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Original article

Segmented sedentary time and physical activity patterns throughout the week from wrist-worn ActiGraph GT3X+ accelerometers among children 7−12 years old

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Abstract

Background: This study examined the volume and patterns of physical activity (PA) and sedentary time (ST) across different segments of the week among boys and girls.

Methods: A total of 188 children aged 7−12 years wore a wrist-mounted ActiGraph GT3X+ accelerometer for 7 days. Time spent in PA and ST was calculated using ActiLife software. The mean number of minutes of light PA, moderate PA, vigorous PA, moderate-to-vigorous PA (MVPA), and ST were calculated per weekday (before school, during school, and after school) and per weekend day (morning and afternoon−evening).

Results: After school represented the greatest accumulation of ST compared with before school and during school segments. Boys engaged in 225.4 min/day of ST (95% confidence interval (CI): 216−235), and girls engaged in 222.2 min/day of ST (95%CI: 213−231). During school, boys engaged in significantly more MVPA than girls (46.1 min/day (95%CI: 44−48) *vs.* 40.7 min/day (95%CI: 39−43)). Across the whole weekday, boys participated in significantly more MVPA than girls (103.9 min/day (95%CI: 99−109) *vs.* 95.7 min/day (95%CI: 90−101)). The weekend afternoon−evening segment represented the larger accumulation of ST, where boys were significantly more sedentary than girls (367.5 min/day (95%CI: 353−382) *vs.* 339.8 min/day (95%CI: 325−355), respectively).

Conclusion: Our findings suggest that children are highly sedentary and spend little of their time in school in MVPA, especially girls. Routine breaks in school elicit increases in light PA and MVPA. Future work should consider the use of more active breaks within school time to encourage PA and reduce ST.

Keywords: Accelerometry; School; Segments; Weekday; Youth

1. Introduction

Global physical activity (PA) guidelines suggest that children should engage in at least 60 min of moderate-to-vigorous PA (MVPA) per day.[1] Yet many children fail to meet these recommendations.[2,3] A European study of 7684 children aged 2−11 years concluded that only 10%−34% of boys and 2%−15% of girls achieved the minimal MVPA recommendations.[4] Given the well-established relationship between PA and measures of health and well-being,[5,6] it is vital that strategies are developed to reverse the current status of youth inactivity levels. Schools are often cited as an ideal setting to introduce multifaceted intervention strategies that provide children with opportunities to be physically active.[7] However, recent large-scale studies have indicated equivocal results.[8,9]

Childhood PA patterns across the segmented week have been examined to identify the most appropriate time within the week to introduce interventions that will have the most influence on PA engagement.[10−17] Nonetheless, the lack of control for known confounders in subsequent analysis[12,18,19] may limit the generalizability of the findings from some of these studies. Evidence of PA patterns across the segmented

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week, assessed objectively using hip-worn accelerometers and controlled for known correlates, suggest that adjusting for known confounders such as age, body mass index (BMI) z-score, socioeconomic status, and device wear time can influence children's PA level measurements.[10,13,15] However, the use of a nonwear time period of 60 min and epoch lengths of 15 s in their methodology[15] may have overestimated participant sample size, failed to capture irregular PA, and overestimated ST.[20,21] Increased nonwear time periods can overestimate ST by classifying time when the device may not have been worn as time spent being sedentary. As a consequence of this, more subjects are likely to meet the wear time inclusion criteria and present an overestimation of ST.[20,22]

Furthermore, the lack of consensus regarding an appropriate definition of a sedentary bout and what constitutes a break in ST adds further challenges for researchers who look to quantify ST.[23] In addition, it may be unusual for children to remain completely sedentary for a full hour,[24] because some movement during an hour would be expected even while watching television or playing video games. With this in mind, the generalizability of the findings proposed by Strugnell et al.[15] may be limited. Moreover, the use of 15-s epochs may have failed to capture the sporadic, intermittent nature of children's PA and consequently may have caused an underestimation of vigorous PA (VPA) and overall activity levels while overestimating ST.[25,26]

Older ActiGraph GT1M accelerometer models used in previous studies[10,13] captured vertical axis data only, which may limit comparisons with more recent studies that have used triaxial accelerometers, particularly because it has been suggested that data captured from vector magnitude (VM) may present a more representative picture of PA in comparison with interpretations based only on vertical axis data.[27–29] Although these studies have aided in our understanding in establishing children's PA throughout the day, there is a need for more recent interpretations that use triaxial devices and control for known confounders.

A common feature of previous studies[10,13,15,19] that have examined PA levels over the segmented week has been the reliance on the hip placement site to capture accelerometer data. Because wrist placement site has been shown to increase compliance,[30–32] which can decrease the risk of selection bias[33,34] and provide researchers with more confidence in their data,[35] recent work by Noonan et al.[18] examined PA levels across the segmented week from accelerometer data captured from the wrist. To the best of our knowledge, this study is the only one that has examined PA levels across the segmented week from accelerometer data captured from the wrist. Nevertheless, their findings are limited given the lack of ST reported and the failure to ensure that only those participants who had full data for each hourly segment were included in their analysis.

Wrist-worn accelerometers are currently being deployed in large population surveys,[36,37] and their use is likely to increase given their enhanced compliance rates and their superior comfort over traditional hip placement. Thus, it is important to build on the findings from Noonan et al.[18] to identify to what extent children's PA patterns vary across the segmented week and to identify which segments offer the most potential for introducing interventions. Moreover, because no study has examined these patterns by gender, it is important to establish the time segments at which girls and boys are most and least active to inform future interventions. Therefore, the purpose of this study was to measure child activity levels using a wrist-mounted ActiGraph GT3X+ device (ActiGraph, Pensacola, FL, USA) to (1) determine at which time frames across a segmented school week children are most and least active and (2) investigate the extent to which PA levels and ST differ between boys and girls. It is hypothesized that the greatest accumulation of PA in this sample will occur during school and that boys will be significantly more active than girls across all time segments.

