Seasonal Shifts in Children's Sedentary Behaviors, Physical Activity, and Sleep

A Systematic Review and meta-Analysis

R. Glenn Weaver, PhD*, Caroline Hensing,
Bridget Armstrong, PhD, Elizabeth L. Adams, PhD,
Michael Beets, PhD

KEYWORDS

• Obesity • 24-h movement • Screen time • Pediatric • Sedentary

KEY POINTS

- Movement behaviors like sedentary behaviors, physical activity, and sleep are related to obesity risk for children and may vary throughout the year due to weather, daylight, and climate.
- Movement behaviors may also vary due to the fluctuation of children's exposure to the structure throughout the year (eg, presence or absence of the school day), but past reviews exploring the seasonal fluctuation in children's movement behaviors have failed to account for structure.
- Findings from this review indicate that children are least active during the summer when children are not in school, and winter.
- However, these findings are preliminary because many studies were unclear about when measures were conducted (eg, unclear if measures were conducted when children were on vacation from school or on weekdays, weekend days, or both).
- There is a paucity of data on seasonal variation in sleep indicating a need for further research in this area.

INTRODUCTION

The movement behaviors of children, which include sleep, sedentary behavior, and all levels of physical activity intensity, are related to health outcomes, including obesity.[1] Children's engagement in movement behaviors varies by season for a variety of reasons including, weather patterns (ie, temperature changes, increased/decreased

Arnold School of Public Health, University of South Carolina, Columbia, SC, USA
* Corresponding author. Department of Exercise Science, Arnold School of Public Health, University of South Carolina, Discovery Building, 921 Assembly Street, Columbia, SC 29201.
E-mail address: weaverrg@mailbox.sc.edu

Pediatr Clin N Am 69 (2022) 671–693
https://doi.org/10.1016/j.pcl.2022.04.005
0031-3955/22/Published by Elsevier Inc.

precipitation) and photoperiod (ie, length of daylight). While the season is not a modifiable predictor of children's movement behaviors it is critical to understand how children's movement behaviors shift in relation to season to better design and deliver interventions. For example, understanding when children's movement behaviors are less optimal can optimize intervention timing by informing which season(s) of the year an intervention would most likely result in improved behaviors, while saving costs and resources by not targeting other season(s) of the year when children already engage in healthier levels of movement behaviors.

Previous systematic reviews have established that children's physical activity and sedentary behaviors fluctuate based on season and weather,[2–5] with summer consistently found to be the most physically active month and winter the least active.[3–5] However, no reviews have explored seasonal changes in children's sleep behaviors. Further, past reviews are limited because they have not meta-analytically combined studies to estimate the effect of season.[2–5] Additionally, previous systematic reviews are limited because they have combined physical activity and sedentary data from adults and children, thus precluding the ability to understand the unique patterns of children's health behaviors across seasons due to child-specific factors.[3] Further, previous systematic reviews of the effect of season on children's movement behaviors were conducted nearly a decade ago,[4,5] before an increased consideration of the importance of behaviors along the movement continuum (ie, sleep to vigorous physical activity) and improvements in behavioral measures. Thus, an updated review that includes recent studies is warranted.

A major limitation of past reviews is the failure to account for the presence or absence of the school day during measurement periods, as the structure of a child's day is emerging as a major contributor to children's movement behaviors.[6] The structured days hypothesis posits that the structure of a child's day, defined as preplanned, segmented, and adult-supervised compulsory environments (like a school day), promotes engagement in more healthful behaviors (eg, reduced sedentary, increased physical activity and sleep). This can prevent children's engagement in unhealthy levels of movement behaviors and, in turn, excessive body mass index (BMI) gain. Thus, seasonal variation in children's movement behaviors may be confounded by the presence of a school day in one season (eg, spring) and the absence of a school day during another season (eg, summer).

The purpose of this systematic review and meta-analysis was to examine seasonal shifts in children's movement behaviors while accounting for the presence or absence of structure during the summer.

METHODS

This systematic review was guided and reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-analyses checklist.[7,8]

Eligibility Criteria

Studies that were repeated cross-sectional or longitudinal were eligible for inclusion if they reported physical activity and/or sleep of children (5–12 years) during 2 or more meteorologic seasons. Baseline and/or control group data from intervention studies was also included as long as it met all other inclusion criteria. Meteorologic seasons were defined as: spring (March 1st–May 31st), summer (June 1st–August 31st), fall (September 1st–November 30th), and winter (December 1st–February 28th). For studies conducted south of the equator meteorological seasons were reversed: fall (March 1st–May 31st), winter (June 1st–August 31st), spring (September 1st–November 30th), and summer (December 1st–February 28th). English language, peer-reviewed published studies were included in the review and no restrictions were placed on the year of publication. Studies were excluded if they only included participants outside of the 5 to 12-year range (ie, younger or older children or adults, unless the study presented data for categorized groups inclusive of ages 5–12); did not report seasonal differences between outcomes; they were intervention studies not including baseline data; and if they selected children because they had a specific health condition (eg, cancer, diabetes) or were part of a select group (eg, elite athletes). Case reports, letters to the editor, conference abstracts, theses or dissertations, and viewpoint articles were excluded.

Information Sources and Search Strategy

A total of 4 electronic databases (PubMed, PsycInfo, Web of Science, and Embase) were searched for relevant studies in September and October of 2020. Search terms in 3 categories; (i) season term (eg, fall), (ii) age group (eg, child), and (iii) outcome (eg, physical activity) were combined using Boolean operators and searched systematically in each database. Titles and abstracts were identified using Medical Subject Heading terms (MeSH-terms) in PubMed. A full list of search terms and an example search strategy for PubMed are included in Supplementary Table 1. When the search strategy identified a systematic review and/or meta-analysis, the references were reviewed for relevant articles.

Data Management and Selection Process

The resulting citations of each search in all databases were downloaded as RIS or XML files and imported into Endnote citation management software (Endnote x9, Clarivate, London, United Kingdom). Duplicates were removed using the Endnote remove duplicate function. Citations were then uploaded into Covidence (Covidence.org, Melbourne, Australia), an online systematic review management software, for screening and review. Titles and abstracts were screened by 2 coauthors (CH & CL) independently to identify those that potentially met inclusion criteria. PDFs for the studies identified for inclusion in the title and abstract screening were then retrieved and reviewed by the same 2 coauthors that completed the title and abstract screening (CH & CL). Where disagreements occurred in both title/abstract and full-text screenings, the first author (RGW) reviewed the disputed article and made the final decision on inclusion.

Data Collection Process

Data extraction on the articles that were passed through the full-text screening was conducted by 2 coauthors (CH & CL). Data were input into a custom extraction spreadsheet created for this review in Microsoft Excel. An author (CL) emailed the corresponding author for articles that did not fully report data to be extracted up to 3 times with a request to provide the missing data.

Data Items

Characteristics extracted from all studies included the following variables: study author, publication year, number of participants, number of female participants, country for which the study was conducted, World Bank Region for which the study was conducted, study design, outcomes measured (physical activity, sedentary behavior, and/or sleep), seasons and months for which the outcomes were measured, if the measure was objective (eg, pedometer, accelerometer) or self-reported, and the mean age of the sample along with a standard deviation when provided. To account for increased structure that might or might not exist during a child's day, 2 pieces of information were extracted. First, data on if measures were collected on weekdays, weekends, or both, and second if the measures included school vacation days. Extraction was customized for each sleep and physical activity/sedentary behavior outcome. For sleep, outcomes included sleep duration (eg, total sleep time), sleep onset, and sleep offset, and sleep other (ie, parent reported if child sleeps more and is tired). Physical activity and sedentary behavior outcomes included sedentary, light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), moderate-to-vigorous physical activity (MVPA), steps, and other physical activity outcomes (eg, number of sports enrolled, active transport [eg, walking or biking to school], activity counts). Point estimates (eg, mean, median) and variability of those estimates (eg, standard deviation, standard error, interquartile range, 95% confidence interval) were extracted for each outcome during each season that it was reported. All point estimates were converted to means and all variability estimates were converted to standard deviations according to guidelines from the Cochrane Handbook for Systematic Reviews of Interventions.[9]

Quality Assessment

Two coauthors (CH & CL) examined the risk of bias for each included study independently using relevant metrics on the National Institutes of Health Quality Assessment Tool for Observational Cohort and Cross-sectional Studies.[10] Studies were examined for quality using 10 items. Each item was rated as meeting, not meeting, or cannot determine. Each item rated as meeting was given a score of 1 and items were summed for each study providing an overall risk of bias score.

