

From volume to pattern: Sustained moderate-to-vigorous physical activity and its sociodemographic distribution in children and adolescents

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ABSTRACT

Most research on children's and adolescents' physical activity focuses on total daily moderate-to-vigorous physical activity (MVPA), with limited attention to its temporal structure. This cross-sectional study characterised MVPA accumulation patterns in 513 participants (256 boys, 257 girls; mean age 11.7 ± 3.2 years) from the Basque Country (Spain) using wrist-worn accelerometry (100 Hz; ENMO ≥ 100 mg; 5-s epochs; GGIR) over seven consecutive days. MVPA bouts were defined using a strict consecutive criterion at thresholds of ≥ 1 , ≥ 5 , and ≥ 10 minutes. On average, 66.2% of daily MVPA was accumulated in bouts ≥ 1 minute, 44.7% in bouts ≥ 5 minutes, and 34.8% in bouts ≥ 10 minutes. Boys accumulated more total MVPA and a greater proportion in sustained bouts than girls (40.9% vs. 28.8%). Both total and sustained MVPA declined progressively with age. In multivariable models, age ($\beta = -1.93$; 95% CI: -2.57 to -1.28) and female sex ($\beta = -14.00$; 95% CI: -18.50 to -9.50) were independently associated with lower sustained MVPA (model $R^2 = .126$). Sustained MVPA was inversely associated with body mass index after adjustment for age, sex, socioeconomic status, and residential setting ($\beta = -9.05 \times 10^{-6}$; $p = .028$; model $R^2 = .359$). These findings indicate that MVPA in youth is predominantly fragmented and that sustained accumulation varies systematically by demographic characteristics.

Keywords: Physical education, Accelerometry, Raw acceleration, ENMO, Bout duration, Adiposity.

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INTRODUCTION

Physical inactivity during childhood and adolescence remains one of the most pressing challenges facing public health systems worldwide. The World Health Organization recommends that children and adolescents accumulate at least 60 minutes of moderate-to-vigorous physical activity (MVPA) per day (WHO, 2020), yet global surveillance data consistently show that a substantial proportion of young people fail to meet this threshold (Guthold et al., 2020). The Global Matrix 4.0 corroborated these trends across the majority of evaluated countries, reinforcing the structural nature of the problem rather than attributing it to isolated contexts (Aubert et al., 2022). These patterns are consistent with broader global stagnation in physical activity promotion efforts observed over recent decades (Sallis et al., 2016). Insufficient physical activity during childhood and adolescence has been associated with adverse physical, metabolic, and psychosocial outcomes, underscoring the relevance of early-life behavioural patterns for long-term health trajectories.

Epidemiological research and health promotion policies have traditionally framed physical activity almost exclusively in terms of total daily volume, affording comparatively little attention to how that activity is distributed across the day (Verswijveren et al., 2018). This framing, however, overlooks a fundamental property of movement behaviour: MVPA is not a homogeneous construct. It can accumulate through brief, repeated bouts or through sustained, continuous efforts, and these structural differences may produce distinct physiological stimuli. Aadland et al. (2018) identified multivariate activity profiles associated with better metabolic indicators in young populations, while Tarp et al. (2018) showed that MVPA bout duration was differentially related to cardiometabolic risk. Compositional analyses have further demonstrated that the relative distribution of time across intensity levels provides information beyond what total volume alone can capture (Carson et al., 2019). Together, these findings challenge the assumption that volume is the sole determinant of health benefit.

Methodological advances in accelerometry have been central to this conceptual shift. Earlier work had already highlighted limitations of cut-point approaches in paediatric populations (Rowlands, 2007), paving the way for the adoption of raw-signal methodologies. The use of raw acceleration data, operationalised through metrics such as Euclidean Norm Minus One (ENMO), allows for more precise estimation of movement intensity (van Hees et al., 2015). Building on this, Rowlands et al. (2016, 2018) argued for moving beyond traditional intensity thresholds towards metrics capable of describing the full intensity profile across the day. Recent studies have applied raw-signal metrics to examine longitudinal trajectories of volume and intensity in paediatric samples, showing that temporal variation affects not only the quantity but also the distribution of effort (Fairclough et al., 2025). Open-source tools such as GGIR have enabled a more standardised approach to these questions, facilitating analysis of both total MVPA time and the continuity or fragmentation of activity bouts. The GRANADA consensus further underlines that the examination of temporal patterns is an essential component of any comprehensive interpretation of motor behaviour in young people (Migueles et al., 2021).

