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Differences in the activity intensity distribution over the day between boys and girls aged 3 to 17 years

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Physical activity (PA) decreases from childhood to adolescence, with girls being less active than boys. The timing of these differences remains unknown. Using accelerometer data from three cross-sectional studies in Norway and Belgium ($n = 2507$, age = 3-17years), we assessed sex differences in sedentary behaviour (SB) and PA levels (light, moderate, vigorous) throughout the day and across the full spectrum of activity intensity distribution on weekdays and weekend days, using linear regression and functional data analyses. Across all age groups (preschoolers (3-5y), children (6-10y), adolescents (11-17y)), girls were less active than boys, particularly on weekdays (e.g., vigorous PA (> 1111 counts/15s) difference:-16.9 min/day (95% Confidence interval:-19.3,-14.4; p-value < 0.001) in children). It was the case throughout the day, particularly during school hours (8h30-15h29) in all age groups. Analysis of the full spectrum of activity intensity distribution (0 to 3000 counts) added to these findings that on weekend days, girls spent less time in zero-count SB than boys (difference=-21.0 min/day (-28.7,-13.4; p-value < 0.001) in children), but higher (17.3 min/day (13.2,21.4; p-value < 0.001)) in the "other SB", 1-180 counts/15s. The sex differences in PA during school hours suggest the need for targeted interventions promoting activities engaging girls. Additionally, the time spent in zero-count, particularly evident in boys on weekend days, deserves further investigation.

Keywords Accelerometers, Physical activity, Sedentary behaviour, Time of day, Children, Adolescents

Physical activity (PA) protects against non-communicable diseases and mortality across the lifespan[1] Childhood is a critical period of life as most lifestyle habits, including PA, are likely to originate early[2] and carry forward into adolescence and adulthood[3] A recent systematic review and meta-analysis indicates that PA begins to decline during preschool years (3-6y)[4] Another study using narrower age groups observed that this decline becomes evident at 5-6y in both boys and girls[5] Other studies also suggest that among girls this decline occurs slightly earlier[6] and more markedly than in boys[7,8] Sex differences in PA patterns have previously been well-documented in the literature, showing that boys are less sedentary and more active than girls at all ages,[5] and that this sex gap starts at early ages[9] These findings highlight the need for effective, tailored PA interventions to increase activity levels in both sexes, particularly among girls. However, more research is needed to understand the timing of these disparities and to develop strategies for promoting equal PA during this period.

Temporal factors, such as the day of the week (i.e., weekday or weekend day) and time across the day (during waking hours), have a significant influence on PA patterns, particularly in youth[10] There is evidence showing that the pattern of PA in school-aged children can vary within and between days of the week[11] However, whether sex differences in PA differ by type and time of the day remains unclear. Two notable studies among adolescents investigated sex differences in PA and sedentary behaviour (SB) during weekdays and weekend days, reporting more pronounced differences on weekdays[12,13] However, these studies did not assess variations across different times of the day. Other studies exploring sex differences of PA over time of the day in youth consistently found that girls were less active than boys throughout the day[14–21] Nonetheless, most of these studies investigated the

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average time spent in SB or in different PA intensities separately by segments of the day, ignoring the continuous nature of acceleration and its correlation over time within individuals, which may introduce bias in estimates[22] Functional Data Analysis (FDA) is a statistical framework for analyzing continuous functions, such as PA distribution over time of the day[23] FDA has been used previously to assess how the PA distribution differs between boys and girls across the day in children aged 7 years,[24] but no studies have explored sex differences in the PA distribution over time of the day or day of the week across age from preschool age to adolescence.

Hence, this study aimed to examine how the PA distribution differed between boys and girls in different age groups (preschoolers (3–5 years), children (6–10 years), adolescents (11–17 years) depending on the day of the week and time of the day. Using accelerometer data from three studies from Norway and Belgium, we investigated sex differences in the PA distribution during weekdays and weekend days using two approaches: (1) the commonly used cut-points based approach considering time in SB, light PA (LIPA), moderate PA (MPA), and vigorous PA (VPA); and (2) as a function of the PA distribution over the hours of the day (from 6h00 to 22h00). Given the large variability in cut-points used to define PA intensities from the accelerometry signal,[25] a secondary aim of this study was to examine the sex differences in the activity distribution across the full spectrum of the activity intensity distribution (time spent at each intensity ranging from 0 to 3000 counts/15s) on weekdays and weekend days.

Methods

Study population

In this study, which is part of the Learning Network for Advanced Behavioural Data Analysis (LABDA) doctoral network (https://labda-project.eu/), we pooled data from three cross-sectional studies from Norway and Belgium.

The Active Learning Norwegian Preschool(er)s (ACTNOW) study, a cluster randomized controlled trial (RCT) conducted to test the effect of a multicomponent preschool PA intervention, included 1255 (48% girls) children aged 3–6 years from 46 preschools in western Norway[26] In this study, we used data collected during the preschool period (no measures during holidays) at baseline in 2019–2020. The Norwegian Center for Research Data (reference number 248220) and the Western Norway University of Applied Sciences institutional ethics committee approved the study. All procedures and methods conform to the ethical guidelines defined by the World Medical Association`s Declaration of Helsinki and its subsequent revisions. The study was registered on clinicaltrials.gov on August 7, 2019 (ID: NCT04048967) (https://clinicaltrials.gov/ct2/show/NCT04048967?term=actnow&rank=1). Written informed consent was obtained from each child's parents or legal guardian and from the responsible school authorities, prior to all the procedures.