2. Methods

2.1. Participants

Participants were recruited across 7 geographically representative primary schools from South Lanarkshire, Scotland. The children were in year groups 5, 6, and 7 of their respective primary schools. A total of 12 schools of varying socioeconomic status (SES) were initially identified and emailed to gauge their interest in participating. Of these 12 schools, 7 agreed to participate. SES was determined from each school's postcode, which was input into the Scottish Index of Multiple Deprivation (SIMD) calculator.[38] Each postcode was then given an SIMD rank between 1 and 10, with 1 representing the most deprived areas and 10 representing the least deprived areas in Scotland. Upon ethical approval being received from the Ethical Committee of the University of the West of Scotland, participants and parents were provided with information packs detailing the aims of the study and their involvement. Across the 7 schools, 2 recruitment strategies were used as requested by the schools' head teachers. The first involved distributing 100 information packs to 3 schools ($n = 300$) to the target age group. This process resulted in the recruitment from School 1 (SIMD 2) of 58 participants (24 boys), from School 2 (SIMD 5) of 92 participants (40 boys), and from School 3 (SIMD 7) of 73 participants (36 boys). The second recruitment strategy required 2 researchers to attend the parents' evenings at the remaining 4 schools to recruit participants face to face. This resulted in the recruitment from School 4 (SIMD 7) of 32 participants (20 boys), from School 5 (SIMD 2) of 16 participants (8 boys), from School 6 (SIMD 2) of 15 participants (9 boys), and from School 7 (SIMD 3) of 21 participants (12 boys). Signed informed parental and child consents were received from all participating children ($n = 307$). No significant differences were evident in the age of participants or distribution of genders across schools. It was clear nonetheless that distributing consent forms to schools rather than recruiting at parents' evenings resulted in greater participation rates.

2.2. Instruments

Participants' height was measured barefoot to the nearest 0.1 cm using a portable stadiometer (Seca Stadiometre, Seca Ltd., Birmingham, UK), and weight was measured barefoot with light clothing to the nearest 0.1 kg on electronic scales

(Seca Digital Scales, Seca Ltd.). From measured stature and body mass, a BMI z-score was calculated relative to the UK 1990 BMI population reference data.[39] Thereafter, all participants wore 1 ActiGraph GT3X+ monitor on their nondominant wrist for 7 days. Verbal confirmation of each participant's nondominant wrist was noted, and device placement was demonstrated. All participants were fitted with their device before leaving the testing session. Before testing, each accelerometer was synchronized with Greenwich Mean Time and initialized to capture data at 80 Hz. Each accelerometer was programmed to commence data collection at 06:00 on the day after participants received the devices. The low-frequency extension was not enabled. Participants were instructed to wear the device at all times (i.e., 24 h/day) for 7 days, except during any water-based activities such as swimming or bathing. Because poor compliance and subsequent selection bias and misclassification is often cited as a limitation of hip-worn accelerometer studies,[36] we used the 24-h wear time protocol to encourage compliance.

2.3. Data processing

Upon the return of the devices, data were downloaded in 5-s epoch lengths using ActiLife (Version 6.13.3; ActiGraph) and saved in raw format as GT3X files. These data were subsequently converted to AgileGraph Data (AGD) format to facilitate data analysis. Patterns of ST and PA during the segmented week were examined using the following time segments: weekdays being before school (06:30−08:59), during school (09:00−14:59), and after school (15:00−21:59). Patterns of ST and PA were also examined during school-specific morning recess and lunch break times. For weekend days, the time segments were morning (06:30−11:59) and afternoon−evening (12:00−21:59). These time segments are similar to those used elsewhere.[18]

Time spent in ST, light PA (LPA), moderate PA (MPA), VPA, and MVPA were calculated by summing the minutes spent in each activity threshold during each segment of the day. The percentage of the total segment time represented by ST, LPA, MPA, VPA, and MVPA was calculated by dividing the mean minutes for each intensity by the total time segment, multiplied by 100, for those with available data.[18] Finally, rather than including sleep time within the analysis, data captured from 22:00 to 06:29 were removed from subsequent analysis. The GT3X+ device can measure accelerations across 3 axes (i.e., vertical, anteroposterior, and mediolateral), which can be examined individually or together, providing the VM. Our decision to report the VM data will be useful for those interested in reporting the total volume of PA. VM data have been provided for all weekly segments and reported as total counts with 95% confidence intervals (CIs). Finally, mean minutes and 95%CI were plotted graphically to demonstrate the hourly pattern of activity during whole weekdays and weekend days.

Participants were included within the weekday analysis if they wore the accelerometers for a minimum of 3 weekdays and a minimum of 10 h each day as described in a previous study.[13] To be included within the during school, school-specific morning recess and lunch break times analysis, participants had to provide 3 days of wear time during both segments. Morning recess across all schools lasted 15 min and occurred between 10:00 and 11:00. Lunch breaks ranged from 45 to 55 min in duration and occurred from 12:00 to 13:15 across the schools. Finally, from those participants included within the weekday analysis, only those participants who wore the device for a minimum of 1 weekend day for a minimum of 10 h were included within the weekend day analysis. Device- and wrist-specific VM counts cut-points proposed by Chandler et al.[40] were used to represent time spent in ST, LPA, MPA, VPA, and MVPA.

2.4. Data analysis

Repeated measures analyses of covariance examined between-segment differences across genders for time spent in ST, LPA, MPA, VPA, and MVPA, as well as VM counts/min, while controlling for the following variables: age, BMI z-score, SES, and device wear time. These variables were identified a priori based on previous research.[10,13] Finally, effect size statistics were established based on Cohen's (d) classifications: small ($0.2 \le d < 0.5$), moderate ($0.5 \le d < 0.8$), and large ($d \ge 0.8$) effect sizes.[41] All analyses were conducted using IBM SPSS Statistics (Version 24.0; IBM, Armonk, NY, USA) and Microsoft Excel 2016 (Microsoft, Redmond, WA, USA). For all analyses, statistical significance was set at $p < 0.05$.

