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Seasonal Variation in Children's Physical Activity and Sedentary Time

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ABSTRACT

ATKIN, A. J., S. J. SHARP, F. HARRISON, S. BRAGE, and E. M. F. VAN SLUIJS. Seasonal Variation in Children's Physical Activity and Sedentary Time. *Med. Sci. Sports Exerc.*, Vol. 48, No. 3, pp. 449–456, 2016. **Purpose**: Understanding seasonal variation in physical activity is important for informing public health surveillance and intervention design. The aim of the current study was to describe seasonal variation in children's objectively measured physical activity and sedentary time. **Methods**: Data are from the UK Millennium Cohort Study. Participants were invited to wear an accelerometer for 7 d on five occasions between November 2008 and January 2010. Outcome variables were sedentary time (<100 counts per minute, min·d^{-1}) and moderate to vigorous physical activity (MVPA) (>2241 counts per minute, min·d^{-1}). The season was characterized using a categorical variable (spring, summer, autumn, or winter) and a continuous function of day of the year. Cross-classified linear regression models were used to estimate the association of each of these constructs with the outcome variables. Modification of the seasonal variation by sex, weight status, urban/rural location, parental income, and day of the week (weekday/weekend) was examined using interaction terms in regression models. **Results**: At least one wave of valid accelerometer data was obtained from 704 participants (47% male; baseline age, 7.6 (0.3) yr). MVPA was lower in autumn and winter relative to spring, with the magnitude of this difference varying by weekday/weekend, sex, weight status, urban/rural location, and family income (*P* for interaction <0.05 in all cases). Total sedentary time was greater in autumn and winter compared with spring; the seasonal effect was stronger during the weekend than during the weekday (*P* for interaction <0.01). **Conclusions**: Lower levels of MVPA and elevated sedentary time support the implementation of intervention programs during autumn and winter. Evidence of greater seasonal variation in weekend behavior and among certain sociodemographic subgroups highlights targets for tailored intervention programs. **Key Words:** SEASON, ACCELEROMETER, SEDENTARY BEHAVIOR, REPEATED MEASURES

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Public health guidelines state that children should accumulate 60 min·d^{-1} of moderate to vigorous physical activity (MVPA) and minimize the amount of time spent sedentary (sitting) for extended periods (28). Surveillance data, however, indicate that many children do not meet the MVPA guidelines and that sedentary behaviors are highly prevalent (8,13,18,24). Continued efforts to identify the primary influences on these behaviors, therefore, are essential to inform the design and delivery of effective behavior change interventions (1). A key recent development in this field has been the increased use of objective methods of behavioral assessment, including accelerometry, which enable more precise estimation of population prevalence and associations with predictor variables than is typically possible with self-report measures (6,31). This is of particular relevance to the child population, where self-reports or proxy reports of behavior are highly susceptible to bias (3).

The application of a socioecological perspective to the study of health behaviors has been widely advocated (26). This approach proposes that alongside personal, social, and institutional influences, environmental factors, including weather and daylight hours, may have an impact on behavior. Readily observable differences in such factors across the seasons clearly have potential to influence children's physical activity and sedentary behavior patterns. Previous research has documented seasonal variation in many phenomena, including disease incidence and outcomes (4,12,19). Knowledge of seasonal variation in children's health behavior may facilitate more precise targeting of behavior change interventions, which can be delivered specifically or with greater intensity during periods of the year when activity levels are lowest. Seasonality is also important in the context of assessing population prevalence or secular trends in behavior because estimates may be biased if data are collected within a restricted period of the year.

