children within the GENOBOX study.

Variable	Value
n	543
Female/Male	286/257
Age (years)	10 ± 2.4
Height (m)	1.46 ± 0.15
Weight (kg)	54.7 ± 20.17
BMI (kg/m^2)	24.9 ± 5.7
BMI Z-Score (index)	1.98 ± 2.06
Hip Circumference (cm)	91.4 ± 14.6
Waist Circumference (cm)	82.5 ± 15.7
Waist-to-height ratio (index)	0.51 ± 0.19
Systolic Blood Pressure (mmHg)	110 ± 13
Diastolic Blood Pressure (mmHg)	66 ± 10

BMI: Body mass index. Data expressed as mean ± standard deviation.

3.1. *Non-wear-time, sedentary behavior and physical activity levels by accelerometry protocols*

The accelerometer wearing time was 4.8±0.8 days. The number of participants meeting the NWT criteria was very similar in both NWT-20 and NWT-60 (535 *vs.* 543, respectively). Moreover, on average, both criteria accumulated the same number of days with valid data. The accelerometry protocols showed differences ($p<0.05$) when comparing the results obtained under NWT-20 *vs.* NWT-60 criteria (Table 2). Regardless of NWT criteria, higher SB were obtained for Puyau et al. [22], higher light PA (LPA) for Mattocks et al. [20], and higher moderate PA (MPA) and MVPA for Freedson et al. [21] (Table 2).

Comparing the accelerometry protocols among them, independently of NWT criteria, differences were observed for SB variables as well as for PA intensities except Evenson et al. [18] *vs.* Mattocks et al. [20]; and Pulsford et al. [19] *vs.*Troiano et al. [15] (only for SB) (Table 2). These differences between accelerometry protocols were reproduced when comparing by pubertal stage, age or BMI classification (results not shown).

The one-sample t-test results (reference=0) showed significant differences on SB and different PA intensities between Eveson et al. [18] compared with the others accelerometry protocols, with exception on SB for Evenson et al. [18] *vs.* Mattocks et al. [20]. These differences revealed by Bland–Altman plots are shown as supplementary material 2.

Table 2. Minutes/day estimated in sedentary behavior and physical activity intensities by different accelerometry protocols in children of the GENOBOX study.

Removed periods of 20 min or more of consecutive zero counts (NWT-20) (n=535)					
Evenson et al. 2008 [18]	473.4 ± 89.9[a]	247.6 ± 61.2[a]	36.4 ± 13.9[a]	15.3 ± 21.3[a]	51.6 ± 27.7[a]
Freedson et al. 2005 [20]	498.1 ± 88.7[c]	92.5 ± 22.5[b]	166.5 ± 46.6[b]	13.6 ± 10.1[b]	180.2 ± 50.3[b]
Mattocks et al. 2007 [22]	473.4 ± 89.9[a]	278.2 ± 67.5[c]	17.6 ± 11.4[c]	3.4 ± 18.4[c]	21 ± 22.5[c]
Pulsford et al. 2001 [19]	471 ± 90[b]	248.2 ± 61.2[d]	36.1 ± 13.5[d]	17.3 ± 21.7[d]	53.4 ± 28[d]
Puyau et al. 2002 [21]	631.5 ± 82.8[d]	113.2 ± 34.2[e]	26.3 ± 15.2[e]	1.5 ± 17.4[e]	27.8 ± 23.7[e]
Troiano et al. 2008 [15]	471 ± 90[b]	239.8 ± 59.1[f]	58.1 ± 22.6[f]	3.7 ± 18.5[f]	61.8 ± 29.6[f]
P-value*	<0.001	<0.001	<0.001	<0.001	<0.001
Removed periods of 60 min or more of consecutive zero counts (NWT-60) (n=543)					
Evenson et al. 2008 [18]	507.1 ± 117.6[a]	245.2 ± 61.1[a]	36 ± 13.7[a]	15 ± 21.1[a]	51 ± 27.5[a]
Freedson et al. 2005 [20]	531.6 ± 116.5[c]	91.6 ± 22.4[b]	165 ± 46.6[b]	13.4 ± 10[b]	178.4 ± 50.3[b]
Mattocks et al. 2007 [22]	507.1 ± 117.6[a]	275.5 ± 67.5[c]	17.4 ± 11.3[c]	3.4 ± 18.3[c]	20.7 ± 22.3[c]
Pulsford et al. 2001 [19]	504.7 ± 117.7[b]	245.8 ± 61.1[d]	35.7 ± 13.3[d]	17.1 ± 21.6[d]	52.8 ± 27.8[d]
Puyau et al. 2002 [21]	663.7 ± 110.4[d]	112.2 ± 34.1[e]	25.9 ± 15.1[e]	1.5 ± 17.3[e]	27.4 ± 23.6[e]
Troiano et al. 2008 [15]	504.7 ± 117.7[b]	237.5 ± 59[f]	57.5 ± 22.4[f]	3.6 ± 18.3[f]	61.1 ± 29.4[f]
P-value*	<0.001	<0.001	<0.001	<0.001	<0.001