3. Results

From the 307 individuals who agreed to participate, data were available for 266 participants (134 boys) aged 9.8 ± 1.1 years. Some participants were unable to provide data for the following reasons: absent ($n = 27$), voluntary withdrawal ($n = 3$), devices lost ($n = 4$), and device malfunction ($n = 7$). Participants not meeting the wear time criteria for inclusion within the weekday analysis ($n = 7.8$) were excluded. This resulted in 96 girls (age = 9.7 ± 1.1 years, BMI z-score = 1.1 ± 1.2, school SIMD = 5 ± 2, and device wear time = 3765.6 ± 1273.0 min) and 92 boys (age = 9.8 ± 1.0, BMI z-score = 0.4 ± 1.1, school SIMD = 5 ± 2, and device wear time = 3789.8 ± 1436.9 min) included for the weekday analysis. Of these 188 participants, those not meeting the wear time inclusion criteria for the weekend analysis ($n = 52$) were excluded from this aspect of the analysis. This resulted in 136 participants (71 boys) being included in the weekend day analysis. There were no significant differences for any of the measured variables between children included in the analyses and those excluded.

Participation in PA and ST across the 3 segmented weekday time periods are presented in Table 1 by gender. Findings for the before school segment revealed significant gender differences, with boys spending more time in VPA (0.5 min, 95%CI: 0−1, $d = 0.72$). For the during school segment, boys participated in significantly more VPA (2.9 min; 95%CI: 2−4; $d = 0.86$) and MVPA (5.4 min; 95%CI: 2−8; $d = 0.5$) compared with girls. Furthermore, significant gender-specific differences were also evident for total VM counts (32.7 min; 95%CI: 17−49; $d = 0.57$) for the during school segment, with boys having higher counts than girls. For the afterschool

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Table 1
Activity outcomes by gender for weekday segments.

	Boys ($n = 92$)		Girls ($n = 96$)		Boys−girls difference	Boys−girls difference
	Mean min/total counts	% Segment time	Mean min/total counts	% Segment time	Min/counts	%
Before school (06:30−08:59)						
ST	37.8 (35 to 40)	54.9 (53 to 57)	37.4 (35 to 40)	54.3 (52 to 56)	0.5 (−3 to 4)	0.7 (−2 to 4)
LPA	20.1 (19 to 21)	31.6 (30 to 33)	21.8 (20 to 23)	32.6 (31 to 34)	−1.8 (−4 to 0)	−1.0 (−3 to 1)
MPA	8.3 (8 to 9)	12.3 (11 to 13)	8.6 (8 to 9)	12.7 (12 to 14)	−0.2 (−1 to 1)	−0.4 (−2 to 1)
VPA	0.9 (1 to 1)	1.3 (1 to 2)	0.3 (0 to 1)	0.5 (0 to 1)	0.5 (0 to 1)***, ##	0.8 (0 to 1)***, ##
MVPA	9.2 (8 to 10)	13.6 (13 to 15)	8.9 (8 to 10)	13.3 (12 to 14)	0.3 (−1 to 1)	0.3 (−1 to 2)
VM (counts)	357.3 (339 to 375)		347.4 (329 to 365)		10.0 (−16 to 35)	
During school (09:00−14:59)						
ST	196.5 (192 to 201)	56.7 (55 to 58)	198.9 (195 to 203)	58.0 (57 to 59)	−2.5 (−9 to 4)	−1.3 (−3 to 0)
LPA	104.1 (101 to 107)	30.0 (29 to 31)	103.8 (101 to 107)	30.2 (29 to 31)	0.3 (−4 to 5)	−0.1 (−1 to 1)
MPA	38.5 (37 to 40)	11.1 (11 to 12)	36.0 (34 to 38)	10.5 (10 to 11)	2.5 (0 to 5)	0.6 (0 to 1)
VPA	7.6 (7 to 8)	2.2 (2 to 2)	4.6 (4 to 5)	1.3 (1 to 2)	2.9 (2 to 4)***, ###	0.8 (0 to 1)***,###
MVPA	46.1 (44 to 48)	13.3 (13 to 14)	40.7 (39 to 43)	11.8 (11 to 12)	5.4 (2 to 8)**, ##	1.5 (1 to 2)**, #
VM (counts)	371.4 (360 to 383)		338.7 (327 to 350)		32.7 (17 to 49)***, ##	
After school (15:00−21:59)						
ST	225.4 (216 to 235)	61.3 (60 to 63)	222.2 (213 to 231)	59.9 (58 to 62)	3.2 (−10 to 16)	1.4 (−1 to 4)
LPA	92.9 (89 to 97)	25.3 (24 to 26)	100.0 (96 to 104)	27.2 (26 to 28)	−7.1 (−13 to −2)*,#	−1.9 (−3 to −1)**,#
MPA	42.2 (39 to 45)	11.5 (11 to 12)	43.0 (40 to 46)	11.7 (11 to 12)	−0.7 (−5 to 3)	−0.2 (−1 to 1)
VPA	7.2 (6 to 8)	2.0 (2 to 2)	4.2 (3 to 5)	1.2 (1 to 2)	3.0 (1 to 5)***,##	0.8 (0 to 1)***,##
MVPA	49.4 (46 to 53)	13.5 (12 to 14)	47.2 (44 to 51)	12.9 (12 to 14)	2.2 (−3 to 7)	0.6 (−1 to 2)
VM (counts)	341.2 (322 to 360)		328.7 (310 to 347)		12.5 (−14 to 39)	

Data are presented as mean (95% CI). Significant difference between boys and girls mean min and percent segment time at: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Effect sizes are indicated as follows: # Small ($0.2 \le d < 0.5$), ## Moderate ($0.5 \le d < 0.8$), ### Large ($d \ge 0.8$).
Abbreviations: CI = confidence interval; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time; VM = vector magnitude; VPA = vigorous physical activity.

segment, girls spent significantly more time in LPA (−7.1 min; 95%CI: −13 to −2; $d = 0.36$) than their male counterparts, whereas boys participated in more VPA (3.0 min; 95%CI: 1−5; $d = 0.53$) compared with girls. No other significant differences were found across the 3 weekday segments between boys and girls.