Recent review evidence supports the existence of seasonal variation in children's objectively measured physical activity, with lower levels of activity consistently observed during

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winter compared with summer (23). Few studies, however, have examined seasonal variation in children's sedentary behavior (10,17,23). Moreover, much of the existing evidence on this topic is drawn from between-subject comparisons of cross-sectional data, which may be subject to selection bias. Of the few repeated-measures analyses that have been published to date, most have been restricted to small samples, which offer little scope for the examination of effect modifiers (2,20,21,25). Because of the differences in the types and patterns of active and sedentary behaviors across social and demographic populations, it is possible that seasonal effects will vary between these groups. Identification of variation in seasonal effect between populations will facilitate more precise targeting of behavior change interventions. Previous analyses in our group indicate that climatic factors, which may in part drive seasonal variations in activity, exert a stronger influence on physical activity in children than in adolescents (16). Further research to quantify seasonal variability in activity and sedentary behavior specifically in this population is therefore warranted. The aim of the current study was to examine seasonal variation in children's objectively measured physical activity and sedentary time, utilizing data from up to five assessments conducted within a 12-month period. Secondarily, we sought to identify differences in seasonal variation across a range of sociodemographic factors, including sex, weight status, and socioeconomic position.

METHODS

Sample and data collection. Data are from the Millennium Cohort Study (MCS), a prospective study of the social, economic, and health-related circumstances of children born in the UK between September 2000 and January 2002 (14). The original cohort comprised 18,818 children (72% of those approached) whose parents were first interviewed at home when their child was age 9 months. Further surveys have since been conducted at ages 3, 5, 7, and 11 yr. Data for the current analysis were obtained from the survey at age 7 yr, which was approved by the Northern and Yorkshire Research Ethics Committee (07/MRE03/32).

A total of 14,043 children were interviewed at the age of 7 yr and invited to participate in the main stage accelerometer study, which took place between May 2008 and August 2009. Parental consent was obtained from 13,219 (94.1%) children, of whom 6675 (50.4% of those who consented) provided reliable accelerometer data (≥2 d with ≥10 h of wear time per day, further details below). All children participating in the main stage study who wore their accelerometer for at least 2 d between November 2008 and January 2009 (T1) were invited to participate in the seasonal study. Overall, 1289 children were invited to participate in the seasonal study, of whom 705 (55.0% of those invited) obtained parental consent. Participants in the seasonal study were requested to wear an accelerometer on three further occasions during the subsequent year: February to April 2009 (T2), May to July 2009 (T3), and August to October 2009 (T4). An additional period of winter monitoring was conducted from November 2009 to January 2010 (T5), for which parental consent was obtained separately. This final assessment was conducted by the MCS investigators to enable examination of longitudinal trends in physical activity, but this was not investigated in the current study. At each assessment, consenting participants were sent, and requested to return, the accelerometer by post. The protocol stated that participants should start wearing the device, on an elastic belt around the waist, the morning after they received it and continue to do so for seven consecutive days. Participants were instructed to remove the accelerometer when bathing or during other aquatic activities.

Physical activity and sedentary time. MVPA and sedentary time were measured using the ActiGraph GT1M accelerometer (ActiGraph, Pensacola, FL), which has demonstrated validity for the assessment of energy expenditure in children under free-living conditions (7). Accelerometers were programmed to record in 15-s epochs. Data were downloaded using the ActiGraph software (version 3.8.3) and processed according to predetermined criteria (11). Periods of 20 min or more of consecutive zero counts were defined as nonwear time and removed from analyses. Extreme count values of ≥11,715 counts per minute were also removed. A valid day of assessment was defined as wear time in excess of 10 h. A minimum of 2 d of valid data at any assessment wave was required for inclusion in the analysis. Count thresholds of <100 and >2241 counts per minute were used to define sedentary time and MVPA, respectively. These cut-points were derived in a validation study in children age 7 yr using indirect calorimetry as the criterion measure (22) and are similar to those obtained by Evenson et al. (9) The count threshold applied to define MVPA equates to walking at approximately 4 $km \cdot h^{-1}$ in children (30).

Season. Two methods were used to describe the season. Firstly, the season of assessment was defined by a four-level categorical variable based on solstices and equinoxes: spring, March 21 to June 20; summer, June 21 to September 20; autumn, September 21 to December 20; and winter, December 21 to March 20. Secondly, seasonal variation was characterized using a continuous function of day of the year, defined as a weighted linear combination of sine and cosine functions (29):

$$\beta_1 \sin(2\pi(\text{day of year}/365.25)) + \beta_2 \cos(2\pi(\text{day of year}/365.25))$$

The weights β_1 and β_2 are estimated using the regression models described in the statistical analysis section. This approach has been used widely in epidemiology for the study of seasonal variation in disease exposures and outcomes (4).