PA: physical activity.

Data expressed as mean ± standard deviation.

No matching superscript letter (a, b, c, d, e, f) indicate significant differences in sedentary behavior or different intensities of physical activity between the different accelerometry protocols by a two-way

ANOVA and Wilcoxon test, depending on variables following or not a normal distribution, with repeated measures (P<0.05).
* *P-value* between the accelerometer protocols for sedentary behavior and different physical activity intensity levels applying a one-way ANOVA.

3.2. *Sedentary behavior and physical activity levels according to puberty stage*

Prepubertal children, regardless of NWT criteria, had lower SB (Figure 1a) and higher LPA, MPA (Figure 1b) and MVPA (Figure 1c), in most accelerometry protocols, than pubertal children (p<0.05).

3.3. Sedentary behavior and physical activity levels according to age.

The sample was divided into age ranges and classified by quartiles (Q): Q1 (<10 years); Q2 (10-11.7 years); Q3 (11.7-13.7 years); Q4 (>13.7 years). The sample size in these quartiles was as follows: Q1, n=136; Q2, n=131: Q3, n=140; Q4, n=136. Regardless of NWT-20 and NWT-60, more SB (p<0.05) (Figure 2a) and lower LPA and MPA (p<0.05) were observed as the age quartile increased (from Q1 to Q4). However, no age-related differences were seen for vigorous PA (VPA) (Figure 2b) (p<0.05). Children in Q1 showed higher MVPA (p<0.05) in the accelerometry protocols of Evenson et al. [18], Freedson et al. [21], Pulsford et al. [19] and Troiano et al. [15] (Figure 2c).

3.4 Sedentary behavior and physical activity levels according to BMI category

Neither other differences were observed when comparing the BMI category, regardless of NWT, in SB min, nor PA intensities within each accelerometry protocol (Figure 3a, 3b and 3c).

4. Discussion

The recent GRANADA consensus on accelerometry [10], determined to establish future lines of research that include different analytical approaches to measure SB and PA by accelerometry. Therefore, the present study compares the application of six validated accelerometry protocols based on specific cut-off points to evaluate PA, showing very different estimations for SB and PA intensity levels in children; even considering the epoch lengths used in their validation studies; and independently of the NWT algorithm selected, NWT-20 or NWT-60, or the puberty stage, age and BMI.