Data Analysis

The key characteristics of the included studies were tabulated. Standardized mean difference (SMD) effect sizes were calculated for each study across all outcomes in Comprehensive Meta-Analysis (v.3.0). Effect sizes were standardized to account for differences in the direction of scales so that a negative effect consistently meant that a health behavior was worse during the comparison season and a positive effect indicated that a health behavior was better during the comparison season. Meta-analyses were conducted in Stata (v.16.1, StataCorp, College Station, Texas). Because no single season was included in all studies, a multi-step process was undertaken to compare effects between seasons. First, because spring was the most common season measured, spring was compared with fall, summer, and winter. Second, fall was then compared with summer and winter as fall was the second most measured season. Third, winter was then compared with summer. Following the primary analysis, and to account for structure when exploring seasonal changes in behaviors, subanalyses were completed for studies that conducted measures on weekdays and weekends and presented outcomes separately. Subanalyses were also completed for studies that conducted measures while children were attending school and while children were on vacation from school. Vacation subanalyses were only possible for vacation days during the summer as only one study identified that measures were taken on vacation days during a different season.[11] Because multiple effects were nested within study, the robumeta command in Stata was used to calculate 95% confidence intervals around point estimates from robust standard errors.[12] All models included study latitude, sample size, participant age, and use of an objective versus self-report measure of the outcome as covariates. Due to the fact that we intended to generalize the findings beyond the included studies and the meta-analysis included more than 5 studies,[13] all models were conducted using random-effects weighting schemes. To be included in the meta-analyses a comparison between seasons had to be made in 2 or more studies for the outcome in question.[14] The

Benjamini–Hochberg procedure with a false discovery rate of 5% was used to account for multiple comparisons.[15] The I^2 statistical was calculated to evaluate the heterogeneity of estimates for each outcome. Values of 25%, 50%, and 75% were considered to represent low, moderate or high heterogeneity, respectively.[9]

RESULTS

Prisma Flow Diagram

The Prisma Flow diagram is presented in **Fig. 1**. Searches identified a total of 18,542 articles for screening with an additional 9 articles identified via the reference lists from systematic reviews. After duplicates were removed a total of 8567 unique titles and abstracts were screened for inclusion. After title and abstract screening, 300 full-text articles were retrieved and screened for inclusion. A total of 252 full-text articles were excluded because they included the wrong age group (n = 100), measured only one season (n = 80), were gray literature (n = 43), could not be located (n = 9), were a review article (n = 8), were not published in English (n = 8), or did not include physical activity or sleep outcomes (n = 5). Thus, 47 articles were included in the narrative synthesis and meta-analysis.

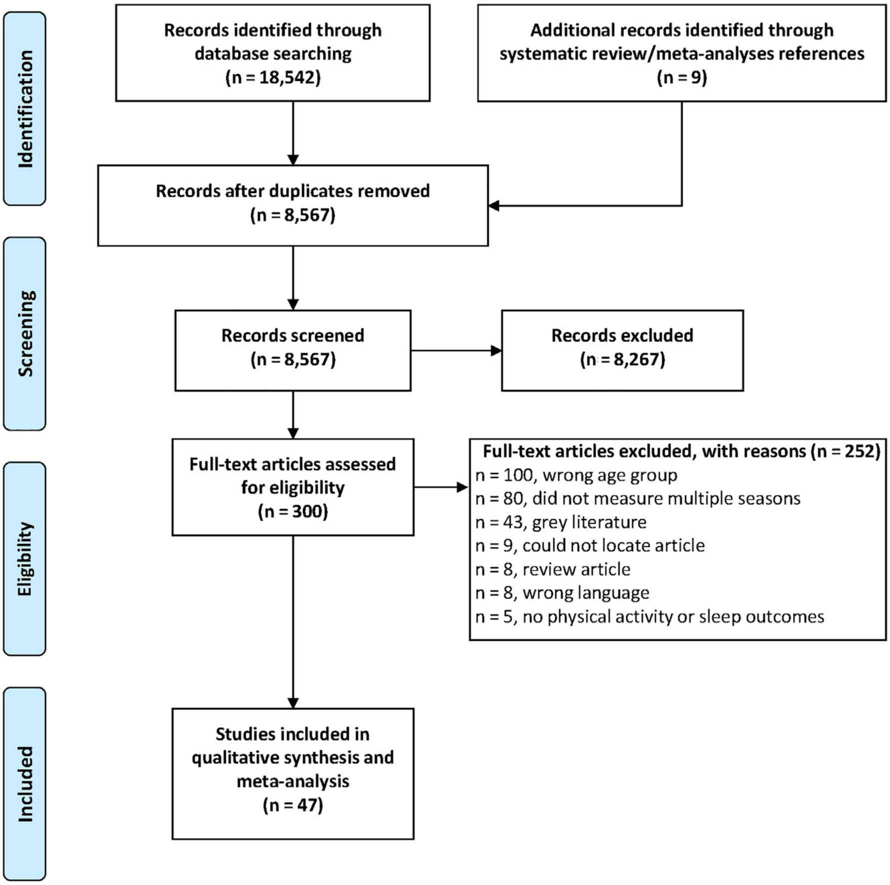

Fig. 1. Prisma flow diagram.

Narrative Synthesis

Study characteristics

Study characteristics are reported in Table 1. A total of 2 studies were conducted in Asia, 23 studies were conducted in Europe, 18 studies were conducted in North America, and 4 studies were conducted in Oceania. The 4 studies conducted in Oceania were the only studies conducted in the southern hemisphere. The latitudes of the studies conducted in the northern hemisphere ranged from 29 to 69°N, while the latitudes of the studies conducted in the southern hemisphere ranged from 31 to 37°S.

Sleep and activity monitoring methods and outcomes

A total of 40 studies measured physical activity only, 5 studies measured sleep only, and 2 studies measured sleep and physical activity. For physical activity, 6 studies measured sedentary behavior, 6 studies measured light physical activity, 7 studies measured MPA, 5 studies measured VPA, 10 studies measured MVPA, 12 studies measured steps, and 21 studies measured other physical activity. For sleep, 6 studies measured sleep duration, 2 studies measured sleep onset, 2 studies measured sleep offset, and 1 study measured sleep other (ie, parent reported if child sleeps more and is tired).

For physical activity, 36 studies included an objective measure while only 2 studies measuring sleep included an objective measure. The mean number of days of assessment of physical activity was 5.5 (SD = 2.5) and ranged from 1 to 14 days. The most common measurement duration was 7 days (16 studies). A total of 9 studies measured movement behaviors for 4 days, 4 studies measured for 5 days, 3 studies measured for 1 day, 3 studies measured for 2 days, 2 studies measured for 6 days, 2 studies measured for 9 days, and 1 study each measured for 1 day, 9 days, and 14 days. For sleep, the mean number of assessment days was 6.8 (SD = 5.1) and ranged from 1 to 14 days. A total of 2 studies measured sleep for 1 day, 2 studies measured sleep for 7 days, 2 studies measured sleep for 14 days, and 1 study measured sleep for 4 days.

Seasonal comparisons of physical activity and sleep

The seasons measured for each study are presented in Table 1. For physical activity, 18 studies measured 2 seasons, 12 studies measured 3 seasons, and 12 studies measured all 4 seasons. For sleep, 2 studies measured 2 seasons, 4 studies measured 3 seasons, and 1 study measured 4 seasons. Across sleep and physical activity, the most common behavior comparison was fall vs. spring with 31 studies, followed closely by winter vs. spring with 30 studies, then fall vs. winter with 25 studies, fall vs. summer with 21 studies, spring vs. summer with 22 studies, and finally winter vs. summer with 20 studies. For physical activity, the most common comparison was fall vs. spring with 27 studies, then winter vs. spring with 26 studies, fall vs. winter with 22 studies, spring vs. summer with 19 studies, fall vs. summer with 18 studies, and winter vs. summer with 17 studies. For sleep, the most common season comparison was fall vs. spring with 6 studies, followed by winter vs. spring with 5 studies. A total of 4 studies each compared children's sleep during fall vs. winter, fall vs. summer, and spring vs. summer. The least common sleep comparison was winter vs. summer with 3 studies.

Studies considering structure

When considering structure, a total of 17 of the 47 studies conducted measures on and presented outcomes separately for weekends and/or weekdays. A total of 8 studies measured summer during vacation from school while 1 study measured winter

Table 1
Table of included studies

Author, Year	Outcomes Measured	Obj Measure	Sample Size (n)	Female (n)	Country	Region	Lat	Study Design	Days Assessed (n)	Seasons Measured F	W	Sp	Su	Months Measured	Mean Age in Years (SD)	Vacation days Included During Fall[a]	Vacation days Included During Winter[a]	Vacation days Included During Spring[a]	Vacation days Included During Summer[a]	Week & Weekend Day[b]
Aadland, 2017[40]	LPA, MPA, MVPA, Sed, VPA	Yes	615	306	Norway	Europe	61.55°N	Cluster-randomized trial	7 d		●	●		Jan, Feb, Apr, May, Jun	10.9 (0.3)		Unclear	Unclear		Combined
Atkin, 2015[41]	MVPA, Sed	Yes	704	370	United Kingdom	Europe	52.18°N	Prospective observational	2 d	●	●	●	●	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	7.6 (0.3)	Unclear	Unclear	Unclear	Unclear	Separate
Bagordo, 2017[42]	PA other	No	250	123	Italy	Europe	43.73°N	Prospective observational	2 d		●	●		NR (winter, and late spring)	7.3 (0.9)		Unclear	Unclear		Combined
Beighle, 2008[43]	Steps	Yes	401	167	United States	North America	38.03°N	Prospective observational	4 d		●	●		Feb, May	9.1 (1.5)		No	No		Weekday only
Beighle, 2012[44]	Steps	Yes	105	65	United States	North America	38.03°N	Prospective observational	4 d	●	●			Feb, Oct	8.9 (0.7)	No	No			Weekday only
Brusseau, 2015[45]	PA other	Yes	289	168	United States	North America	40.76°N	Prospective observational	7 d	●		●		Apr, Oct	9.5 (0.7)	No		No		Separate
Carskadon, 1993[46]	Sleep other	No	1680	892	United States	North America	60.79°N to 28.53°N	Retrospective observational	1 d	●		●		Jan, Feb, Mar, Apr, May, Sep, Oct, Nov, Dec	10.5 (1.0	No		No		Combined
Cooper, 2010[47]	PA other	Yes	1010	472	United Kingdom	Europe	51.45°N	Repeated cross-sectional	4 d	●	●	●	●	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	11.0 (0.4)	No	No	No	No	Weekday only
Cullen, 2017[48]	LPA, MVPA, Sed, Steps	Yes	342	342	United States	North America	29.76°N	Repeated cross-sectional	7 d	●	●	●	●	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	8–10 (–)	Unclear	Unclear	Unclear	Unclear	Combined

