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Biological, Social, and Structural Gaps in Physical Activity: Age, Gender and Sport in Basque Youth

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Received: 21/10/2025; Accepted: 10/04/2026; Published: 30/06/2026

Abstract: This study aimed to identify age-related turning points in physical activity (PA) and sedentary behaviour trajectories among children and adolescents, considering activity intensity, sex, age, and participation in organised sport (OS). A cross-sectional design was applied to data from the Mugikertu study, conducted in the Basque Country between 2020 and 2022. A representative sample of 1,073 schoolchildren aged 5–17 years was recruited, and 1,032 participants with valid accelerometer data were included in the analyses (510 girls and 520 boys). PA and sedentary behaviour were objectively measured using ActiGraph WGT3X-BT accelerometers worn on the non-dominant wrist for seven consecutive days. Daily minutes spent in sedentary, light, moderate, vigorous, and moderate-to-vigorous physical activity (MVPA) were estimated. Age-related trajectories were examined using LOWESS smoothing, and segmented regression models were used to identify inflection points. Moderate and vigorous activity declined earlier in girls than in boys, with turning points emerging at 8 years in girls and 9 years in boys. MVPA decline occurred at 9 years in girls and 10 years in boys. Sedentary behaviour increased from 12 years in girls and 13 years in boys. OS participation delayed the onset of sedentary behaviour in the total sample (12.3 vs. 14.8 years) and attenuated the decline in MVPA, particularly among girls. These findings suggest that PA trajectories are shaped by the interaction between biological maturation, sex-related differences, and structural opportunities for sport participation. Preventive strategies should begin before adolescence and prioritise equitable access to organised sport, especially for girls.

Keywords: Accelerometry, cut-off points, children, sedentary behaviour, adolescent, organised sport.



1. Introduction

The health benefits of a physically active lifestyle during youth are well established. Regular physical activity (PA) enhances cardiorespiratory and muscular fitness, bone and cardiometabolic health, contributes to healthy weight management, and reduces the risk of obesity, cardiovascular diseases, type 2 diabetes, and mental health disorders later in life (Piercy et al., 2018; Tremblay et al., 2011).

In recognition of these benefits, the World Health Organization (WHO) recommends that children and adolescents aged 5–17 years engage in at least 60 minutes per day of moderate- to vigorous-intensity physical activity (MVPA), alongside vigorous aerobic and muscle-strengthening activities at least three times per week (Bull et al., 2020). Despite these guidelines, more than 80% of young people worldwide do not achieve recommended PA levels (Guthold et al., 2018). In Europe, and specifically in the Basque Country, recent evidence confirms this worrying trend, with large proportions of school-aged children failing to meet PA guidelines and showing strong associations between low PA, poor sleep, and adverse health outcomes (Larrinaga-Undabarrena et al., 2023; Aubert et al., 2022). This situation is consistent with international surveillance initiatives such as the Global Matrix, which have documented insufficient PA levels in more than 90% of children and adolescents across 49 countries (Aubert et al., 2022).

Establishing active habits early in life is critical, as social determinants such as family, peers, and community strongly shape PA trajectories (Carlson et al., 2019; Hamilton et al., 2017). In addition, sociodemographic

and biological factors—including sex, age, maturation, nutritional status, and school environment—play a decisive role in adherence to active lifestyles (Silva et al., 2016). Recent normative values of sedentary behaviour and PA intensities in Basque schoolchildren obtained through accelerometry highlight sharp age- and sex-related differences, providing a valuable reference framework for monitoring inequalities (Albisua-Kaperotxi et al., 2025). Importantly, these sex-related disparities intersect with gendered social norms and opportunities, underlining the need to address inequalities between boys and girls from the earliest stages of adolescence. These findings are aligned with European and WHO policy frameworks (European Commission, 2014; World Health Organization, 2020), which stress the importance of tailored strategies to reduce inequalities in youth PA.

