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QUANTITATIVE RESEARCH

Stay in or play out? The influence of weather conditions on physical activity of grade 5 children in Canada

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Abstract

Objectives Regular physical activity (PA) in children is essential for their development and prevention of overweight and obesity. Little is known about the effect of day-to-day variations in weather conditions on PA levels in school-aged children, particularly with regard to school compared to non-school days and girls compared to boys.

Methods Daily step count (7:00 a.m.–9:00 p.m.) from 972 grade 5 students aged 10–11 years from 60 schools across Alberta, Canada, was collected using time-stamped pedometers (minimum wear time of two school and one non-school days) during March–June 2013. Time-matched weather conditions (actual and feels-like temperature, cloud coverage, and precipitation amount) were obtained from local weather stations in Alberta during the same period. Multilevel mixed-effect regression models were used to estimate the effect of each weather condition on daily step count.

Results A 1 °C increase in feels-like temperature was associated with 26 more steps/day ($p < 0.05$), while 1-unit increase in cloud coverage was associated with 61 fewer steps/day ($p < 0.01$). Compared to no precipitation, heavy precipitation (> 5 mm/day) was associated with 1022 fewer steps/day ($p < 0.01$). Students' PA levels were associated with weather conditions more on non-school vs. school days and more among girls vs. boys.

Conclusion Results suggest that daily weather conditions can affect PA in school children, particularly outside school hours, and should be considered when evaluating PA levels or designing interventions to promote PA in children. Findings provide support for increased investment toward creating weather-appropriate physical activity opportunities for wet and colder days to prevent PA decline in children during inclement weather conditions.

Résumé

Objectifs L'activité physique (AP) pratiquée régulièrement par les enfants est essentielle à leur développement et à la prévention du surpoids et de l'obésité. Les effets des variations quotidiennes des conditions météorologiques sur les niveaux d'AP des enfants d'âge scolaire sont méconnus, particulièrement entre les jours de classe et de congé et entre les filles et les garçons.

Méthode Entre mars et juin 2013, nous avons compté le nombre de pas quotidien (entre 7 h et 21 h) de 972 élèves de 5e année de 60 écoles de l'Alberta, au Canada, âgés de 10 ou 11 ans à l'aide de podomètres avec horodateurs (portés pendant au moins deux jours de classe et un jour de congé). Les conditions météorologiques appariées dans le temps (température réelle et ressentie, couverture nuageuse et quantité de précipitations) ont été obtenues auprès de stations météorologiques locales durant la même période. Des modèles de régression multiniveaux à effets mixtes ont servi à estimer l'effet de chaque condition météorologique sur le nombre de pas quotidien.

Résultats Une hausse d'un degré Celsius de la température ressentie était associée à 26 pas/jour de plus ($p < 0{,}05$), mais une hausse d'une unité de couverture nuageuse était associée à 61 pas/jour de moins ($p < 0{,}01$). Comparativement à l'absence de précipitations, les fortes précipitations (> 5 mm/jour) étaient associées à 1022 pas/jour de moins ($p < 0{,}01$). Les niveaux d'AP des

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élèves étaient plus associés aux conditions météorologiques les jours de congé que les jours de classe, et plus chez les filles que chez les garçons.

Conclusion Les résultats montrent que les conditions météorologiques quotidiennes peuvent avoir un effet sur l'AP des enfants d'âge scolaire, surtout hors des heures de classe, et qu'il faut en tenir compte en évaluant les niveaux d'AP ou en concevant des interventions pour promouvoir l'AP chez les enfants. Ces constatations confirment la nécessité d'investir davantage dans la création de possibilités d'activité physique adaptées à la météo pour les jours de pluie ou de froid afin d'empêcher une baisse d'AP des enfants par mauvais temps.

Keywords Physical activity · Weather conditions · Step count · School children · Mixed-effect modeling

Mots-clés Activité physique · Conditions météorologiques · Nombre de pas · Enfants d'âge scolaire · Modélisation à effets mixtes

Introduction

Regular physical activity (PA) in childhood protects against future chronic disease, such as diabetes and hypertension, and is an important component of childhood overweight and obesity prevention (Poitras et al. 2016). Yet, the majority of Canadian children are not sufficiently active. Nationally representative data show that only 9% of boys and 4% of girls meet the current recommendations for 5–17 year olds of at least 60 min of moderate-to-vigorous physical activity (MVPA) per day to achieve associated health benefits (Colley et al. 2017). In Canada, PA is weather dependent as most regions experience a wide fluctuation in weather conditions, such as ambient and feels-like temperature, cloud coverage, and precipitation amount. These fluctuations are most pronounced in Canadian Prairie provinces of Alberta, Saskatchewan, and Manitoba (Zhang et al. 2000). Thus, the importance of weather influence on PA in children is particularly relevant in these regions and may need to be considered when designing obesity and chronic disease prevention interventions, or assessing PA levels in children.