The Active Smarter Kids (ASK) study, a cluster RCT that investigated the effect of a school-based PA intervention on academic performance and health markers, included 1137 (48% girls) children in fifth grade (age 9–11 years) from 60 schools in western Norway[27] In this study, we used data assessed during the school period (no measures during holidays) at baseline between April and October 2014. The South-East Regional Committee for Medical Research Ethics in Norway approved the study protocol (reference number 2013/1893). The procedures and methods used in the study conform to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions. The study was registered in clinicaltrials.gov on April 7, 2014 (ID: NCT02132494.) (https://www.clinicaltrials.gov/study/NCT02132494?cond=NCT02132494&rank=1). Written informed consent from each child's parents or legal guardian and from the responsible school authorities was obtained, prior to all testing.

The *Belgian food consumption survey* (BFCS) aimed to evaluate the habitual food, energy, and nutrient intake, as well as the PA and SB, in a nationally representative sample of the Belgian population in 2014. Persons aged 3–64 years were randomly selected from the Belgian national population register, following a multistage stratified sampling procedure that has been described previously[28] For this study, participants aged 3–17 years and during school period were retained for the analysis ($n = 1295$), excluding those who wore the accelerometer during school holidays to match with Norwegian studies. Approval of an Ethical Committee (University of Ghent) and the Commission for the Protection of Privacy were obtained on December 19, 2013 (Belgian registration number: B670201319129). The study was conducted under the ethical principles for medical research involving human subjects (Declaration of Helsinki). Written informed consent to participate in the study was obtained from participants or parent(s)/legal guardian(s) of participants younger than 12 years old.

Accelerometer-measure of activity

In each study, participants were asked to wear the tri-axial accelerometer ActiGraph GT3X + on the right hip at all times over seven consecutive days, except during water activities (e.g., swimming, showering) or while sleeping, with the exception of participants in ACTNOW who wore also the device at night.

Accelerometer data recorded in activity counts of 15s epoch were processed using GGIR R package version 3.0-9[29] The three-dimensional counts information at each time point was summarized by the vector magnitude of the ActiGraph counts[30] Non-wear time was defined as periods of ≥ 20 min of consecutives zero counts[31] The non-wear periods were excluded from the analyses, except for the analysis of sex difference across time of the day to avoid overestimation of activities close to the sleep periods as in ASK and BFCS studies, participants were asked to remove the device when going to bed. Participants were included in the analyses if they wore the accelerometer for at least 8 h per day for a minimum of 3 weekdays and 1 weekend day[31].

The analysis exploring sex differences in activity intensity as a function of time of day was based on data captured between 06h00 and 22h00. For analyses on time in activity intensities levels (time in SB, LIPA, MPA, VPA) and on the full spectrum of activity intensity distribution (0-3000 counts/s), the nocturnal sleep period was additionally removed to avoid overestimation of SB time. Waking periods (i.e., the period between waking and sleep onset) for each day were identified using a combination of two algorithms developed in GGIR for count acceleration metrics: HASIB.algo="Sadeh1994", an algorithm for sleep detection,[32] and HASPT.algo="NotWorn", which identifies the largest window of non-wear during the night as the sleep window[33] As the device recorded for the whole observation period irrespective of the study wear protocol and participant's compliance to this protocol, combining these approaches ensures analyses to be conducted on waking and wear daytime periods in all three studies.

For analyses using the traditional cut-point approach, we calculated time spent in each activity intensity based on Romanizi's cut-points, which defines SB as < 180 counts/15s, LIPA 180–756, MPA 757–1111, and VPA > 1111 counts/15s.[34] Next, we calculated the daily activity distribution during waking periods over the time of the day (counts per minute as a function of time of the day) using a FDA approach (See details in Supplementary Methods 1).

Age, sex, day of the week and time of the day

Participants were categorized based on their *age* as Preschoolers (3–5 years), Children (6–10 years), or Adolescents (11–17 years) and *sex*, defined as boy or girl. *Sex* and *age* data were obtained from parental questionnaires in Norway and from national registers in Belgium. The *day of the week* was categorised as weekday (Monday to Friday) or weekend day (Saturday and Sunday). *Time of day* was considered between 6h00 and 22h00. To ease interpretation, we defined specific segments of the day as before school (06h00–08h29), during school (08h30–15h29), and after school (15h30–21h59) for weekdays, and morning (6h00-11h59) and afternoon-evening (12h00-21h59) for weekend days.

Covariates

Parents' education was evaluated through a questionnaire completed by each child's mother and/or father, selecting the highest education level attained by either parent. It was categorized as: Upper secondary education (used as reference), University (3 years of university), and Higher university (more than 3 years of university) levels. *Season* was classified as Winter (21/12–20/03; used as reference), Spring (21/03–20/06), Summer (21/06–20/09), or Autumn (21/09–20/12).