(*continued on next page*)

Table 1
(*continued*)

Author, Year	Outcomes Measured	Obj Measure	Sample Size (n)	Female (n)	Country	Region	Lat	Study Design	Days Assessed (n)	Seasons Measured: F	W	Sp	Su	Months Measured	Mean Age in Years (SD)	Vacation days Included During Fall[a]	Vacation days Included During Winter[a]	Vacation days Included During Spring[a]	Vacation days Included During Summer[a]	Week & Weekend Day[b]
Erwin, 1934[49]	Sleep duration	No	644	329	United States	North America	42.03°N	Repeated cross-sectional	7 d	●	●	●	●	Feb, May, July, Nov	8.5 (0.2)	Unclear	Unclear	Unclear	Unclear	Combined
Fu, 2017[50]	Steps	Yes	1232	624	United States	North America	39.54°N	Prospective observational	5 d	●		●		NR (beginning fall semester, end spring semester)	9.5 (1.8)	No		No		Weekday only
Harrison, 2017[51]	MVPA	Yes	591	302	United Kingdom	Europe	52.62°N	Prospective observational	2 d	●	●	●	●	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	7.3 (0.2)	Unclear	Unclear	Unclear	Unclear	Combined
Heelan, 2009[52]	PA other	Yes	123	73	United States	North America	41.27°N	Quasi-experimental	4 d	●	●	●		Feb, May, Aug	8.1 (1.7)	No	No	No		Weekday only
Hjorth, 2013[53]	Sleep duration, MVPA, Sed	Yes	730	354	Denmark	Europe	55.68°N	Prospective observational	4 d	●	●	●		Feb, Mar, Jun, Aug, Sep, Oct, Nov	10.0 (0.6)	No	No	No		Separate
Hopkins, 2011[54]	Steps, PA other	Yes	116	70	Australia	Oceania	31.98°S	Prospective observational	3 d	●			●	Jun, Nov	10.7 (0.3)	No			No	Combined
Kolle, 2009[55]	PA other	Yes	1291	598	Norway	Europe	60.47°N	Prospective observational	4 d	●	●	●		Jan, Feb, Mar, Apr, May, Jun, Sep, Oct, Nov	9.0 (–)	No	No	No		Combined
Kolle, 2008[56]	PA other	Yes	1127	525	Norway	Europe	60.47°N	Prospective observational	4 d	●	●	●		Jan, Feb, Mar, Apr, May, Jun, Sep, Oct, Nov	9.0 (–)	No	No	No		Combined
Kristensen, 2008[57]	PA other	Yes	793	437	Denmark	Europe	55.40°N	Repeated cross-sectional	5 d	●	●	●	●	Mar, Apr, May, Jun, Aug, Sep, Oct, Nov, Dec	9.6 (0.4)	Unclear	Unclear	Unclear	Unclear	Combined

Langlois, 2012[58]	PA other	No	1206	627	Canada	North America	45.50°N	Prospective observational	7 d	●	●	●		Jan, Feb, Mar, Apr, May, Jun, Sep, Oct, Dec,	12.3 (0.6)	No	No	No		Combined
Larouche, 2019[59]	PA other	No	932	516	Canada	North America	46.57°N	Prospective observational	7 d	●	●	●		NR	10.6 (0.7)	No	No	No		Weekday only
Loucaides, 2004[60]	Steps	Yes	144	71	Cyprus	Europe	35.19°N	Prospective observational	4 d		●		●	Jan, Feb, May, Jun	12.0 (–)	No		No		Weekday only
Loucaides, 2018[61]	Steps	Yes	73	37	Cyprus	Europe	34.71°N	Prospective observational	6 d		●	●		Jan, May	11.5 (0.5)		No	No		Separate
Mattocks 2007[62]	PA other	Yes	315	167	United Kingdom	Europe	51.45°N	Prospective observational	7 d	●	●	●	●	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	11.7 (0.2)	Unclear	Unclear	Unclear	Unclear	Combined
McCorie, 2017[63]	PA other	Yes	774	427	Scotland	Europe	56.49°N	Repeated cross-sectional	8 d	●	●	●	●	Mar, Jun, Sep, Dec	10–11 (–)	Unclear	Unclear	Unclear	Unclear	Combined
McCorie, 2020[64]	MVPA	Yes	774	427	Scotland	Europe	55.87°N	Repeated cross-sectional	1 d	●	●	●	●	Mar, Jun, Sep, Dec	11.1 (0.3)	Unclear	Unclear	Unclear	Unclear	Combined
Nagy, 2019[65]	PA other	Yes	104	53	United Kingdom	Europe	53.81°N	Prospective observational	9 d		●	●	●	NR (3 school terms and 2 holiday terms)	7.5 (0.5)		No	No	Yes	Combined
Nilsen, 2019[66]	PA other	Yes	704	332	Norway	Europe	61.55°N	Prospective observational	4 d	●		●	●	Jan, Feb, March, Apr, May, Jun, Sep, Oct, Nov, Dec	5–6 (–)	No		No	No	Combined
Nixon, 2008[67]	Sleep duration	Yes	591	262	New Zealand	Oceania	37.92°S	Repeated cross-sectional	1 d	●	●	●	●	Jan, Feb, March, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	7.3 (0.2)	Unclear	Unclear	Unclear	Unclear	Combined
Oreskovic, 2012[68]	PA other	Yes	24	14	United States	North America	42.41°N	Repeated cross-sectional	7 d		●	●	●	Mar, Jul, Dec	11–12 (–)		No	No	Yes	Combined

(*continued on next page*)

Table 1
(*continued*)

Author, Year	Outcomes Measured	Obj Measure	Sample Size (n)	Female (n)	Country	Region	Lat	Study Design	Days Assessed (n)	Seasons Measured: F	W	Sp	Su	Months Measured	Mean Age in Years (SD)	Vacation days Included During Fall[a]	Vacation days Included During Winter[a]	Vacation days Included During Spring[a]	Vacation days Included During Summer[a]	Week & Weekend Day[b]
Ostrin, 2018[69]	Sleep duration, PA other	Yes	60	24	Unites States	North America	29.76°N	Prospective observational	14 d	●		●	●	Jan, Feb, March, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	7.6 (1.8)	No		No	Yes	Combined
Pagels, 2016[70]	PA other	Yes	179	87	Sweden	Europe	59.33°N	Prospective observational	5 d	●		●		Mar, May, Sep	10.2 (0.4)	No		No		Weekday only
Pagels, 2020[71]	PA other	Yes	159	78	Sweden	Europe	56.4°N to 60.3°N	Prospective observational	7 d		●	●		Mar, May, Sep	10.1 (0.5)		No	No		Weekday only
Remmers, 2017[72]	LPA, MPA, Sed, VPA	Yes	326	170	Australia	Oceania	37.81°S	Prospective observational	7 d	●	●	●	●	Feb, Mar, May, Jun, Aug, Sep, Oct, Nov	11.4 (0.7)	No	No	No	No	Combined
Ridgers, 2015[73]	MPA, MVPA, VPA	Yes	326	164	Australia	Oceania	37.81°S	Prospective observational	9 d	●	●	●	●	Feb, Mar, May, Jun, Aug, Sep, Oct, Nov	10.2 (0.7)	No	No	No	No	Combined
Rowlands, 2006[11]	Steps	Yes	36	0	England	Europe	51.31°N	Prospective observational	7 d		●		●	Jan, Feb, Jun, Jul	8.8 (0.8)		Yes		Yes	Separate
Rowlands, 2009[74]	MPA, VPA	Yes	64	39	United Kingdom	Europe	50.74°N	Prospective observational	6 d		●		●	Jan, Feb, Jun, Jul	9.9 (0.3)		No		No	Separate
Sethre-Hofstad, 2012[75]	Sleep duration, Sleep offset, Sleep onset	No	79	-	Norway	Europe	69°N	Prospective observational	7 d		●	●		Jan, May	7.7 (1.5)		No	No		Separate
Stevens, 2003[76]	PA other	No	683	329	United States	North America	34.05–43.97°N	Quasi-experimental	1 d	●		●		NR	8–12 (–)	No		No		Weekday only
Szymczak, 1993[77]	Sleep duration, Sleep offset, Sleep onset	No	64	33	Poland	Europe	53.01°N	Prospective observational	14 d	●	●	●	●	Jan, Feb, March, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	10–12 (–)	Unclear	Unclear	Unclear	Unclear	Combined

