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Temporal and intensity-distribution differences in physical activity among schoolchildren and adolescents from the Basque Country: weekday-weekend and school-after-school comparisons

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Introduction: This study examined temporal and intensity-distribution differences in objectively measured physical activity among schoolchildren and adolescents from the Basque Country, Spain, comparing weekdays with weekend days, Saturday with Sunday, and school time with after-school time.

Methods: Raw wrist-accelerometer data were reprocessed for 540 participants in the Mugikertu study. The final exact-linked regional sample comprised 503 participants aged 6–17 years from 42 schools, contributing 2,979 valid days. Euclidean Norm Minus One (ENMO), waking average acceleration, intensity gradient, M30, M60, and time in moderate (MPA), vigorous (VPA), and moderate-to-vigorous physical activity (MVPA) were derived in GGIR. Pediatric non-dominant-wrist thresholds were applied (MPA 201.4–<707 mg; VPA ≥ 707 mg). Paired comparisons and multilevel models examined day-type differences, with days nested within participants and participants within schools.

Results: Mean MVPA was 65.19 ± 34.85 min/day, and 51.1% of participants accumulated an average of ≥ 60 min/day. Weekday values exceeded weekend values for 24-h ENMO (47.97 ± 17.82 vs. 41.28 ± 20.46 mg) and MVPA (68.25 ± 35.31 vs. 59.12 ± 41.94 min/day; mean difference 9.13 min/day, 95% CI 6.51–11.75). Sunday MVPA was lower than Saturday MVPA (55.81 ± 45.30 vs. 64.09 ± 48.86 min/day). During weekdays, MVPA density was lower in the 09:00–14:30 school window than in the 14:30–22:00 after-school window (4.49 ± 2.82 vs. 5.12 ± 2.89 min/h). The weekday-weekend association varied by age but not by sex or socioeconomic context for MVPA.

Conclusion: In this Basque regional sample, activity volume and intensity were lower on weekends, particularly Sundays, and declined sharply with age. School time contributed meaningfully to daily activity, but after-school time showed slightly higher MVPA density. The regional context and the age-specific pattern should be considered when transferring these findings to other settings.

KEYWORDS

accelerometry, adolescents, children, intensity gradient, physical activity, school time, weekend

1 Introduction

Regular physical activity during childhood and adolescence supports physical fitness, cardiometabolic health, psychological well-being, and cognitive and social development [Aadland et al., 2018; Poitras et al., 2016; World Health Organization (WHO), 2020]. Current guidelines recommend an average of at least 60 min/day of moderate-to-vigorous physical activity (MVPA) across the week for children and adolescents (Bull et al., 2020; WHO, 2020). Nevertheless, global surveillance indicates that approximately four in five adolescents do not meet this recommendation, making insufficient physical activity a persistent public health and educational concern (Guthold et al., 2020).

Accelerometer-based evidence shows that physical activity declines from childhood into adolescence and that activity levels differ according to sex, socioeconomic circumstances, and environmental context (Chen et al., 2023; Cooper et al., 2015; Farooq et al., 2018; García et al., 2025; Stalsberg and Pedersen, 2018). Boys generally accumulate more high-intensity activity than girls, although the size and timing of this difference vary across age and day type (García et al., 2025; Kallio et al., 2020). These patterns highlight the need to identify not only who is less active, but also when activity is most likely to decline.

The school setting is strategically important because it reaches most children and structures a substantial proportion of their waking day. Whole-school and systems-oriented frameworks therefore advocate coordinated opportunities for movement across physical education, recess, active lessons, school policy, the physical environment, and links with families and communities (Craig et al., 2024; Daly-Smith et al., 2020; Langford et al., 2015; WHO and UNESCO, 2021). However, school-based initiatives alone may be insufficient if activity is displaced or lost during after-school and weekend periods (Moeller et al., 2024).

International studies consistently report higher physical activity on weekdays than on weekend days (Brazendale et al., 2021; Brooke et al., 2014; Burchartz et al., 2022). The Structured Days Hypothesis proposes that externally organized days, such as school days, constrain opportunities for prolonged sedentary behavior and create more regular occasions for movement than less structured days (Brazendale et al., 2017). Weekend days may also differ from one another because organized sport, family routines, travel, and leisure opportunities are not distributed evenly across Saturday and Sunday.

Methodological decisions strongly influence accelerometer-derived estimates. Wrist-worn devices improve compliance in pediatric populations, but estimates based on intensity cut-points can vary substantially according to device placement and calibration threshold (Fairclough et al., 2016; Hildebrand et al., 2014; Migueles et al., 2017). Continuous metrics can complement time-in-intensity estimates. Average acceleration summarizes movement volume, the intensity gradient describes how accumulated time decreases as intensity increases, and Mx metrics identify the acceleration above which the most active $\times$ minutes are accumulated (Rowlands et al., 2018, 2019). Together, these outcomes characterize complementary dimensions of activity without relying exclusively on a single cut-point.

Evidence from Spain remains limited across the full school-age range. Previous work in adolescents identified weekday-weekend

differences using hip-worn accelerometry (Aibar et al., 2014), while a systematic review confirmed that school hours make a meaningful contribution to youth activity (Grao-Cruces et al., 2020). However, fewer studies have simultaneously separated Saturday from Sunday, compared a defined school window with a duration-adjusted after-school window, incorporated cut-point-independent metrics, and accounted for the nesting of repeated days within participants and participants within schools.

Accordingly, the primary aim was to examine differences in activity volume and intensity distribution between weekdays and weekend days, between Saturday and Sunday, and between the 09:00–14:30 school window and the 14:30–22:00 after-school window in children and adolescents from the Basque Country. Secondary aims were to quantify adherence to the 60-min/day MVPA recommendation, examine whether weekday-weekend associations varied by age and sex, and estimate the proportion of residual variability attributable to participants and schools.

2 Materials and methods

2.1 Study design and participants

This cross-sectional observational analysis used data from the Mugikertu study, whose protocol has been published previously (Larrinaga-Undabarrena et al., 2022; ISRCTN65573865). The parent study used stratified sampling based on historical territory, age, sex, school network, and socioeconomic context. The present reanalysis included all 540 raw accelerometer files available in the analytical repository. Accelerometer records in the final analytical dataset were collected between 10 November 2020 and 6 April 2022.

A valid day required at least 16 h of usable recording. Participants were eligible if they contributed at least four valid days, including at least one valid weekend day. These criteria were selected to ensure broad daily coverage and representation of both weekday and weekend exposure, consistent with recommendations to require multiple valid days in pediatric accelerometer studies (Migueles et al., 2017).