Statistical analysis

We first tested for three-way interactions $(age * sex * daytype)$ using full factorial models in linear mixed model regression with daily time in each activity intensity as the dependent variable and a random intercept for subject. Then, we examined the sex differences (boys as reference) in time spent in each activity intensity (SB, LIPA, MPA and VPA averaged separately on weekdays and weekend days) in each age group using linear regressions.

Finally, we estimated sex differences in the PA distribution over the time of the day using FDA (See details in Supplementary Methods 1). This method uses the distribution of counts per minute over time of the day during waking hours as the dependent term in the form of a function and sex and other covariates as independent variables. All models were adjusted for age, season, study, accelerometer wear time and parents' education.

Two sets of sensitivity analyses were conducted: (1) in order to examine whether findings were influenced by a specific study, sex differences in each age group were calculated for each study separately; (2) to assess whether findings were influenced by the use of cut-points to define activity level, we estimated sex differences using the full spectrum of activity intensity distribution as the dependent function in FDA (See details in Supplementary Methods 2).

Given observed differences in the SB range in the analysis of the full spectrum of activity intensity distribution (Sensitivity analysis 2), post-hoc analyses were conducted for each age group to examine sex differences in two specific SB ranges: time spent at 0 counts/15s, referred to as "zero-count SB", and time spent at 1–180 counts/15s, referred to as "other SB". We first investigated sex differences in these specific SB categories using linear regression and then examined how the sex differences in zero-count SB (min/h) were distributed over the day using FDA.

All statistical analyses were performed using R statistical software version 3.6.1 (R Project for Statistical Computing), and results were considered statistically significant at p-value < 0.05.

Results

Participant's characteristics

Out of the 3687 participants from the three studies, 3337 had demographic and accelerometer data. Of these, 2507 participants (872 from ACTNOW, 827 from ASK and 808 from BFCS) had at least 3 weekdays and 1 weekend day with valid accelerometer wear time (i.e., ≥8 h/day) and were included in the analysis (See Supplementary Figure S1). Participants excluded (*n* = 830) from the analyses due to insufficient wear time were older than those included (9.2y (Standard deviation (SD) = 4.2) vs. 8.0y (SD = 3.5), p-value < 0.001), and their parents had a lower education level (upper secondary education, 37.8 vs. 30.1%, p-value < 0.001). We found no other significant differences between included and excluded participants (all p-value > 0.05) (See Supplementary Table S1). Among the 2507 included participants, no differences were observed between boys (50.6%) and girls (49.4%) in terms of age or parental education (See Supplementary Table S2).

Overall, the accelerometer was worn for a longer time during weekdays than weekend days (p-value < 0.001) in all age groups (Table 1). SB and all PA intensities largely differed between age groups in both boys and girls during both weekdays and weekend days. Time in SB increased, and time in MPA and VPA decreased with age across all age groups. Sex differences were evident for all age groups, with boys being more active and less sedentary than girls. However, these differences varied by day of the week: for example, sex differences in SB were observed on weekdays (all p-value < 0.01), but not on weekend days among preschoolers, children and adolescents (all p-value > 0.15).

SB and PA variables	Pre-schoolers (3-5y) ($n = 1057$) Boys $n = 533$ (50.4%)	Girls $n = 524$ (49.6%)	p-value* (sex)	Children (6-10y) ($n = 1153$) Boys $n = 599$ (51.9%)	Girls $n = 554$ (48.1%)	p-value* (sex)	Adolescents (11-17y) ($n = 297$) Boys $n = 136$ (45.8%)	Girls $n = 161$ (54.2%)	p-value* (sex)	p-value** (age in boys)	p-value** (age in girls)
Accelerometer wear time (min/day), mean (SD)											
Weekdays	737.6 (53.4)	732.7 (55.9)	0.114	762.4 (58.0)	769.9 (54.5)	0.024	760.2 (72.7)	760.3 (67.3)	0.915	< 0.001	< 0.001
Weekend days	710.0 (90.9)	699.4 (88.0)	0.034	681.7 (85.6)	668.0 (81.3)	0.007	669.4 (88.7)	667.8 (82.7)	0.875	< 0.001	< 0.001
p-value* (daytype)	< 0.001	< 0.001	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	-	-
Time in SB (min/day), mean (SD)											
Weekdays	313.4 (54.2)	332.0 (56.9)	< 0.001	429.2 (66.2)	449.1 (64.2)	< 0.001	527.4 (79.6)	551.4 (79.2)	0.008	< 0.001	< 0.001
Weekend days	335.8 (83.5)	341.2 (76.1)	0.265	388.2 (92.8)	378.2 (83.8)	0.155	464.5 (86.4)	474.4 (88.8)	0.335	< 0.001	< 0.001
p-value* (daytype)	< 0.001	0.025	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	-	-
Time in LIPA (min/day), mean (SD)											
Weekdays	282.8 (33.9)	279.8 (34.0)	0.159	206.1 (37.8)	217.5 (36.6)	< 0.001	157.4 (43.0)	150.6 (42.3)	0.099	< 0.001	< 0.001
Weekend days	245.7 (44.1)	246.8 (43.8)	0.703	182.4 (51.8)	194.6 (46.2)	< 0.001	139.3 (56.2)	142.4 (49.8)	0.478	< 0.001	< 0.001
p-value * (daytype)	< 0.001	< 0.001	-	< 0.001	< 0.001	-	< 0.001	0.043	-	-	-
Time in MPA (min/day), mean (SD)											
Weekdays	80.5 (16.6)	70.5 (15.0)	< 0.001	62.2 (14.8)	54.7 (13.5)	< 0.001	39.9 (15.0)	33.6 (13.1)	< 0.001	< 0.001	< 0.001
Weekend days	71.9 (19.5)	63.7 (17.9)	< 0.001	53.4 (21.8)	49.7 (18.0)	0.005	35.9 (23.7)	30.0 (16.0)	0.012	< 0.001	< 0.001
p-value* (daytype)	< 0.001	< 0.001	-	< 0.001	< 0.001	-	< 0.001	0.007	-	-	-
Time in VPA (min/day), mean (SD)											
Weekdays	60.8 (21.2)	50.4 (17.8)	< 0.001	64.9 (25.8)	48.6 (19.9)	< 0.001	35.6 (20.9)	24.8 (16.5)	< 0.001	< 0.001	< 0.001
Weekend days	56.6 (24.1)	47.7 (21.3)	< 0.001	57.7 (38.5)	45.5 (27.9)	< 0.001	29.7 (25.8)	21.0 (20.3)	0.002	< 0.001	< 0.001
p-value* (daytype)	< 0.001	0.004	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	-	-