The decline in PA during childhood and adolescence, particularly in MVPA, is consistently associated with a rise in sedentary behaviour (Pearson et al., 2014). Global literature has documented general age-related decreases in PA (Dumith et al., 2011; Corder et al., 2019; Farooq et al., 2020). While longitudinal studies in Brazil, United Kingdom and Canada have mapped these declines, they have not identified sex- and intensity-specific inflection points, which remain largely unexplored. Identifying such turning points is essential to detect critical intervention windows and inform both research and policy (Ikeda et al., 2022). Furthermore, most existing studies rely on self-reported measures, whereas accelerometry provides an objective and more precise method to detect subtle but

clinically relevant changes in activity trajectories.

Participation in organised sport (OS) has been consistently highlighted as a protective factor, since adolescents engaged in OS are more likely to meet PA guidelines and maintain higher MVPA compared with their non-participating peers (Marques et al., 2016; Ikeda et al., 2022). Moreover, OS participation has been explicitly promoted in European and WHO health-enhancing physical activity (HEPA) strategies as a key lever to promote lifelong PA engagement (European Commission, 2014; World Health Organization, 2018). However, little is known about whether OS participation can modify the age at which PA declines and sedentary behaviour accelerates, particularly among socially and economically disadvantaged groups who often face structural barriers to organised sport access.

This study addresses a critical gap in the international literature by providing, for the first time, age- and sex-specific accelerometer-based turning points across all physical activity intensities and sedentary behaviour among Basque youth. The primary objective was to identify the specific developmental stages at which declines in light, moderate, vigorous, and moderate-to-vigorous physical activity occur, alongside increases in sedentary behaviour, and to examine whether these trajectories differ by sex and participation in organised sport. Accordingly, the study was guided by the following research question: At which ages do inflection points in physical activity and sedentary behaviour emerge, and how are these temporal windows shaped by biological (sex) and structural (organised sport participation) factors? By clarifying

these age-specific thresholds, the study seeks to inform global efforts aimed at identifying optimal timing for equity-focused intervention strategies.

2. Materials and Methods

Participants and Procedure - This cross-sectional study analysed a representative sample of 1,073 schoolchildren aged 5–17 years from the Basque Country (Euskadi), comprising 537 girls (50.05%) and 536 boys (49.95%). Data were obtained from the Mugikertu study conducted in the Basque Country (2020–2022), following the published protocol (Larrinaga- Undabarrena et al., 2022). The schools were selected to represent the entire Basque population, including public and private schools, low, middle and high socioeconomic levels, rural and urban areas and in the three provinces that compose the Basque Country (Araba, Bizkaia, and Gipuzkoa). Eligible participants were selected after schools confirmed willingness to participate. Families received detailed written information, and informed consent was obtained from parents or legal guardians, with child assent also secured. Once participation was confirmed, trained researchers coordinated the placement and retrieval of accelerometers in collaboration with schools. Ethical approval was granted by the Euskadi Research Ethics Committee for Medicinal Products (reference PI2020011), in accordance with Spanish Law 14/2007 on biomedical research, the principles of the Declaration of Helsinki (2013), and applicable legislation.

Inclusion criteria were enrolment in a participating school, age between 5 and 17 years, provision of written informed consent from parents/guardians and child assent, and

valid accelerometer data meeting wear-time criteria. Exclusion criteria included medical conditions or disabilities preventing regular participation in physical activity, withdrawal of consent, or insufficient accelerometer wear-time data.

Instruments and Data Processing - Physical activity was objectively measured using the ActiGraph WGT3X-BT accelerometer (ActiGraph LLC, Pensacola, FL, USA), worn on the non-dominant wrist for seven consecutive days under 24 h/day monitoring. Devices were initialised at a sampling frequency of 30 Hz, and raw acceleration files were converted into activity counts and aggregated into 60-second epochs using ActiLife software (v6.13.4, ActiGraph LLC), following internationally recommended protocols for accelerometer-based research in youth (Migueles et al., 2017; Trost et al., 2005).