The available evidence suggests that children's physical activity is inherently intermittent in nature. Longitudinal studies have identified adolescence as a critical period of progressive decline in activity levels (Dumith et al., 2011; Farooq et al., 2018), and activity patterns established during childhood tend to track into adulthood, underscoring the preventive relevance of early intervention (Telama, 2009). Research has also documented meaningful differences in MVPA accumulation between school days and weekends, pointing to the role of contextual factors in shaping how effort is distributed over time (Brazendale et al., 2021). Understanding the temporal organisation of physical activity is therefore not a methodological refinement, but a substantive question for interpreting its health relevance.

Sex-related inequalities constitute another central axis of this research field. Objective measurement consistently shows that girls accumulate less MVPA and spend more time sedentary than boys (Cooper et al., 2015), with this gap widening through adolescence (Sherar et al., 2007). More recent evidence indicates that these differences extend beyond total volume: girls tend to exhibit less intense and more homogeneous activity profiles compared to boys (Kretschmer et al., 2023), suggesting that sex inequalities may manifest in the temporal structure of activity just as much as in the amounts accumulated.

Socioeconomic position and residential environment also shape how physical activity is organised. The Health Behaviour in School-aged Children study has documented systematic differences in the likelihood of meeting MVPA recommendations according to socioeconomic status (Inchley et al., 2020), and reviews of the built environment have shown that access to sports facilities and availability of recreational spaces are meaningful predictors of participation in physical activity (Ding et al., 2011). In addition, whole-school approaches have been identified as effective frameworks for embedding physical activity within daily routines (Langford et al., 2015), underscoring the role of institutional contexts in shaping behavioural patterns. Despite this body of evidence, the extent to which socioeconomic and environmental inequalities also affect the temporal structure of activity — rather than simply its total volume — remains insufficiently characterised.

Taken together, the literature reveals a number of persistent gaps. Population-level data on the proportion of MVPA accumulated in sustained versus fragmented bouts are scarce in large paediatric samples. Evidence on whether sociodemographic inequalities extend to the temporal structure of activity remains limited. And studies examining the independent association between sustained MVPA and body mass index (BMI) — after accounting for total volume — are few and present heterogeneous findings.

Against this background, the present study pursued two primary objectives: (1) to characterise MVPA accumulation patterns in a population-based sample of children and adolescents using wrist-worn accelerometry and raw-signal analysis; and (2) to examine differences in sustained MVPA according to sex, age, socioeconomic status, and residential setting. As a secondary aim, the study explored the association between sustained MVPA accumulation and BMI, premised on the notion that not all MVPA generates equivalent physiological stimuli and that continuous bouts may be linked to lower adiposity independently of total volume and sociodemographic characteristics.

MATERIAL AND METHODS

Participants

This study presents a secondary analysis of data collected as part of the Mugikertu study, a population-based cross-sectional investigation whose protocol has been previously published (Larrinaga-Undabarrena et al., 2022). For the present analysis, only participants from the historical territories of Álava and Gipuzkoa (Basque Country, Spain) were included. Recruitment followed a stratified, multi-stage cluster sampling design that ensured representativeness across territory, school type (state-funded or semi-private), and educational stage (Primary, Secondary, and Baccalaureate). Schools were randomly selected within each stratum, and all students from the selected classes were invited to participate.

The final analytical sample comprised 513 participants (256 boys, 257 girls) aged 6–17 years, all of whom provided valid accelerometry records according to pre-established criteria. Participation was voluntary. Written informed consent was obtained from parents or legal guardians prior to data collection, and assent was obtained from the students themselves. Ethical approval was granted by the Euskadi Research Ethics Committee for Medicinal Products (reference PI2020011).

Measures

Wrist-worn accelerometry. Physical activity was assessed using a triaxial accelerometer worn on the non-dominant wrist for seven consecutive days under free-living conditions. Participants were instructed to remove the device only during water-based activities or situations involving risk of damage. Raw acceleration data were recorded at 100 Hz.