Covariates. The following covariates were measured: sex, age, ethnicity (parent reported: White, Asian, Black or Black British, mixed, or other), country of residence (England, Wales, Scotland, or Northern Ireland), home location (postcode derived: urban or rural), family income (parent reported: <£20,800 annually, £20,800 to £31,300 annually, >31,200

TABLE 1. Baseline characteristics of participants who provided valid accelerometer data for at least one wave of assessment.

	All (n = 704)	Boys (n = 334)	Girls (n = 370)
Age (yr), mean (SD)	7.6 (0.3)	7.7 (0.4)	7.6 (0.3)
BMI, mean (SD)	16.4 (2.1)	16.4 (2.0)	16.4 (2.2)
Weight status, n (%)			
Normal[a]	592 (84.2)	290 (86.8)	302 (81.8)
Overweight	79 (11.2)	31 (9.3)	48 (13.0)
Obese	32 (4.6)	13 (3.9)	19 (5.2)
Ethnicity (% White)[b]	92.9	94.5	91.3
Family income (%) (>£31,200 per annum)[b]	32.7	34.4	31.1
Country, n (%)[b]			
England	330 (48.0)	165 (50.3)	165 (46.0)
Wales	91 (13.3)	47 (14.3)	44 (12.2)
Scotland	198 (28.8)	86 (26.2)	112 (31.2)
Northern Ireland	68 (9.9)	30 (9.2)	38 (10.6)

[a]Includes underweight.
[b]Due to missing data: ethnicity, all, n = 686; boys, n = 328; girls, n = 358; family income, all, n = 640; boys, n = 309; girls, n = 331; country, all, n = 687; boys, n = 328; girls, n = 359.

annually, missing, or do not know), child weight status (measured height and weight used to derive BMI: underweight/normal, overweight, or obese (5)), year of assessment (2008, 2009, or 2010), weekday or weekend, and accelerometer wear time. For nonstatic covariates, data were obtained from the survey at age 7 yr. Weight status (underweight/normal, overweight/obese) and family income (less than or greater than £31,200 annually) were collapsed to binary variables for ease of interpretation in interaction models.

Statistical analysis. Analyses were conducted using Stata/SE 13.1 (StataCorp, College Station, TX). Descriptive statistics are presented as frequencies and percentages, means with SD, or medians with interquartile ranges. Both sedentary time and MVPA were nonnormally distributed; however, residual plots from regression models suggested that it was reasonable to analyze the outcomes without transformation. The association of the categorical season variable and the continuous function of day of the year with sedentary time and MVPA were examined using cross-classified linear regression models, in which repeated measures of the outcomes were cross-classified by both wave of data collection and individuals. In preliminary analyses, effect modification by sex, weight status, home location, family income, and weekday/weekend was examined separately, using cross-product terms. A P value of <0.05 from a likelihood ratio test comparing models with and without interaction terms was considered indicative of effect modification. Results indicated that the association of season with MVPA and sedentary time differed for weekday and weekend. Additionally, the association of season with MVPA differed by sex, weight status, home location, and family income. Analyses were therefore stratified by weekday/weekend for sedentary time and by sex, weight status, home location, family income, and weekday/weekend for MVPA. All models were adjusted for age, ethnicity, country of residence, year of assessment, and accelerometer wear time and mutually adjusted for sex, weight status, home location, family income, and weekday/weekend as appropriate

Estimated mean sedentary time and MVPA (based on the fitted regression model, including the continuous function of day of year and setting all other covariates to their mean values) were plotted against day of the year to illustrate their variation throughout the year, stratified by relevant effect modifiers. The days of the year on which sedentary time and MVPA were at their lowest/highest and the difference in activity levels (min) between these dates were derived using formulae described by Stolwijk et al. (29)