Table 1. Mean and standard deviation of accelerometer data stratified by age and sex. Abbreviations: SD = standard deviation; SB = sedentary behaviour (0-180 counts/15s); LIPA = light physical activity (181–756 counts/15s); MPA = moderate physical activity (757-1111counts/15s); VPA = vigorous physical activity (> 1111counts/15s). *A t- Student's tests and a Wilcoxon Mann-Whitney tests were performed to compare the means of two normally and not normally distributed groups, respectively. Assumptions of normality were verified using the Shapiro-Wilk test. **A one-way ANOVA test and a Kruskal-Wallis test were performed to compare the means across multiple normally and not normally distributed groups, respectively.

		Mean difference (95%CI) in time (min/day) in:							
		SB		LIPA		MPA		VPA	
Age groups	**n**	**Weekdays**	**Weekend days**	**Weekdays**	**Weekend days**	**Weekdays**	**Weekend days**	**Weekdays**	**Weekend days**
Pre-schoolers (3-5y)	1057	**20.9 (15.2, 26.6)**	**11.7 (4.8, 18.6)**	-1.0 (-4.6, 2.5)	**4.7 (0.4, 9.1)**	**-9.5 (-11.3, -7.8)**	**-7.5 (-9.7, -5.4)**	**-10.3 (-12.5, -8.1)**	**-8.9 (-11.6, -6.2)**
Children (6-10y)	1153	**14.5 (8.8, 20.2)**	-3.7 (-11.4, 4.1)	**10.3 (6.9, 13.8)**	**17.4 (13.0, 21.9)**	**-8.0 (-9.4, -6.5)**	**-2.4 (-4.5, -0.4)**	**-16.9 (-19.3, -14.4)**	**-11.4 (-14.9, -7.8)**
Adolescents (11-17y)	297	**23.4 (11.7, 35.2)**	11.3 (-4.6, 27.3)	-6.7 (-14.4, 1.0)	2.8 (-7.4, 13.0)	**-6.1 (-8.9, -3.3)**	**-5.7 (-9.8, -1.5)**	**-10.7 (-14.7, -6.7)**	**-8.5 (-13.6, -3.4)**

Table 2. Sex differences in activity intensity levels at each age during weekdays and weekend days. Abbreviations: CI = confidence interval; SB = sedentary behaviour (0-180 counts/15s); LIPA = light physical activity (181–756 counts/15s); MPA = moderate physical activity (757-1111counts/15s); VPA = vigorous physical activity (> 1111counts/15s). Positive values indicate that girls spend more time in the specific activity intensity level. Bold estimates means that differences are significant at $p < 0.05$.

Sex differences in SB and activity intensities using cut-point approach

We found significant interactions for $age * sex * daytype$ for time in LIPA and VPA (p-value < 0.001), leading us to conduct further analysis of sex differences separately by age and type of day. In analyses adjusted for age, parental education, season, study and accelerometer wear time, we found that on weekdays, girls spent on average more time in SB than boys in preschoolers (sex difference in min/day (time in girls minus in boys): 20.9 (95% Confidence interval (CI): 15.2, 26.6); p-value < 0.001), children (14.5 (8.8, 20.2); p-value < 0.001) and adolescents (23.4 (11.7, 35.2); p-value < 0.001), as shown in Table 2. These differences were not evident on weekend days, except in preschoolers (11.7 (4.8, 26.6) min/day; p-value < 0.001). Girls also spent more time in LIPA in children on both weekdays and weekend days ($p < 0.001$), but no differences were observed for the other age groups (all $p > 0.05$) except in preschoolers on weekend days (4.7 (0.4, 9.1) min/day, p-value = 0.03). Furthermore, girls spent less time in MPA and VPA across all age groups and day types (p-value < 0.001), with the largest differences observed during weekdays, particularly in VPA during childhood (-16.9 (-19.3, -14.4) min/day; p-value < 0.001).