Data were considered valid if participants accumulated ≥ 10 h of wear time per day on at least three days, including two weekdays and one weekend day, consistent with international consensus for youth surveillance studies (Migueles et al., 2017; Chandler et al., 2016; Cooper et al., 2015). Non-wear time was identified using the Troiano algorithm, defined as ≥ 60 consecutive minutes of zero counts with allowance for ≤ 2 minutes of non-zero interruptions, a method widely applied in NHANES and other large-scale cohorts (Troiano et al., 2008).

Activity intensity was classified using Evenson cut-points (Evenson et al., 2008), which were originally developed for hip placement but have been widely adapted for wrist accelerometry in youth despite ongoing debate on optimal thresholds

(Chandler et al., 2016; Hildebrand et al., 2014). Categories were expressed in counts per minute: sedentary < 100 ; light 100–2295; moderate 2296–4011; vigorous ≥ 4012 . The following variables were extracted: mean daily minutes spent in sedentary, light, moderate, vigorous activity, and moderate-to-vigorous physical activity (MVPA, sum of moderate and vigorous).

Statistical Analysis - All statistical analyses were conducted using R (version 4.5.2; R Foundation for Statistical Computing, Vienna, Austria). The physical activity variables analysed included sedentary time, light, moderate, vigorous, and MVPA, stratified by sex and decimal age. Age-related trajectories were modelled across the full decimal age range (5.0–17.9 years) using Locally Weighted Scatterplot Smoothing (LOWESS; smoothing parameter $\text{frac} = 0.3$), a robust non-parametric regression technique widely used in epidemiology to capture non-linear trends while avoiding overfitting. To ensure data quality, outliers were identified and removed using the interquartile range rule (values $< Q1 - 1.5 \times \text{IQR}$ or $> Q3 + 1.5 \times \text{IQR}$).

Turning points were operationally defined as ages at which the first derivative of the smoothed curve shifted consistently from positive to negative, signalling the onset of sustained declines in physical activity or increases in sedentary time. To statistically validate these inflection points, independent Student's t-tests were applied to compare age groups immediately before and after the identified turning point (e.g., age 8 vs. age 9), using a significance level of $\alpha = 0.05$. Sensitivity analyses with Bonferroni correction for multiple comparisons were performed. For visualisation, individual

observations were plotted with LOWESS-smoothed trends and 95% confidence intervals, while critical ages were highlighted with vertical reference lines to facilitate interpretation.

3. Results

The analysis revealed distinct age and sex specific inflection points in physical activity and sedentary behaviour trajectories, differentiated across all intensities (sedentary, light, moderate, vigorous and MVPA). These critical transitions marked the onset of accelerated declines in activity and sharp increases in sedentary time as children progressed into adolescence.

A total of 1,032 participants (520 boys and 510 girls) were included in the analyses. The mean age of the total sample was 11.65 ± 3.43 years, with similar values for boys (11.67 ± 3.40 years) and girls (11.64 ± 3.48 years). Detailed descriptive characteristics of the study sample are presented in Table 1.

Table 1. Baseline characteristics of the study sample.

Sex	n	Mean age (years)	SD
Boys	520	11.67	3.40
Girls	510	11.64	3.48
Total	1032	11.65	3.43

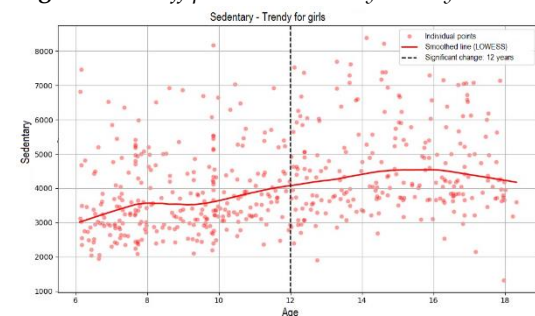
Age- and sex-related differences - Sedentary behaviour increased in both sexes but began significantly earlier in girls (12 years) than in boys (13 years), with a steady upward trajectory thereafter (Figure 1). Light activity exhibited a similar sex-specific pattern, with girls showing an earlier decline (10 years) compared with boys (12 years). Moderate activity declined from 8 years in girls and 9 years in boys, while vigorous activity displayed the earliest and steepest reductions, beginning at 8 years in girls and 9 years in boys (Figures 2–4).