Participation in PA and ST across the 2-segment weekend day time periods are presented in Table 2 by gender. Findings revealed significant gender differences, with boys spending more time in VPA (2.0 min; 95%CI: 0−3; $d = 0.46$) in the morning segment than girls. In the afternoon−evening segment, boys spent significantly more time being sedentary (27.6 min; 95%CI: 7−48; $d = 0.45$) than girls. Furthermore, in the afternoon−evening segment, girls spent significantly more time in LPA (−21.8 min; 95%CI: −33 to −10; $d = 0.62$) and MPA (−8.7 min; 95%CI: −16 to −1; $d = 0.37$) than boys.

Participation in PA and ST by gender across entire weekdays, weekend days, and the week is presented in Table 3. For the whole weekday, findings revealed significant gender differences, with boys spending more time in VPA (6.4 min; 95%CI: 4−9; $d = 0.78$) and MVPA (8.2 min; 95%CI: 1−16; $d = 0.14$) than girls. Similarly, significant gender-specific differences were also evident for total VM counts (21.1counts; 95%CI: 3−39; $d = 0.09$) during the whole weekday segment, with boys presenting higher counts than girls. For the whole weekend, boys spent significantly more time in ST (32.3 min; 95%CI: 8−56; $d = 0.47$) and VPA (4.0 min; 95%CI: 1−7; $d = 0.48$) than girls. In contrast, girls spent significantly more time in LPA (−20.9 min; 95%CI: −34 to −8; $d = 0.61$) than boys. For the whole week, girls spent significantly more time in LPA (−13.6 min; 95%CI: −23 to −4; $d = 0.45$) than boys. Furthermore, boys spent significantly more time in VPA (5.0 min; 95%CI: 3−7; $d = 0.78$) than girls.

Participation in PA and ST during morning recess and the lunch break is presented in Table 4. During morning recess, boys spent significantly more time in MPA (0.7 min; 95%CI: 0−1; $d = 0.64$), VPA (0.5 min; 95%CI: 0−1; $d = 0.83$), and MVPA (1.3 min; 95%CI: 1−2; $d = 0.78$), but significantly less time in ST (−1.1 min; 95%CI: −2 to −1; $d = 0.59$) than girls. Boys also presented with significantly greater total VM counts (29.1 counts; 95%CI: 10−48; $d = 0.43$) than girls during this segment. During the lunch break, boys spent significantly more time in MPA (1.8 min; 95%CI: 1−3; $d = 0.52$) and MVPA (3.3 min; 95%CI: 2−4; $d = 0.73$), but significantly less time in ST (−2.8 min; 95%CI: −4 to -1; $d = 0.64$) than girls. Boys also presented with significantly greater total VM counts (34.8 counts; 95%CI: 20−50; $d = 0.64$) than girls during this segment. In addition to calculating differences between mean minutes spent in ST and PA, percentage time segment differences between boys and girls were calculated for all time segments (Tables 1−4). These largely followed the findings of the mean min differences, although boys did spend significantly less time in LPA (-1.1%; 95%CI: -2 to 0; $d = 0.3$) during the whole weekday than girls.

The participants' average ST, LPA, and MVPA for each hour across all waking hours on weekdays and weekend days are presented in Figs. 1 and 2, respectively. Children were highly sedentary during weekdays (Fig. 1), particularly between 11:00 and 11:59 (38 ± 9 min; 95%CI: 37−39). The duration of ST decreased between 12:00 and 12:59 (29 ±

Table 2
Activity outcomes by gender for weekend day segments.

	Boys (n = 71)		Girls (n = 65)		Boys−girls difference	Boys−girls difference
	Mean min/total counts	% segment time	Mean min/total counts	% segment time	Min/counts	%
Morning (06:30−11:59)						
ST	120.4 (112 to 128)	64.2 (61 to 67)	118.9 (111 to 127)	66.0 (63 to 69)	1.5 (−10 to 13)	−1.8 (−6 to 3)
LPA	42.8 (39 to 46)	23.1 (22 to 25)	42.6 (39 to 46)	24.4 (23 to 26)	0.2 (−5 to 5)	−1.2 (−3 to1)
MPA	19.0 (17 to 21)	9.0 (8 to 10)	16.8 (15 to 19)	8.7 (8 to 10)	2.1 (−1 to 5)	0.3 (−1 to 2)
VPA	2.9 (2 to 4)	1.4 (1 to 2)	0.9 (0 to 2)	0.5 (0 to 1)	2.0 (0 to 3)*,#	1.0 (0 to 2)**,##
MVPA	21.9 (19 to 25)	10.4 (10 to 12)	17.7 (15 to 21)	9.2 (8 to 11)	4.1 (0 to 8)	1.2 (0 to 3)
VM (counts)	277.5 (251 to 304)		260.9 (233 to 289)		16.6 (−22 to 55)	
Afternoon−evening (12:00−21:59)						
ST	367.5 (353 to 382)	65.7 (64 to 68)	339.8 (325 to 355)	60.4 (58 to 63)	27.6 (7 to 48)*,#	5.3 (2 to 8)***,##
LPA	132.2 (124 to 140)	23.5 (22 to 25)	154.0 (146 to 162)	27.5 (26 to 29)	−21.8 (−33 to −10)***,##	−4.0 (−6 to −2)***,##
MPA	53.8 (49 to 59)	9.5 (9 to 10)	62.5 (57 to 68)	11.2 (10 to 12)	−8.7 (−16 to −1)*,#	−1.7 (−3 to 0)*,#
VPA	7.7 (6 to 9)	1.4 (1 to 2)	5.4 (4 to 7)	0.9 (0 to 1)	2.3 (0 to 5)	0.4 (0 to 1)
MVPA	61.5 (55 to 68)	10.8 (10 to 12)	67.9 (61 to 75)	12.1 (11 to 13)	−6.4 (−16 to 3)	−1.3 (−3 to 0)
VM (counts)	291.5 (271 to 312)		318.7 (297 to 340)		−27.2 (−56 to 2)	

Data are presented as mean (95% CI). Significant difference between boys and girls mean min and percent segment time at: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Effect sizes are indicated as follows: # Small ($0.2 \le d < 0.5$), ## Moderate ($0.5 \le d < 0.8$), ### Large ($d \ge 0.8$).