RESULTS

At least one wave of valid accelerometer data was obtained from 704 participants, who collectively contributed 14,990 person-days of observation. Eighty-eight percent of participants provided data for two or more waves of assessment, and 42% provided data for all five waves. At each wave, over 90% of participants provided four or more days of valid accelerometer data. Participant characteristics are summarized in Table 1. No sex or age differences were observed between the analytical sample and the broader MCS sample surveyed at age 7 yr. However, the analytical sample had marginally lower BMI (16.4 vs 16.7 kg·m^{-2}, P < 0.01), were more likely to have a family income exceeding £31.2 k per annum (30.4% vs 19.5%, P < 0.01), and more likely to be of white ethnicity (92.9% vs 85.4%, P < 0.01). The number of days of observation and summary accelerometer outcomes are presented for each month in Table 2. The number of person-days of observation was 4729 for spring,

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TABLE 2. Number of observation days and accelerometer outcomes by month.

	Person-Days	Wear Time (h·d^{-1})	MVPA (min·d^{-1})	Sedentary Time (h·d^{-1})
	n	Median (IQR)	Median (IQR)	Median (IQR)
January	3224	12.2 (11.4, 13.0)	48.3 (34.3, 67.0)	7.1 (6.3, 7.9)
February	124	12.2 (11.5, 13.2)	47.8 (33.5, 64.5)	7.1 (6.4, 8.1)
March	—	—	—	—
April	3071	12.1 (11.3, 13.0)	65.3 (43.5, 91.0)	6.4 (5.4, 7.3)
May	654	12.2 (11.4, 13.1)	61.6 (43.3, 85.3)	6.3 (5.4, 7.3)
June	1091	12.4 (11.6, 13.1)	63.5 (46.0, 85.5)	6.6 (5.7, 7.4)
July	1065	12.0 (11.2, 13.0)	62.0 (42.3, 87.5)	6.1 (5.2, 7.2)
August	110	11.7 (10.8, 12.6)	57.0 (36.8, 78.8)	6.0 (5.2, 7.1)
September	—	—	—	—
October	2271	12.3 (11.4, 13.1)	53.3 (37.3, 73.3)	6.9 (6.0, 7.8)
November	2063	12.1 (11.3, 13.0)	53.0 (37.3, 71.3)	6.8 (6.0, 7.6)
December	1317	12.2 (11.4, 13.1)	51.8 (36.8, 69.3)	6.8 (6.1, 7.7)

IQR, interquartile range.

TABLE 3. Association of date-derived season with MVPA (min·d^{-1}), stratified by sex, weight status, home location, family income, and weekday/weekend.

		Summer			Autumn			Winter		
	Spring	β	95% CI	% Diff[a]	β	95% CI	% Diff[a]	β	95% CI	% Diff[a]
Boys	Ref	−3.8	−6.8 to −0.8*	−4.7	−14.9	−18.3 to −11.6**	−18.5	−21.0	−23.5 to −18.6**	−26.1
Girls	Ref	−1.5	−3.8 to 0.8	−2.5	−10.6	−13.2 to −8.0**	−17.6	−14.9	−16.8 to −13.0**	−24.6
Normal weight	Ref	−3.3	−5.3 to −1.3**	−4.6	−13.6	−15.9 to −11.4**	−19.0	−18.5	−20.2 to −16.8**	−25.7
Overweight	Ref	0.6	−4.3 to 5.4	0.9	−9.1	−15.2 to −3.1*	−14.4	−14.2	−18.4 to −10.0**	−22.4
Urban	Ref	−3.2	−5.3 to −1.1**	−4.5	−12.6	−14.9 to −10.3**	−18.0	−17.7	−19.4 to −15.9**	−25.2
Rural	Ref	−0.9	−5.0 to 3.1	−1.3	−13.3	−18.6 to −7.9**	−18.3	−20.0	−23.6 to −16.4**	−27.6
High income	Ref	−4.0	−7.0 to −1.1**	−5.8	−13.2	−16.4 to −10.0**	−19.0	−15.2	−17.7 to −12.7**	−21.8
Low income	Ref	−1.6	−4.1 to 0.9	−2.3	−11.0	−13.7 to −8.2**	−15.6	−19.4	−21.5 to −17.4**	−27.6
Weekdays	Ref	−0.3	−2.2 to 1.5	−0.5	−11.2	−12.3 to −10.1**	−16.2	−15.2	−16.5 to −13.9**	−22.0
Weekend	Ref	−6.5	−11.2 to −1.8**	−8.7	−18.8	−24.1 to −13.4**	−25.2	−25.2	−31.0 to −19.5**	−33.9