Tanaka, 2016[78]	LPA, MPA, MVPA, Sed, Steps	Yes	209	111	Japan	Asia	35.58°N	Prospective observational	7 d			●	●	May, Jul, Aug	9.0 (1.8)			No	Yes	Combined
Tanaka, 2018[79]	LPA, MPA, MVPA, Steps, PA	Yes	209	111	Japan	Asia	35.58°N	Prospective observational	7 d			●	●	May, Jul, Aug	9.0 (1.8)			No	Yes	Combined
Vadiveloo, 2009[80]	Steps	Yes	32	24	United States	North America	42.36°N	Prospective observational	7 d	●	●	●		Jan, Feb, May, Jun, Oct, Nov	9.5 (–)	No	No	No		Combined
Volmut, 2020[81]	LPA, MPA, MVPA, VPA	Yes	93	45	Slovenia	Europe	51.22°N	Prospective observational	5 d	●		●	●	May, Jun, Aug, Sep	7.6 (1.1)	No		No	Yes	Combined
Wickel, 2010[82]	Steps	Yes	80	38	United States	North America	36.15°N	Prospective observational	7 d	●	●			Jan, May, Sep	9.8 (0.9)	No	No			Separate
Ylitalo, 2019[83]	PA other	Yes	174	43	United States	North America	31.20°N	Prospective observational	7 d	●			●	Jun, Jul, Aug, Sep, Oct, Nov, Dec	8.3 (1.6)	No			Yes	Combined
Zelener, 2016[84]	PA other	Yes	139	72	United States	North America	33.68°N	Prospective observational	1 d	●		●		Apr, May, Sep, Oct	11.1 (0.4)	No		No		Combined
Sera, 2017[85]	PA other	Yes	6497	3321	United Kingdom	North America	55.38°N	Repeated cross-sectional	7 d	●	●	●	●	Jan, Feb, March, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	7.5 (–)	Unclear	Unclear	Unclear	Unclear	Separate

Abbreviations: "Obj" Objective "Lat" Latitude, "LPA" light physical activity, "MPA" moderate physical activity, "VPA" vigorous physical activity, "MVPA" Moderate-to-vigorous Physical Activity, "PA Other" Physical Activity Other, "F" fall, "W" winter, "Sp" Spring, "Su" Summer.

[a] Yes = measures occurred during vacation from school (ie, winter, summer, spring vacation), No = measures occurred while children were attending school, Unclear = study does not present enough information to determine if measures occurred during vacation from school.

[b] Weekday only = only measured children on weekdays, combined = measured data on week and weekend days but presented a combined estimated, separate = presented separated estimates by week and weekend days for each season measured.

during vacation from school. No studies measured fall or spring during vacation from school.

Study quality

The risk of bias ratings by the study on all individual indicators is presented in Fig. 2. Overall, the scores ranged from 3 to 9 and the mean score was 6.8 (SD = 1.4) while the median score was 7.0. Indicators that were frequently rated as not meeting or could not be determined were, “was the participation rate of eligible persons at least 50%,” “were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants,” “was a sample size justification provided,” “was loss to follow-up after baseline 20% or less,” and “were key potential

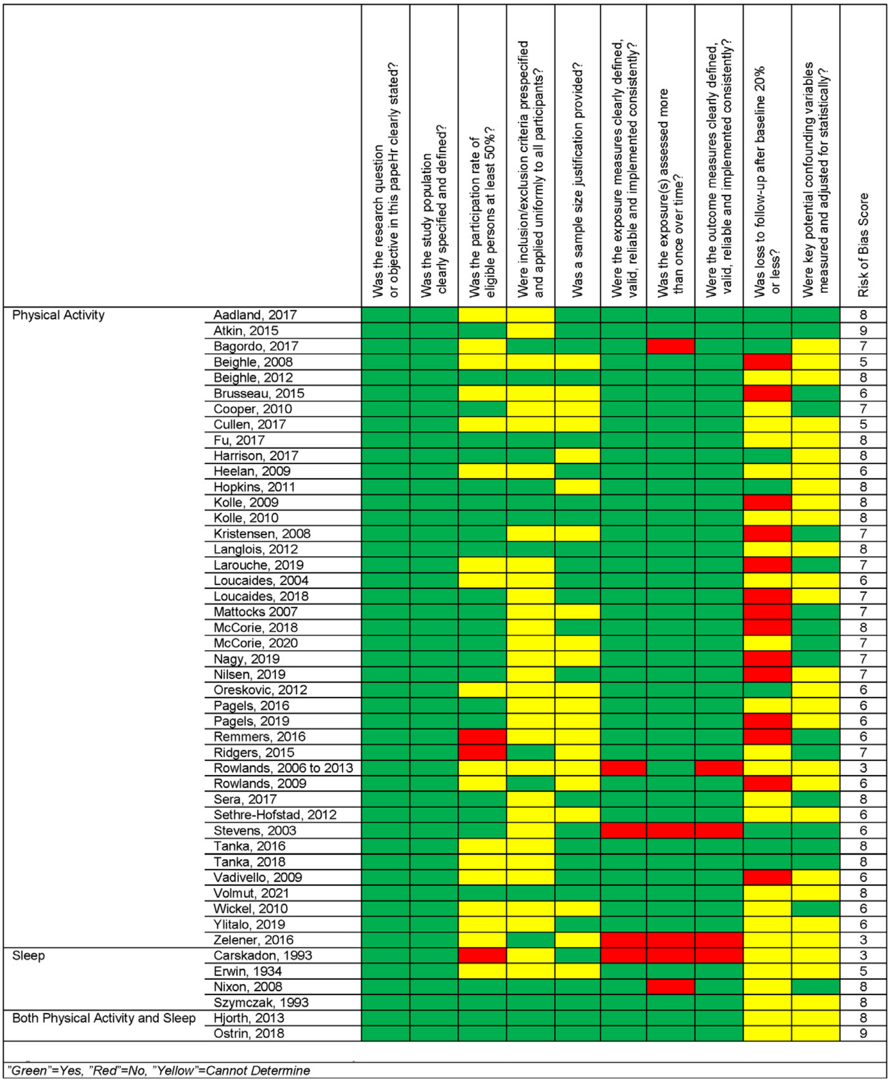

Fig. 2. Risk of bias scores for each study.

confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)."

Meta-Analysis

Differences in activity levels and sleep by season

Table 2 presents the findings of the meta-regression analyses along with estimates of heterogeneity (ie, I^2 statistics). For PA, overall PA behaviors showed that spring was healthier than fall (SMD = −0.25, 95CI = −0.26, −0.24) with only MPA and VPA healthier in the fall. Overall spring was healthier than winter (SMD = −0.35, 95CI = −0.36, −0.34) with only MPA and VPA showing no difference between spring and winter. Spring was healthier than summer when considering overall PA behaviors (SMD = −0.03, 95CI = −0.05, −0.01), LPA, MPA, steps, and TPA. However, summer was healthier than spring when considering MVPA and there was no difference between spring and summer for VPA, sedentary time, or PA other.

Overall fall was healthier than winter (SMD = −0.17, 95CI = −0.18, −0.16) with MPA, sedentary, steps, TPA, and PA other being consistent with the overall finding. LPA, VPA, and MVPA showed no difference between fall and winter. Overall, summer was healthier than fall (SMD = 0.15, 95CI = 0.13, 0.18). However, findings on specific PA behaviors were mixed with MPA and VPA being healthier in the fall but MVPA, sedentary, TPA, and PA Other being healthier in the summer. Overall, summer was healthier than the winter (SMD = 0.12, 95CI = 0.10, 0.14). Again, findings for specific PA behaviors were mixed with MPA and VPA being healthier in the winter and MVPA, sedentary, steps, TPA, and PA Other being healthier in the summer.

For sleep, overall sleep was healthier in the fall compared with spring (SMD = 0.10, 95CI = 0.05, 0.15). Sleep was also healthier in the winter compared with spring (SMD = 0.32, 95CI = 0.27, 0.36). Both sleep duration and sleep offset followed this pattern when comparing spring to winter, but no difference was found between the 2 seasons for sleep onset. Overall summer was healthier than spring for sleep as well (SMD = 0.74, 95CI = 0.66, 0.83). When comparing fall to winter, fall to summer, and winter to summer, the only sleep behavior measured was sleep duration. These findings indicated that sleep duration was not different between fall and winter and was healthier in the summer compared with the fall (SMD = 1.56, 95CI = 1.43, 1.68) and in the summer compared with the winter (SMD = 0.72, 95CI = 0.61, 0.84).