Data processing was performed using the GGIR package (version 4.5.2) in R, which applies automatic calibration against local gravity, identifies non-wear time through a low-signal-variability algorithm, and derives intensity metrics directly from raw acceleration (van Hees et al., 2013; Migueles et al., 2017). Data processing and wear-time criteria were aligned with established methodological recommendations for accelerometer-based research in paediatric populations (Migueles et al., 2017). Movement intensity was quantified using the Euclidean Norm Minus One (ENMO) metric, calculated as the Euclidean norm of the three acceleration axes minus 1g, with negative values truncated to zero and no additional smoothing applied. ENMO values were summarised in non-overlapping 5-second epochs.

MVPA was defined as ENMO ≥ 100 mg, a threshold widely adopted in wrist-accelerometry studies with paediatric populations (Rowlands et al., 2016; Migueles et al., 2017). Daily MVPA was expressed as the accumulated ENMO (mg) across all 5-second epochs classified as MVPA and averaged per valid day. To characterise the temporal structure of motor behaviour, daily MVPA was disaggregated by bout duration, identifying sustained blocks of ≥ 1 , ≥ 5 , and ≥ 10 consecutive minutes above the threshold. Bout identification followed a strict consecutive criterion: all 5-second epochs within the specified duration were required to remain above the cut-off, with no interruptions permitted.

Anthropometric and contextual variables. Body mass and height were measured directly at each school using standardised protocols. Body mass index (BMI) was calculated as body mass in kilograms divided by height in metres squared (kg/m^2) and used as a continuous indicator of adiposity. Socioeconomic status was estimated using an area-level deprivation index assigned according to census tract of residence, integrating indicators of income, employment, and educational attainment. Residential setting was classified as urban or rural according to official administrative criteria.

Procedures

Data collection took place during the academic year in coordination with participating schools. Trained research personnel provided standardised instructions on device fitting and use at each school visit. All measurements, including anthropometric assessments, were conducted by the same team under uniform conditions to minimise inter-observer variability.

Analysis

Analyses were conducted at the individual level using mean daily values as the unit of analysis. Descriptive statistics are reported as means and standard deviations. To identify independent predictors of sustained MVPA (≥ 10 minutes), multivariable linear regression models were fitted including age (continuous), sex, socioeconomic status, and residential setting as independent variables. A second model was estimated with BMI as the dependent variable, incorporating sustained MVPA alongside the same sociodemographic covariates as predictors. The significance threshold was set at $p < .05$. All analyses were conducted in R (version 4.5.2).

RESULTS

Overall MVPA accumulation pattern

Across the full sample, MVPA was predominantly accumulated in shorter and intermittent bouts. Mean daily total MVPA was $108,529 \pm 49,120$ ENMO units, of which $35,508 \pm 27,729$ were accumulated in sustained bouts ≥ 10 minutes, representing 34.8% of total MVPA. The proportion of MVPA declined progressively as bout duration increased (Table 1). Boys accumulated higher total MVPA than girls ($111,336 \pm 52,943$ vs. $105,744 \pm 44,939$ ENMO units). They also accumulated greater absolute amounts of MVPA in sustained bouts. In bouts ≥ 10 minutes, boys accumulated $42,467 \pm 31,333$ compared with $28,603 \pm 21,555$ in girls. In proportional terms, 40.9% of total MVPA in boys was accumulated in bouts ≥ 10 minutes, compared with 28.8% in girls. The difference in sustained MVPA (≥ 10 min) between boys and girls corresponded to a moderate effect size (Cohen's $d = 0.51$), indicating a meaningful sex-related disparity in the temporal accumulation of MVPA.

Table 1. MVPA accumulation patterns by sex.

Group	N	MVPA total (mean \pm SD)	MVPA ≥ 1 min (mean \pm SD)	MVPA ≥ 5 min (mean \pm SD)	MVPA ≥ 10 min (mean \pm SD)	% ≥ 1 min	% ≥ 5 min	% ≥ 10 min
Total	513	108,529 \pm 49,120	65,442 \pm 33,525	44,941 \pm 29,230	35,508 \pm 27,729	66.2%	44.7%	34.8%
Boys	256	111,336 \pm 52,943	68,298 \pm 36,045	51,347 \pm 32,682	42,467 \pm 31,333	68.4%	50.6%	40.9%
Girls	257	105,744 \pm 44,939	62,610 \pm 30,629	38,584 \pm 23,753	28,603 \pm 21,555	64.1%	38.9%	28.8%

Note. MVPA values are expressed as mean daily ENMO units \pm standard deviation. Percentages refer to the proportion of total daily MVPA accumulated within each bout-duration category.