Models adjusted for age, ethnicity, country of residence, year of assessment, and accelerometer wear time and mutually adjusted for sex, weight status, home location, family income, and weekday/weekend as appropriate.
Season × sex *P* for interaction = <0.01. Season × weight status *P* for interaction = <0.01. Season × home location *P* for interaction = 0.05. Season × family income *P* for interaction = 0.02. Season × weekday/weekend *P* for interaction = <0.01.
Estimated mean for spring (min·d^{-1} (SE)): boys = 80.6 (1.1), girls = 60.4 (0.9), normal weight = 71.8 (0.8), overweight = 63.4 (2.1), urban = 70.2 (0.8), rural = 72.4 (1.6), high income = 69.8 (1.2), low income = 70.4 (0.9), weekdays = 68.9 (0.7), weekend = 74.4 (1.7).
*P = <0.05.
**P = <0.001.
[a]Percentage difference in mean relative to spring season.
β, beta-coefficient; Ref, reference category.

1262 for summer, 5597 for autumn, and 3402 for winter. Accelerometer wear time was consistent across the months of the year.

Categorical season variable. The association of date-derived seasonal categories with MVPA and sedentary time is presented in Tables 3 and 4, respectively. Across all subgroups, MVPA was lower in autumn and winter compared with spring. MVPA was also lower in summer compared with spring in boys, children of normal weight, those living in urban areas, those from high-income families, and at the weekend. Seasonal variation in MVPA was greater in boys than in girls, in normal weight children relative to those who were overweight, and during the weekend compared with the weekday. Differences in the impact of season on MVPA between children from low- and high-income families were inconsistent and varied between individual seasons. On weekdays and at the weekend, sedentary time was higher in autumn and winter compared with spring, although the magnitude of the association was greater at the weekend. Relative to spring, sedentary time in summer was lower on weekdays but higher during the weekend.

Continuous function of day of the year. To complement the categorical analysis, we also examined seasonal variation using a continuous day of the year function, which enabled us to illustrate fluctuations in MVPA and sedentary time across the year (Figs. 1 and 2). Across all subgroups, MVPA was predicted to be lowest during December and highest during June. The difference in daily MVPA between days of minimum/maximum participation ranged from 14 (girls) to 24 min (weekend). Predicted sedentary time peaked during December and was lowest in June. Greater seasonal variation in sedentary time was observed during the weekend compared with the weekday. Over the year, daily sedentary time differed by 55 min between days of minimum/maximum participation at the weekend and by 39 min on weekdays.

DISCUSSION

Overall findings. Children's objectively measured MVPA was lower in autumn and winter relative to spring, with the magnitude of this difference greater at the weekend compared to during the week and amongst certain socio-demographic subgroups. Total sedentary time was higher in autumn and winter compared with spring and also exhibited greater seasonal variation during the weekend than during the weekday. To our knowledge, this is the largest existing analysis of seasonal variation in children's physical activity and sedentary time to utilize objective methods of measurement and conduct assessments in all four seasons of a single year. Findings are broadly consistent with previous research, but the identification of differences in seasonal variation by day of the week and between population subgroups is novel and will facilitate more precise targeting of behavior change intervention programs.

TABLE 4. Association of date-derived season with sedentary time (min·d^{-1}), stratified by day of the week.

