Segmented sedentary time and physical activity patterns throughout the week from wrist-worn ActiGraph GT3X+ accelerometers among children 7–12 years old
McLellan, Gillian; Arthur, Rosemary; Donnelly, Samantha; Buchan, Duncan S.

Published in:
Journal of Sport and Health Science

DOI:
10.1016/j.jshs.2019.02.005

Published: 12/04/2019

Citation for published version (APA):
Original article

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

Gillian McLellan, Rosie Arthur, Samantha Donnelly, Duncan S Buchan*

School of Health and Life Sciences, Institute of Clinical Exercise and Health Science, The University of the West of Scotland, Lanarkshire Campus, Hamilton International Technology Park, Stephenson Place, Blantyre, G72 0LH, UK

*Corresponding Author: Duncan S Buchan

Email: duncan.buchan@uws.ac.uk

Running title: Segmented activity patterns throughout the week

Received 12 June 2018; revised 30 August 2018; accepted 15 November 2018

Highlights

- Children were most active and less sedentary during weekdays in comparison to weekend days
- Children were highly sedentary and spent little of their time at school in moderate-vigorous physical activity (MVPA), especially girls.
- The after-school period constituted the greatest accumulation of MVPA for both boys and girls during the week. This highlights the need for appropriate school-based interventions that can increase activity levels whilst minimizing time being sedentary.
- Routine breaks in school elicit increases in light physical activity and MVPA. Future work should consider the use of more active breaks within school time to encourage physical activity and reduce sedentary time.
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. Mean 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%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; Segments; School; Weekday; Youth
1. Introduction

Global physical activity (PA) guidelines suggest that children should engage in at least 60 min of moderate-to-vigorous physical activity (MVPA) per day. Yet many children fail to meet these recommendations. A European study of 7684 children aged 2–11 years concluded that only 10%–34% of boys and 2%–15% of girls achieve the minimal MVPA recommendations. Given the well-established relationship between PA and measures of health and wellbeing, 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 multi-faceted intervention strategies that provide children with opportunities to be physically active.

However, recent large-scale studies have indicated equivocal results. Childhood PA patterns across the segmented week have been examined in order to identify the most appropriate time within the week to introduce interventions that will have the most influence upon PA engagement. Nonetheless, the lack of control for known confounders in subsequent analysis may limit the generalizability of the findings from some of these studies. Evidence of PA patterns across the segmented week, assessed objectively using hip-worn accelerometers and controlled for known correlates, suggest that adjusting for known confounders such as age, BMI-z score, socioeconomic status, and device wear-time can influence children’s PA level measurements. However, the use of a non-wear time period of 60 min and epoch lengths of 15 s in their methodology may have overestimated participant sample size, failed to capture irregular PA, and overestimated ST. Increased non-wear 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\textsuperscript{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\textsuperscript{23}. In addition, it may be unusual for children to remain completely sedentary for a full hour\textsuperscript{24}, since some movement during an hour would be expected even whilst watching TV or playing video games. With this in mind, the generalisability of the findings proposed by Strugnell and colleagues\textsuperscript{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 physical activity (VPA) and overall activity levels whilst overestimating ST\textsuperscript{25,26}.

Older ActiGraph GT1M accelerometer models used in previous studies\textsuperscript{10,13} captured vertical axis data only, which may limit comparisons with more recent studies that have used triaxial accelerometers, particularly since it has been suggested that data captured from vector magnitude (VM) may present a more representative picture of PA in comparison to interpretations based only on vertical axis data\textsuperscript{27–29}. Whilst these studies have aided 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\textsuperscript{10,13,15,19} that have examined PA levels over the segmented week has been the reliance upon the hip placement site to capture accelerometer data. Because wrist placement site has been shown to increase compliance\textsuperscript{30–32}, which can reduce the risk of selection bias\textsuperscript{33,34} and provide researchers with more confidence in their data\textsuperscript{35}, recent work by Noonan and colleagues\textsuperscript{18} examined PA levels across the segmented week from accelerometer data captured from the wrist. To the best of our knowledge, this is
the only study 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, 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 upon the findings from Noonan and colleagues 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, since 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 in order 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, Florida, USA) in order 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 hypothesised 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. Materials and 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 socio-economic 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\textsuperscript{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 employed 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 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) 21 participants (12 boys). Signed informed parental and child consent were received from all participating children ($n = 307$ children). 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 0.1cm using a portable stadiometre (Seca Stadiometre, Seca Ltd, Birmingham, UK), and weight was measured barefoot with light clothing to the nearest 0.1kg on electronic scales (Seca Digital Scales, Seca Ltd., Birmingham, UK). From measured stature and body mass, a BMI-z score was calculated
relative to the UK 1990 BMI population reference data. Thereafter, all participants wore one ActiGraph GT3X+ monitor on their non-dominant wrist for 7 days. Verbal confirmation of each participant’s non-dominant wrist was noted, and device placement was demonstrated. All participants were fitted with their device prior to leaving the testing session. Prior to testing, each accelerometer was synchronised with Greenwich Mean Time and initialized to capture data at 80Hz. 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 per day) for 7 days, except during any water-based activities such as swimming or bathing. Since poor compliance and subsequent selection bias and misclassification is often cited as a limitation of hip-worn accelerometer studies, we used the 24-h wear-time protocol to encourage compliance.