Table 2
Meta-regression effects of season by physical activity and sleep outcome

	Spring vs. Fall					Spring vs. Winter					Spring vs. Summer				
	n	k	I^2	eff	95CI	k	n	I^2	eff	95CI	k	n	I^2	eff	95CI
Physical Activity															
Overall	24	96	98.0	**-0.25**	**(-0.26, -0.24)**	25	139	96.9	**-0.35**	**(-0.36, -0.34)**	16	64	92.0	**-0.03**	**(-0.05, -0.01)**
LPA	2	2	66.6	**-0.15**	**(-0.26, -0.05)**	3	4	0.0	**-0.12**	**(-0.20, -0.04)**	4	5	76.4	**-0.29**	**(-0.38, -0.20)**
MPA	2	5	97.2	**0.27**	**(0.20, 0.34)**	3	7	95.0	-0.01	(-0.07, 0.05)	4	8	86.5	**-0.11**	**(-0.17, -0.05)**
VPA	2	5	96.1	**0.32**	**(0.25, 0.39)**	3	7	97.5	-0.03	(-0.09, 0.03)	3	6	93.7	0.01	(-0.06, 0.07)
MVPA	7	20	98.8	**-0.47**	**(-0.50, -0.44)**	9	32	98.0	**-0.39**	**(-0.42, -0.37)**	9	21	94.4	**0.08**	**(0.05, 0.12)**
Sed	4	6	89.5	**-0.10**	**(-0.15, -0.05)**	5	8	95.2	**-0.17**	**(-0.21, -0.12)**	4	5	13.9	-0.05	(-0.12, 0.02)
Steps	4	12	78.0	**-0.24**	**(-0.30, -0.19)**	4	12	60.4	**-0.34**	**(-0.43, -0.25)**	3	4	77.1	**-0.48**	**(-0.59, -0.37)**
TPA	7	11	97.8	**-0.48**	**(-0.51, -0.44)**	7	18	97.8	**-0.72**	**(-0.76, -0.69)**	3	8	92.9	**-0.17**	**(-0.29, -0.04)**
PA Other	7	35	97.7	**-0.21**	**(-0.23, -0.20)**	9	51	93.6	**-0.35**	**(-0.37, -0.33)**	4	7	54.0	-0.02	(-0.08, 0.04)
Sleep															
Overall	6	38	90.3	**0.10**	**(0.05, 0.15)**	5	52	90.5	**0.32**	**(0.27, 0.36)**	4	28	96.0	**0.74**	**(0.66, 0.83)**
Sleep Duration	6	32	91.8	**0.12**	**(0.07, 0.17)**	5	34	91.9	**0.40**	**(0.35, 0.45)**	4	22	94.4	**1.32**	**(1.21, 1.43)**
Sleep Onset	-	-	-	-	- -	2	9	82.3	-0.07	(-0.18, 0.04)	-	-	-	-	- -
Sleep Offset	-	-	-	-	- -	2	9	69.1	**0.35**	**(0.24, 0.46)**	-	-	-	-	- -

	Fall vs. Winter					Fall vs. Summer					Winter vs. Summer				
	k	n	I^2	eff	95CI	k	n	I^2	eff	95CI	k	n	I^2	eff	95CI
Physical Activity															
Overall	18	88	93.9	**-0.17**	**(-0.18, -0.16)**	12	57	95.5	**0.15**	**(0.13, 0.18)**	14	100	93.2	**0.12**	**(0.10, 0.14)**
LPA	2	2	0.0	0.07	(-0.04, 0.18)	2	2	59.9	-0.04	(-0.14, 0.07)	3	13	0.0	-0.06	(-0.15, 0.02)
MPA	2	5	92.6	**-0.11**	**(-0.18, -0.04)**	2	5	90.8	**-0.33**	**(-0.40, -0.26)**	3	20	8.9	**-0.17**	**(-0.23, -0.11)**
VPA	2	5	93.3	-0.01	(-0.08, 0.06)	2	5	44.9	**-0.28**	**(-0.35, -0.21)**	3	20	52.1	**-0.19**	**(-0.25, -0.13)**
MVPA	6	18	98.1	-0.02	(-0.04, 0.01)	6	14	97.3	**0.33**	**(0.29, 0.37)**	6	15	97.3	**0.20**	**(0.16, 0.23)**
Sed	4	6	49.3	**-0.15**	**(-0.20, -0.11)**	4	5	90.5	**0.23**	**(0.16, 0.30)**	3	3	95.8	**0.33**	**(0.25, 0.41)**
Steps	4	19	77.3	**-0.18**	**(-0.25, -0.11)**	2	4	85.0	-0.02	(-0.14, 0.10)	3	7	97.5	**0.31**	**(0.20, 0.42)**
TPA	6	10	81.1	**-0.29**	**(-0.33, -0.26)**	4	17	48.4	**0.25**	**(0.18, 0.32)**	3	11	89.7	**0.21**	**(0.09, 0.32)**
PA Other	3	23	51.9	**-0.23**	**(-0.24, -0.21)**	2	5	95.2	**0.43**	**(0.37, 0.50)**	4	9	93.8	**0.42**	**(0.36, 0.48)**
Sleep															
Overall	3	26	62.9	0.00	(-0.05, 0.06)	3	19	91.3	**1.56**	**(1.43, 1.68)**	2	18	73.2	**0.72**	**(0.61, 0.84)**
Sleep Duration	3	26	62.9	0.00	(-0.05, 0.06)	3	19	91.3	**1.56**	**(1.43, 1.68)**	2	18	73.2	**0.72**	**(0.61, 0.84)**
Sleep Onset	-	-	-	-	- -	-	-	-	-	- -	-	-	-	-	- -
Sleep Offset	-	-	-	-	- -	-	-	-	-	- -	-	-	-	-	- -

Abbreviations: "n" number of studies, "k" number of effects, "eff" effect, "LPA" Light Physical Activity, "MPA" Moderate Physical Activity, "VPA" Vigorous Physical Activity, "MVPA" Moderate-to-vigorous Physical Activity, "Sed" Sedentary, "PA Other" Physical Activity Other.
Bolded text indicates statistically significant value at p<0.05

Favors Fall | Favors Winter | Favors Spring | Favors Summer

Changes in the activity level and sleep by season when considering structure

Findings on weekdays and weekends are presented in Table 3 and were similar in magnitude and direction except for overall physical activity in fall compared with winter. The only comparison that was substantively different was fall compared with winter. During weekdays fall was healthier than winter (SMD = −0.11, 95CI = −0.16, −0.05) while there was a nonstatistically SMD of 0.02 (95CI = −0.03, 0.07) in favor of the winter on weekend days. Given the lack of studies measuring during vacation from school in the fall, winter, and spring meta-analytic comparisons between summer and other seasons were the only comparisons possible. When examining these analyses (Table 4), a pattern emerged whereby physical activity was less healthy (ie, direction of difference changes and/or magnitude of difference grew) during the months of summer when physical activity was measured while school was not in session. Specifically, overall physical activity during the summer was healthier than spring when physical activity was measured during the months of summer while school was in session (SMD = 0.03, 95CI = 0.00, 0.05). However, spring was healthier than the summer when physical activity was measured during the months of summer while school was not in session (SMD = −0.46, 95CI = −0.54, −0.39). This pattern was consistent for all physical activity outcomes when comparing spring to summer. Only one study compared winter to summer when school was not in session so meta-analyses were not completed. There were no studies comparing fall to summer that measured physical activity during the months of summer when school was not in session. For sleep, only one study measured sleep during the summer when school was not in session so meta-analyses were not completed. Findings indicated that when sleep was measured during the months of summer and school was in session, summer was healthier than spring (SMD = 0.74, 95CI = 0.65, 0.83).

DISCUSSION

This systematic review and meta-analysis sought to summarize the difference between children's movement behaviors by season. Overall, it seems that children engaged in the healthiest levels of sedentary behavior and physical activity in the spring and the healthiest levels of sleep in the summer, although this varied for specific physical activity and sleep behaviors. It seems that structure during a given season may play a large role in the variation in children's movement behaviors. Thus, the findings above may be confounded by structure. However, the evidence in this area is limited as very few studies measured children when they were not in school during

Table 3
Meta-regression effects of seasons on weekend and weekdays

		Spring vs. Fall					Spring vs. Winter					Fall vs. Winter					Winter vs. Summer				
		n	k	effect	95CI		k	n	effect	95CI		k	n	effect	95CI		k	n	effect	95CI	
Physical Activity																					
Overall	Weekday	2	7	**-0.51**	**(-0.56,**	**-0.46)**	2	7	**-0.57**	**(-0.62,**	**-0.52)**	2	7	**-0.11**	**(-0.16,**	**-0.05)**	2	26	0.09	(-0.01,	0.18)
	Weekend	2	7	**-0.39**	**(-0.44,**	**-0.34)**	2	7	**-0.54**	**(-0.59,**	**-0.49)**	2	11	0.02	(-0.03,	0.07)	2	26	0.11	(0.01,	0.20)
Sleep																					
Overall	Weekday	-	-	-	-	-	2	10	**0.42**	**(0.34,**	**0.50)**		-	-	-	-	-	-	-	-	-
	Weekend	-	-	-	-	-	2	9	**0.34**	**(0.26,**	**0.42)**		-	-	-	-	-	-	-	-	-
Duration	Weekday	-	-	-	-	-	2	4	**0.54**	**(0.43,**	**0.64)**		-	-	-	-	-	-	-	-	-
	Weekend	-	-	-	-	-	2	3	**0.43**	**(0.32**	**0.54)**		-	-	-	-	-	-	-	-	-

Abbreviations: "n" number of studies, "k" number of effects, "SMD" Standardized Mean Difference, "LPA" Light Physical Activity, "MPA" Moderate Physical Activity, "VPA" Vigorous Physical Activity, "MVPA" Moderate-to-vigorous Physical Activity, "Sed" Sedentary, "PA Other" Physical Activity Other.
Bolded text indicates statistically significant value at $p<0.05$

Favors Fall | Favors Winter | Favors Spring | Favors Summer

Table 4
Meta-regression effects of seasons compared to summer when considering structure