2.2 Accelerometer assessment and processing

Physical activity was measured using ActiGraph wGT3X-BT triaxial accelerometers worn on the non-dominant wrist for seven consecutive days, including weekdays and weekend days. Devices sampled raw acceleration at 100 Hz. Data were processed in R version 4.5.2 using GGIR version 3.3.6. Processing included autocalibration using local gravity, detection of non-wear from variability and range in the raw signal, and imputation of invalid segments from corresponding time points on other valid days (van Hees et al., 2013, 2014).

Euclidean Norm Minus One (ENMO) was calculated from the three orthogonal axes as $\max[\sqrt{x^2 + y^2 + z^2} - 1 \text{ g}, 0]$ and expressed in milligravity units (mg). 24-h ENMO represented average dynamic acceleration across the valid day. Waking average acceleration (AvACC) represented mean ENMO during the accelerometer-detected waking period.

Intensity categories were defined using pediatric thresholds developed for raw acceleration from the non-dominant wrist: light physical activity, 35.6–<201.4 mg; moderate physical activity (MPA), 201.4–<707 mg; vigorous physical activity (VPA), ≥ 707 mg; and MVPA, ≥ 201.4 mg (Hildebrand et al., 2014; Migueles et al., 2017). MPA, VPA, and MVPA were expressed in minutes per day or minutes per predefined time window.

To reduce dependence on cut-points, the analysis also included the intensity gradient and M60 and M30 metrics. The intensity gradient is the negative slope of the log-log relationship between activity intensity and time accumulated at that intensity; a less negative value indicates relatively more time at higher intensities. M60 and M30 represent the minimum acceleration above which the most active accumulated 60 and 30 min of the day occurred, respectively (Rowlands et al., 2018, 2019).

2.3 Temporal exposures and participant characteristics

Days were classified as weekdays (Monday–Friday) or weekend days (Saturday–Sunday). Saturday and Sunday were also compared separately among participants with valid averages for both days. For each temporal contrast, summary metrics were calculated as participant-level averages within the relevant day type or predefined time window. For weekday segment analyses, 09:00–14:30 was defined as the central school-time window and 14:30–22:00 as the after-school window. Because the windows differed in duration, both accumulated minutes and MVPA density (min/h) were examined. This revised comparison excludes overnight sleep from the after-school denominator.

Age was grouped as 6–9, 10–12, 13–15, and 16–17 years. Sex was coded as boys or girls where available. Socioeconomic context was represented by the five-category MEDEA index, ranging from 1 (more advantaged) to 5 (more disadvantaged). Residential setting was classified as rural or urban. Body mass index (BMI; kg/m²), school network, height, weight, valid wear time, and season of assessment were also summarized. Participants were classified as meeting the activity recommendation when their mean MVPA across valid days was ≥ 60 min/day.

2.4 Statistical analysis

Continuous variables are presented as mean $\pm$ standard deviation (SD), and categorical variables as number and percentage. Participant-level weekday and weekend averages, Saturday and Sunday averages, and school and after-school averages were compared using paired t-tests. Paired Cohen's *d* was calculated as the mean within-participant difference divided by the SD of those differences and interpreted as small (0.20), moderate (0.50), or large (0.80). Two-sided *p* values < 0.05 were considered statistically significant.

Linear mixed-effects models were fitted for daily 24-h ENMO, MPA, VPA, MVPA, and intensity gradient. Daily observations were nested within participants, and participants were nested within schools through random intercepts. Fixed effects included day type, age group, their interaction, sex, MEDEA score, residential setting, BMI, and valid wear time. Weekday, girls, ages 6–9 years, and rural

setting were the reference categories; continuous covariates were standardized. Age-specific weekday-weekend contrasts were obtained from estimated marginal means.

Potential effect modification by sex was examined in models containing all two-way interactions among day type, age group, and sex, followed by the age $\times$ sex $\times$ day-type interaction. Socioeconomic moderation was examined separately by adding a day type $\times$ standardized MEDEA interaction to the same adjusted model for each activity outcome. Likelihood-ratio tests compared nested maximum-likelihood models. Adjusted participant- and school-level variance proportions were calculated from model variance components. No statistical imputation of missing participant covariates was performed; adjusted models used complete cases.

2.5 Ethical considerations

The study was approved on 14 October 2020 by the Euskadi Drug Research Ethics Committee (reference PI2020011). Participation was voluntary. Parents or legal guardians provided written informed consent, and participating children and adolescents provided assent.

3 Results

3.1 Participant flow and characteristics

Figure 1 summarizes participant selection. Of the 540 raw files processed, 523 participants met accelerometer validity criteria and 503 were linked exactly to participant metadata. The final sample comprised 249 boys, 252 girls, and two participants with missing sex. Mean age was 11.9 ± 3.5 years and mean BMI was 18.7 ± 2.9 kg/m². The age-group distribution was 182 participants aged 6–9 years, 125 aged 10–12 years, 108 aged 13–15 years, and 88 aged 16–17 years. Participants contributed a mean of 5.92 ± 0.32 valid days and 23.62 ± 0.75 valid h/day. Demographic characteristics are shown in Table 1.

Mean MVPA was 65.19 ± 34.85 min/day, comprising 53.38 ± 25.78 min/day of MPA and 11.81 ± 10.42 min/day of VPA. Overall, 257 participants (51.1%) accumulated an average of ≥ 60 min/day of MVPA. Adherence declined from 87.9% among participants aged 6–9 years to 60.0% at ages 10–12, 17.6% at ages 13–15, and 3.4% at ages 16–17 (Table 2; Figure 2). All activity-volume, intensity-distribution, and Mx outcomes declined across age groups.