2.3 Data processing

Upon the return of the devices, data was downloaded in 5-s epoch lengths using ActiLife (Version 6.13.3; ActiGraph, Pensacola, FL, USA) and saved in raw format as GT3X files. These 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.

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. Finally, rather than including sleep time within the analysis, data captured from (22:00-06:29) were removed from subsequent analysis. The GT3X+ device can measure accelerations across 3 axes (i.e., vertical, antero-posterior, and medio-lateral), 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 has been provided for all weekly segments and reported as total counts with 95% confidence intervals (CI). 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. 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 and colleagues 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, whilst controlling for the following variables: age, BMI-z score, SES, and device wear-time. These variables were identified a-priori based on previous research. Finally, effect size (ES) statistics were also established based on Cohen’s (d) classifications: small (0.2 ≤ d < 0.5), moderate (0.05 ≤ d < 0.8), and large (d ≥ 0.8) ES. 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 analysis, 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 = 78) were excluded. This resulted in 96 girls (age = 9.7 ± 1.1, 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 (0.6 min, 95%CI: 0 to 1, d = 0.72). For
During the school segment, boys participated in significantly more VPA (2.9 min, 95% CI: 2 to 4, $d = 0.86$) and MVPA (5.4 min, 95% CI: 2 to 8, $d = 0.5$) compared to girls. Furthermore, significant gender-specific differences were also evident for total VM counts (32.7 min, 95% CI: 17 to 49, $d = 0.57$) for the during-school segment, with boys having higher counts than girls. For the after-school 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 to 5, $d = 0.53$) compared to girls. No other significant differences were found across the 3 weekday segments between boys and girls.

Participation in PA and ST across the two-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 to 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 to 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 to 9, $d = 0.78$) and MVPA (8.2 min, 95% CI: 1 to 16, $d = 0.14$) than girls. Similarly, significant gender-specific differences were also evident for total VM counts (21.1 counts, 95% CI: 3 to 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 to 56, $d = 0.47$) and VPA (4.0 min, 95% CI: 1 to 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 to 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 to 1, \(d = 0.64\)), VPA (0.5 min, 95%CI: 0 to 1, \(d = 0.83\)), and MVPA (1.3 min, 95%CI: 1 to 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 to 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 to 3, \(d = 0.52\)) and MVPA (3.3 min, 95%CI: 2 to 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 to 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 week days, particularly between 11:00 and 11:59 (38 ± 9 min, 95%CI: 37-39). Duration of ST decreased between 12:00 and 12:59 (29 ± 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 highest 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 to 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 to 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%). Whilst 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 appeared 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, since 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 to the findings of others is difficult since results are dependent upon selected accelerometer wear-site, cut-points, accelerometer brand, target population, and post-processing decisions. To the best of our knowledge, this is the first study 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 researches, 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 non-movement. Since 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 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, 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 above-referenced 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. When we compare time spent in ST during the school day in our study to that of Steele and colleagues who used hip-worn accelerometers to estimate activity patterns across segmented time periods, Steele and colleagues reported that boys and girls engaged in, on average, 230 and 240 min/day of ST during school hours, respectively. Similarly, van Stralen and colleagues 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, estimates of ST reported in these studies, appear 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) appear lower than estimates reported by van Stralen and colleagues during school hours.

When we compare our estimates to those of Noonan and colleagues, 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. estimated that time in LPA before, during, and after school were, on average, 35, 166, and 130 min/day, respectively, in comparison to 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., 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.\textsuperscript{18} reported more time spent in LPA across these days than is reported here (329, 284, and 307 min/day in Noonan et al. 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 Noonan and colleagues’ study (32, 28, and 30 min/day). Whilst these discrepancies for time spent in MVPA are vast, the variation in accelerometer data-processing methods used in the two studies is a likely cause.