For MVPA, the critical decline occurred at 9 years in girls and 10 years in boys, underscoring an accelerated and earlier deterioration among girls (Figure 5). Overall, female participants showed consistently earlier and more pronounced declines across intensities, particularly in moderate and vigorous activity, while male participants exhibited delayed but parallel trajectories (Table 2). These inflection points, derived from accelerometer-based data, provide novel evidence in European youth cohorts that complements and extends global surveillance findings.

Table 2. Summary of cut-off points and direction of change in physical activity and sedentary behaviour.

Activity level	Gender	Age of Significant Change	Direction of change
Sedentary	Boys	13 years	Increase
Sedentary	Girls	12 years	Increase
Light	Boys	12 years	Decrease
Light	Girls	10 years	Decrease
Moderate	Boys	9 years	Decrease
Moderate	Girls	8 years	Decrease
Vigorous	Boys	9 years	Decrease
Vigorous	Girls	8 years	Decrease
MVPA	Boys	10 years	Decrease
MVPA	Girls	9 years	Decrease

Figure 1. Cut-off points in sedentary time by sex.



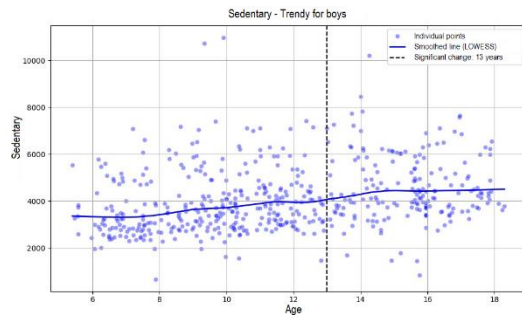


Figure 2. Cut-off points for light activity by sex.

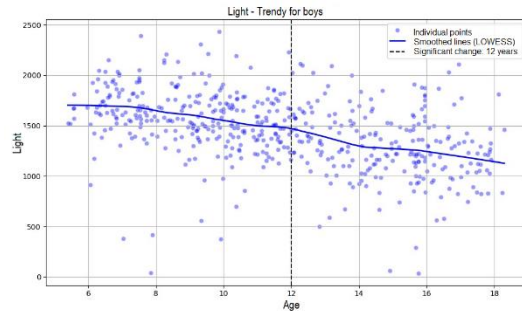
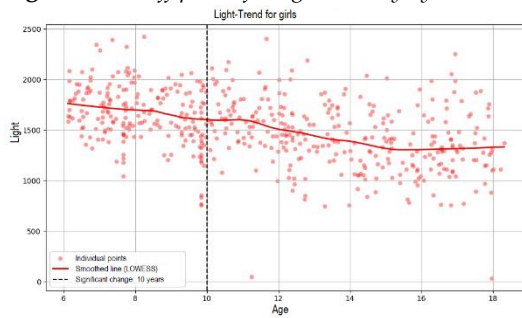


Figure 3. Cut-off points for moderate activity by sex.

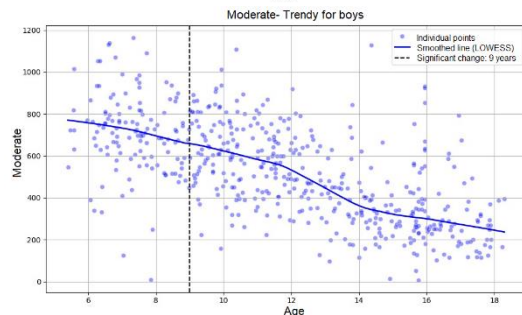
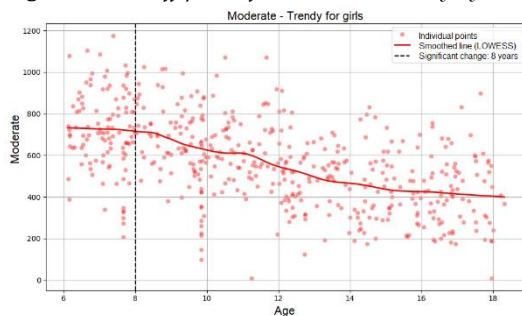


Figure 4. Cut-off points for vigorous activity by sex.