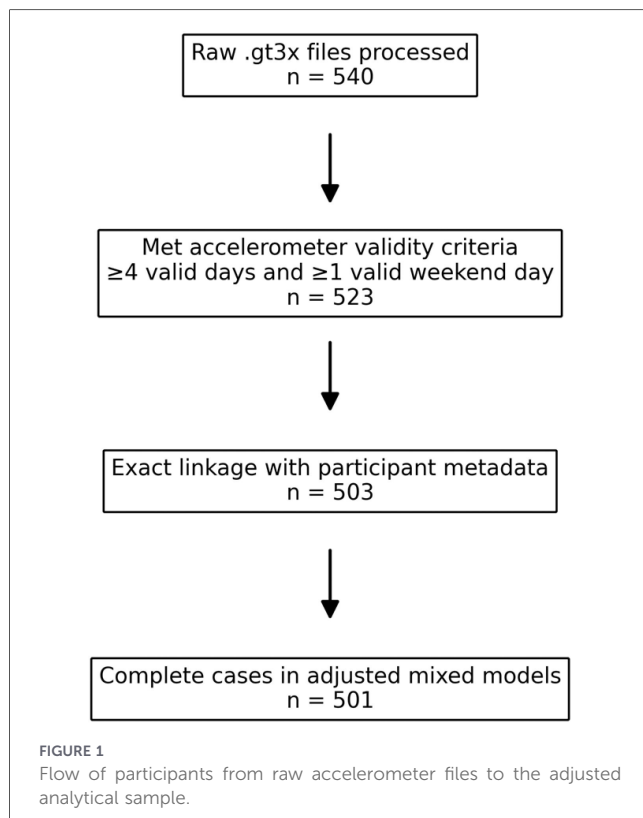
3.2 Weekday-weekend differences

In paired analyses ($n = 503$), 24-h ENMO was higher on weekdays than on weekend days (47.97 ± 17.82 vs. 41.28 ± 20.46 mg; mean difference 6.68 mg, 95% CI 5.43–7.94; $d = 0.47$; $p < 0.001$). MVPA was also higher on weekdays (68.25 ± 35.31 vs. 59.12 ± 41.94 min/day; difference 9.13 min/day, 95% CI 6.51–11.75; $d = 0.31$; $p < 0.001$). Weekday advantages were observed for MPA, VPA, M60, M30, and the intensity gradient; the gradient was less negative on weekdays, indicating a relatively greater contribution of higher intensities (Table 2 and Table 3; Supplementary Figure S1).

Weekday-weekend MVPA differences were 9.98 min/day in boys and 8.22 min/day in girls. The difference was largest descriptively at ages 6–9 years (12.92 min/day) and 16–17 years (9.60 min/day), while all paired subgroup effects were small to moderate (Table 3).

3.3 Saturday-Sunday differences

Among 485 participants with valid averages for both weekend days, MVPA was 64.09 ± 48.86 min/day on Saturday and 55.81 ± 45.30 min/day on Sunday (difference 8.27 min/day, 95% CI 4.46–12.08; $d_z = 0.19$; $p < 0.001$). Saturday values were also higher for 24-h ENMO, MPA, VPA, and intensity gradient. Subgroup estimates are reported in Supplementary Table S1.



3.4 School and after-school windows

During weekdays, participants accumulated 24.64 ± 15.48 min of MVPA during the 09:00–14:30 school window and 37.91 ± 21.25 min during the 14:30–22:00 after-school window (Table 4). After accounting for window duration, MVPA density remained slightly lower during school than after school (4.49 ± 2.82 vs. 5.12 ± 2.89 min/h; difference -0.63 min/h, 95% CI -0.83 to -0.44 ; $d_z = -0.28$; $p < 0.001$). After-school values were also higher for MPA, VPA, and waking AvACC, whereas the school-window intensity gradient was less negative.

The density difference was similar in boys (-0.65 min/h) and girls (-0.63 min/h). It was not evident at ages 6–9 years (-0.06 min/h; $p = 0.726$) but was progressively larger in the older age groups. Participants meeting the 60-min/day recommendation had higher density in both windows, but the after-school advantage was present in both adherence groups (Figure 3). Full subgroup results for MPA, VPA, AvACC, intensity gradient, M60, and M30 are provided in Supplementary Table S2 and Figure S2.

3.5 Adjusted models, interactions, and variance components

After adjustment, weekend days were associated with lower MVPA at ages 6–9 years ($\beta = -12.86$ min/day, 95% CI -16.45 to -9.27 ; $p < 0.001$), 13–15 years ($\beta = -8.09$, 95% CI -12.88 to -3.30 ; $p = 0.001$), and 16–17 years ($\beta = -9.44$, 95% CI -14.67 to -4.20 ; $p < 0.001$). The estimate at ages 10–12 years was smaller and did not meet the prespecified significance threshold ($\beta = -4.24$, 95% CI -8.60 to 0.13 ; $p = 0.057$). Adjusted weekday-weekend contrasts for ENMO, MPA, VPA, and intensity gradient are presented in Table 5.

For MVPA, the day type $\times$ age interaction was significant [likelihood-ratio $\chi^2(3) = 9.12$, $p = 0.028$], whereas the day type $\times$ sex interaction was not ($\chi^2[1] = 0.68$, $p = 0.409$). The age $\times$ sex interaction was significant ($\chi^2[3] = 19.21$, $p < 0.001$), reflecting different age-related activity trajectories in boys and girls. The age $\times$ sex $\times$ day-type interaction was not significant ($\chi^2[3] = 1.77$, $p = 0.621$). Similar conclusions were obtained for ENMO: day type $\times$ age $p = 0.013$, day type $\times$ sex $p = 0.283$, and the three-way interaction $p = 0.592$. Adjusted MVPA means by age, sex, and day type are displayed in Figure 4.

TABLE 1 Demographic and participant characteristics.

Group	N	Age, years	BMI, kg/m ²	Height, cm	Weight, kg	Urban, n (%)	Public school, n (%)	MEDEA (1–5)	Valid days
All	503	11.9 ± 3.5	18.7 ± 2.9	148.5 ± 19.2	42.9 ± 15.9	398 (79.1)	240 (47.7)	2.78 ± 1.25	5.92 ± 0.32
Boys	249	11.9 ± 3.6	18.7 ± 2.9	150.4 ± 20.7	44.3 ± 17.2	196 (78.7)	119 (47.8)	2.74 ± 1.25	5.90 ± 0.35
Girls	252	11.9 ± 3.6	18.6 ± 3.0	146.5 ± 17.4	41.5 ± 14.4	200 (79.4)	119 (47.2)	2.81 ± 1.25	5.94 ± 0.28
6–9 y	182	8.1 ± 1.1	16.9 ± 2.2	128.6 ± 8.8	28.3 ± 6.8	127 (69.8)	81 (44.5)	3.03 ± 1.26	5.98 ± 0.20
10–12 y	125	11.5 ± 0.8	18.1 ± 2.3	147.6 ± 8.4	39.8 ± 7.8	102 (81.6)	59 (47.2)	2.78 ± 1.21	5.97 ± 0.18
13–15 y	108	14.5 ± 0.8	20.5 ± 2.8	164.0 ± 9.3	55.4 ± 11.0	97 (89.8)	53 (49.1)	2.34 ± 1.21	5.84 ± 0.44
16–17 y	88	17.3 ± 0.7	21.1 ± 2.3	171.7 ± 9.0	62.3 ± 9.2	72 (81.8)	47 (53.4)	2.78 ± 1.21	5.83 ± 0.43

Values are mean $\pm$ SD unless otherwise indicated. MEDEA ranges from 1 (more advantaged) to 5 (more disadvantaged). Two participants had missing sex.