	Spring vs. Summer					Fall vs. Summer					Winter vs. Summer				
All PA Metrics	n	k	effect	95CI		n	k	effect	95CI		n	k	effect	95CI	
Summer Structure	14	28	**0.03**	**(0.00,**	**0.05)**	14	46	**0.12**	**(0.10,**	**0.14)**	14	86	**0.07**	**(0.05,**	**0.09)**
No Summer Structure	2	15	**-0.46**	**(-0.54,**	**-0.39)**	-	-	-	-	-	-	-	-	-	-
Light PA															
Summer Structure	2	2	**-0.20**	**(-0.30,**	**-0.09)**	2	2	-0.04	(-0.14,	0.07)	3	14	-0.06	(-0.15,	0.02)
No Summer Structure	2	3	**-0.50**	**(-0.65,**	**-0.34)**	-	-	-	-	-	-	-	-	-	-
Moderate PA															
Summer Structure	2	5	-0.06	(-0.13,	0.01)	2	5	**-0.33**	**(-0.40,**	**-0.26)**	3	21	**-0.17**	**(-0.23,**	**-0.11)**
No Summer Structure	2	3	**-0.38**	**(-0.53,**	**-0.22)**	-	-	-	-	-	-	-	-	-	-
Vigorous PA															
Summer Structure	2	5	0.04	(-0.02,	0.11)	2	5	**-0.28**	**(-0.35,**	**-0.21)**	3	21	**-0.19**	**(-0.25,**	**-0.13)**
No Summer Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MVPA															
Summer Structure	7	12	**0.11**	**(0.07,**	**0.14)**	6	12	**0.33**	**(0.29,**	**0.37)**	6	12	**0.21**	**(0.17,**	**0.25)**
No Summer Structure	2	3	**-0.46**	**(-0.62,**	**-0.30)**	-	-	-	-	-	-	-	-	-	-
Sedentary															
Summer Structure	3	3	-0.03	(-0.11,	0.04)	4	4	**0.25**	**(0.18,**	**0.33)**	3	3	**0.33**	**(0.25,**	**0.41)**
No Summer Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Steps															
Summer Structure	-	-	-	-	-	2	4	-0.02	(-0.14,	0.10)	3	5	**0.17**	**(0.05,**	**0.28)**
No Summer Structure	2	3	**-0.67**	**(-0.83,**	**-0.51)**	-	-	-	-	-	-	-	-	-	-
Total PA															
Summer Structure	-	-	-	-	-	4	15	**0.30**	**(0.22,**	**0.38)**	3	4	0.02	(-0.21,	0.25)
No Summer Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PA Other															
Summer Structure	-	-	-	-	-	-	-	-	-	-	4	6	**0.16**	**(0.05,**	**0.27)**
No Summer Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All Sleep Metrics															
Summer Structure	3	27	**0.74**	**(0.65,**	**0.83)**	**2**	**18**	**1.77**	**(1.64,**	**1.90)**	2	18	**0.72**	**(0.61,**	**0.84)**
No Summer Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sleep Duration															
Summer Structure	-	-	-	-	-	**2**	**18**	**1.77**	**(1.64,**	**1.90)**	2	18	**0.72**	**(0.61,**	**0.84)**
No Summer Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Abbreviations: "n" number of studies, "k" number of effects, "SMD" Standardized Mean Difference, "Lat" Latitude, "PA Other" Physical Activity Other.
Bolded text indicates statistically significant value at $p<0.05$

Favors Fall | Favors Winter | Favors Spring | Favors Summer

summer vacation and even fewer studies made comparisons on weekdays and weekends between seasons.

This systematic review and meta-analysis extend previous reviews of the literature on seasonal change in movement behaviors in several key ways. First, previous reviews have focused on physical activity exclusively, with no reviews examining the variation in children's sleep behaviors by season.[2–5] Second, previous systematic reviews have not used meta-analytic approaches to combine study estimates.[2–5] Rather studies have *P*-value counted to draw conclusions about the impact of season on children's movement behaviors. This is a limitation of previous studies because this approach is highly subjective, focuses on the statistical significance of findings rather than the magnitude of the effect, and there is no way to correct for study features such as study design and sample characteristics.[16,17] Finally, this systematic review accounted for structure when considering the difference in children's movement behaviors across seasons. Structure has been shown to impact children's physical activity and sleep behaviors[18,19] and is critical to consider when examining shifts in children's movement behaviors by season.

The current study found that children's physical activity was the healthiest during the spring. This is a refinement of previous literature as we used meta-analytic techniques to estimate the magnitude of differences between seasons (rather than nominal significance). This refinement may, therefore, explain the contrasting results between previous findings, indicating that summer was the healthiest season for chidlren's physical activity. Further, the current review focused exclusively on children's movement behaviors rather than including all age groups (ie, adults, adolescents, and so forth).

The findings of this study, and previous systematic reviews on seasonal shifts in children's movement behaviors, call into question the validity of the findings of studies that evaluate interventions when baseline measures are conducted in one season and outcome measures in a different season (ie, baseline in the fall and outcome in the spring). This approach is common in large-scale physical activity interventions,[20–22] and is especially concerning given the findings of the current study indicate that physical activity is the healthiest in the spring. Thus, the findings of past studies should be considered in the context of seasonal variability of children's movement behaviors.

This is the first systematic review to specifically delineate the relation of structure with seasonal changes in children's movement behaviors. A major finding of this review is that very few studies have accounted for structure when exploring seasonal shifts in children's movement behaviors. This is a major gap in the literature. Only one study conducted measures while children were in school and on vacation from school during 2 different seasons.[11] This study measured 36 children on weekdays and weekends during winter vacation from school and winter school term and then measured the same children during summer vacation from school and summer term. The study found that children were generally most active during the summer vacation days on both weekdays and weekends. However, winter weekdays were more active than summer weekend days and were similarly active to summer weekdays. While the findings of this study are preliminary (ie, only 36 children) they highlight the impact that the presence or absence of the school day (ie, structure) may have on children's activity levels. These findings are also contradictory to the findings of the meta-analyses in this review whereby a pattern of less healthy physical activity levels emerged in studies that conducted summer measures when school was not in session compared with studies that conducted summer measures when school was in session. For instance, studies that conducted summer measures when school *was in session* showed that MVPA was healthier during the summer (SMD = 0.11, 95CI = 0.07, 0.14) compared with spring. However, studies that conducted summer measures when school *was not in session* showed that MVPA was less healthy during the summer (SMD = −0.46, 95CI = −0.62, −0.30) compared with spring. Nonetheless, these findings suggest that structure plays a major role in the physical activity of children and may override any seasonal variations that occur due to factors associated with season (ie, weather, photoperiod). However, more work with larger more representative samples of children that compare activity levels across seasons during vacation and school days is needed. This work is especially important as the popularity of year-round schools has grown in the United States, with 3700 year-round schools[23] serving more than 2,000,000 students across 45 states.[24] Year-round schools operate on a 180-day schedule, similar to traditional schools. However, year-round schools incorporate shorter, frequent breaks throughout the calendar year rather than taking one prolonged 2–3-month break over summer. Thus, understanding the interaction of structure and seasonal changes in children's physical activity, sedentary behaviors, and sleep is critically important for this small but growing subgroup of children.

This systematic review also found that sleep duration is the healthiest in the summer. This is surprising given that the photoperiod is the longest in the summer compared with the other months of the year, and thus, suggests that children should be sleeping for shorter durations compared with other seasons that have shorter photoperiods. This is consistent with studies that have examined the impact of structure on children's sleep duration.[19,25] These studies show that children's sleep duration is longer when children are not in school, which typically occurs during the months of summer. In the current review, when considering structure for sleep, the data are sparse (ie, only 3 studies measured sleep outcomes during the months of summer while children were in school and 1 study measured sleep outcomes during the months of summer while children were not in school). Findings were mixed with all sleep metrics showing the minimal difference between seasonal changes in summer versus spring (SMD = 0.74 vs SMD = 0.80). However, sleep duration was considerably healthier during the summer compared with the spring (SMD = 1.37, 95CI = 1.25, 1.48) in the one study that conducted summer measures while children were in school. The SMD fell to 0.80 (95CI = 0.43,1.17) in the one study that compared spring and summer and conducted summer measures while children were not in school. Again, this pattern is consistent with past studies that show that children sleep less on school days compared with nonschool days.[19,25] This suggests that structure plays a major role in the sleep behaviors of children and may override any seasonal variations that occur due to photoperiod length. However, the evidence is limited and more studies that explore the impact of season and structure on children's sleep are needed.

This study has several strengths. The review presents a comprehensive synthesis of the literature exploring seasonal fluctuations in children's movement behaviors. The review focused on both sleep, sedentary behaviors, and physical activity to provide a comprehensive evaluation of the literature in this area. Further, minimal exclusion criteria were used to ensure that all pertinent studies were included. A meta-analysis was also performed to estimate the relationship of season with children's movement behaviors. Additionally, one must consider the current review in light of its limitations. Large heterogeneity was observed in study effects. This may have been due to the minimal inclusion/exclusion criteria, variability in participant inclusion criteria, heterogeneity in study protocols, and the widespread use of self-report measures.[26,27] Perhaps most notably, few studies considered the potential of structure to confound findings related to seasonal fluctuations in movement behaviors. Studies were either unclear when measures were conducted during the summer or conducted summer measures when children were on vacation from school. This is more a limitation of the current state of the literature than the current review. Future studies should be more transparent with reporting when measures are conducted, and future studies should consider structure when exploring seasonal changes in movement behaviors. Nonetheless, preliminary findings on the unique effects of structure versus season on children's movement behaviors highlight the need for future studies that explicitly measure and/or manipulate children's exposure to structure.