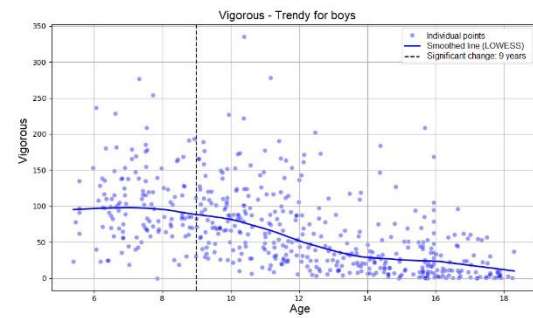
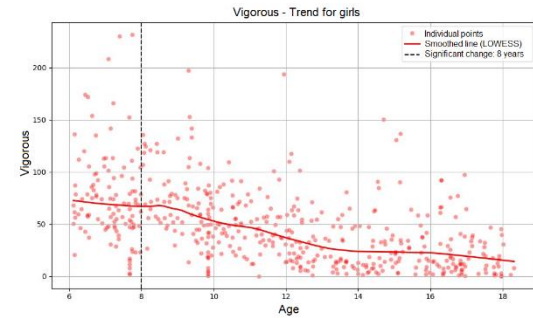
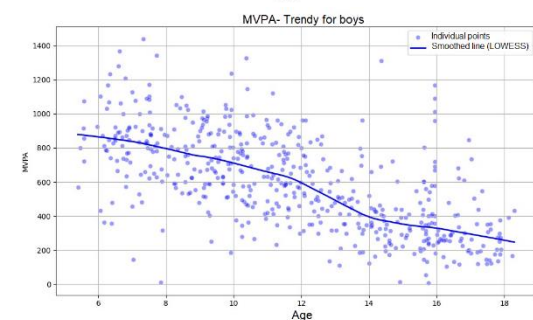
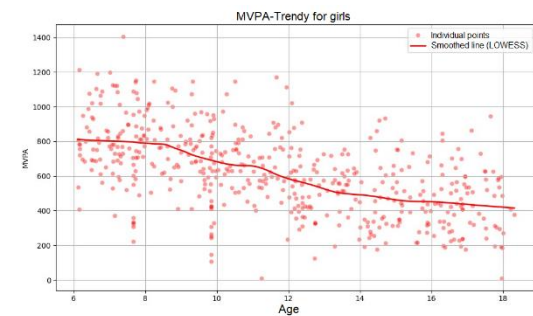


Figure 5. Cut-off points for moderate to vigorous activity by sex.



Organised sport participation - Participation in organised sport (OS) emerged as a protective factor against early transitions, delaying sedentary increases and attenuating the decline in MVPA. At the total sample level, sedentary behaviour increased significantly earlier in adolescents not engaged in OS (12.26 years) compared with

participants (14.79 years), a difference of 2.53 years (Tables 3–4, Figure 6). For MVPA, turning points occurred at a similar age in both groups (12.0 vs. 11.82 years), but the decline was notably less steep in participants, reflecting a buffering effect of sport engagement.

Sex-stratified analyses showed even clearer protective effects. Among boys, sedentary behaviour rose at 10 years in non-participants but was delayed until ~14 years in OS participants. Although MVPA declined at 9 years in girls and 10 years in boys, the reduction was substantially sharper among non-participants. Among girls, sedentary behaviour increased at 13 years in non-participants but was postponed until almost 17 years in OS participants. For MVPA, non-participants showed a decline at 14–15 years, whereas participants displayed an earlier turning point (10 years) but maintained a more gradual subsequent reduction, allowing them to sustain higher levels of activity throughout adolescence.