TABLE 2 Accelerometer-derived physical activity characteristics by sex and age group.

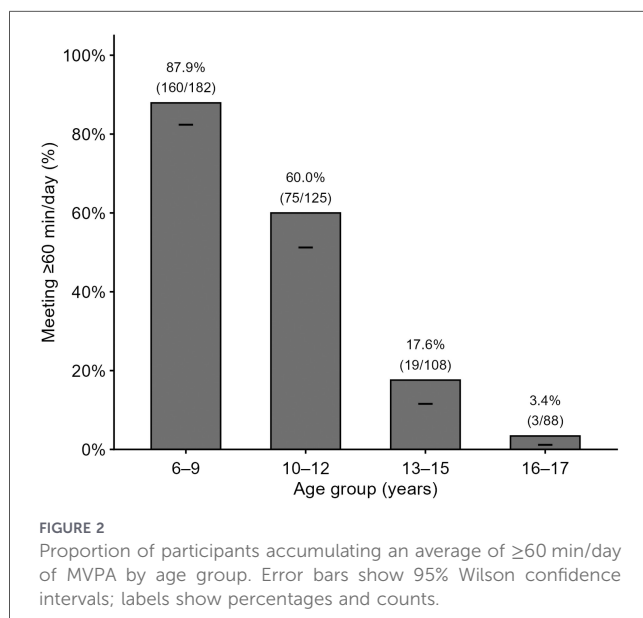
Variable	Period	All (<i>n</i> = 503)	Boys (<i>n</i> = 249)	Girls (<i>n</i> = 252)	6–9 years (<i>n</i> = 182)	10–12 years (<i>n</i> = 125)	13–15 years (<i>n</i> = 108)	16–17 years (<i>n</i> = 88)
Valid wear (h/day)	All days	23.62 ± 0.75	23.56 ± 0.94	23.68 ± 0.49	23.74 ± 0.42	23.76 ± 0.44	23.53 ± 0.70	23.25 ± 1.34
24-h ENMO (mg)	All days	45.73 ± 17.44	48.76 ± 19.87	42.84 ± 14.09	57.36 ± 14.86	49.93 ± 16.02	35.35 ± 10.24	28.45 ± 7.49
–	Weekdays	47.97 ± 17.82	51.20 ± 20.09	44.86 ± 14.66	60.43 ± 14.59	51.68 ± 16.23	37.03 ± 10.19	30.34 ± 8.87
–	Weekend days	41.28 ± 20.46	43.98 ± 23.74	38.75 ± 16.24	51.34 ± 20.11	46.43 ± 20.46	31.95 ± 14.99	24.64 ± 7.92
Waking AvACC (mg)	All days	70.15 ± 29.77	74.84 ± 33.65	65.70 ± 24.64	91.56 ± 24.84	77.18 ± 26.26	50.90 ± 15.39	39.52 ± 10.83
–	Weekdays	72.56 ± 30.13	77.60 ± 33.69	67.73 ± 25.34	95.19 ± 23.49	79.04 ± 26.72	52.40 ± 15.33	41.28 ± 12.61
–	Weekend days	65.36 ± 34.71	69.43 ± 40.17	61.57 ± 27.86	84.48 ± 34.91	73.43 ± 32.89	47.86 ± 22.22	35.83 ± 12.13
Intensity gradient	All days	−2.023 ± 0.213	−1.987 ± 0.222	−2.058 ± 0.200	−1.898 ± 0.116	−1.933 ± 0.143	−2.133 ± 0.188	−2.275 ± 0.198
–	Weekdays	−1.996 ± 0.222	−1.962 ± 0.232	−2.029 ± 0.207	−1.870 ± 0.114	−1.904 ± 0.138	−2.110 ± 0.211	−2.249 ± 0.223
–	Weekend days	−2.076 ± 0.247	−2.036 ± 0.256	−2.115 ± 0.233	−1.955 ± 0.159	−1.988 ± 0.190	−2.178 ± 0.245	−2.328 ± 0.237
M60 (mg)	All days	229.94 ± 98.73	250.53 ± 116.12	210.15 ± 72.88	288.48 ± 94.02	250.73 ± 98.62	177.73 ± 57.79	143.43 ± 33.70
–	Weekdays	237.44 ± 97.83	258.75 ± 113.24	216.86 ± 74.59	298.94 ± 89.93	254.94 ± 98.44	183.42 ± 54.23	151.70 ± 39.62
–	Weekend days	215.08 ± 121.37	234.65 ± 146.08	196.44 ± 87.01	268.24 ± 129.24	242.31 ± 125.50	165.96 ± 82.46	126.75 ± 39.54
M30 (mg)	All days	373.96 ± 184.53	418.22 ± 215.21	331.25 ± 135.65	485.64 ± 169.08	411.27 ± 188.13	272.36 ± 111.12	214.69 ± 69.44
–	Weekdays	391.96 ± 188.81	438.80 ± 216.98	346.60 ± 142.81	511.02 ± 166.91	425.07 ± 190.86	284.90 ± 114.79	230.07 ± 87.49
–	Weekend days	338.27 ± 212.30	378.15 ± 255.74	300.08 ± 149.19	435.77 ± 219.31	383.66 ± 222.18	247.34 ± 147.69	183.76 ± 74.49
MVPA (min/day)	All days	65.19 ± 34.85	70.85 ± 38.70	59.81 ± 29.68	88.77 ± 28.52	73.99 ± 31.86	44.18 ± 21.21	29.71 ± 14.78
–	Weekdays	68.25 ± 35.31	74.23 ± 38.65	62.52 ± 30.71	93.15 ± 28.11	75.47 ± 32.15	46.75 ± 20.84	32.87 ± 18.21
–	Weekend days	59.12 ± 41.94	64.26 ± 47.09	54.30 ± 35.59	80.23 ± 39.39	71.04 ± 42.82	38.96 ± 29.91	23.28 ± 16.28
MPA (min/day)	All days	53.38 ± 25.78	56.41 ± 27.91	50.55 ± 23.20	71.05 ± 19.68	60.10 ± 23.14	37.94 ± 17.11	26.26 ± 12.16
–	Weekdays	55.41 ± 26.19	58.70 ± 27.91	52.29 ± 24.05	73.92 ± 20.08	60.70 ± 23.39	39.90 ± 16.78	28.65 ± 14.56
–	Weekend days	49.34 ± 31.53	51.92 ± 34.19	46.98 ± 28.54	65.48 ± 27.34	58.91 ± 32.57	33.90 ± 23.91	21.32 ± 14.15
VPA (min/day)	All days	11.81 ± 10.42	14.44 ± 12.08	9.26 ± 7.69	17.72 ± 10.08	13.89 ± 10.73	6.25 ± 6.22	3.45 ± 3.91
–	Weekdays	12.84 ± 10.57	15.53 ± 12.08	10.23 ± 8.04	19.23 ± 9.56	14.77 ± 10.77	6.86 ± 6.58	4.22 ± 5.01
–	Weekend days	9.78 ± 12.41	12.34 ± 14.89	7.32 ± 8.70	14.75 ± 13.92	12.13 ± 12.85	5.06 ± 8.31	1.95 ± 3.97
Meeting ≥60 min/day	<i>n</i> (%)	257 (51.1)	140 (56.2)	117 (46.4)	160 (87.9)	75 (60.0)	19 (17.6)	3 (3.4)