Age-related differences

MVPA volume and sustained accumulation declined markedly across age groups (Table 2). The youngest participants (6–9 years) exhibited the highest total MVPA and the greatest absolute accumulation in sustained bouts, whereas adolescents aged 16–17 years showed the lowest values. Between these age groups, mean daily MVPA decreased by approximately 44%, and MVPA accumulated in ≥ 10 -minute bouts declined by around 38%. The contrast in sustained MVPA between the youngest and oldest age groups represented a moderate-to-large effect size (Cohen's $d = 0.63$), reflecting a substantial age-related reduction in sustained physical effort. Although absolute values decreased with age, the relative proportions of MVPA accumulated within each bout-duration category remained broadly similar across age groups.

Table 2. MVPA accumulation patterns by age group.

Age group	N	MVPA total (mean \pm SD)	MVPA ≥ 1 min (mean \pm SD)	MVPA ≥ 5 min (mean \pm SD)	MVPA ≥ 10 min (mean \pm SD)	% ≥ 1 min	% ≥ 5 min	% ≥ 10 min
6–9	128	132,818 \pm 45,849	79,059 \pm 33,474	51,649 \pm 29,809	39,246 \pm 29,706	65.3%	41.0%	30.7%
10–12	138	124,004 \pm 45,202	76,433 \pm 33,457	54,738 \pm 32,245	44,028 \pm 31,256	66.4%	46.1%	36.0%
13–15	119	101,232 \pm 49,584	61,823 \pm 30,882	41,095 \pm 28,327	30,593 \pm 21,908	61.1%	40.6%	30.2%
16–17	108	74,950 \pm 32,543	44,513 \pm 22,774	32,377 \pm 18,328	24,406 \pm 16,996	59.4%	43.2%	32.6%

Note. MVPA values are expressed as mean daily ENMO units \pm standard deviation. Percentages refer to the proportion of total daily MVPA accumulated within each bout-duration category.

Socioeconomic status

Total MVPA differed across socioeconomic categories (Table 3). Children from lower-SES backgrounds accumulated higher overall MVPA compared with those from very high SES groups. For example, mean total MVPA increased from $93,805 \pm 40,478$ ENMO units in the very high SES group to $119,602 \pm 38,834$ in the very low SES group. However, this higher overall volume was not consistently reflected in the proportional distribution of sustained MVPA. The difference in sustained MVPA (≥ 10 min) between the highest and lowest

socioeconomic categories was small-to-moderate in magnitude (Cohen's $d = 0.35$), suggesting that socioeconomic disparities were more evident in total volume than in sustained accumulation patterns.

Table 3. MVPA accumulation patterns by socioeconomic status.

SES	N	MVPA total (mean ± SD)	MVPA ≥1 min (mean ± SD)	MVPA ≥5 min (mean ± SD)	MVPA ≥10 min (mean ± SD)	%≥1 min	%≥5 min	%≥10 min
Very high	93	93,805 ± 40,478	58,091 ± 33,163	39,122 ± 29,135	28,933 ± 25,966	61.9%	42.2%	32.0%
High	137	100,760 ± 52,504	63,476 ± 33,168	40,413 ± 29,259	37,174 ± 29,878	63.0%	41.1%	34.1%
Medium	122	104,627 ± 49,860	77,498 ± 35,442	53,421 ± 32,661	37,349 ± 22,091	73.1%	49.6%	35.7%
Low	111	114,998 ± 53,983	71,199 ± 37,388	50,387 ± 33,785	40,039 ± 29,912	68.2%	46.7%	38.4%
Very low	50	119,602 ± 38,834	70,379 ± 28,693	49,003 ± 24,024	37,350 ± 22,091	62.1%	43.0%	32.2%

Note. SES categories derived from an area-level deprivation index. MVPA values are expressed as mean daily ENMO units ± standard deviation.