Being outdoors is a key determinant of overall PA levels, since time spent outdoors is generally spent more actively than time spent indoors (Stone and Faulkner 2014). Growing evidence from Western Europe, Canada, and the United States supports the existence of seasonal variation in PA, irrespective of study design and PA measurement tools, with PA levels being highest during spring and summer and lowest during fall and winter (Carson and Spence 2010). Day-to-day variation in weather conditions, particularly increased precipitation and lower temperature, are negatively associated with step count (Katapally et al. 2015; Aibar et al. 2013; O'Neill et al. 2011; Duncan et al. 2008). A recent Canadian study of school-aged children demonstrated that children's PA levels decline on non-school days compared to school days, particularly among boys (Vander Ploeg et al. 2012). However, few studies have considered whether day-to-day variation in weather conditions, such as temperature, cloud coverage, and precipitation, affects PA levels differently on school vs. non-school days and in girls vs. boys. Characterizing whether and to what extent day-to-day variability in weather conditions, such as temperature, cloud coverage, and precipitation, may act as barriers or facilitators to PA in children is important to inform, plan, and design effective strategies for promoting PA in children (Brockman et al. 2011). Therefore, the objective of this study was to examine the effect of day-to-day variability in weather conditions on PA levels in school-aged children in Alberta on school vs. non-school days and in girls vs. boys.

Methods

Data were collected between March and June 2013 using the Raising Healthy Eating and Active Living (REAL) Kids Alberta survey in two provincial school-based programs in Alberta, Canada: the Alberta Project Promoting Active Living and Healthy Eating (APPLE) Schools and the Healthy Schools-Healthy Future (HSHF). All invited schools and their school boards agreed to the research. All grade 5 students, aged 10–11 years, of the 60 involved schools were invited to participate. Information on PA levels, anthropometric measurements, diet quality, socio-economic backgrounds, school environment, programs, and practices were collected through a home survey, a student survey, and a principal survey. The overall survey completion rate was 92.5%. All students provided assent, and their parents/guardians provided signed informed consent. This data collection received ethics approval from the Human Research Ethics Board (REB) of the University of Alberta.

Physical activity PA was measured using Omron HJ-720 ITC time-stamped pedometer. The reliability and validity of the Omron pedometer has been previously demonstrated under various conditions (De Vries et al. 2009). This pedometer has a 41-day storable memory that records hourly steps along with the time and date of recording and automatically resets at midnights so participants do not need to record their step counts at the end of each day. This pedometer also has a sensitive motion detector to indicate whether it was worn, which allowed us to distinguish periods of non-wear time.

The students were instructed to wear the pedometer on their right hip directly in line with their right knee for nine consecutive days during all waking hours except when showering, swimming, or participating in high impact sports and activities due to safety regulations. Due to differing administration and collection times, the first and last days of pedometer records were not included in the analysis. This resulted in seven full days of PA data for each participant. Data from pedometers were considered valid and complete if the students wore a pedometer for a minimum of 8 h per day (Vander Ploeg et al. 2012) and for at least two school days (i.e., Monday through Friday) and one non-school day (i.e., Saturday, Sunday, and holidays) (Rowe et al. 2004). Daily step counts of < 1000 ($n = 83$) or > 30,000 ($n = 41$) were considered as outliers and excluded from analysis (Rowe et al. 2004). Students were also asked to record for every 2-h block between 7:00 a.m. and 9:00 p.m. the type and duration of their activities in activity logs, regardless of whether the pedometer was worn. The pedometer-measured steps were complemented with non-wear-time activities that students recorded in their activity logs. This was estimated by assigning each recorded activity a metabolic equivalent task (MET) unit. With consideration for the duration of the activity, these METs were converted into step equivalents and added to the pedometer-measured steps (De Vries et al. 2009). For non-wear time during which students forgot to complete their activity log, we imputed information from another randomly selected day while giving consideration to the duration of the non-wear time and whether this was on a school day or non-school day. The proportion of students meeting current recommendations was based on ≥ 12,000 steps per day, which is approximately equivalent to 60 min of MVPA daily (Colley et al. 2012). Of 1344 students who had recorded pedometer data for at least 3 days, 972 students met the inclusion criteria (minimum of 8 h of wear time on at least two school days and one non-school day) and were collectively responsible for 5958 valid days of observations: 18.0% of these observations were in March (1080 days), 39.8% in April (2370 days), 31.0% in May (1842 days), and 11.2% in June (666 days). Analyses were limited to 972 students and their PA recordings between 7:00 a.m. and 9:00 p.m. since children of this age tend to be either less active or inactive outside this period and since the little PA outside this period is unlikely to be affected by weather conditions (Comte et al. 2013).