AvACC, average acceleration during waking time; ENMO, Euclidean Norm Minus One; M30/M60, acceleration above which the most active 30/60 min were accumulated; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity. Guideline adherence was defined as mean MVPA ≥60 min/day.

Exploratory moderation analyses did not identify evidence that the weekday-weekend difference in MVPA varied linearly across the MEDEA socioeconomic index ($\chi^2[1] = 1.83$, $p = 0.176$). Corresponding day type $\times$ MEDEA interactions were also non-significant for ENMO ($p = 0.177$), MPA ($p = 0.242$), and VPA ($p = 0.140$). An interaction was observed for intensity gradient ($\chi^2[1] = 8.34$, $p = 0.004$), but this isolated finding was treated as exploratory because it was not accompanied by moderation of the volume or time-in-intensity outcomes (Supplementary Table S5).

In the adjusted MVPA model, 7.6% of residual variance was attributable to schools and 30.4% to participants. The adjusted school variance proportions were 10.1% for ENMO, 6.7% for MPA, 8.0% for VPA, and 3.1% for intensity gradient (Table 6).

Valid observations were distributed across winter (42.4%), spring (35.1%), summer (4.2%), and autumn (18.4%) (Supplementary Table S3).



4 Discussion

The revised analysis identified four principal findings. First, activity volume and intensity were lower on weekend days than on weekdays across ENMO, MPA, VPA, MVPA, intensity gradient, and Mx metrics. Second, Sunday was less active than Saturday. Third, the 09:00–14:30 school window made a substantial contribution to daily activity, but MVPA density was slightly higher during the 14:30–22:00 after-school window. Fourth, activity and guideline adherence declined sharply with age. These findings describe differences between predefined days and time windows; they should not be interpreted as a continuous characterization of the complete 24-h activity profile.

The weekday advantage is consistent with systematic reviews and multi-country accelerometer studies (Brazendale et al., 2021; Brooke et al., 2014; Burchartz et al., 2022). School days provide scheduled travel, recess, physical education, transitions, and extracurricular routines that may support movement, whereas weekend activity depends more heavily on family organization, access to facilities, and discretionary choices. The small-to-moderate paired effects indicate that the weekday-weekend contrast was systematic rather than large for every participant. The significant day type $\times$ age interaction further suggests that the size of this contrast was not constant across development. The mean weekday-weekend difference in 24-h ENMO was 6.68 mg; although statistically robust, this magnitude should not be interpreted as evidence of a clinically meaningful health difference. The present study was not designed to establish a minimal clinically important difference in ENMO or to link the day-type contrast directly to health outcomes.

Separating Saturday and Sunday revealed additional within-weekend heterogeneity. Sunday MVPA was approximately 8 min/day lower than Saturday MVPA, although the standardized effect was small. Organized sport and active family travel may occur more frequently on Saturdays, while Sundays may involve more recovery, screen-based leisure, or less structured activity. These mechanisms were not measured and remain hypotheses. Nevertheless, treating the weekend as a

TABLE 3 Paired weekday-weekend comparisons in the total sample and for MVPA by sex and age group.

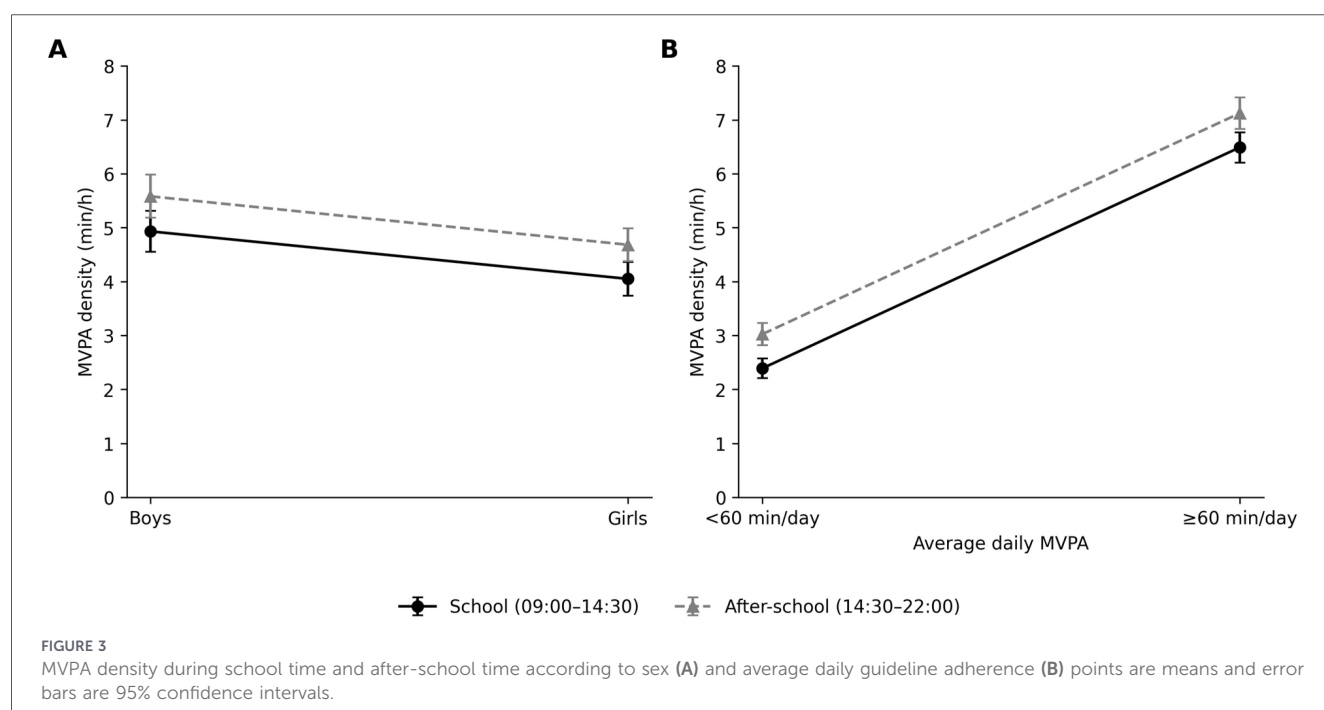
Group	Outcome	N	Weekdays, mean $\pm$ SD	Weekend, mean $\pm$ SD	Mean difference	95% CI	p value	Cohen's dz
All	24-h ENMO (mg)	503	47.97 $\pm$ 17.82	41.28 $\pm$ 20.46	6.68	5.43 to 7.94	<0.001	0.47
All	MPA (min/day)	503	55.41 $\pm$ 26.19	49.34 $\pm$ 31.53	6.07	4.02 to 8.12	<0.001	0.26
All	VPA (min/day)	503	12.84 $\pm$ 10.57	9.78 $\pm$ 12.41	3.06	2.29 to 3.82	<0.001	0.35
All	MVPA (min/day)	503	68.25 $\pm$ 35.31	59.12 $\pm$ 41.94	9.13	6.51 to 11.75	<0.001	0.31
All	Intensity gradient	503	−2.00 $\pm$ 0.22	−2.08 $\pm$ 0.25	0.08	0.06 to 0.10	<0.001	0.43
Boys	MVPA (min/day)	249	74.23 $\pm$ 38.65	64.26 $\pm$ 47.09	9.98	5.95 to 14.00	<0.001	0.31
Girls	MVPA (min/day)	252	62.52 $\pm$ 30.71	54.30 $\pm$ 35.59	8.22	4.80 to 11.63	<0.001	0.30
6–9 y	MVPA (min/day)	182	93.15 $\pm$ 28.11	80.23 $\pm$ 39.39	12.92	8.24 to 17.60	<0.001	0.40
10–12 y	MVPA (min/day)	125	75.47 $\pm$ 32.15	71.04 $\pm$ 42.82	4.43	−1.92 to 10.78	0.170	0.12
13–15 y	MVPA (min/day)	108	46.75 $\pm$ 20.84	38.96 $\pm$ 29.91	7.79	3.15 to 12.44	0.001	0.32
16–17 y	MVPA (min/day)	88	32.87 $\pm$ 18.21	23.28 $\pm$ 16.28	9.60	5.37 to 13.83	<0.001	0.48