Residential setting differences

Children living in rural areas accumulated greater total MVPA than their urban counterparts (115,577 ± 53,169 vs. 106,689 ± 47,906 ENMO units; Table 4). However, the proportional distribution of MVPA across bout durations differed slightly between settings. Urban participants accumulated a higher proportion of their MVPA in sustained bouts ≥10 minutes (35.7%) compared with rural participants (31.6%), despite similar absolute values of sustained MVPA.

Table 4. MVPA accumulation patterns by residential setting.

Setting	N	MVPA total (mean ± SD)	MVPA ≥1 min (mean ± SD)	MVPA ≥5 min (mean ± SD)	MVPA ≥10 min (mean ± SD)	%≥1 min	%≥5 min	%≥10 min
Rural	106	115,577 ± 53,169	72,045 ± 37,522	48,565 ± 32,065	35,775 ± 28,766	68.9%	43.9%	31.6%
Urban	407	106,689 ± 47,906	63,719 ± 32,228	43,995 ± 28,409	35,438 ± 27,488	65.5%	44.9%	35.7%

Note. MVPA values are expressed as mean daily ENMO units ± standard deviation.

Multivariable regression models

The multivariable linear regression model examining predictors of sustained MVPA (accumulated in ≥10-minute bouts) was statistically significant ($F(4, 507) = 19.42$; $p < .001$) and explained 12.6% of the variance ($R^2 = .126$), corresponding to an approximately medium overall effect size (Cohen's $f^2 = 0.14$). Older age was independently associated with lower sustained MVPA ($\beta = -1.927$; 95% CI: -2.570 to -1.283 ; $p < .001$), and female sex was likewise associated with lower sustained MVPA ($\beta = -14.001$; 95% CI: -18.504 to -9.498 ; $p < .001$). Socioeconomic status showed a small positive association, whereas residential setting was not statistically significant in the adjusted model (Figure 1).

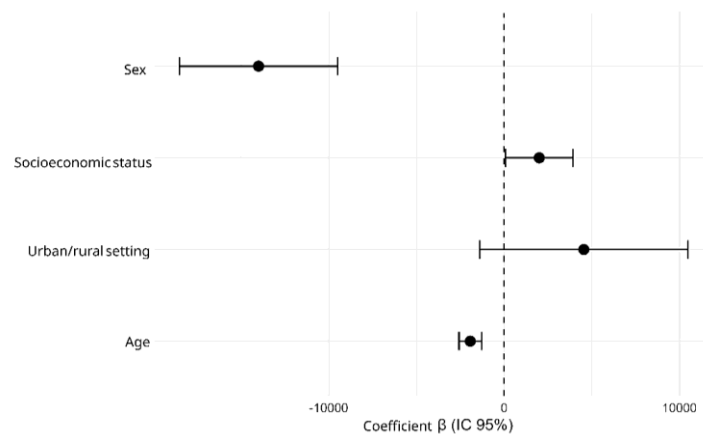


Figure 1. Sociodemographic predictors of sustained moderate-to-vigorous physical activity (≥10 min).

The regression model including BMI as the dependent variable was also statistically significant ($F(5, 506) = 58.19$; $p < .001$) and explained 35.9% of the variance ($R^2 = .359$), representing a large overall effect size (Cohen's $f^2 = 0.56$). Sustained MVPA (accumulated ENMO in ≥ 10 -minute bouts) was inversely associated with BMI ($\beta = -9.05 \times 10^{-6}$; 95% CI: -1.71×10^{-5} to -1.00×10^{-6} $p = .028$) after adjustment for age, sex, socioeconomic status, and residential setting. Although the regression coefficient is numerically small due to the scale of the ENMO metric, the association indicates that greater accumulation of sustained MVPA is independently related to lower BMI. Age was positively associated with BMI, whereas sex, socioeconomic status, and residential setting were not statistically significant predictors in the adjusted model (Figure 2).