		Summer			Autumn			Winter		
	Spring	β	95% CI	% Diff[a]	β	95% CI	% Diff[a]	β	95% CI	% Diff[a]
Weekdays	Ref	−6.7	−11.5 to −1.9**	−1.7	28.7	21.2 to 36.2**	7.3	27.7	19.9 to 35.4**	7.0
Weekend	Ref	9.1	0.6 to 17.6*	2.5	40.3	32.1 to 48.5**	11.1	53.6	46.3 to 60.9**	14.7

Models adjusted for age, sex, ethnicity, country of residence, home location, family income, child weight status, year of assessment, and accelerometer wear time.
Season × weekday/weekend *P* for interaction = <0.01.
Estimated mean for spring (min·d^{-1} (SE)): weekdays = 393.5 (2.6), weekend = 364.2 (2.4).
*P = <0.05.
**P = <0.001.
[a]Percentage difference in mean relative to spring season.
β, beta-coefficient; Ref, reference category.

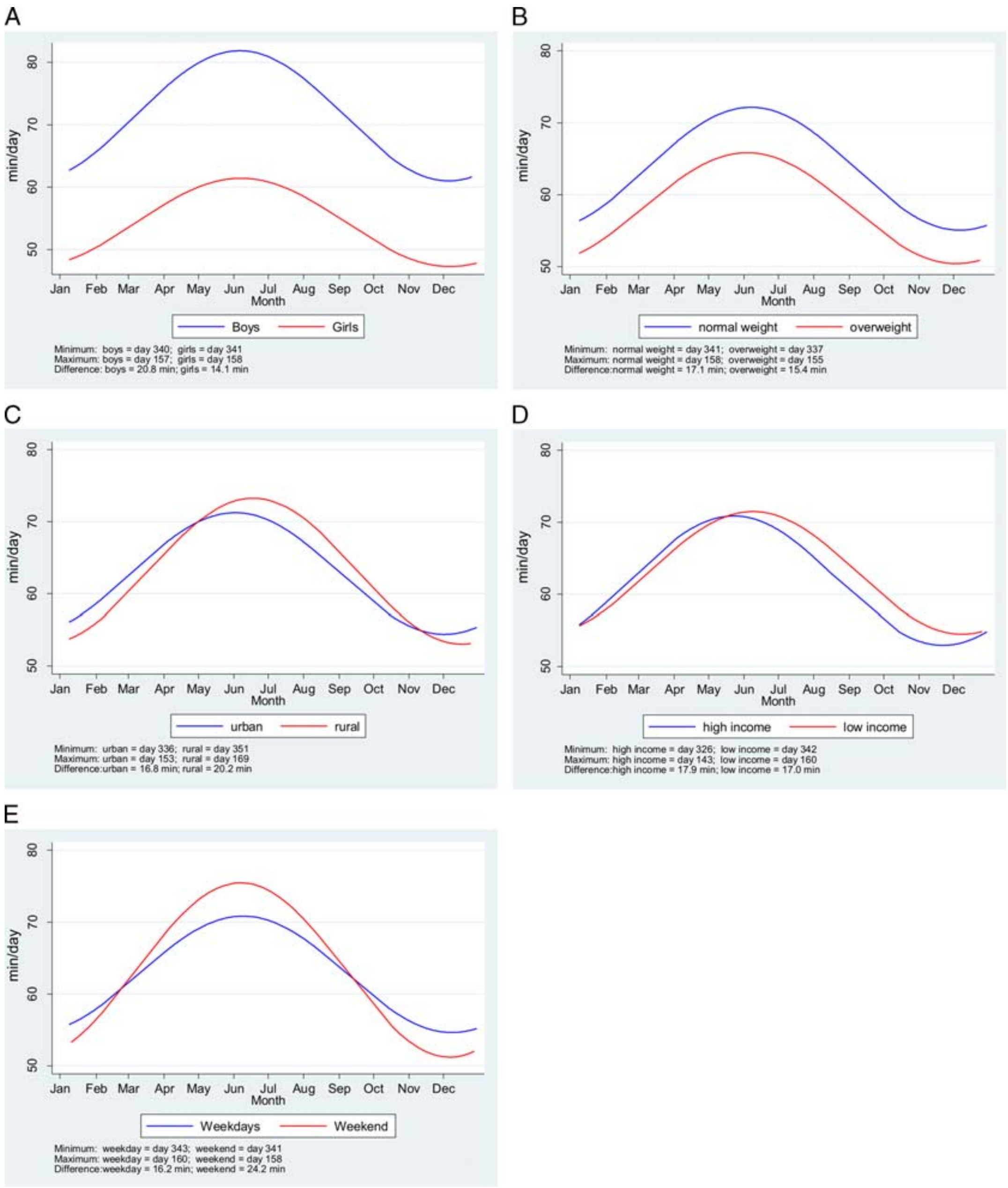

FIGURE 1—Estimated mean MVPA across the calendar year, stratified by sex (A), weight status (B), home location (C), family income (D), and weekday/weekend (E). Estimates calculated from cross-classified linear regression models where model covariates were set to their mean values. Models adjusted for age, ethnicity, country of residence, year of assessment, accelerometer wear time and mutually adjusted for sex, weight status, home location, family income and weekday/weekend as appropriate.

Comparison with previous research. In the current analysis, MVPA was 15% to 30% lower during autumn and winter compared with spring. Findings are consistent with previous cross-sectional and longitudinal studies conducted in the UK (23). Using data from up to four assessments in children age 11 yr, for example, Mattocks et al. (20) observed that overall physical activity (accelerometer counts per minute) was approximately 15% higher in summer than in winter. In a cross-sectional analysis of children age 7 yr, King et al. (17) reported that MVPA and counts per minute were lower during winter and spring/autumn (combined) relative to summer but did not provide an estimate of the magnitude of difference between seasons. In contrast to these studies, we chose to focus our analysis on MVPA rather than on counts per minute, because this is consistent with current public health guidelines in this population. However, the correlation between MVPA and counts per minute in our data was high ($r = 0.9$), and regression models with counts per minute as the outcome produced essentially the same results (data not shown).