Sex differences throughout the day using functional approach

Findings from FDA (Fig. 1) show sex differences in the distribution of PA over time of the day in all age groups and both types of days (all p-value < 0.001). On weekdays, boys were more active than girls throughout the day across all age groups, except for preschoolers after school between 20h00 and 21h00. Among children, sex differences were observed *before school* and persisted *during school* hours, with a notable peak between 11h00 and 13h00. Sex differences – girls being less active – were less pronounced *after-school* in preschoolers but remained evident in children and more pronounced in adolescents. On weekend days, no sex differences were observed during the *morning* hours, and differences emerged during the *afternoon-evening*, particularly between 17h00 and 21h00 in children.

Sensitivity analysis

Impact of each individual study on sex differences analysis

Sensitivity analysis examining the sex differences in time in activity levels within each study showed consistent findings with the main analyses (See Supplementary Table S3). Slight differences were observed in the sex differences across the time of the day in each study (See Supplementary Figure S2, Figure S3 and Figure S4). In preschoolers, boys were more active in the evening (18h00 to 21h00) in BFCS, while the opposite was observed in ACTNOW. In children, during weekend days, boys tended to be more active in the afternoon-evening (15h00 to 22h00) in a more pronounced manner in ASK than in BFCS.

Impact of the use of cut-points to categorize the activity intensity distribution using functional approach

The second sensitivity analysis using the full spectrum of activity intensity distribution showed that in children boys spent more time in activity where counts were at zero during weekend days (Fig. 2). This is in contrast with findings from linear regressions that did not show sex differences in time in SB defined as 0-180 counts/15s during weekend days in childhood. No substantial differences were observed in the LIPA, MPA, and VPA ranges when comparing associations observed over full spectrum of activity intensity distribution with those based on cut-point approach, apart among adolescents over the week-end days where most of the sex differences were found to not reach significance in the functional data analyses while significant differences were found with linear regression using VPA level (> 1111 count/15s).

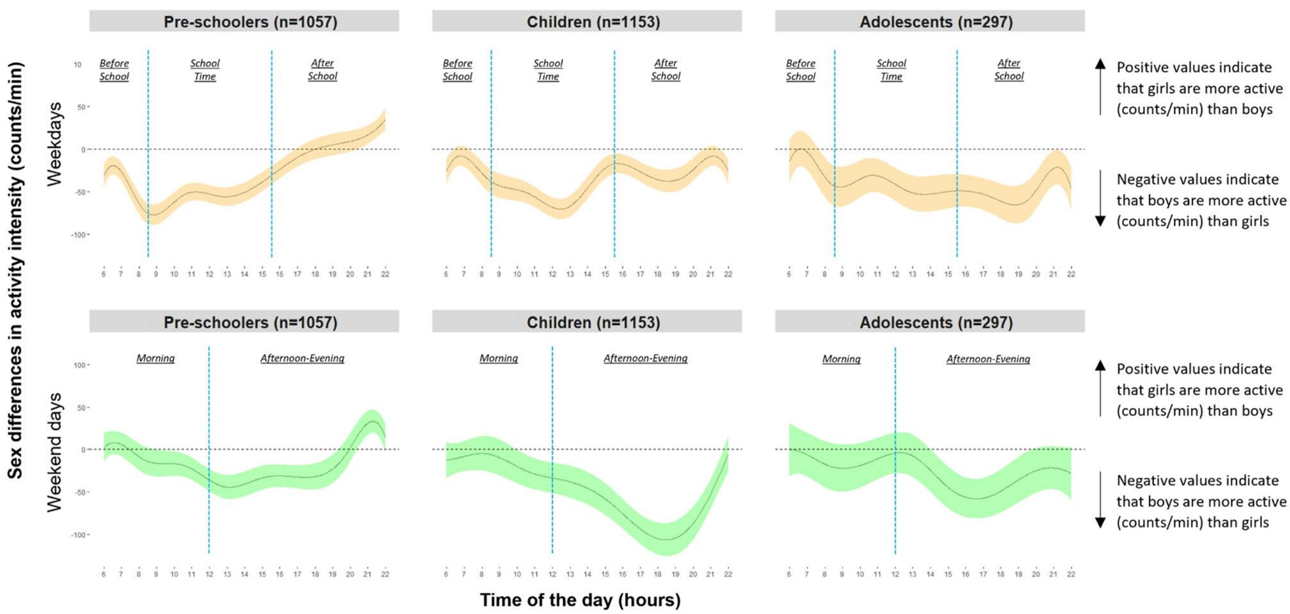

Fig. 1. Sex differences in activity intensity (day time) at each age during weekdays and weekend days. The present figure illustrates how activity intensity differs between boys and girls throughout the day in preschoolers, children, and adolescents separately. At the top of the figure, sex differences (95% CI) on weekdays are shown, divided into three-time segments: before school (06h00–08h29), school time (08h30–15h29), and after school (15:30–22:00). At the bottom, sex differences (95% CI) for weekend days are illustrated, divided into morning (06h00–11h59) and afternoon-evening (12h00–22h00). In this figure, a positive value indicates that girls are more active (counts/min) than boys during that time.