Positive differences indicate higher weekday values. Cohen's dz: 0.20 small, 0.50 moderate, and 0.80 large. Bold p values indicate statistical significance at $p < 0.05$.

TABLE 4 Paired school and after-school comparisons in the total sample and MVPA density by sex and age group.

Group	Outcome	N	School 09:00–14:30, mean $\pm$ SD	After-school 14:30–22:00, mean $\pm$ SD	Mean difference	95% CI	p value	Cohen's dz
All	MVPA (min/window)	503	24.64 $\pm$ 15.48	37.91 $\pm$ 21.25	–13.27	–14.63 to –11.91	<0.001	–0.86
All	MVPA density (min/h)	503	4.49 $\pm$ 2.82	5.12 $\pm$ 2.89	–0.63	–0.83 to –0.44	<0.001	–0.28
All	MPA (min/window)	503	19.83 $\pm$ 11.53	30.25 $\pm$ 15.56	–10.42	–11.42 to –9.41	<0.001	–0.90
All	VPA (min/window)	503	4.81 $\pm$ 4.47	7.66 $\pm$ 6.88	–2.86	–3.32 to –2.39	<0.001	–0.53
All	Waking AvACC (mg)	503	74.64 $\pm$ 35.04	80.02 $\pm$ 36.10	–5.38	–7.74 to –3.02	<0.001	–0.20
All	Intensity gradient	503	–1.84 $\pm$ 0.25	–1.89 $\pm$ 0.22	0.04	0.03 to 0.06	<0.001	0.23
Boys	MVPA density (min/h)	249	4.93 $\pm$ 3.04	5.58 $\pm$ 3.20	–0.65	–0.96 to –0.34	<0.001	–0.26
Girls	MVPA density (min/h)	252	4.05 $\pm$ 2.51	4.68 $\pm$ 2.48	–0.63	–0.88 to –0.39	<0.001	–0.32
6–9 y	MVPA density (min/h)	182	6.75 $\pm$ 2.28	6.81 $\pm$ 2.43	–0.06	–0.40 to 0.28	0.726	–0.03
10–12 y	MVPA density (min/h)	125	4.78 $\pm$ 2.16	5.78 $\pm$ 2.84	–1.00	–1.39 to –0.61	<0.001	–0.45
13–15 y	MVPA density (min/h)	108	2.72 $\pm$ 1.54	3.50 $\pm$ 2.11	–0.78	–1.21 to –0.35	<0.001	–0.35
16–17 y	MVPA density (min/h)	88	1.56 $\pm$ 1.41	2.67 $\pm$ 1.77	–1.12	–1.51 to –0.72	<0.001	–0.60

Difference = school minus after-school. Density is expressed as MVPA min/h. Cohen's dz: 0.20 small, 0.50 moderate, and 0.80 large. Bold p values indicate statistical significance at $p < 0.05$.



single exposure can conceal a potentially relevant low-activity period.

The revised school comparison materially changes the interpretation of the submitted analysis. Comparing 09:00–14:30 with the remainder of a 24-h day had included overnight sleep and therefore artificially reduced out-of-school activity density. When school time was compared specifically with 14:30–22:00, after-school MVPA density was 0.63 min/h higher. School time remained important, particularly for younger children, but the results do not support describing it as the most activity-dense part of the day. The after-school period appears at least as