One of the first aspects to be considered are the selection of the two possible criteria for NWT, the NWT-20 proposed by Cain et al. [7] or the NWT-60 proposed by Troiano et al. [15]. Both proposals showed several differences when compared among authors, with the exception that NWT-60 criteria led to a higher SB, and NWT-20 criteria that accumulated more time on PA intensities. For adults, NWT-20 has shown the lowest misclassification error, although it presents the inconvenience that it may result in slightly greater data loss (6% of the sample size) [9,23]. As the precision between NWT-20 and NWT-60 seems similar, the literature has suggested using NWT-60 without allowing interruptions in the collect criterion of counts as a general recommendation for adults [9]. However, in children, it could be very

different. Thus, in our study, only a loss of 1.5% of the participants (n=8) with NWT-20 was detected. Therefore, it seems more adequeate NWT-20 for children. However, more studies are needed to examine the accuracy of different NWT detection algorithms in all age groups of children and adolescents.

Although it is difficult to establish a recommendation, in the present study, there are differences between both NWT. These results might be due to the time interval that must elapse without counts for NWT-60 is greater than in NWT-20; so, NWT-60 criteria may be interpreting this time as SB instead of NWT. Despite children or adolescents with OW or OB might present a longer time of consecutive 0 counts per minute (CPM) associated with a higher SB [24], especially in prepubertal children [25], this time could be misclassified as NWT.

Traditionally, SB and PA intensity have been estimated based on the number of CPM accumulated in a given period (length of time). The cut-off points are the thresholds of the activity counts used to categorize the activity as light, moderate and vigorous PA. This study selected 6 validated protocols based on different cut-off points and standards for PA interpretation. Although other standard measures can be found in the literature with similar mean cut-off points [7,9], the accelerometry protocol criteria were selected to represent the group of protocols more frequently used to estimate PA in school-age children, mainly with Actigraph accelerometers. These are also the protocols provided by ActiLife for estimating PA in school-aged children [7,9].

To calibrate the different range of accelerometer counts corresponding to predefined SB, the intensity levels or to estimate energy expenditure, authors usually involved movements as walking, running or stationary bicycle (only in the case of Evenson et al. [18]) alone or in combination with free-living activities (TV watching, arts and crafts) [21] in their study protocols. However, the methods used to analyze and quantify the physiological response of participants were different in each accelerometry protocol, such as: oxygen consumption (VO2) and the heart rate [18]; refitting the energy expenditure model with VO_2 as the outcome [20]; calibrated against energy expenditure measures (kcal.kg−1.hr−1) obtained over a range of exercise intensities using a COSMED K4b2 portable metabolic unit [19]; 6-hour energy expenditure measurements by room respiration calorimetry, activity by microwave detector, and heart rate by telemetry [22]; reviewed the calibration of different accelerometers used most frequently to assess PA and SB in children [21]; or based on the results of the National Health and Nutritional Examination Survey (NHANES)'s [15]. Although most of the accelerometry protocols used objective, validated, and standardized methods to associate the movement with their physiological response, Puyau et al. [22] seems to present a more controlled environment, specially to measure the SB, furthermore, Evenson et al. [18] used a robust statistical analysis compared to other accelerometry protocols.

On the other hand, the accelerometry protocols included in the present study only used the vertical axis to measure the movement. Nevertheless, the current Actigraph models (as GT3X) also include two more axes. Even though it has been verified that the Actigraphs with a single vertical axis are comparable with those with a triaxial axis [26,27], new protocols are trying to get recognition by the scientific community

and the Actigraph Corporation for the GT3X model [28–31]. These accelerometry protocols were not considered for the present study, as they did not provide cut-off points for the different PA intensities.

The number of epochs established at the set-up moment also seems to determine the protocol precision. In a recent systematic review, Migueles et al. [9] recommend for children the Hänggi et al. [31] cut-off points developed in 1-sec epoch for the hip due to the excellent classification accuracy (ROC-AUC > 0.90 for all cut-points) obtained and the cover for almost the whole spectrum of PA intensities. The ranges obtained by Hänggi et al. [31] were "<3 counts for SB, 3–56 counts for LPA and > 56 counts for MVPA". If values from 1-sec epoch to 60-sec epochs are transformed, the results are within the following ranges " <180 for SB, 180- 3360 for LPA and > 3360 for MVPA". These are very similar to those proposed by Mattocks' et al. [20] (SB: ≤ 100; LPA: 101-3580; MPA: 3581-6129; VPA: ≥ 6130), that was the protocol included in the present study. The latter has the advantage of being able to study separately MPA and VPA intensities.