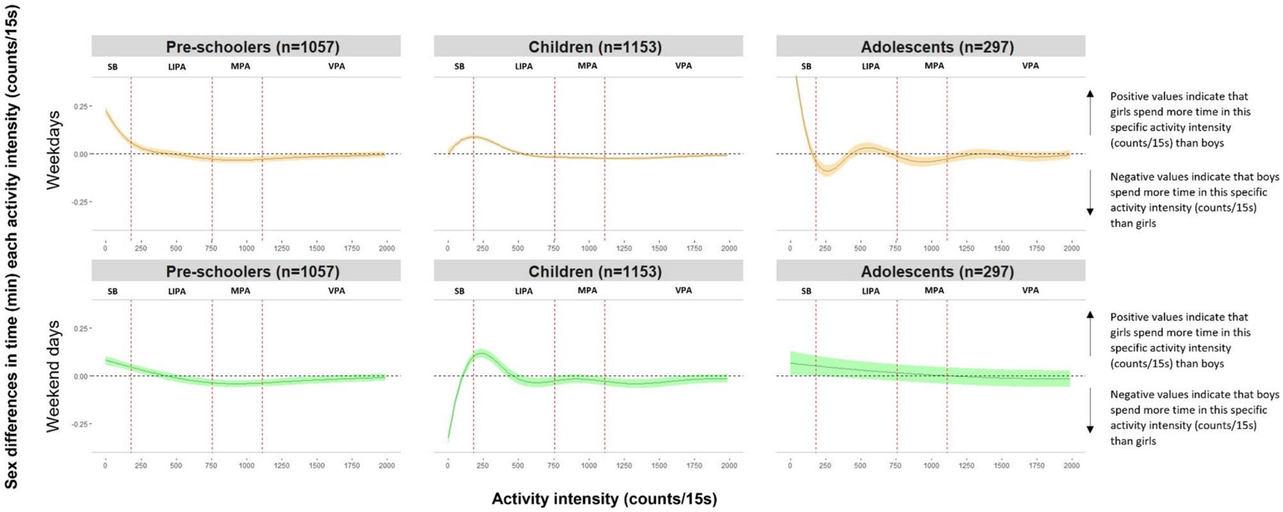

Fig. 2. Sex differences in the activity intensity distribution at each age during weekdays and weekend days. The present figure illustrates how the full spectrum of activity intensity (counts/15s) differs between boys and girls in preschoolers, children, and adolescents separately. Sex differences (95% CI) are shown separately for weekdays (at the top) and weekend days (at the bottom). To ease interpretation of the activity intensity distribution, the red dashed lines represent the common intensity categories: SB (sedentary behaviour, 0–180 counts/15s), LIPA (light physical activity, 181–756 counts/15s), MPA (moderate physical activity, 757–1111 counts/15s), and VPA (vigorous physical activity, > 1111 counts/15s). In this figure, a positive value indicates that girls spend more time in this specific intensity range (counts/15s) than boys.

		Mean difference (95%CI) in time (min/day) in:					
		SB (0-180 counts/15s)		**Zero-count SB (0 count/15s)**		**Other SB (1-180 counts/15s)**	
Age groups	**n**	**Weekdays**	**Weekend days**	**Weekdays**	**Weekend days**	**Weekdays**	**Weekend days**
Pre-schoolers (3-5y)	1057	**20.9 (15.2, 26.6)**	**11.7 (4.8, 18.6)**	**4.4 (0.1, 8.7)**	0.0 (-5.9, 6.0)	**16.4 (13.5, 19.3)**	**12.0 (8.5, 15.5)**
Children (6-10y)	1153	**14.5 (8.8, 20.2)**	-3.7 (-11.4, 4.1)	**-6.4 (-12.4, -0.3)**	**-21.0 (-28.7, -13.4)**	**20.6 (17.4, 23.8)**	**17.3 (13.2, 21.4)**
Adolescents (11-17y)	297	**23.4 (11.7, 35.2)**	11.3 (-4.6, 27.3)	**18.1 (0.3, 35.9)**	1.8 (-18.2, 21.8)	4.3 (-5.1, 13.8)	8.8 (-1.3, 18.8)

Table 3. Sex differences in zero-count SB and other SB at each age during weekdays and weekend days. Abbreviations: CI = confidence interval; SB = sedentary behaviour (0-180 counts/15s). Positive values indicate that girls spend more time in the specific activity intensity level. Bold estimates means that differences are significant at $p < 0.05$.

These findings led us to conduct a post-hoc analysis investigating time in SB (0-180 counts/15s) separately in time in zero-count SB (0 count/15s) and other SB (1-180 counts/15s) (Table 3). On weekdays, we found that girls spent more time in zero-count SB in preschoolers and adolescents (p-value < 0.05). In children, boys spent more time in zero-count SB, particularly during weekend days (-21.0 (-28.7, -13.4) min/day; p-value < 0.001). Girls spent more time in other SB in preschoolers and children (p-value < 0.001), but not in adolescents.