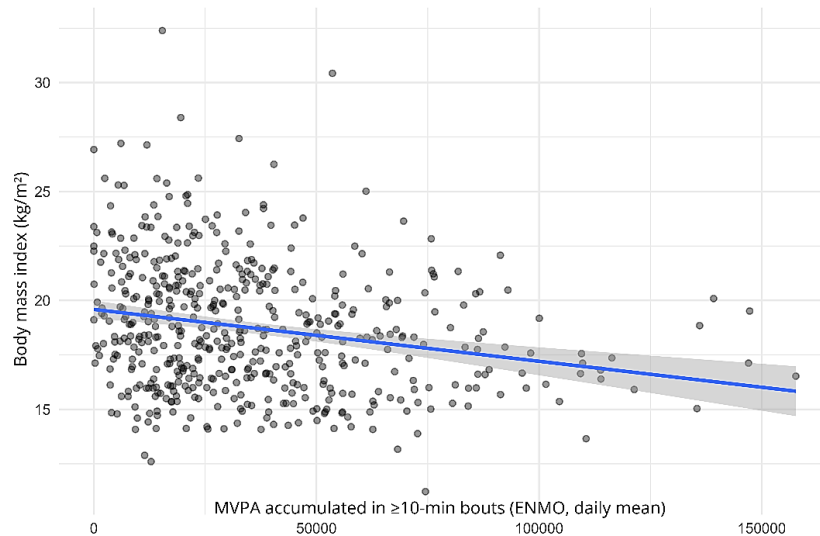


Figure 2. Association between sustained moderate-to-vigorous physical activity (≥ 10 -min bouts) and body mass index in Basque schoolchildren.

DISCUSSION

The present study provides population-based evidence that moderate-to-vigorous physical activity (MVPA) in children and adolescents is predominantly accumulated in fragmented bouts, with only approximately one third of daily MVPA occurring in sustained episodes of ≥ 10 minutes. While total volume remains a central indicator in surveillance systems (Tremblay et al., 2016; Physical Activity Guidelines Advisory Committee, 2018; WHO, 2020), the present findings demonstrate that the temporal structure of accumulation varies meaningfully across demographic groups and may represent an additional dimension of behavioural inequality. Emerging accelerometry frameworks have increasingly emphasised distribution- and profile-based metrics beyond simple threshold-derived minutes (Rowlands et al., 2018; Aadland et al., 2018), supporting the relevance of examining how activity is organised, not only how much is accumulated.

Sex differences were not only statistically significant but also of moderate magnitude ($d = 0.51$), indicating that boys accumulated a substantially greater proportion of their MVPA in sustained bouts compared with girls. Previous accelerometry-based research has consistently documented lower total MVPA in girls (Cooper et al., 2015; Sherar et al., 2007; Kretschmer et al., 2023), yet fewer studies have examined how this activity is temporally organised. The present results suggest that sex-related disparities extend beyond volume to include the continuity of effort. Evidence indicates that both intensity and bout duration may be relevant for

cardiometabolic health in youth (Tarp et al., 2018; Verswijveren et al., 2018). If sustained activity provides a distinct physiological stimulus—through prolonged cardiovascular loading or metabolic demand—such differences may have implications for long-term health trajectories that are not captured by volume alone.

Age-related differences were even more pronounced. The contrast between the youngest and oldest age groups yielded a moderate-to-large effect ($d = 0.63$), reflecting a substantial decline in sustained MVPA across adolescence. This finding is consistent with longitudinal evidence showing progressive reductions in overall activity during adolescence (Dumith et al., 2011; Farooq et al., 2018) but extends it by indicating that the decline affects not only quantity but also the structure of effort. International accelerometry data have shown marked age-related reductions in MVPA and shifts in intensity distribution (Cooper et al., 2015). School-based structures represent one of the most consistent settings for promoting sustained physical activity in youth (Dobbins et al., 2013), yet engagement tends to decline with increasing age.

Socioeconomic differences were smaller in magnitude ($d = 0.35$) and did not follow a clear linear gradient. Although lower socioeconomic groups accumulated higher total MVPA, this did not consistently translate into a higher proportion of sustained bouts. One possible interpretation is that activity in more deprived contexts may be more utilitarian or informal in nature—characterised by frequent, shorter episodes—rather than structured or sport-based participation that encourages sustained effort. This interpretation aligns with broader literature on contextual and environmental influences on youth physical activity opportunities (Ding et al., 2011; Giles-Corti et al., 2016; Inchley et al., 2020). Together, these findings highlight that volume-based inequalities may not fully reflect structural differences in activity patterns.