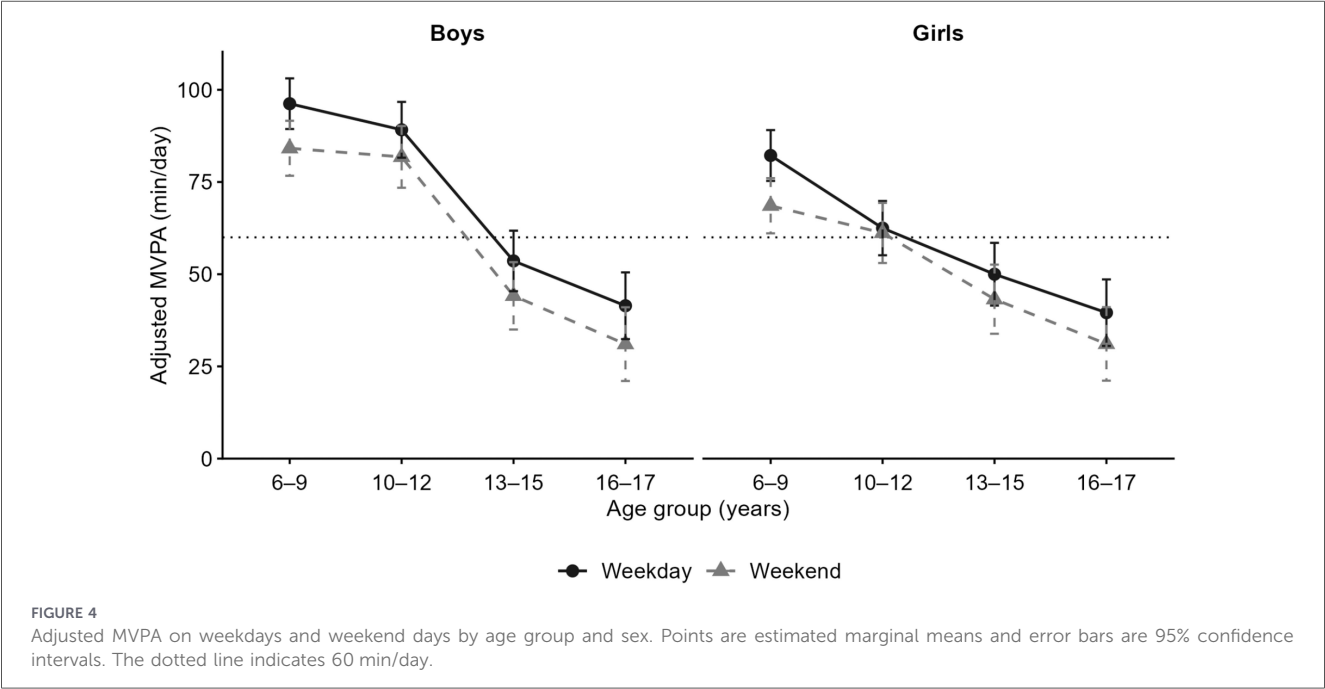
important for total activity and may offer greater flexibility for active travel, organized sport, outdoor play, and community programs.

The age gradient was substantial. Mean MVPA declined from 88.8 min/day at ages 6–9 years to 29.7 min/day at ages 16–17 years, and guideline adherence declined from 87.9% to 3.4%. These results align with longitudinal and meta-analytic evidence showing that accelerometer-measured activity begins to decline during childhood and continues through adolescence (Chen et al., 2023; Farooq et al., 2018; van Sluijs et al., 2021). The low adherence among older adolescents

TABLE 5 Adjusted weekday-weekend contrasts by age group from mixed-effects models.

Outcome	Age group	Adjusted weekend vs weekday β	SE	95% CI	<i>p</i> value
24-h ENMO (mg)	6–9	−9.07	0.91	−10.85 to −7.28	<0.001
24-h ENMO (mg)	10–12	−5.18	1.11	−7.35 to −3.01	<0.001
24-h ENMO (mg)	13–15	−5.28	1.21	−7.66 to −2.90	<0.001
24-h ENMO (mg)	16–17	−5.62	1.33	−8.22 to −3.02	<0.001
MVPA (min/day)	6–9	−12.86	1.83	−16.45 to −9.27	<0.001
MVPA (min/day)	10–12	−4.24	2.23	−8.60 to 0.13	0.057
MVPA (min/day)	13–15	−8.09	2.44	−12.88 to −3.30	<0.001
MVPA (min/day)	16–17	−9.44	2.67	−14.67 to −4.20	<0.001
MPA (min/day)	6–9	−8.42	1.40	−11.15 to −5.68	<0.001
MPA (min/day)	10–12	−1.60	1.70	−4.93 to 1.73	0.346
MPA (min/day)	13–15	−6.21	1.86	−9.85 to −2.56	<0.001
MPA (min/day)	16–17	−7.18	2.04	−11.17 to −3.19	<0.001
VPA (min/day)	6–9	−4.44	0.57	−5.57 to −3.32	<0.001
VPA (min/day)	10–12	−2.64	0.70	−4.00 to −1.27	<0.001
VPA (min/day)	13–15	−1.89	0.76	−3.39 to −0.39	0.013
VPA (min/day)	16–17	−2.26	0.84	−3.89 to −0.62	0.007
Intensity gradient	6–9	−0.08	0.01	−0.11 to −0.06	<0.001
Intensity gradient	10–12	−0.08	0.01	−0.11 to −0.05	<0.001
Intensity gradient	13–15	−0.07	0.02	−0.10 to −0.04	<0.001
Intensity gradient	16–17	−0.08	0.02	−0.11 to −0.05	<0.001

Negative coefficients indicate lower weekend values. Models adjusted for sex, MEDEA score, residential setting, BMI, and valid wear time, with random intercepts for participant and school. Bold *p* values indicate statistical significance at *p* < 0.05.



indicates that population averages can mask a concentrated deficit in late adolescence.

Boys accumulated more activity than girls overall, especially at vigorous intensities. The age × sex interaction indicates that sex differences varied across age, consistent with recent analyses of the intensity distribution across the day (García et al., 2025). However, neither the day type × sex interaction nor the three-way interaction was significant. Thus, boys

TABLE 6 Interaction tests and adjusted variance proportions.

Outcome	Day × age	Day × sex	Age × sex	Day × age × sex	Adjusted school variance proportion	Adjusted participant variance proportion
24-h ENMO (mg)	χ^2 (3) = 10.70 ; p = 0.013	χ^2 (1) = 1.15; p = 0.283	χ^2 (3) = 19.68 ; p < 0.001	χ^2 (3) = 1.91; p = 0.592	10.1%	29.9%
MVPA (min/day)	χ^2 (3) = 9.12 ; p = 0.028	χ^2 (1) = 0.68; p = 0.409	χ^2 (3) = 19.21 ; p < 0.001	χ^2 (3) = 1.77; p = 0.621	7.6%	30.4%
MPA (min/day)	χ^2 (3) = 10.01 ; p = 0.018	χ^2 (1) = 0.81; p = 0.368	χ^2 (3) = 16.92 ; p < 0.001	χ^2 (3) = 2.09; p = 0.554	6.7%	28.9%
VPA (min/day)	χ^2 (3) = 5.68; p = 0.128	χ^2 (1) = 0.13; p = 0.715	χ^2 (3) = 12.00 ; p = 0.007	χ^2 (3) = 0.65; p = 0.886	8.0%	33.6%
Intensity gradient	χ^2 (3) = 0.50; p = 0.920	χ^2 (1) = 0.36; p = 0.549	χ^2 (3) = 3.77; p = 0.287	χ^2 (3) = 1.08; p = 0.782	3.1%	30.1%

Interaction tests are likelihood-ratio tests comparing nested maximum-likelihood models. Variance proportions are from covariate-adjusted random-intercept models. Bold interaction tests indicate statistical significance at $p < 0.05$.

and girls differed in absolute level and age-related trajectory, but there was no evidence that the weekday-weekend contrast followed fundamentally different sex-specific developmental patterns.