Abbreviation: CI = confidence interval; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time. Activity; VM=vector magnitude; VPA= vigorous physical activity.

9 min, 95%CI: 28−30) because of lunch recess, but steadily increased upon returning to class and for the remainder of the day. Time in LPA and MVPA remained stable throughout the weekday and peaked at lunchtime for both LPA (20 ± 4 min; 95%CI: 19−21) and MVPA (11 ± 7 min, 95%CI: 10−12). Time in LPA then steadily decreased after 16:00 for the remainder of the day, whereas time in MVPA remained stable up until 18:59 and then decreased for the remainder of the day.

On weekend days (Fig. 2), time spent in ST was greatest between 07:00 and 09:59 (range: 40−42 min) but decreased slightly up until 20:59 (10:00−20:00, range: 35−40 min). Time spent in MVPA was stable throughout the weekend day, with the highest values seen between 11:00 and 19:59 (range, 7−8 min) and the lowest between 08:00 and 08:59 (5 min, 95%CI: 4−7). Finally, time spent in LPA was highest between 12:00 and 12:59 (17 min, 95%CI: 16−18) but remained stable throughout the entire weekend day (range: 13−17 min).

4. Discussion

Our findings suggest that children were more active and less sedentary during weekdays in comparison with weekend days. When examining the ST and PA patterns by gender, boys spent significantly more time in MVPA than girls during weekdays and more time in ST than girls during the weekend days. A unique element of this study is the comparison of activity patterns by gender across specific time segments, which revealed minimal differences in activity patterns before school. During school hours, boys spent significantly more time in MVPA than girls, which is reflected in boys having significantly higher VM counts in comparison with girls. After school, boys spent significantly less time in LPA but more time in VPA than girls. During weekend days, boys and girls both spent a similar proportion of their time in ST (range: 62%−66%). Although the proportion of time spent in ST and MVPA was broadly similar between the morning and afternoon−evening segments on the weekend days for boys, girls seemed to spend more time in ST but less time in MVPA in the morning segment than in the afternoon−evening segment. These objectively measured time-specific observations are a strength of this study, because only participants with the full 60 min of wear time for each hourly segment were included in the analysis. The results from this study extend the current literature by providing a detailed analysis of gender differences in ST, LPA, MPA, VPA, and MVPA as captured from a wrist-worn accelerometer across specific segments of the week. These observations may be useful for the implementation and delivery of interventions that can be developed to target specific time segments when children are least active.

Comparing our findings with the findings of others is difficult because results depend on the selected accelerometer wear site, cut-points, accelerometer brand, target population, and postprocessing decisions. To the best of our knowledge, this study is the first to provide a detailed analysis of gender differences in ST, LPA, MPA, VPA, and MVPA captured from a wrist-worn ActiGraph GT3X+ accelerometer across specific segments of the week. It is encouraging, therefore, that our findings are comparable with previous research, which suggests that boys engage in significantly more daily MVPA than girls during school hours.[11,14,15] Unlike these studies, however, we did not observe any significant differences in ST between boys and girls during the school hours. One plausible explanation for this discrepancy is the use of wrist-worn accelerometers in our study instead of hip-worn accelerometers to capture activity levels. Previous studies have highlighted the difficulties in capturing estimates of ST from wrist accelerometers given the lack of wrist movement.[35,42] At present, devices such as the ActiGraph GT3X+ can be used to estimate ST, but they do this based on minimal or nonmovement. Because previous studies have reported considerable differences in estimates of time spent in ST from accelerometers worn at the wrist and hip,[32,34] it is encouraging to note that the estimates

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Table 3
Activity outcomes by gender for whole weekdays, weekend days, and the whole week.

	Boys		Girls		Boys−girls difference	Boys−girls difference
	Mean min/total counts	% segment time	Mean min/total counts	% segment time	Min/counts	%
Whole weekday (*n* = 188, boys = 92, 06:30−21:59)						
ST	458.5 (447 to 470)	58.9 (58 to 60)	453.0 (442 to 464)	58.8 (58 to 60)	5.4 (−10 to 21)	0.1 (−2 to 2)
LPA	216.2 (210 to 222)	27.8 (27 to 29)	223.1 (217 to 229)	28.9 (28 to 30)	−6.9 (−15 to 1)	−1.1 (−2 to 0)$^{*,\#}$
MPA	88.4 (84 to 93)	11.3 (11 to 12)	86.5 (82 to 91)	11.2 (11 to 12)	1.9 (−4 to 8)	0.1 (−1 to 1)
VPA	15.6 (14 to 17)	2.0 (2 to 2)	9.2 (8 to 11)	1.2 (1 to 1.4)	6.4 (4 to 9)$^{***,\#\#}$	0.8 (0 to 1)$^{***,\#\#\#}$
MVPA	103.9 (99 to 109)	13.3 (13 to 14)	95.7 (90 to 101)	12.4 (12 to 13)	8.2 (1 to 16)$^{*,\#}$	0.9 (0 to 2)$^{*,\#}$
VM (counts)	354.2 (341 to 367)		333.2 (321 to 346)		21.1 (3 to 39)$^{*,\#}$	
Whole weekend (*n* = 136, boys = 71, 06:30−21:59)						
ST	488.8 (472 to 505)	65.7 (64 to 68)	456.5 (439 to 474)	62.0 (60 to 64)	32.3 (8 to 56)$^{**,\#}$	3.7 (1 to 6)$^{**,\#}$
LPA	175.0 (166 to 184)	23.4 (22 to 25)	196.0 (186 to 206)	26.6 (25 to 28)	−20.9 (−34 to −8)$^{**,\#\#}$	−3.2 (−5 to −1)$^{***,\#\#}$
MPA	71.1 (65 to 77)	9.5 (9 to 10)	78.1 (72 to 84)	10.6 (10 to 11)	−7.0 (−16 to 2)	−1.1 (−2 to 0)
VPA	10.1 (8 to 12)	1.4 (1 to 2)	6.2 (4 to 8)	0.8 (0 to 1)	4.0 (1 to 7)$^{**,\#}$	0.6 (0 to 1)$^{**,\#}$
MVPA	81.3 (74 to 89)	10.9 (10 to 12)	84.3 (77 to 92)	11.4 (10 to 12)	−3.1 (−14 to 7)	−0.6 (−2 to 1)
VM (counts)	291.9 (274 to 310)		302.9 (284 to 321)		−11.0 (−37 to 15)	
Whole week (*n* = 136, boys = 71, 06:30−21:59)						
ST	469.2 (458 to 480)	61.0 (60 to 62)	454.0 (442 to 466)	59.4 (58 to 61)	15.2 (−1 to 31)	1.6 (0 to 3)
LPA	203.8 (197 to 210)	26.5 (26 to 27)	217.5 (211 to 224)	28.4 (28 to 29)	−13.6 (−23 to −4)$^{**,\#}$	−1.9 (−3 to −1)$^{**,\#\#}$
MPA	83.3 (79 to 88)	10.8 (10 to 11)	85.4 (81 to 90)	11.1 (11 to 12)	−2.1 (−9 to 4)	−0.3 (−1 to 0)
VPA	13.6 (12 to 15)	1.8 (1 to 2)	8.5 (7 to 10)	1.1 (0 to 1)	5.0 (3 to 7)$^{***,\#\#}$	0.6 (0 to 1)$^{***,\#\#\#}$
MVPA	96.9 (91 to 102)	12.5 (12 to 13)	93.9 (88 to 100)	12.2 (12 to 13)	3.0 (−5 to 11)	0.3 (−1 to 1)
VM (counts)	646.0 (608 to 684)		617.2 (577 to 657)		28.8 (−26 to 84)	