Once analyzed the accelerometer protocols, it was found that the lower value in min obtained for SB was 471/504.7 min [18] *vs* 631.5/663.7 min in the upper value [22], respectively for NWT-20 and NWT-60; and highlighting the MVPA which was 21/20.7 min [20] *vs* 180.2/178.4 min [21] (Table 3). Indeed, the current literature reporting PA children data measured by accelerometry must be interpreted with caution, paying attention to the analysis protocol when comparing one study's results with others [11].

To evaluate PA in children is essential to consider age and puberty stage. All selected accelerometry protocols for this study included criteria for school-age children and some of them for adolescents. Although the puberty stages were not specified in the protocols' validation, the age range was between 5 to 19 years. Usually, the studies include an age range higher than a couple of years and usually comprises children from 5-6 to 14. During puberty, males gain greater amounts of fat free mass and skeletal mass, whereas females acquire significantly more fat mass [32]. Therefore, an age range very wide, e.g., 6-18 years, may lead to a less specific measure. Only Mattocks et al. [20], and Puyau et al. [22] did not show differences when compared by puberty stage or age quartiles in the MPA and MVPA intensities, both for NWT-20 and NWT-60. This may indicate that both accelerometry protocols seem to be less precise for ages outside those included in their protocols.

Other consideration is that all the selected protocols used children with NW to validate their cut-off, except for Troiano et al. [15], who included 2-3% of OW, but no OB. Despite establishing various cut-off by each accelerometry protocol, no differences were obtained by BMI category in SB and the different PA intensities comparing them. The fact that none of the accelerometry protocols has included OB children in their validation makes wonder whether the estimates of SB and PA in children with OB measured with accelerometry are reliable or not, considering that this methodology is commonly used in the evaluation or in interventions related with childhood obesity [33]. This question has not been exactly resolved so far, although few studies have provided approximations and interesting data [12,34–36]. Robertson et al. [34] conducted an investigation only in children with OB, concluding that accelerometers are acceptable to most of the children, although their use at school is problematic for some of them because

they may underestimate children's PA, as some children with OB are unwilling to wear accelerometers at school and during sports because they feel they are at risk of stigma and bullying. The aim of Moura et al. study [35] was to analyze the impact of cut-off points in defining SB time and prevalence in adolescents from Northeastern Brazil. Also in this context, Migueles et al. [12], aimed to examine how cut-points relative to different attachment sites affect the final estimations of SB and PA in children with overweight/OB. Similar to our study, the cut-off points examined by them produced significant differences in SB and PA estimates. Gaba et al. [36] reported a curvilinear analysis that indicated the optimal thresholds for CPM and MVPA derived from the Puyau et al. [22], which was very useful in classifying children according to their BMI and fat mass percentage to overweight and obesity prevention but only considering MVPA.

According to the Bland-Altman plots, the accelerometry protocol of Evenson et al. [18] method showed large mean differences with that of Puyau et al. [22] for SB and LPA, which had a more controlled environment to validate cut-off points with energy expenditure. However, despite there being also differences, the mean differences were lower for Eveson et al. [18] vs. Puyau et al. [22], and Evenson et al. [18] *vs* Mattocks et al. [20] for MPA, VPA and MVPA.

5. Conclusions

This study found that data processing and analysis of SB and PA intensity levels in children using six accelerometry protocols could lead to substantially different results. The time spent in daily SB varied from 471 to 663.7 min and total PA ranged from 141 to 301.6 min, and the MVPA was reported between 20.7 and 180.2 min. There were wide differences, in puberty stages, age and BMI category, as well as in different algorithms for NWT and CPM. Therefore, to avoid erroneous estimates of SB and PA, it is necessary to select the best adapted protocol to suit the characteristics of the sample researched. Although cut-off points proposed by Evenson et al. [18] seems to be the most supported by the present study and the scientific community so far, the high estimed PA differences between the accelerometry protocols currently used represent an important gap in the research, forming the scientific literature with different PA estimates. In this sense, it seems necessary to establish future lines of research that include different analytical approaches to measure SB and PA by accelerometry.