IMPLICATIONS FOR CLINICAL PRACTICE

The findings of this systematic review and meta-analysis have implications important implications for pediatric care. First, it is clear that children's behaviors vary seasonally. Thus, the timing of recommendations for increasing children's physical activity and reducing sedentary behaviors should coincide with these fluctuations (ie, recommendations for increasing physical activity and reducing sedentary behaviors before the summer months). Further linking children with structured activities when school is not in session could be critical for managing physical activity, sedentary behavior, and sleep and in-turn risk for overweight or obesity. The timing of clinic-based screenings for physical activity, sedentary behavior, and sleep at well-child visits is also crucial as screening occurs across seasons or during school vs. vacation may not be reliable or valid. Ideally, children's movement behaviors should be measured in multiple seasons. However, this is likely not feasible, and a suitable alternative is for screenings to be completed in the same season annually.

IMPLICATIONS FOR INTERVENTION DESIGN

These findings are also crucial for the design and evaluation of interventions targeting children's movement behaviors. Similar to clinic-based screenings studies evaluating interventions to impact children's movement behaviors should measure children's behaviors in multiple seasons before and following the intervention. At the very least, measurements should be completed in the same season before and following the intervention. Second, interventions targeting children's physical activity during the winter and fall (when children are in school) and during the summer (when children are not in school) may have a greater impact on children's physical activity behaviors given that children are already the most active during the spring. Third, there were surprisingly few studies that examined seasonal changes in children sleep behaviors, and even fewer studies examining metrics outside of sleep duration. Understanding seasonal shifts children's sleep timing and consistency (unique from duration) have both been shown to be related to overweight and obesity risk independent of sleep duration[28–31] may be salient targets for interventions to improve children's sleep. Finally, the data from this systematic review indicated that seasonal shifts in children's physical activity behavior, specifically those during the summer, are dependent on the presence of the school day. This can likely be explained by the structured days' hypothesis that posits that the presence of the school day positively impacts children's health behaviors.[18] These findings combined with recent studies showing that children's physical activity levels decreased during school closures,[32–36] and subsequent studies showing children's BMI gain increased during the COVID-19 pandemic,[37–39] bolster the argument that school positively impacts children's movement behaviors, and these positive behaviors mitigate unhealthy BMI gain. This information can inform when interventions targeting children's movement behaviors should be delivered and may provide novel intervention strategies (ie, providing access to structured programs during unstructured times).

CLINICS CARE POINTS

- Timing of recommendations for increasing children's physical activity and reducing sedentary behaviors should coincide with children's fluctuations in physical activity, sedentary behaviors, and sleep (ie, recommendations for increasing physical activity and reducing sedentary behaviors before the summer months).
- Linking children to structured activities when school is not in session could be critical for managing physical activity, sedentary behavior, and sleep and in-turn risk for overweight or obesity.
- Screenings for physical activity, sedentary behavior, and sleep at well-child visits should be completed in the same season annually.

POTENTIAL CONFLICTS OF INTEREST

The authors have nothing to disclose.

FUNDING

Research reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health under Award Number 1P20GM130420 The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

ACKNOWLEDGMENTS

None

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.pcl.2022.04.005.

REFERENCES

1. Rollo S, Antsygina O, Tremblay MS. The whole day matters: understanding 24-hour movement guideline adherence and relationships with health indicators across the lifespan. J Sport Health Sci 2020.
2. Tucker P, Gilliland J. The effect of season and weather on physical activity: a systematic review. Public Health 2007;121(12):909–22.
3. Turrisi TB, Bittel KM, West AB, et al. Seasons, weather, and device-measured movement behaviors: a scoping review from 2006 to 2020. Int J Behav Nutr Phys Act 2021;18(1):1–26.
4. Rich C, Griffiths LJ, Dezateux C. Seasonal variation in accelerometer-determined sedentary behaviour and physical activity in children: a review. Int J Behav Nutr Phys Act 2012;9:49.
5. Carson V, Spence JC. Seasonal variation in physical activity among children and adolescents: a review. Pediatr Exerc Sci 2010;22(1):81–92.
6. Brazendale K, Beets M, Pate RR, et al. Understanding differences between summer vs. school obesogenic behaviors of children: the structured days hypothesis. Int J Behav Nutr Phy 2017;14(1):100.
7. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PloS Med 2009;6(7):e1000097.
8. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ 2021;372.
9. Higgins JP, Thomas J, Chandler J, et al. Cochrane handbook for systematic reviews of interventions. John Wiley & Sons; 2019.
10. National Institutes of Health. Study quality assessment tools. Available at. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools. Accessed May 17, 2021.
11. Rowlands AV, Hughes DR. Variability of physical activity patterns by type of day and season in 8-10-year-old boys. Res Q Exerc Sport 2006;77(3):391–5.
12. Hedberg E. ROBUMETA: Stata module to perform robust variance estimation in meta-regression with dependent effect size estimates 2014.

13. Tufanaru C, Munn Z, Stephenson M, et al. Fixed or random effects meta-analysis? Common methodological issues in systematic reviews of effectiveness. Int J Evid Based Healthc 2015;13(3):196–207.
14. Ryan R. Cochrane consumers and communication group: meta-analysis. Cochrane Consumers and Communication Review Group; 2016.
15. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J R Stat Soc Ser B (Methodological) 1995;57(1):289–300.
16. Cheung MW-L, Vijayakumar R. A guide to conducting a meta-analysis. Neuropsychol Rev 2016;26(2):121–8.
17. Cooper H, Hedges LV, Valentine JC. The handbook of research synthesis and meta-analysis. Russell Sage Foundation; 2019.
18. Brazendale K, Beets MW, Weaver RG, et al. Understanding differences between summer vs. school obesogenic behaviors of children: the structured days hypothesis. Int J Behav Nutr Phys Act 2017;14(1):100.
19. Weaver R, Armstrong B, Hunt E, et al. The impact of summer vacation on children's obesogenic behaviors and body mass index: a natural experiment. Int J Behav Nutr Phys Act 2020;153.
20. Folta SC, Kuder JF, Goldberg JP, et al. Changes in diet and physical activity resulting from the Shape Up Somerville community intervention. BMC Pediatr 2013;13:157.
21. Sallis JF, McKenzie TL, Alcaraz JE, et al. The effects of a 2-year physical education program (SPARK) on physical activity and fitness in elementary school students. sports, play and active recreation for kids. Am J Public Health 1997;87(8):1328–34.
22. Luepker RV, Perry CL, McKinlay SM, et al. Outcomes of a field trial to improve children's dietary patterns and physical activity: the child and adolescent trial for cardiovascular health (CATCH). JAMA 1996;275(10):768–76.
23. Skinner RR. Year-round schools: in brief 2014. Available at. https://fas.org/sgp/crs/misc/R43588.pdf. Accessed February 25, 2017.
24. McGlynn A. Districts That School Year-Round. 2002. Available at. http://www.aasa.org/SchoolAdministratorArticle.aspx?id=10416. Accessed February 25, 2017.
25. Weaver RG, Beets MW, Perry M, et al. Changes in children's sleep and physical activity during a 1-week versus a 3-week break from school: A natural experiment. Sleep 2019;42(1):zsy205.
26. O'Brien KT, Vanderloo LM, Bruijns BA, et al. Physical activity and sedentary time among preschoolers in centre-based childcare: a systematic review. Int J Behav Nutr Phys Act 2018;15(1):117.
27. Hnatiuk JA, Salmon J, Hinkley T, et al. A review of preschool children's physical activity and sedentary time using objective measures. Am J Prev Med 2014;47(4):487–97.
28. Golley RK, Maher CA, Matricciani L, et al. Sleep duration or bedtime? Exploring the association between sleep timing behaviour, diet and BMI in children and adolescents. Int J Obes (Lond) 2013;37(4):546–51.
29. Jarrin DC, McGrath JJ, Drake CL. Beyond sleep duration: distinct sleep dimensions are associated with obesity in children and adolescents. Int J Obes 2013;37(4):552.
30. Arora T, Taheri S. Associations among late chronotype, body mass index and dietary behaviors in young adolescents. Int J Obes 2015;39(1):39.