Data are presented as mean (95%CI). Significant difference between boys and girls mean min and percent segment time at: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Effect sizes are indicated as follows: $^{\#}$ Small ($0.2 \le d < 0.5$), $^{\#\#}$ Moderate ($0.5 \le d < 0.8$), $^{\#\#\#}$ Large ($d \ge 0.8$).
Abbreviations: CI = confidence interval; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time. Activity; VM = vector magnitude; VPA = vigorous physical activity.

of time in ST derived from the wrist-worn accelerometers reported in the present study are broadly similar to estimates from studies using hip-worn accelerometers.

In a recent Australian study,[15] the authors examined time spent in ST during the school day and found that boys and girls engaged in, on average, 246 and 260 min/day of ST, respectively. These findings are similar to the estimates reported in our study, where boys and girls engaged in, on average, 196.5 and 198.9 min/day of ST, respectively. In the same Australian study, the authors reported that boys and girls engaged in, on average, 102 and 103 min/day of LPA and 62 and 45 min/day of MVPA, respectively. These LPA estimates are very similar to ours, although participants in the Australian sample engaged in more MVPA than was evident in our study. Furthermore, Steele et al.,[10] who used hip-worn accelerometers to estimate activity patterns across segmented time periods, reported that boys and girls engaged in, on average, 230 and 240 min/day of ST during school hours, respectively. Similarly, van Stralen et al.,[14] using hip-worn accelerometers, reported that children across 5 European countries engaged in, on average, 209 min/day of ST and 16 min/day of MVPA, respectively, during the school day. Therefore, the estimates of ST reported in these studies[10,14] seem to be higher than our estimates (196.5 min/day and 198.9 min/day for boys and girls, respectively), although it was evident that time spent in MVPA from this study (46.1 min/day and 40.7 min/day for boys and girls, respectively) seems to be lower than estimates reported by van Stralen et al.[14] during school hours.

When we compare our estimates with those of Noonan et al.,[18] who also used a wrist-worn accelerometer to estimate activity patterns across segmented times of the week, there were wide differences in estimates for time spent in LPA and MVPA. For instance, Noonan et al.[18] estimated that time in LPA before, during, and after school were, on average, 35, 166, and 130 min/day, respectively, in comparison with the estimates reported in this study, which were 20, 104, and 93 min/day, respectively. Similar discrepancies in our findings for time spent in MVPA before, during, and after school were also evident when compared with those of Noonan et al.,[18] who reported, on average 2, 17, and 13 min/day, respectively. Our estimates for MVPA before, during, and after school were 9, 46, and 42 min/day, respectively. When comparing the estimates across the whole weekday, weekend, and whole week, Noonan et al.[18] reported more time spent in LPA across these days than is reported here (329, 284, and 307 min/day in Noonan et al.[18] *vs.* 216, 175, and 204 min/day in our study). Conversely, when comparing estimates for time spent in MVPA across these segments, it was evident that the children in our study engaged in, on average, more MVPA (104, 81, and 97 min/day) than the children in the study by Noonan et al. (32, 28, and 30 min/day). Although these discrepancies for time spent in MVPA are vast, the variation in accelerometer data processing methods used in the 2 studies is a likely cause.

The low estimates of MVPA reported by Noonan et al.[18] are similar to those reported by Kim et al., [31] who reported estimates ranging from 8.0 to 12.8 min/day when using nearly identical processing methods. In the 2 studies, raw acceleration data were processed in R (R Foundation for Statistical Computing, Vienna, Austria; https://cran.r-project.org/) using the GGIR package, which allows raw accelerations (gravitational acceleration) to be processed and analyzed[43] using the

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Table 4
Activity outcomes by gender for school special segments.