The addition of cut-point-independent metrics strengthens the interpretation. Weekday ENMO, waking AvACC, M60, M30, and intensity gradient all indicated a more active profile than weekend values. The less negative weekday intensity gradient suggests that the difference was not limited to total movement volume; relatively more time was accumulated at higher intensities. The separate MPA and VPA analyses also showed that both components contributed to the weekday advantage. These converging outcomes reduce reliance on a single MVPA threshold while retaining a metric that is directly interpretable against public health guidance.

Cut-point estimates remain calibration-dependent and should not be treated as device-independent. The pediatric thresholds used in the revised analysis are aligned with non-dominant-wrist calibration evidence (Hildebrand et al., 2014; Migueles et al., 2017), while the continuous metrics provide complementary confirmation of the temporal comparisons without relying exclusively on time-in-intensity thresholds.

Residual between-school variance in adjusted MVPA was 7.6%. This proportion is smaller than the original estimate but remains compatible with a role for school context. Timetable structure, recess provision, physical education, playground access, active travel policies, and connections with extracurricular opportunities may contribute to between-school differences. Because school characteristics were not modeled directly, the variance component should be interpreted as clustering rather than evidence for any specific school mechanism.

The regional scope is central to interpretation. All participants were drawn from the Basque Country, and the observed temporal pattern may reflect local combinations of school scheduling, urban-rural geography, climate, transport, community sport provision, and family routines. The study did not measure these contextual features directly, so it cannot determine whether any particular Basque cultural or institutional characteristic buffered or amplified weekend

differences. The results should therefore be understood as evidence from a specific regional education and public-health context rather than as estimates that are automatically representative of Spain or other European settings.

Practical implications differ by developmental stage and policy actor. For children of primary-school age, weekend and Sunday opportunities are likely to depend strongly on family logistics; family-centered active travel, outdoor play, and accessible weekend programs may therefore be appropriate. For adolescents, the most urgent finding is the very low absolute activity and guideline adherence, suggesting a need for flexible, low-cost, peer-relevant, and self-organized opportunities after school and at weekends rather than relying only on adult-directed programs. Schools should protect physical education, recess, active travel, and movement opportunities as a universal safety net, while recognizing that the school window was not the most activity-dense period. Importantly, the school setting remains a structured and recurrent opportunity to reach adolescents, the group with the lowest absolute MVPA and guideline adherence in this study. Strengthening school-based movement opportunities should therefore remain part of a broader strategy that also addresses after-school and weekend periods. Municipal and community organizations can complement this role by maintaining accessible after-school facilities and targeting the Sunday activity gap. Regional education, health, and sport authorities are positioned to coordinate these settings and monitor whether access differs by socioeconomic context.

Several limitations should be considered. The cross-sectional design precludes causal inference. Although wrist placement can support wear compliance, the ActiGraph wGT3X-BT is relatively bulky for continuous wrist wear compared with consumer-grade wrist devices; discomfort or device salience may therefore have influenced wear behavior in some participants, despite the high valid wear time observed. Fixed clock windows may not correspond exactly to every school's timetable, and the after-school window did not include before-school activity. The analysis used predefined segments and summary metrics rather

than functional data analysis, so it does not preserve continuous within-day trajectories. Twenty otherwise valid accelerometer records were excluded because metadata linkage could not be resolved unambiguously. Data collection was unevenly distributed across seasons, with limited summer observations. BMI was modeled as a raw continuous covariate; standardized BMI z-scores, weight-status categories, cardiorespiratory fitness, and other health indicators were not available in the harmonized analytical dataset. Consequently, we did not examine associations between the magnitude of the weekend activity difference and health outcomes, because such analyses would be difficult to interpret across ages 6–17 using raw BMI alone. Organized sport, family routines, screen time, school scheduling, and other regional contextual factors were also not measured. These omissions limit explanation of the observed temporal differences and should be addressed in future longitudinal and context-rich studies.

Strengths include reprocessing of raw accelerometer data using transparent pediatric thresholds, high daily wear time, inclusion of a broad age range and 42 schools, separation of MPA and VPA, incorporation of ENMO, AvACC, intensity gradient, and Mx metrics, explicit comparison of Saturday and Sunday, a sleep-free after-school comparison, and multilevel models accounting for repeated days and school clustering. The processing and analysis code is supplied as [supplementary material](#) to support reproducibility.

5 Conclusions

In this sample of schoolchildren and adolescents from the Basque Country, physical activity volume and intensity were lower on weekend days than on weekdays, and Sunday was less active than Saturday. These differences were observed across cut-point-based and cut-point-independent outcomes. Activity and adherence to the 60-min/day recommendation declined markedly with age, with particularly low adherence among participants aged 13–17 years. No consistent socioeconomic moderation of the MVPA weekend difference was detected, although further equity-focused analyses remain warranted.

The school window contributed meaningfully to weekday movement but did not have a higher MVPA density than the 14:30–22:00 after-school period. For younger children, family-supported weekend opportunities are relevant; for adolescents, flexible and socially attractive after-school and weekend options are a priority. Schools, families, municipal services, community sport organizations, and regional authorities should therefore coordinate activity opportunities while recognizing that these Basque regional findings may not transfer unchanged to other contexts. Longitudinal, functional, and health-linked analyses are needed to determine how continuous daily activity trajectories change across development and to identify the mechanisms underlying temporal and socioeconomic differences.

Data availability statement

The raw accelerometer data and participant-level data are not publicly available due to ethical and privacy restrictions related to

research involving minors. These data contain potentially identifiable information and were collected under informed consent that does not permit unrestricted public sharing.

Ethics statement

The study was approved on 14 October 2020 by the Euskadi Drug Research Ethics Committee (reference PI2020011). The study was conducted in accordance with local legislation and institutional requirements. Parents or legal guardians provided written informed consent, and participating children and adolescents provided assent.

Author contributions

NA-K: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. XR: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. AG: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. XM-M: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. IS: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. AL-U: Conceptualization, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2026.1855527/full#supplementary-material>

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