The multivariable analyses further clarified these associations. Age and sex independently predicted sustained MVPA, and the model explained a moderate proportion of variance ($R^2 = .126$; $f^2 = 0.14$), consistent with the multifactorial determinants of youth physical activity behaviour. In contrast, the BMI model demonstrated a large overall effect size ($R^2 = .359$; $f^2 = 0.56$), indicating that the included predictors collectively accounted for a substantial proportion of BMI variability. Sustained MVPA was inversely associated with BMI after adjustment for sociodemographic factors. Although the regression coefficient appears numerically small due to the scaling of ENMO-derived units, the direction and independence of the association indicate that greater accumulation of sustained effort is related to lower BMI. While BMI is not a direct measure of body composition, it remains a widely used anthropometric proxy in paediatric epidemiology and public health surveillance (Ekelund et al., 2012; Poitras et al., 2016; WHO, 2020). The present findings therefore suggest that temporal accumulation patterns may be relevant to weight-related health indicators beyond demographic influences.

From a conceptual perspective, these findings align with the growing shift in accelerometry research from threshold-based minutes toward intensity distribution and pattern metrics (Rowlands et al., 2018; Aadland et al., 2018; Carson et al., 2019). Traditional cut-point approaches quantify time spent above predefined thresholds but do not capture how activity is structured across the intensity continuum. Analytical approaches incorporating bout duration and intensity gradients have demonstrated that cardiometabolic risk markers may relate not only to total MVPA but also to its accumulation pattern (Tarp et al., 2018; Verswijveren et al., 2018). While current guidelines emphasise total accumulated MVPA regardless of bout duration (Physical Activity Guidelines Advisory Committee, 2018; WHO, 2020), the present data suggest that examining how activity is structured may provide complementary insight. This does not imply that short bouts are ineffective; rather, it indicates that behavioural patterning may reflect underlying physiological exposure in ways not captured by volume alone.

Several limitations should be considered. The cross-sectional design precludes causal inference, and reverse causality between BMI and sustained MVPA cannot be excluded. The strict definition of consecutive bouts without interruption tolerance may underestimate physiologically meaningful activity accumulated with brief pauses. In addition, MVPA was expressed in accumulated ENMO units rather than minutes per day, prioritising intensity-based profiling over guideline-aligned metrics; while this approach is consistent with current raw-accelerometry recommendations (van Hees et al., 2013; Rowlands et al., 2016; Migueles et al., 2017), it may limit direct comparison with time-based studies.

Nevertheless, the study has notable strengths. It employed wrist-worn raw accelerometry processed using open-source GGIR methodology, applied a strict and transparent bout-definition criterion, and examined multiple sociodemographic dimensions within a population-based sample. By integrating total volume and temporal accumulation within a single analytical framework, the present study contributes to a more refined characterisation of youth physical activity behaviour.

CONCLUSIONS

The findings of this study indicate that moderate-to-vigorous physical activity in children and adolescents is predominantly accumulated in fragmented bouts, with sustained episodes representing a limited proportion of total daily MVPA. The temporal organisation of activity varied meaningfully by sex and age, with boys and younger participants accumulating a greater proportion of sustained MVPA. Moreover, sustained MVPA was independently and inversely associated with BMI after adjustment for sociodemographic factors.

These results suggest that the structure of MVPA accumulation may represent an additional behavioural dimension beyond total volume, potentially contributing to weight-related health indicators in paediatric populations. While current public health guidelines appropriately emphasise total MVPA, the present findings indicate that considering how activity is accumulated may provide complementary insight for research and surveillance.

Future longitudinal studies are warranted to determine whether sustained activity patterns confer distinct health advantages over more fragmented accumulation and to clarify the directionality of the association between sustained MVPA and BMI across developmental stages.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Material preparation and data collection were performed by N. A., A. L-U., and X. R. Statistical analyses were performed by N. A. The first draft of the manuscript was written by N. A., and X. R. and A. L-U. contributed to subsequent revisions and refinement of the manuscript. All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

INFORMED CONSENT

All participants and their families or legal guardians were informed in advance about the aims and procedures of the study. Participation was voluntary. Written informed consent was obtained from parents or legal guardians, as well as assent from participating students, prior to data collection.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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