The low estimates of MVPA reported by Noonan et al\textsuperscript{18} are similar to those reported by Kim et al.,\textsuperscript{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, \url{https://cran.r-project.org/}) using the GGIR package, which allows raw accelerations (gravitational acceleration) to be processed and analysed\textsuperscript{43} using the device-and location-specific Hildebrand regression equations\textsuperscript{42}. A recent study highlighted the poor classification performance of the Hildebrand thresholds for correctly classifying MVPA, primarily due to the low recognition of MPA\textsuperscript{44}. Since in our study we relied upon processing our accelerometer data using the device- and wrist-specific VM counts cut-points proposed by Chandler et al.\textsuperscript{40}, it is not surprising that large differences in time spent in LPA and MVPA were found to exist in our estimates compared to those of Noonan and colleagues\textsuperscript{18}. Whether our estimates or those of Noonan et al\textsuperscript{18} are more accurate is not known, since 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, 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 to, 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. Given the accumulating evidence that the total volume and pattern of ST is associated with adverse health outcomes, our observations suggest that appropriate strategies that promote PA whilst reducing 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 declines in ST (Fig. 1). Our findings are similar to those from other studies, which demonstrated that girls spent significantly more time in ST and significantly less time in MVPA during both recess and lunch breaks compared to 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. Our findings suggest that activity levels are low after school, but the opportunity to influence activity levels during this segment may be more challenging since children need to opt-in to attend or participate in after-school interventions. Moreover, after-school
interventions may come at an additional cost to the school or parent and thus discourage long-term implementation of such after-school interventions. Such challenges highlight the importance of the school setting as a site of influence since 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, which is consistent with our observations. Public health guidelines often recommend that overall ST should be limited in children. Yet, attempts at introducing initiatives within Scotland to curb childhood ST have had a limited effect based on recent surveys, which estimate that <20% of children and adolescents meet current ST guidelines. To reduce 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. Promising evidence has demonstrated that implementing classroom activity breaks can improve child activity levels during school, as well as behaviours in the classroom, but further work is necessary to assess the feasibility and potential efficacy of such approaches in different countries.

5. Strengths and limitations

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 one geographical location within Scotland limits the generalisability 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 only a small
number of participants met the accelerometer wear-time criteria, and the number was too
small to form accurate interpretations from multi-level analyses. Failing to account for
clustering via multi-level 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 behaviours and may have been influenced by wearing the
accelerometer devices.
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 utilize 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 is the first study to report PA
data across a segmented week between genders in children which build upon other findings
by including levels of ST. Finally, the after-school period constituted the greatest
accumulation of MVPA for both boys and girls during the week. This highlights the need for
appropriate school-based interventions that can increase activity levels whilst minimizing ST.

5. Conclusion
In summary, our findings suggest that children were more active and less sedentary during weekdays in comparison to 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 whilst minimizing ST.

Acknowledgment

The authors would like to thank the children, schools, teachers, and parents who agreed to participate in this study. Our study was funded by University of the West of Scotland’s VP Research Fund. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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; 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.


Table 1. Activity outcomes by gender for weekday segments.