Together, these findings demonstrate that sex, age, and structural opportunities interact to shape physical activity trajectories. Organised sport participation delayed sedentary transitions by up to four years and mitigated MVPA decline, with particularly strong and sustained benefits observed in girls. These results highlight critical intervention windows and reinforce the role of organised sport as a strategic lever to counteract the early deterioration of physical activity during adolescence.

Figure 6. Age-related inflection points in sedentary behaviour, stratified by organised sport participation, with 95% confidence intervals and individual data distribution.

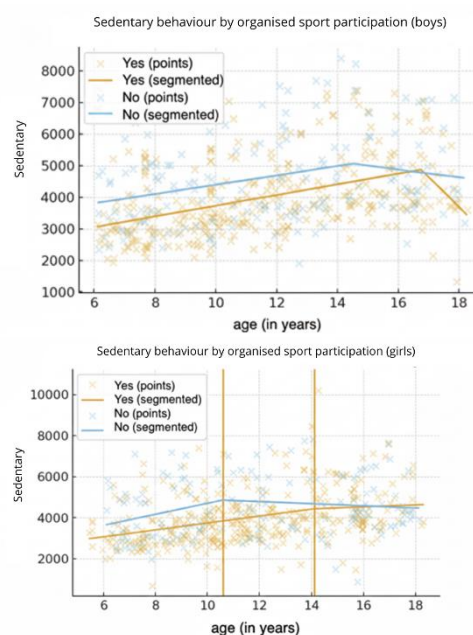


Figure 7. Inflection points in MVPA by organised sport participation, with 95% confidence intervals (scatter plot).

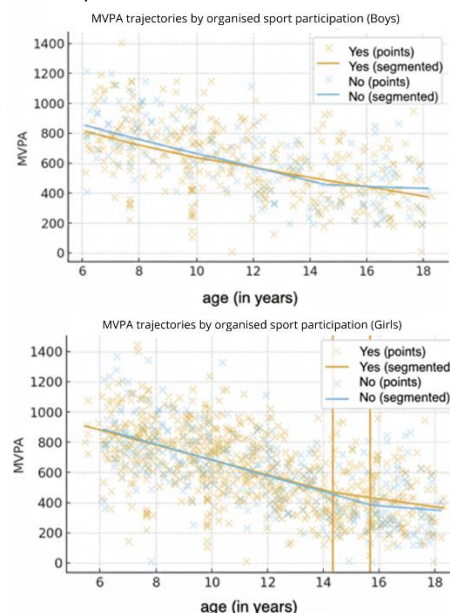


Table 3. Bootstrap of the inflection point (Total).

Variable	Group*	Direction of Change	Age at inflection point (bootstrap mean)	95% CI (lower)	95% IC (upper)	n
Sedentary	Yes	Increase	14.79	13.83	16.62	674
Sedentary	No		12.26	6.92	16.96	318
Light	Yes	Decrease	11.87	7.09	16.58	674
Light	No		14.24	7.45	16.17	318
Moderate	Yes	Decrease	11.77	7.13	16.01	674
Moderate	No		12.41	6.79	16.63	318
Vigorous	Yes	Decrease	10.78	7.11	14.62	674
Vigorous	No		11.26	6.79	14.29	318
MVPA	Yes	Decrease	11.82	7.2	15.92	674
MVPA	No		12.0	6.79	16.5	318

*Note: “Yes” = participation in organised sport; “No” = non-participation.

Table 4. Differences in age at inflection point between non-participants and participants in organised sport (Total sample).