Our findings indicate that seasonal variation in MVPA is greater during the weekend compared with the weekday and also differs by sex, weight status, home location, and family income. Previous research examining moderators of seasonal

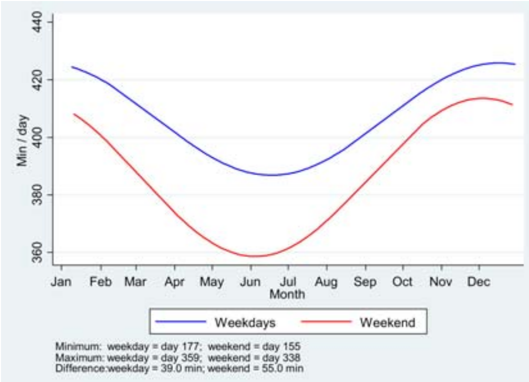

FIGURE 2—Estimated mean sedentary time across the calendar year, stratified by weekday/weekend. Estimates calculated from cross-classified linear regression models where model covariates were set to their mean values. Models adjusted for age, sex, ethnicity, country of residence, home location, family income, child weight status, year of assessment, and accelerometer wear time.

variation in physical activity is limited, as noted in a recent review (23). Mattocks et al. (20), however, also reported greater variability in physical activity during the weekend than during the weekday. It may be that the structure of the school day, including the need to travel to and from school, partially protects against the impact of season on children's activity. The more volitional nature of activity at the weekend, by contrast, may make it more susceptible to seasonal influence. Research indicating that rainfall (one of the potential drivers of seasonal variation) is inversely associated with children's activity across the whole day but not specifically during school commute times (8 to 9 a.m./3 to 4 p.m.) supports this hypothesis (16). A contrasting composition or pattern of physical activity between weight status, home location, or family income subgroups may also account for the difference in seasonal effect observed among these populations. For example, the contribution of active travel and organized sport to overall levels of activity likely differs across socioeconomic groups, and these individual behaviors may be more or less susceptible to seasonal influence (27). Research into seasonal variation in specific activity types, such as those noted above, may help to explain why the seasonal effect varies between population groups.