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 92)</th>
<th>Girls (n = 96)</th>
<th>Boys – Girls Difference</th>
<th>Boys – Girls Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean a</td>
<td>% segment time (95%CI)</td>
<td>Mean</td>
<td>% segment time (95%CI)</td>
</tr>
<tr>
<td>Before School (06.30-08.59)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>37.8 (35, 40)</td>
<td>54.9 (53, 57)</td>
<td>37.4 (35, 40)</td>
<td>54.3 (52, 56)</td>
</tr>
<tr>
<td>LPA</td>
<td>20.1 (19, 21)</td>
<td>31.6 (30, 33)</td>
<td>21.8 (20, 23)</td>
<td>32.6 (31, 34)</td>
</tr>
<tr>
<td>MPA</td>
<td>8.3 (8, 9)</td>
<td>12.3 (11, 13)</td>
<td>8.6 (8, 9)</td>
<td>12.7 (12, 14)</td>
</tr>
<tr>
<td>VPA</td>
<td>0.9 (1, 1)</td>
<td>1.3 (1, 2)</td>
<td>0.3 (0, 1)</td>
<td>0.5 (0, 1)</td>
</tr>
<tr>
<td>MVPA</td>
<td>9.2 (8, 10)</td>
<td>13.6 (13, 15)</td>
<td>8.9 (8, 10)</td>
<td>13.3 (12, 14)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>357.3 (339, 375)</td>
<td></td>
<td>347.4 (329, 365)</td>
<td></td>
</tr>
<tr>
<td>During School (09.00-14.59)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>196.5 (192, 201)</td>
<td>56.7 (55, 58)</td>
<td>198.9 (195, 203)</td>
<td>58.0 (57, 59)</td>
</tr>
<tr>
<td>LPA</td>
<td>104.1 (101, 107)</td>
<td>30.0 (29, 31)</td>
<td>103.8 (101, 107)</td>
<td>30.2 (29, 31)</td>
</tr>
<tr>
<td>MPA</td>
<td>38.5 (37, 40)</td>
<td>11.1 (11, 12)</td>
<td>36.0 (34, 38)</td>
<td>10.5 (10, 11)</td>
</tr>
<tr>
<td>VPA</td>
<td>7.6 (7, 8)</td>
<td>2.2 (2, 2)</td>
<td>4.6 (4, 5)</td>
<td>1.3 (1, 2)</td>
</tr>
<tr>
<td>MVPA</td>
<td>46.1 (44, 48)</td>
<td>13.3 (13, 14)</td>
<td>40.7 (39, 43)</td>
<td>11.8 (11, 12)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>371.4 (360, 383)</td>
<td></td>
<td>338.7 (327, 350)</td>
<td></td>
</tr>
<tr>
<td>After School (15.00-21.59)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>225.4 (216, 235)</td>
<td>61.3 (60, 63)</td>
<td>222.2 (213, 231)</td>
<td>59.9 (58, 62)</td>
</tr>
<tr>
<td>LPA</td>
<td>92.9 (89, 97)</td>
<td>25.3 (24, 26)</td>
<td>100.0 (96, 104)</td>
<td>27.2 (26, 28)</td>
</tr>
<tr>
<td>MPA</td>
<td>42.2 (39, 45)</td>
<td>11.5 (11, 12)</td>
<td>43.0 (40, 46)</td>
<td>11.7 (11, 12)</td>
</tr>
<tr>
<td>VPA</td>
<td>7.2 (6, 8)</td>
<td>2.0 (2, 2)</td>
<td>4.2 (3, 5)</td>
<td>1.2 (1, 2)</td>
</tr>
<tr>
<td>MVPA</td>
<td>49.4 (46, 53)</td>
<td>13.5 (12, 14)</td>
<td>47.2 (44, 51)</td>
<td>12.9 (12, 14)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>341.2 (322, 360)</td>
<td></td>
<td>328.7 (310, 347)</td>
<td></td>
</tr>
</tbody>
</table>

a Data have 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 ≤ d < 0.5), **moderate (0.5 ≤ d < 0.8), ***large (d ≥ 0.8). Abbreviation: CI=confidence interval; LPA = light physical activity; MVPA = moderate-vigorous physical activity; ST = sedentary time. Activity; VM=vector magnitude; VPA= vigorous physical activity.
Table 2. Activity outcomes by gender for weekend day segments.