Variable	Inflection point (Non-participants)	Inflection point (Participants)	Difference Non-Participants vs. Participants (years)	95% CI diff (lower)	95% CI diff (upper)
Sedentary	12.26	14.79	-2.53	-9.70	3.13
Light	14.24	11.87	2.37	-9.13	9.08
Moderate	12.41	11.77	0.65	-9.22	9.50
Vigorous	11.26	10.78	0.48	-7.83	7.18
MVPA	12.00	11.82	0.19	-9.13	9.30

4. Discussion

The present study identified sex- and age-specific cut-off points for declines in physical activity (PA) intensities and increases in sedentary behaviour among Basque youth. The results revealed that girls experienced earlier and more pronounced reductions in moderate and vigorous PA, with sedentary behaviour increasing from age 12, compared to age 13 in boys. These findings extend prior international evidence documenting general age-related declines in PA (Dumith et al., 2011; Corder et al., 2019; Farooq et al., 2020), by demonstrating the precise turning points at which activity trajectories begin to deteriorate,

thereby addressing a critical gap in the literature. By adopting internationally standardised accelerometry protocols, these findings are directly comparable with global surveillance initiatives such as the Global Matrix, HBSC, and large-scale cohort studies in the UK, Canada, and Brazil.

The earlier onset of the decline in MVPA and the increase in sedentary behaviour observed in girls (8 and 12 years, respectively) compared to boys (9 and 13 years, respectively) likely reflects the influence of biological maturation. Girls typically enter puberty and reach peak height velocity approximately two

years earlier than boys, a developmental transition accompanied by significant hormonal and body composition changes. These physiological shifts—often including increased body fat, menarche, and heightened body image awareness—may reduce engagement in vigorous or competitive physical activities (Gómez-Campos et al., 2013; Silva et al., 2016). In addition, discrepancies between biological and chronological age have been shown to influence motor competence and perceived ability, further shaping participation patterns during adolescence (Sherar et al., 2010). Although our analysis relied on chronological age as a proxy, the close alignment between the identified turning points and typical pubertal timing suggests that maturation processes may partially underpin the observed sex gap. Future studies incorporating direct indicators of somatic or sexual maturation would allow a more precise differentiation between biological and socio-environmental influences. The school environment also emerges as a structural determinant. Despite WHO recommendations for children and adolescents to achieve 60 minutes of MVPA daily (Bull et al., 2020), schools often allocate insufficient time to physical education and fail to provide active breaks throughout the day (Aubert et al., 2022). This structural limitation may exacerbate the earlier decline observed among girls, particularly when PE curricula do not adapt to diverse interests, motivational profiles, or developmental needs (Thompson et al., 2005). Evidence from systematic reviews further underscores the effectiveness of school-based interventions in mitigating declines, provided they are multicomponent and equity-oriented (Dobbins et al., 2013). However, one-size-fits-all school programmes may inadvertently

reinforce disparities if they fail to target groups at earlier risk of PA drop-out, such as girls.

Beyond physical health outcomes, the consequences of reduced PA are wide-ranging. Insufficient PA is consistently associated with overweight, obesity, and increased cardiometabolic risk (Piercy et al., 2018; Tremblay et al., 2011), while sedentary behaviour exacerbates these risks (Pearson et al., 2014). Psychosocially, PA enhances self-esteem, emotional well-being, and social inclusion (Hamilton et al., 2017; Carlson et al., 2019; Bourke et al., 2023), whereas inactivity has been linked to heightened anxiety and depressive symptoms during adolescence. These findings support calls for policies that integrate PA into daily life as a protective factor for both health and psychosocial development.

Importantly, our analysis of organised sport (OS) participation demonstrated that OS serves as a protective factor, delaying the increase in sedentary behaviour and attenuating the decline in MVPA, particularly among girls. This aligns with prior studies showing that OS participants are more likely to achieve PA guidelines (Marques et al., 2016; Ikeda et al., 2022). Moreover, these results resonate with broader European and WHO policy frameworks, which highlight OS as a critical strategy for health promotion and lifelong engagement (European Commission, 2014; World Health Organization, 2018). At the same time, OS may not be equally accessible to all, with socioeconomic and structural barriers limiting participation among disadvantaged groups. Addressing this inequity is crucial if OS is to serve as a universal protective factor.