Abbreviations

BMI: body mass index

CPM: counts per minute

LPA: light physical activity

MPA: moderate physical activity

MVPA: moderate-vigorous physical activity

NWT: non-wear-time

NWT-20: 20 minutes of non-wear-time

NWT-60: 60 minutes of non-wear-time

NW: normoweight

PA: physical activity

SB: sedentary behavior

OB: obesity

OW: overweight

VPA: vigorous physical activity

Declarations

Ethics approval and Consent to participate: The study was conducted in accordance with the Declaration of Helsinki. The Ethics Committees approved all experiments and procedures (Code IDs: Córdoba 01/2017, Santiago de Compostela 1011/198, Zaragoza 10/2010).All parents or guardians provided written informed consent and the children gave their assent.

Conset for publication: All authors have approved and consent to the publication of this article.

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Manuel Jurado-Castro, Luis A. Moreno and Francisco Jesus Llorente-Cantarero; Project Administration: Mercedes Gil-Campos, Rosaura Leis, Gloria Bueno and Concepción Maria Aguilera; Supervision: Francisco Jesus Llorente-Cantarero and Mercedes Gil-Campos.; Validation, Mercedes Gil-Campos and Angel Gil; Writing—Original Draft Preparation, Angel Gil, Jose Manuel Jurado-Castro, Francisco Jesus Llorente-Cantarero, and Mercedes Gil-Campos; Writing—Review and Editing: all the group.

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Authors' information:

Francisco Jesus Llorente-Cantarero[1,2†], Jose Manuel Jurado-Castro[3†], Rosaura Leis[2,4†], Rocío Vázquez-Cobela[2,4], Esther M González-Gil[2,5], Concepción María Aguilera[2,6], Gloria Bueno [2,5,7*], Luis A. Moreno[2,5], Angel Gil[2,6], Mercedes Gil-Campos[2,3]

1 Department of Specific Didactics , Faculty of Education, University of Córdoba, Spain.

2 CIBEROBN, (Physiopathology of Obesity and Nutrition) Institute of Health Carlos III (ISCIII); Madrid, Spain.

3 Metabolism and Investigation Unit, Reina Sofia University Hospital. Maimónides Institute of Biomedicine Research of Córdoba (IMIBIC). University of Córdoba, Spain.

4 Pediatric Nutrition Research Group. Institute of Sanitary Research of Santiago de Compostela (IDIS). Unit of Pediatric Gastroenterology, Hepatology and Nutrition. Pediatric Service. University Clinical Hospital of Santiago (CHUS). Santiago de Compostela, Spain.

5 GENUD Research Group, University of Zaragoza, Instituto Agroalimentario de Aragón (IA2), Instituto de Investigación Sanitaria (IIS) Aragón, Zaragoza, Spain.

6 Department of Biochemistry and Molecular Biology II, Institute of Nutrition and Food Technology "José Mataix", Center of Biomedical Research, , University of Granada, Instituto de Investigación Biosanitaria IBS, Granada, Spain.