To explore when sex differences in zero-count SB occurred, we examined sex differences in time in this specific activity intensity level over time of the day (Fig. 3). On weekdays, we found that time in zero-count SB tended to be higher in girls during *school time*, and in boys *after-school*, particularly in preschoolers and children. On weekend days, only children boys spent more time in zero count SB throughout the day, particularly in the *afternoon-evening*.

Discussion

This study examining sex differences in objectively measured PA and SB depending on the day of the week and across the time of the day for preschoolers, children, and adolescents, presents four key findings. First, we observed that time in SB increased with age, while time in PA intensities decreased, with a pronounced decline in moderate and vigorous activities during adolescence. Second, sex differences were observed as early as in preschool age, were most pronounced in children, and persisted during adolescence, particularly during weekdays. Third, girls were less active than boys throughout the day, particularly during school time. Fourth, using the full spectrum of activity intensity distribution, we found that during childhood, boys spent more time

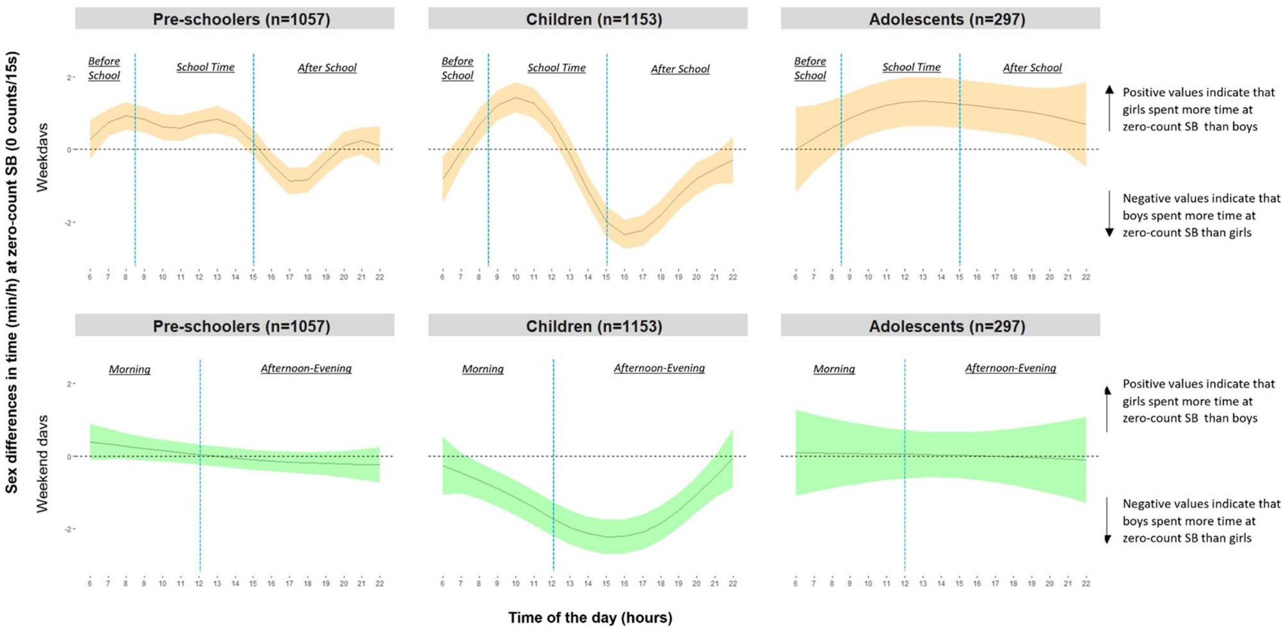

Fig. 3. Sex differences in time zero-count SB at each age during weekdays and weekend days. The present figure illustrates how the time spent in zero count SB differs between boys and girls throughout the day in preschoolers, children, and adolescents separately. At the top of the figure, sex differences (95% CI) on weekdays are shown, divided into three-time segments: before school (06h00–08h29), school time (08h30–15h29), and after school (15h30–22h00). At the bottom, sex differences (95% CI) for weekend days are illustrated, divided into morning (06h00–11h59) and afternoon-evening (12h00–22h00). In this figure, a positive value indicates that girls are more active (counts/min) than boys during that time.

in zero-count SB than girls during weekday evenings and weekend days, while girls spent more time in this behaviour during school time, irrespective of the age group.

Previous studies have reported that PA starts declining in preschool age group (3-6y),[4] with findings from another paper using year-by-year comparisons showing this decline to start at age 5–6 years[5] Our findings are consistent with these previous studies, showing a decrease in PA between preschool and childhood, and being more pronounced at adolescence, particularly, among girls. One study covering the lifespan indicates that sex differences in PA patterns emerge in early ages and peaks during childhood,[9] as also found in the present study. Our findings also show different patterns depending on the type and time of day.