Building upon these findings, the identified turning points suggest that the decline in PA is not a linear developmental process but rather the result of a complex

interplay between biological maturation and social structures. The earlier decline observed in girls (8–9 years) indicates a potential “dual burden,” whereby physiological transitions coincide with gendered social expectations that may discourage engagement in vigorous or competitive activities. Consequently, policy responses should move beyond generic PA promotion strategies and adopt a life-course, gender-sensitive framework. School-based interventions should particularly target the transition from primary to secondary education (ages 11–12), identified here as a critical window for the acceleration of sedentary behaviour. Furthermore, given that organised sport (OS) appears to function as a structural protective factor, public policies should prioritize equitable access, subsidization, and diversification of OS opportunities, including non-competitive and expressive movement modalities that may better align with diverse motivational profiles.

Several limitations should be acknowledged. First, the cross-sectional design does not allow causal inference, and longitudinal studies are needed to confirm developmental trajectories. Second, accelerometry data were collected using wrist placement, which, while validated, may reduce direct comparability with hip-based studies. Third, although sampling was stratified and representative of Euskadi, the findings may not generalise to other cultural or geographic contexts. Finally, contextual factors such as nutrition, screen time, or family support were not included and could interact with PA trajectories.

Taken together, these findings provide precise, age-specific evidence to guide the timing and targeting of interventions aimed at preventing physical activity decline. By

identifying critical developmental turning points, this study contributes actionable insights for equity-oriented strategies that acknowledge the interplay between biological maturation and social structures. Such evidence is essential not only for the Basque context but also for informing international physical activity surveillance and policy frameworks.

5. Practical Applications

The identification of sex- and age-specific cut-off points for declines in moderate and vigorous physical activity provides actionable guidance for coaches, physical educators, and sport practitioners seeking to optimise youth engagement. Specifically, interventions aimed at sustaining activity levels should be implemented before the identified turning points—around age 12 for girls and age 13 for boys—to maximise effectiveness. Coaches and educators may benefit from tailoring training and recreational programmes to accommodate the physiological and psychosocial transitions associated with puberty, prioritising inclusive, competence-based activities that enhance motivation and perceived ability. Moreover, structured participation in organised sport should be promoted as a protective factor, particularly for girls, through school–club partnerships and policies that reduce socioeconomic and accessibility barriers.

For researchers, these findings highlight the importance of integrating maturational status, motivational determinants, and environmental context when modelling physical activity trajectories. The cross-sectional design of the present study limits causal inference, and future longitudinal and mixed-method approaches are warranted to validate the observed inflection points and

uncover underlying mechanisms. Expanding analyses to include nutritional, psychosocial, and family-related variables could strengthen the ecological validity of future models. Finally, replication of this protocol in other cultural and geographical contexts will enhance generalisability and support the development of evidence-based strategies for promoting lifelong engagement in physical activity across diverse populations.

6. Conclusions

This study identifies clear age- and sex-specific turning points in physical activity decline, providing precise developmental windows for targeted intervention. Although the cross-sectional design limits causal inference and wrist-based accelerometry may affect direct comparability with hip-based protocols, the consistency of the observed thresholds reinforces their practical relevance.

The findings indicate that preventive strategies should begin before adolescence, particularly among girls, and that structural supports such as organised sport may mitigate early declines when equitably accessible. By aligning intervention timing with developmental trajectories, these results offer actionable guidance for schools, policymakers, and public health stakeholders. Future longitudinal research incorporating direct measures of biological maturation will be essential to refine these equity-oriented strategies.

Supplementary Materials: No supplementary material

Funding: This research received no external funding.

Acknowledgments: This study was conducted with the support of the Basque Government and all participating centers. We also extend our sincere gratitude to all children, adolescents, and their families who have contributed or will contribute to this research.

Conflicts of Interest: The authors declare no conflict of interest

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