7 Pediatric Endocrinology Unit, Lozano Blesa University Hospital, University of Zaragoza, Spain.

† Equally contributed

* Corresponding author

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Figures

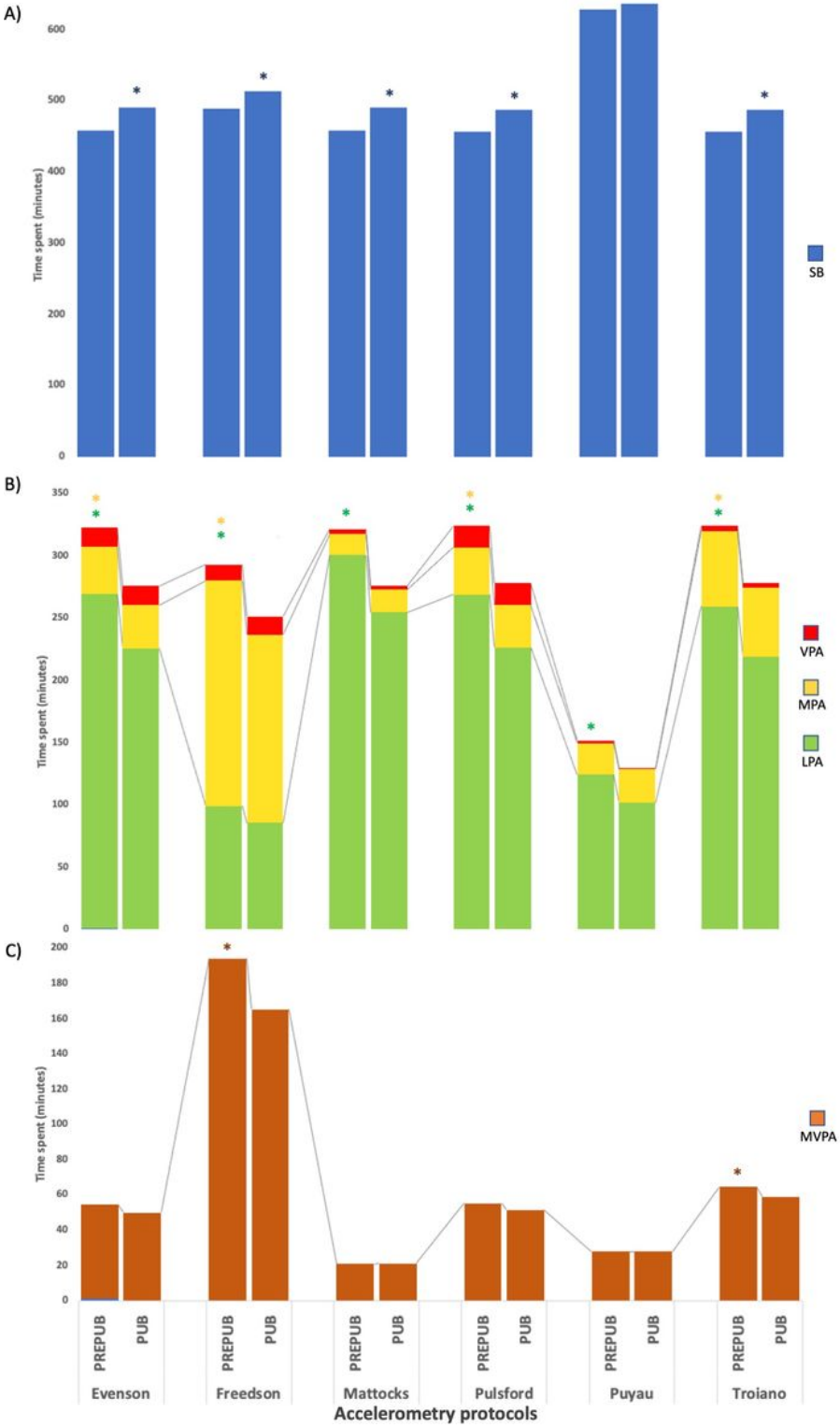


Figure 1

Min/day spent in sedentary behavior and physical activity in prepubertal and pubertal children of the GENOBOX study, estimated using selected accelerometry protocols.