	Boys ($n = 88$)		Girls ($n = 94$)		Boys−girls difference	Boys−girls difference
	Mean min/total counts	% segment time	Mean min/total counts	% Segment time	Min/counts	%
Morning recess						
ST	5.6 (5 to 6)	37.9 (35 to 40)	6.7 (6 to 7)	45.3 (43 to 48)	−1.1 (−2 to −1)***,##	−7.3 (−11 to −4)***,##
LPA	5.1 (5 to 5)	33.9 (33 to 35)	5.2 (5 to 5)	35.0 (34 to 36)	−0.2 (−1 to 0)	−1.1 (−3 to 1)
MPA	3.2 (3 to 3)	21.1 (20 to 23)	2.4 (2 to 3)	16.2 (15 to 18)	0.7 (0 to 1)***,##	4.9 (3 to 7)***,##
VPA	1.1 (1 to 1)	7.1 (6 to 8)	0.5 (0 to 1)	3.6 (3 to 4)	0.5 (0 to 1)***,##	3.5 (2 to 5)***,###
MVPA	4.2 (4 to 5)	28.2 (26 to 30)	3.0 (3 to 3)	19.8 (18 to 22)	1.3 (1 to 2)***,##	8.4 (5 to 11)***,##
VM (counts)	156.9 (143 to 171)		127.9 (115 to 141)		29.1 (10 to 48)**,#	
Lunch break						
ST	18.8 (18 to 20)	39.4 (37 to 42)	21.6 (21 to 23)	45.4 (43 to 47)	−2.8 (−4 to −1)***,##	−5.9 (−9 to −3)***,##
LPA	16.1 (16 to 17)	33.8 (33 to 35)	16.6 (16 to 17)	34.9 (34 to 36)	−0.5 (−1 to 0)	−1.1 (−2 to 0)
MPA	9.8 (9 to 10)	20.7 (19 to 22)	8.0 (7 to 9)	16.9 (16 to 18)	1.8 (1 to 3)***,#	3.9 (2 to 6)***,#
VPA	2.9 (2 to 3)	6.0 (5 to 7)	1.4 (1 to 2)	2.9 (2 to 3)	1.5 (1 to 2)***,###	3.2 (2 to 4)***,###
MVPA	12.7 (12 to 14)	26.8 (25 to 28)	9.4 (9 to 10)	19.7 (18 to 21)	3.3 (2 to 4)***,##	7.0 (5 to 9)***,##
VM (counts)	146.9 (136 to 158)		112.2 (102 to 123)		34.8 (20 to 50)***,##	

Data are presented as mean (95%CI). Significant difference between boys and girls mean min and % segment time at * $p < 0.05$,** $p < 0.01$, *** $p < 0.001$.
Effect sizes are indicated as follows: # small ($0.2 \le d < 0.5$), ## moderate ($0.5 \le d < 0.8$), ### large ($d \ge 0.8$).
Abbreviations: CI = confidence interval; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time; VM = vector magnitude; VPA = vigorous physical activity.

device- and location-specific Hildebrand regression equations.[42] A recent study highlighted the poor classification performance of the Hildebrand thresholds for correctly classifying MVPA, primarily owing to the low recognition of MPA.[44] Because, in our study, we relied on processing our accelerometer data using the device- and wrist-specific VM counts cut-points proposed by Chandler et al.,[40] it is not surprising that large differences in time spent in LPA and MVPA were found to exist in our estimates compared with those of Noonan et al.[18] Whether our estimates or those of Noonan et al.[18] are more accurate is not known, because the processing methods used in our study have yet to be validated in an independent study, thus making it difficult to determine which processing technique is more accurate.

Findings in previous studies have suggested that girls are less active and more sedentary than boys,[3,45−47] which partly supports our observations. For instance, we found that boys engaged in significantly more MVPA during weekdays than girls (104 *vs.* 96 min/day, respectively), but boys also engaged in significantly more ST during the weekend than girls (498 *vs.* 457 min/day, respectively). With no comparable studies to compare our ST estimates with, it is not clear why we found boys to be more sedentary than girls during the weekend. What is concerning is that both boys and girls were reported to be sedentary for nearly 8 h/day throughout the week. These estimates are similar to those provided from a large representative sample of 8- to 9-year-old UK children, which estimated that these children spent, on average, 7 h/day being sedentary.[47] Given the accumulating evidence that the total volume and pattern of ST is associated with adverse health outcomes,[48,49] our observations suggest that appropriate strategies that promote PA while decreasing ST are vital.

Both weekday and weekend day hourly patterns for all levels of activity show striking similarities, despite the obvious differences in the amount of available leisure time. The main difference between weekdays and weekend days was the inclusion of a routine morning and lunchtime break during school hours, which is reflected in peak levels of time spent in LPA and MVPA, with concomitant decreases in ST (Fig. 1). Our findings are similar to those from other studies,[11,12,50] which demonstrated that girls spent significantly more time in ST and significantly less time in MVPA during both recess and lunch breaks compared with boys. Schools provide key opportunities for children to engage in PA because of the ability to target a large population, regardless of SES. Moreover, we also observed that children did not record more activity after school than during school, which is in line with recent observations.[15,50] Our findings suggest that activity levels are low after school, but the opportunity to influence activity levels during this segment may be more challenging because children need to opt-in to attend or participate in afterschool interventions. Moreover, afterschool interventions may come at an additional cost to the school or parent and, thus, discourage the long-term implementation of such afterschool interventions. Such challenges highlight the importance of the school setting as a site of influence because all children are exposed to changes in school policies, environments, and curriculums, each of which can affect levels of PA.