31. Olds TS, Maher CA, Matricciani L. Sleep duration or bedtime? Exploring the relationship between sleep habits and weight status and activity patterns. Sleep 2011;34(10):1299–307.
32. Moore SA, Faulkner G, Rhodes RE, et al. Impact of the COVID-19 virus outbreak on movement and play behaviours of Canadian children and youth: a national survey. Int J Behav Nutr Phys Act 2020;17(1):1–11.
33. Burkart S, Parker H, Weaver RG, et al. Impact of the COVID-19 pandemic on elementary schoolers' physical activity, sleep, screen time and diet: A quasi-experimental interrupted time series study. Pediatr Obes 2021;e12846.
34. Bates LC, Zieff G, Stanford K, et al. COVID-19 Impact on behaviors across the 24-hour day in children and adolescents: physical activity, sedentary behavior, and sleep. Children 2020;7(9):138.
35. Hemphill NM, Kuan MTY, Harris KC. Reduced physical activity during COVID-19 pandemic in children with congenital heart disease. Can J Cardiol 2020;36(7): 1130–4.
36. Okely A, Kariippanon K, Guan H, et al. Global effect of COVID-19 pandemic on physical activity, sedentary behaviour and sleep among 3-to 5-year-old children: a longitudinal study of 14 countries. 2020.
37. Weaver RG, Hunt ET, Armstrong B, et al. COVID-19 leads to accelerated increases in children's BMI z-score gain: An interrupted time-series study. Am J Prev Med 2021;61(4):e161–9.
38. Browne NT, Snethen JA, Greenberg CS, et al. When pandemics collide: The impact of COVID-19 on childhood obesity. J Pediatr Nurs 2020;56(90).
39. Woolford SJ, Sidell M, Li X, et al. Changes in body mass index among children and adolescents during the COVID-19 pandemic. JAMA 2021;326(14):1434–6.
40. Aadland E, Andersen LB, Skrede T, et al. Reproducibility of objectively measured physical activity and sedentary time over two seasons in children; comparing a day-by-day and a week-by-week approach. PLoS One 2017;12(12):e0189304.
41. Atkin AJ, Sharp SJ, Harrison F, et al. Seasonal variation in children's physical activity and sedentary time. Med Sci Sports Exerc 2016;48(3):449–56.
42. Bagordo F, De Donno A, Grassi T, et al. Lifestyles and socio-cultural factors among children aged 6-8 years from five Italian towns: the MAPEC_LIFE study cohort. BMC Public Health 2017;17(1):233.
43. Beighle A, Alderman B, Morgan CF, et al. Seasonality in children's pedometer-measured physical activity levels. Res Q Exerc Sport 2008;79(2):256–60.
44. Beighle A, Erwin H, Morgan CF, et al. Children's in-school and out-of-school physical activity during two seasons. Res Q Exerc Sport 2012;83(1):103–7.
45. Brusseau TA. The intricacies of children's physical activity. J Hum Kinet 2015;47: 269–75.
46. Carskadon MC, Acebo C. Parental reports of seasonal mood and behavior changes in children. J Am Acad Child Adolesc Psychiatry 1993;32(2):264–9.
47. Cooper AR, Page AS, Wheeler BW, et al. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. Int J Behav Nutr Phys Act 2010;7:31.
48. Cullen KW, Liu Y, Thompson D. Diet and physical activity in african-american girls: seasonal differences. Am J Health Behav 2017;41(2):171–8.
49. Erwin D. An analytical study of children's sleep. Pedagogical Seminary J Genet Psychol 1934;45(1):199–226.
50. Fu Y, Brusseau TA, Hannon JC, et al. Effect of a 12-week summer break on school day physical activity and health-related fitness in low-income children from CSPAP schools. J Environ Public Health 2017;2017.

51. Harrison F, Atkin AJ, van Sluijs EMF, et al. Seasonality in swimming and cycling: exploring a limitation of accelerometer based studies. Prev Med Rep 2017; 7:16–9.
52. Heelan KA, Abbey BM, Donnelly JE, et al. Evaluation of a walking school bus for promoting physical activity in youth. J Phys Act Health 2009;6(5):560–7.
53. Hjorth MF, Chaput JP, Michaelsen K, et al. Seasonal variation in objectively measured physical activity, sedentary time, cardio-respiratory fitness and sleep duration among 8-11 year-old Danish children: a repeated-measures study. BMC Public Health 2013;13:808.
54. Hopkins N, Stratton G, Ridgers ND, et al. Lack of relationship between sedentary behaviour and vascular function in children. Eur J Appl Physiol 2012;112(2): 617–22.
55. Kolle E, Steene-Johannessen J, Andersen LB, et al. Seasonal variation in objectively assessed physical activity among children and adolescents in Norway: a cross-sectional study. Int J Behav Nutr Phys Act 2009;6:36.
56. Kolle E, Steene-Johannessen J, Andersen LB, et al. Objectively assessed physical activity and aerobic fitness in a population-based sample of Norwegian 9- and 15-year-olds. Scand J Med Sci Sports 2010;20(1):e41–7.
57. Kristensen PL, Korsholm L, Møller NC, et al. Sources of variation in habitual physical activity of children and adolescents: the European youth heart study. Scand J Med Sci Sports 2008;18(3):298–308.
58. Langlois KA, Birkett N, Garner R, et al. Trajectories of physical activity in Montreal adolescents from age 12 to 17 years. J Phys Act Health 2012;9(8):1146–54.
59. Larouche R, Gunnell K, Bélanger M. Seasonal variations and changes in school travel mode from childhood to late adolescence: a prospective study in New Brunswick, Canada. J Transport Health 2019;12:371–8.
60. Loucaides CA, Chedzoy SM, Bennett N. Differences in physical activity levels between urban and rural school children in Cyprus. Health Educ Res 2004;19(2): 138–47.
61. Loucaides CA. Seasonal differences in segmented-day physical activity and sedentary behaviour in primary school children. Early Child Development Care 2018;188(3):410–20.
62. Mattocks C, Leary S, Ness A, et al. Intraindividual variation of objectively measured physical activity in children. Med Sci Sports Exerc 2007;39(4):622–9.
63. McCrorie P, Mitchell R, Ellaway A. Comparison of two methods to assess physical activity prevalence in children: an observational study using a nationally representative sample of Scottish children aged 10-11 years. BMJ open 2018;8(1): e018369.
64. McCrorie P, Mitchell R, Macdonald L, et al. The relationship between living in urban and rural areas of Scotland and children's physical activity and sedentary levels: a country-wide cross-sectional analysis. BMC Public Health 2020; 20(1):304.
65. Nagy LC, Horne M, Faisal M, et al. Ethnic differences in sedentary behaviour in 6-8-year-old children during school terms and school holidays: a mixed methods study. BMC Public Health 2019;19(1):152.
66. Nilsen AKO, Anderssen SA, Ylvisaaker E, et al. Physical activity among Norwegian preschoolers varies by sex, age, and season. Scand J Med Sci Sports 2019;29(6):862–73.
67. Nixon GM, Thompson JM, Han DY, et al. Short sleep duration in middle childhood: risk factors and consequences. Sleep 2008;31(1):71–8.

68. Oreskovic NM, Blossom J, Field AE, et al. Combining global positioning system and accelerometer data to determine the locations of physical activity in children. Geospat Health 2012;6(2):263–72.
69. Ostrin LA, Sajjadi A, Benoit JS. Objectively measured light exposure during school and summer in children. Optom Vis Sci 2018;95(4):332–42.
70. Pagels P, Raustorp A, Guban P, et al. Compulsory school in- and outdoors-implications for school children's physical activity and health during one academic year. Int J Environ Res Public Health 2016;13(7).
71. Pagels P, Wester U, Mårtensson F, et al. Pupils' use of school outdoor play settings across seasons and its relation to sun exposure and physical activity. Photodermatol Photoimmunol Photomed 2020;36(5):365–72.
72. Remmers T, Thijs C, Timperio A, et al. Daily weather and children's physical activity patterns. Med Sci Sports Exerc 2017;49(5):922–9.
73. Ridgers ND, Salmon J, Timperio A. Too hot to move? objectively assessed seasonal changes in Australian children's physical activity. Int J Behav Nutr Phys Act 2015;12:77.
74. Rowlands AV, Pilgrim EL, Eston RG. Seasonal changes in children's physical activity: an examination of group changes, intra-individual variability and consistency in activity pattern across season. Ann Hum Biol 2009;36(4):363–78.
75. Sethre-Hofstad L, Dahl TI. Arctic larks and owls: children's sleeping patterns north of the arctic circle. Individual Differences Res 2012;10(1):1–18.
76. Stevens J, Story M, Ring K, et al. The impact of the pathways intervention on psychosocial variables related to diet and physical activity in American Indian schoolchildren. Prev Med 2003;37(6 Pt 2):S70–9.
77. Szymczak J, Jasińska M, Pawlak E, et al. Annual and weekly changes in the sleep-wake rhythm of school children. Sleep 1993;16(5):433–5.
78. Tanaka C, Reilly JJ, Tanaka M, et al. Seasonal changes in objectively measured sedentary behavior and physical activity in Japanese primary school children. BMC Public Health 2016;16(1):969.
79. Tanaka C, Reilly JJ, Tanaka M, et al. Changes in weight, sedentary behaviour and physical activity during the school year and summer vacation. Int J Environ Res Public Health 2018;15(5).
80. Vadiveloo M, Zhu L, Quatromoni PA. Diet and physical activity patterns of school-aged children. J Am Diet Assoc 2009;109(1):145–51.
81. Volmut T, Pišot R, Planinšec J, et al. Physical activity drops during summer holidays for 6-to 9-year-old children. Front Public Health 2020;8.
82. Wickel EE, Welk GJ. Applying generalizability theory to estimate habitual activity levels. Med Sci Sports Exerc 2010;42(8):1528–34.
83. Ylitalo KR, Bridges CN, Gutierrez M, et al. Sibship, physical activity, and sedentary behavior: a longitudinal, observational study among Mexican-heritage sibling dyads. BMC Public Health 2019;19(1):1–9.
84. Zelener J, Schneider M. Adolescents and self-reported physical activity: An evaluation of the modified Godin Leisure-time exercise questionnaire. Int J Exerc Sci 2016;9(5):587.
85. Sera F, Griffiths LJ, Dezateux C, et al. Using functional data analysis to understand daily activity levels and patterns in primary school-aged children: cross-sectional analysis of a UK-wide study. PLoS One 2017;12(11):e0187677.