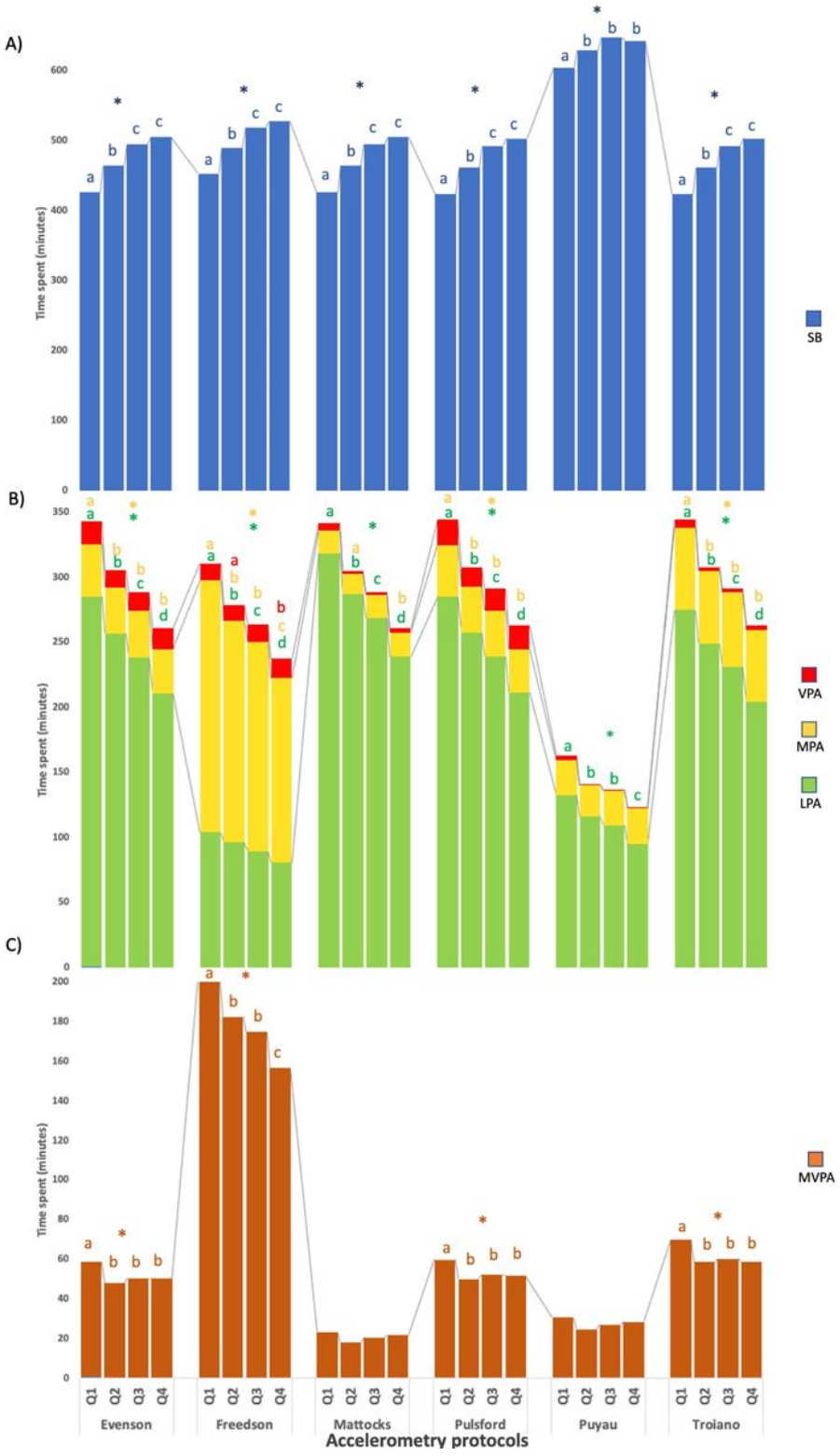


Figure 2

Min/day spent in sedentary behavior and physical activity among quartiles of age in children of the GENOBOX study, estimated using selected accelerometry protocols.