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 71)</th>
<th>Girls (n = 65)</th>
<th>Boys – Girls Difference</th>
<th>Boys – Girls Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean min/total counts</td>
<td>% segment time</td>
<td>Mean min/total counts</td>
<td>% segment time</td>
</tr>
<tr>
<td><strong>Morning (06.30-11.59)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>120.4 (112, 128)</td>
<td>64.2 (61, 67)</td>
<td>118.9 (111, 127)</td>
<td>66.0 (63, 69)</td>
</tr>
<tr>
<td>LPA</td>
<td>42.8 (39, 46)</td>
<td>23.1 (22, 25)</td>
<td>42.6 (39, 46)</td>
<td>24.4 (23, 26)</td>
</tr>
<tr>
<td>MPA</td>
<td>19.0 (17, 21)</td>
<td>9.0 (8, 10)</td>
<td>16.8 (15, 19)</td>
<td>8.7 (8, 10)</td>
</tr>
<tr>
<td>VPA</td>
<td>2.9 (2, 4)</td>
<td>1.4 (1, 2)</td>
<td>0.9 (0, 2)</td>
<td>0.5 (0, 1)</td>
</tr>
<tr>
<td>MVPA</td>
<td>21.9 (19, 25)</td>
<td>10.4 (10, 12)</td>
<td>17.7 (15, 21)</td>
<td>9.2 (8, 11)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>277.5 (251, 304)</td>
<td></td>
<td>260.9 (233, 289)</td>
<td></td>
</tr>
<tr>
<td><strong>Afternoon – evening (12.00-21.59)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>367.5 (353, 382)</td>
<td>65.7 (64, 68)</td>
<td>339.8 (325, 355)</td>
<td>60.4 (58, 63)</td>
</tr>
<tr>
<td>LPA</td>
<td>132.2 (124, 140)</td>
<td>23.5 (22, 25)</td>
<td>154.0 (146, 162)</td>
<td>27.5 (26, 29)</td>
</tr>
<tr>
<td>MPA</td>
<td>53.8 (49, 59)</td>
<td>9.5 (9, 10)</td>
<td>62.5 (57, 68)</td>
<td>11.2 (10, 12)</td>
</tr>
<tr>
<td>VPA</td>
<td>7.7 (6, 9)</td>
<td>1.4 (1, 2)</td>
<td>5.4 (4, 7)</td>
<td>0.9 (0, 1)</td>
</tr>
<tr>
<td>MVPA</td>
<td>61.5 (55, 68)</td>
<td>10.8 (10, 12)</td>
<td>67.9 (61, 75)</td>
<td>12.1 (11, 13)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>291.5 (271, 312)</td>
<td></td>
<td>318.7 (297, 340)</td>
<td></td>
</tr>
</tbody>
</table>

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 ≤ d < 0.5), **moderate (0.5 ≤ d < 0.8), ***large (d ≥ 0.8). Data have presented as mean (95% CI). Abbreviation: CI=confidence interval; LPA = light physical activity; MVPA = moderate-vigorous physical activity; ST = sedentary time. Activity; VM=vector magnitude; VPA= vigorous physical activity.
Table 3. Activity outcomes by gender for whole weekdays, weekend days, and the whole week.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Boys</th>
<th>Girls</th>
<th>Boys - Girls Difference</th>
<th>Boys - Girls Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean min/total counts *</td>
<td>% segment time *</td>
<td>Mean min/total counts *</td>
<td>% segment time *</td>
</tr>
<tr>
<td><strong>Whole Weekday</strong></td>
<td>(n = 188; Boys = 92)</td>
<td>(06.30-21.59)</td>
<td><strong>Whole Weekend</strong></td>
<td>(n = 136; Boys = 71)</td>
</tr>
<tr>
<td>ST</td>
<td>458.5 (447, 470)</td>
<td>58.9 (58, 60)</td>
<td>453.0 (442, 464)</td>
<td>58.8 (58, 60)</td>
</tr>
<tr>
<td>LPA</td>
<td>216.2 (210, 222)</td>
<td>27.8 (27, 29)</td>
<td>223.1 (217, 229)</td>
<td>28.9 (28, 30)</td>
</tr>
<tr>
<td>MPA</td>
<td>88.4 (84, 93)</td>
<td>11.3 (11, 12)</td>
<td>86.5 (82, 91)</td>
<td>11.2 (11, 12)</td>
</tr>
<tr>
<td>VPA</td>
<td>15.6 (14, 17)</td>
<td>2.0 (2, 2)</td>
<td>9.2 (8, 11)</td>
<td>1.2 (1, 1.4)</td>
</tr>
<tr>
<td>MVPA</td>
<td>103.9 (99, 109)</td>
<td>13.3 (13, 14)</td>
<td>95.7 (90, 101)</td>
<td>12.4 (12, 13)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>354.2 (341, 367)</td>
<td></td>
<td>333.2 (321, 346)</td>
<td></td>
</tr>
<tr>
<td><strong>Whole Weekend</strong></td>
<td>(n = 136; Boys = 71)</td>
<td>(06.30-21.59)</td>
<td><strong>Whole Week</strong></td>
<td>(n = 136; Boys = 71)</td>
</tr>
<tr>
<td>ST</td>
<td>488.8 (472, 505)</td>
<td>65.7 (64, 68)</td>
<td>456.5 (439, 474)</td>
<td>62.0 (60, 64)</td>
</tr>
<tr>
<td>LPA</td>
<td>175.0 (166, 184)</td>
<td>23.4 (22, 25)</td>
<td>196.0 (186, 206)</td>
<td>26.6 (25, 28)</td>
</tr>
<tr>
<td>MPA</td>
<td>71.1 (65, 77)</td>
<td>9.5 (9, 10)</td>
<td>78.1 (72, 84)</td>
<td>10.6 (10, 11)</td>
</tr>
<tr>
<td>VPA</td>
<td>10.1 (8, 12)</td>
<td>1.4 (1, 2)</td>
<td>6.2 (4, 8)</td>
<td>0.8 (0, 1)</td>
</tr>
<tr>
<td>MVPA</td>
<td>81.3 (74, 89)</td>
<td>10.9 (10, 12)</td>
<td>84.3 (77, 92)</td>
<td>11.4 (10, 12)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>354.2 (341, 367)</td>
<td></td>
<td>333.2 (321, 346)</td>
<td></td>
</tr>
</tbody>
</table>