We found that children's overall sedentary time was greater in autumn and winter compared with spring. This seasonal variation in sedentary time was greater during the weekend than during the weekday, but the relative difference between seasons was smaller than that seen for MVPA. To date, UK-based studies of seasonal variation in overall sedentary time have been limited to cross-sectional analyses, the findings of which are comparable but not entirely consistent with those observed here. For example, King et al. (17) found that sedentary time (expressed as a proportion of monitor wear time) in children age 7 yr was higher in spring, autumn, and winter compared with summer. We observed a similar reduction in sedentary time in summer relative to spring, but only on weekdays, and found an opposing pattern at the weekend. Contrasting findings may be attributable to geographical or methodological differences between studies. Nonetheless, the difference in sedentary time between spring and summer was small (<3%), suggesting that further research and intervention efforts may be better targeted at the autumn and winter seasons.

Implications. Our observations have important implications for both public health surveillance and the design and delivery of behavior change interventions. Data on the prevalence of physical inactivity, for example, may be biased if assessments were conducted over a restricted time frame. This may lead to either under- or overestimation of the burden of inactivity. Failure to account for seasonal variability also limits the comparability of data between studies, hindering evidence synthesis.

This analysis provides further support for the implementation of physical activity promotion interventions in children during winter, with a particular focus upon weekend activity which appears most susceptible to seasonal influence. Greater seasonal variation in MVPA was also observed among boys compared with girls and in children of normal weight compared with those who were overweight. To accommodate these differences, intervention programs may need to focus on *maintaining* elevated levels of activity throughout the year among boys and normal weight children while seeking to promote increased activity and protect against seasonal declines in girls and children who are overweight. Two potential drivers of the decline in activity during autumn and winter are limited daylight hours and adverse weather conditions (e.g., increased rain or low temperature). Such factors may be addressed through improved access to indoor spaces in which to be active or through the modification of school policies related to use of indoor and outdoor spaces in bad weather (15). Further research aimed at identifying the social, organizational, and environmental mediators of seasonal variation in activity may be valuable for intervention design information.

Strengths and limitations. To our knowledge, this is the largest study to date to analyze objective assessments of children's physical activity and sedentary time across all four seasons in a single calendar year. Compliance to the measurement protocol was high, with over 90% of participants providing four or more days of valid data within each assessment wave. We employed two complimentary approaches to the characterization of season, which collectively provide a more comprehensive picture of seasonal variation in behavior than either method alone. Characterization of season as a continuous function is statistically more powerful than the traditional categorical approach and better reflects the gradual transition between seasons than date-derived boundaries. A key strength of this analysis is the examination of differences in seasonal variation across sociodemographic subgroups, which have been understudied to date and provide valuable information for intervention development. We recognize the limitation of waist-worn accelerometry for the measurement of certain activity types (e.g., cycling or water-based activities); this may have introduced information bias if participation in such activities varied across the year. In addition, assessments were not evenly distributed across the year; no measurements were conducted in March or September, for example, and the summer season as a whole was relatively undersampled. Estimates obtained for summer, therefore, may be less stable than those for the other seasons and should be interpreted with caution. It was not possible to account for the potential impact of school holidays on behavior patterns, as school-level information is not available within this data set. However, little data were collected during the month of August, which corresponds to the main summer break, and the remaining school holidays are distributed relatively evenly across the year, thus minimizing the potential impact on our analyses. Although our data were obtained from solely within the UK, results may be applicable to other countries of similar climate and latitude. Findings may be generalizable to children age 1 to 2 yr on either side of the age range studied, but may not be relevant to children outside this range because of the differences in the composition of their physical activity and sedentary behavior patterns.

CONCLUSIONS

Children's physical activity and sedentary time fluctuate across the year, with greater seasonal variability seen during the weekend compared with the weekday and among certain sociodemographic subgroups. Seasonality may, in part, account for divergent prevalence estimates derived from studies that conducted assessments within limited (and different) segments of the year and should be accounted for in surveillance systems. This study highlights opportunities for the specific targeting of behavior change interventions during the autumn and winter months. Accompanied by knowledge of the season-specific determinants of behavior, this information may contribute to the development of intervention programs that are more efficient and effective.

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