Evidence suggests that children spend more than 60% of their waking hours being sedentary,[51] which is consistent with our observations. Public health guidelines often recommend that overall ST should be limited in children.[52−54] Yet, attempts at introducing initiatives within Scotland to curb childhood ST have had a limited effect based on recent surveys, which estimate that less than 20% of children and adolescents meet current ST guidelines.[55,56] To decrease ST at school, introducing activity breaks during class time with the aim of replacing ST with LPA could be a feasible strategy that is time efficient, feasible, and appealing to teachers.[57−59] Promising evidence has demonstrated that implementing classroom activity breaks can improve child activity levels during school, as well as behaviors in the classroom,[57] but further

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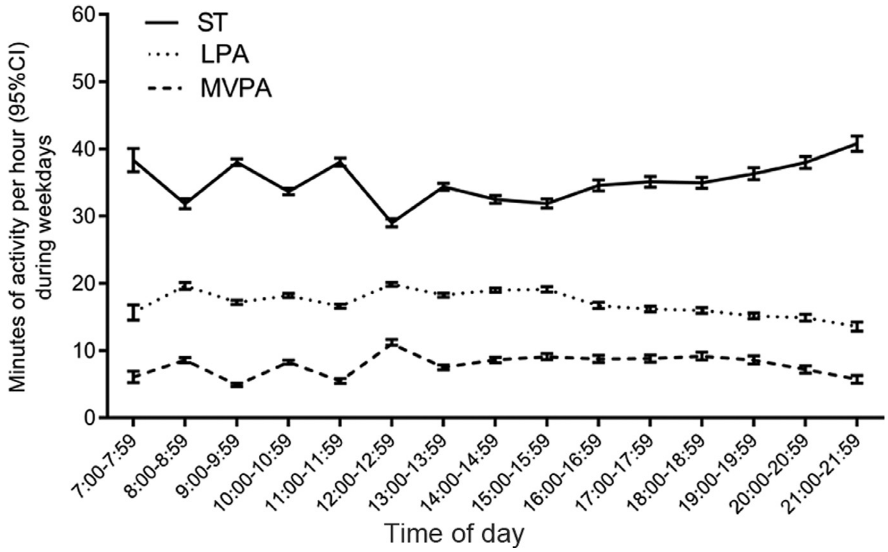

Fig. 1. The hourly average physical activity and sedentary time on weekdays (*n* = 188, boys = 92). Data are presented as mean (95%CI). CI = confidence interval; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time.

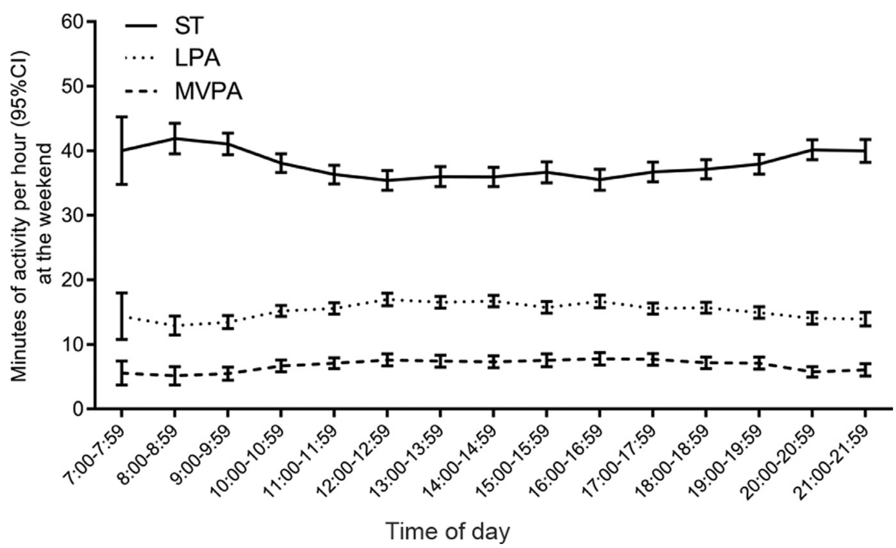

Fig. 2. The hourly average physical activity and sedentary time on weekend days (*n* = 136, boys = 71). Data are presented as mean (95%CI). CI = confidence interval; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; ST = sedentary time.

work is necessary to assess the feasibility and potential efficacy of such approaches in different countries.

When considering the findings from this study, it is important to acknowledge several limitations. First, the fact that the modest sample size of those who met the accelerometer wear time criteria were from 1 geographical location within Scotland limits the generalizability of our findings. Second, although the use of objectively measured PA is a strength of this study, the methods used to collect and process the accelerometer data can directly influence the reported duration spent in activity intensities, which may preclude comparisons with other studies. For instance, given the lack of sleep logs, we assumed that every participant slept between 22:00 and 06:29, which may not have been the case. Furthermore, the ActiGraph GT3X+ device is unable to assess body position, which may overestimate ST by not accurately detecting breaks between ST bouts. Another limitation possibly affecting the results is that we were unable to adjust our analysis for possible clustering of participants within schools, given the low number of participants who met the accelerometer wear time criteria. Moreover, it was evident that for some classes that only a small number of participants met the accelerometer wear time criteria, and the number was too small to form accurate interpretations from multilevel analyses.[60] Failing to account for clustering via multilevel analysis may have therefore affected the coverage of the 95%CI and estimation of the *p* values. The types of activities in which participants engaged were not recorded throughout the monitoring period, which could also be considered as a limitation. It should also be acknowledged that the estimates of PA and ST may not be a true representation of typical behaviors and may have been influenced by wearing the accelerometer devices.[61]

Crucially, estimates of time spent in ST and activity intensities were derived from age- and device-appropriate wrist VM cut-points. Because the use of VM cut-points are likely to increase as researchers continue to use triaxial accelerometers, we hope that our findings will allow future studies to compare time spent in ST, LPA, and MVPA across specific time segments with the estimates reported here. Furthermore, this study is the first to report PA data across a segmented week between genders in children, which build on other findings by including levels of ST. Finally, the afterschool period constituted the greatest accumulation of MVPA for both boys and girls during the week. This finding highlights the need for appropriate school-based interventions that can increase activity levels while minimizing ST.

5. Conclusion

Our findings suggest that children were more active and less sedentary during weekdays in comparison with weekend days. When examining the ST and PA patterns by gender, boys spent significantly more time in MVPA than girls during weekdays and more time in ST than girls during the weekend days. These observations highlight the importance of the school environment as an important setting for introducing initiatives that can encourage PA while minimizing ST.

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Authors' contributions

GM carried out the study methods, performed the statistical analysis, and drafted the manuscript; RA participated in the study design and coordination; SD participated in carrying out the study methods; and DSB designed and coordinated the study and the statistical analysis and helped draft the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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