On weekdays, we found that girls spent more time in SB but less in MPA and VPA than boys in all age groups. Previous studies investigating how sex differences change over time of the day, showed that boys were consistently more active than girls across all day,[14–21] however, most of these studies calculated the average time in SB or each PA intensity per hour or segment of the day separately, ignoring the correlation over time within a subject[22] FDA addresses this limitation by using the complete PA distribution for each individual over time, preserving its continuity and accounting for correlation within subjects[23] One notable study using FDA in children aged 7 years reported that girls were consistently less active than boys throughout the day, with largest sex differences observed during the lunch break. Consistent with this study, our study, based on participants aged from 3 to 17 years, suggested that sex differences are present all day, but more pronounced during school time in all age groups, with the largest differences between 12h00 and 13h00. One possible explanation could be that the school environment modulates the pattern of PA in children. It is recognised that schools are key settings for promoting PA in youth[35] and represent the most important place for achieving moderate-to-vigorous physical activity recommendations[36] However, larger sex differences have been reported previously during both preschool[17] and school time,[19] and particularly, during lunch breaks[37,38] Hence, these findings along with ours suggest that in order to reduce sex differences in PA, future sex-targeted interventions at preschool and school may specifically focus on girls, for example, by offering activities that are more appealing to them.

Sex differences in PA and SB in youth during weekend days have been little explored in the literature. A study in Canadian adolescents showed that sex differences in SB time were attenuated on weekend days[12] Another study in Finnish adolescents observed more time in SB among boys than among girls during weekend days[13] Our study showed similar findings and extended them by using FDA of the full spectrum of activity intensity distribution (from 0 to the highest count/15s), which revealed that the attenuated sex differences on weekends we observed in children was due to boys spending more time in zero-count SB, particularly during the afternoon-evening. Considering the wear-site of the accelerometer and the timing of these sex differences in zero-count SB, a possible explanation is that time at this intensity reflects sedentary seated activities that boys engage in more than girls, such as playing computer or video games — an activity more frequently reported by boys[39,40] This is consistent with findings from the recent BFCS report, which showed that more boys exceed the recommended daily screen time in both children and adolescents[41] Further research including contextual information is needed to better understand sex differences across the full spectrum of activity intensity distribution. Moreover, future studies should investigate the impact of time spent at this specific intensity on health.

The main strengths of the present study include its relatively large sample of participants from Norway and Belgium, spanning a wide age range, the objective measure of PA, and use of an FDA approach. Our study also has some limitations. First, despite the relatively large sample size, it only includes youth from Norway and Belgium, limiting the generalizability of our findings to other populations. Yet, sensitivity analyses showed consistency across the studies, which indicate that patterns could be relevant to other European countries. Second, hip-worn count-based activity monitors have limitations capturing certain activities (e.g., cycling, resistance training, …) and differentiating waking from sleep states during daytime, which may result in measurement error particularly for SB time (naps being likely to be classified as SB). However, we do not expect these limitations to affect boys and girls differently. Third, the lack of detailed information regarding school schedules, such as timing and frequency of physical education classes, breaks or lunch, prevent us from investigating physical activity levels in specific school time activities. Fourth, accelerometers do not provide qualitative information on the type and context of PA, which could be valuable to understand differences in activity intensity between boys and girls. Thus, research using other methodological approaches is needed to better understand PA preferences and develop and evaluate targeted PA interventions.

Conclusion

Our findings suggest that sex differences in activity patterns vary across the day and between weekdays and weekend days. Girls had lower PA levels and higher SB levels than boys, particularly during school time on weekdays in all age groups, with the most pronounced differences in children aged 6–10 years. Analysis of the full spectrum of activity intensity distribution showed that boys were more likely than girls to engage in zero-count SB on weekend days, a specific behaviour that has not been studied previously and thus deserves further investigation. These findings have important implications for youth PA interventions, suggesting that successful programs should be tailored by type of day and considering school time as a potential period to promote equal opportunities for PA for boys and girls.

Data availability

Datasets used in the current study are subject to privacy protection regulations and may be shared by the respective coordinators of the cohorts on reasonable request. The codes and all documentations that supporting the conclusions of this article are available in the GitHub repository corresponding to the first author in: https://github.com/jaimelopez98/Sex-differences-in-youth-using-functional-data-analysis-FDA-.git.

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Author contributions
JL, SS, EA, BH, NB conceived the idea for the study. SS and JL designed the study methodology and functional approach was reviewed by MAB and ID. Data sharing was done by NB and EA. VH reviewed and updated the code to process the data. SS and ID validated the procedure and codes used during the analysis. JL and SS prepared the first draft of the manuscript. All authors reviewed and edited the manuscript. JL had the final responsibility to submit for publication.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics approval
The Active Learning Norwegian Preschool(er)s study, the Norwegian Center for Research Data (reference number 248220) and the Western Norway University of Applied Sciences institutional ethics committee approved the study protocol. Written informed consent was obtained from each child's parents or legal guardian and from the responsible school authorities, prior to all the procedures. The Active Smarter Kids study, the South-East Regional Committee for Medical Research Ethics approved the study protocol (reference number 2013/1893). Written informed consent from each child's parents or legal guardian and from the responsible school authorities was obtained, prior to all testing. The Belgian food consumption survey was conducted in accordance with the ethical principles for medical research involving human subjects and was approved by the Ethical Committee of the University of Ghent (reference number 2013/1025). Written informed consent to participate in the study was obtained from participants or parent(s)/legal guardian(s) of participants younger than 12 years old.

Additional information
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