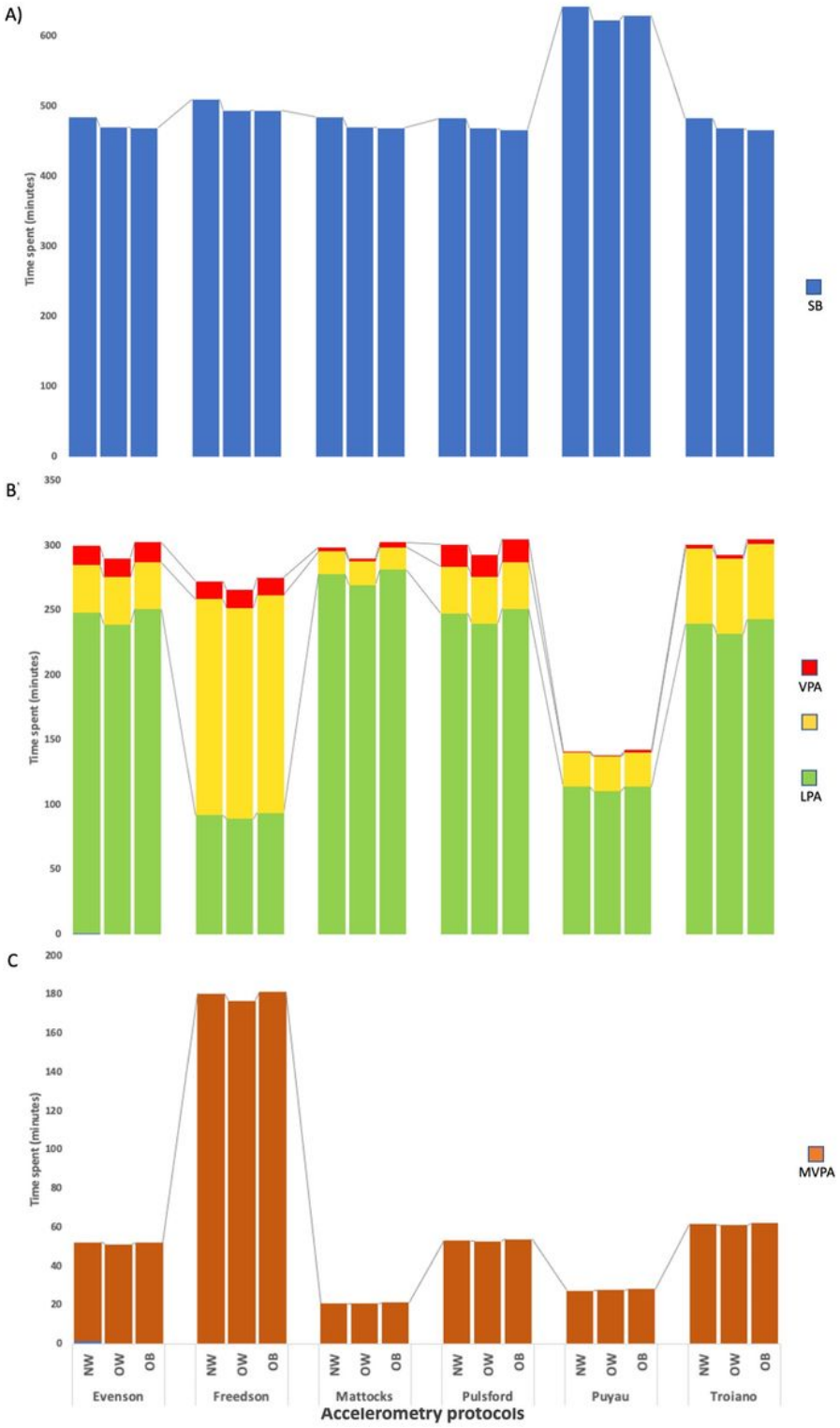


Figure 3

Min/day spent in sedentary behavior and physical activity between BMI category in children of the GENOBOX study classified on BMI, estimated using selected accelerometry protocols.

Supplementary Files

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- Supplementarymaterial.docx