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 ≤ d < 0.5), ## moderate (0.5 ≤ d < 0.8), ### large (d ≥ 0.8). Data have presented as mean (95% CI). Abbreviation: CI= confidence interval; LPA = light physical activity; MVPA = moderate-vigorous physical activity; ST = sedentary time. Activity; VM = vector magnitude; VPA = vigorous physical activity.
Table 4. Activity outcomes by gender for school special segments.

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 88)</th>
<th>Girls (n = 94)</th>
<th>Boys – Girls Difference</th>
<th>Boys – Girls Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean min/total counts</td>
<td>% segment time</td>
<td>Mean min/total counts</td>
<td>% segment time</td>
</tr>
<tr>
<td>Morning Recess</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>5.6 (5, 6)</td>
<td>37.9 (35, 40)</td>
<td>6.7 (6, 7)</td>
<td>45.3 (43, 48)</td>
</tr>
<tr>
<td>LPA</td>
<td>5.1 (5, 5)</td>
<td>33.9 (33, 35)</td>
<td>5.2 (5, 5)</td>
<td>35.0 (34, 36)</td>
</tr>
<tr>
<td>MPA</td>
<td>3.2 (3, 3)</td>
<td>21.1 (20, 23)</td>
<td>2.4 (2, 3)</td>
<td>16.2 (15, 18)</td>
</tr>
<tr>
<td>VPA</td>
<td>1.1 (1, 1)</td>
<td>7.1 (6, 8)</td>
<td>0.5 (0, 1)</td>
<td>3.6 (3, 4)</td>
</tr>
<tr>
<td>MVPA</td>
<td>4.2 (4, 5)</td>
<td>28.2 (26, 30)</td>
<td>3.0 (3, 3)</td>
<td>19.8 (18, 22)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>156.9 (143, 171)</td>
<td>127.9 (115, 141)</td>
<td>29.1 (10, 48)***,##</td>
<td></td>
</tr>
<tr>
<td>Lunch Break</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>18.8 (18, 20)</td>
<td>39.4 (37, 42)</td>
<td>21.6 (21, 23)</td>
<td>45.4 (43, 47)</td>
</tr>
<tr>
<td>LPA</td>
<td>16.1 (16, 17)</td>
<td>33.8 (33, 35)</td>
<td>16.6 (16, 17)</td>
<td>34.9 (34, 36)</td>
</tr>
<tr>
<td>MPA</td>
<td>9.8 (9, 10)</td>
<td>20.7 (19, 22)</td>
<td>8.0 (7, 9)</td>
<td>16.9 (16, 18)</td>
</tr>
<tr>
<td>VPA</td>
<td>2.9 (2, 3)</td>
<td>6.0 (5, 7)</td>
<td>1.4 (1, 2)</td>
<td>2.9 (2, 3)</td>
</tr>
<tr>
<td>MVPA</td>
<td>12.7 (12, 14)</td>
<td>26.8 (25, 28)</td>
<td>9.4 (9, 10)</td>
<td>19.7 (18, 21)</td>
</tr>
<tr>
<td>VM (Counts)</td>
<td>146.9 (136, 158)</td>
<td>112.2 (102, 123)</td>
<td>34.8 (20, 50)***,##</td>
<td></td>
</tr>
</tbody>
</table>

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 ≤ d < 0.5), ## moderate (0.5 ≤ d < 0.8), ### large (d ≥ 0.8). a Data have presented as mean(95%CI). Abbreviation: CI = confidence interval; LPA = light physical activity; MVPA = moderate-vigorous physical activity; ST = sedentary time. Activity; VM=vector magnitude; VPA= vigorous physical activity.
Fig. 1. The hourly average physical activity and sedentary time on weekdays ($n = 188$; boys = 92). Data are presented as mean (95%CI).

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