Weather conditions Access to meteorological data collected by Environment Canada was obtained through the Weather Network Commercial Services (TWNCS). The 24-hourly meteorological variables for the period March to June 2013, ascribed to 23 sites across Alberta where the participating schools are located, included hourly actual temperature (°C), hourly "feels-like" temperature (°C), hourly cloud coverage (0–10 scale), and daily precipitation amount (mm). Cloud coverage refers to the amount of sky that is covered by layers of cloud and is reported on a 10-point scale, with 0 being clear sky and 10 being overcast (Environment and Climate Change Canada (ECCC) 2016). Daily precipitation refers to the water equivalent from all types of precipitation, including rainfall and snowfall. Precipitation had a skewed distribution and was categorized as none (0 mm/day), light (0.01–5 mm/day) and heavy precipitation (> 5 mm/day).

Covariates Participants self-reported their sex. Height was measured to the nearest 0.1 cm using stadiometers and body weight to the nearest 0.1 kg on calibrated weighting digital scale by evaluation assistants after students were asked to take off their shoes. Body mass index (BMI) was calculated as weight (in kilograms) divided by height squared (in metres). Weight status was categorized as normal, overweight, and obese based on WHO age- and sex-specific cutoffs for children (Canadian Task Force on Preventive Health Care 2015). Information was collected on parental educational attainment (secondary school or less [reference], college diploma, and university or graduate school) and household income ($50,000 or less [reference], $50,000–100,000, and more than $100,000) through home surveys completed by students' parents/guardians. Weekdays were categorized as school days (Monday through Friday) and non-school days (Saturday, Sunday, and holidays). School regions were categorized as rural (< 40,000), urban (> 40,000), and metropolitan (> 1 million) based on the 2011 Statistics Canada classification of the census areas (Fung et al. 2012).

Statistical analyses

Meteorological and step count data were combined based on the identification numbers assigned to each school and each participant and were matched for date, month of observation, and school region to assess day-to-day variation. Hourly data between 7:00 a.m. and 9:00 p.m. were averaged to obtain a daily estimate for each weather condition, except precipitation, which was provided as total daily amount (mm). Multilevel mixed-effect regression modeling was used to assess the association between daily weather conditions and total number of steps per day (outcome) to take into account the nested data structure (i.e., repeated days of observations of students, students nested within schools, and schools located within the same region of weather data collected). In all models, the random effects (random intercepts) included weather region variance (23 sites across Alberta), school variance (60 schools), and between-subject variance (972 participants). Models were adjusted for the following fixed-effect covariates: student's sex, weight status, parent's income, parent's education, school region (rural, urban, metropolitan), and day of the week (school day vs. non-school day). A random

intercept was included with repeated term for each participant to adjust for day-to-day variation in daily PA levels within individuals, as theoretically day-to-day variation in PA might influence the association between weather conditions and PA. Linearity assumption in the association between daily PA step count with each weather condition was verified and met. Finally, analyses were stratified by day type (school vs. non-school) and by sex (girls vs. boys). Statistical significance was set at 0.05, and Stata Version 13 (Stata Corp, College Station, TX) was used for all analyses.

Results

Students were, on average, 10.9 ± 0.4 years old, 58% were girls, and almost half were either overweight (20.6%) or obese (25.2%) (Table 1). Similar proportions of boys and girls were overweight, and more boys than girls were classified as obese (30.0% vs. 19.5%, $p < 0.05$). About half (49.5%) of participants were from families with annual household income > $100,000 and had a parent with post-secondary diploma or degree. During a typical week of five school days and two non-school days, students took on average 11,011 ± 5751 steps per day. The daily step count was higher on school days compared to non-school days (11,483 ± 5008 vs. 9953 ± 6974, respectively, $p < 0.001$). On average, boys recorded 1476 more steps per day than girls in a typical week (11,889 ± 6453 vs. 10,413 ± 5135, respectively, $p < 0.001$). More students met the recommended 12,000 or more steps per day on school days compared to non-school days (40% vs. 30%, respectively, $p < 0.05$). Compared to girls, more boys met the MVPA recommendation on school days (49% boys vs. 34% girls) and non-school days (33% boys vs. 29% girls, $p < 0.001$).

The temperature gradually increased during the 4 months of the study (Fig. 1), with a mean difference of 27 °C between March and June ($p < 0.05$). The average temperature (°C) was − 12 ± 5.7 in March (lowest − 28, highest 7), 1 ± 5.3 in April (lowest − 14, highest 20), 12 ± 6.5 in May (lowest − 5, highest 30), and 14.6 ± 3.6 in June (lowest 7, highest 24). Cloud coverage and total precipitation did not exhibit a clear trend during this period. The average cloud coverage was higher in March (6.4 ± 4.3) and April (6.2 ± 4.0), compared to May (4.6 ± 3.3) and June (5.0 ± 3.6). Total daily precipitation was zero or near zero millimetres, while light precipitation (0.01–5 mm/day) occurred on 33.6% of days in March, 23.7% of days in April, 9% of days in May, and 27% of days in June. Heavy precipitation (> 5 mm/day) occurred on 1–2% of days in March and April, but more in May and June (12.7% and 19%, respectively).

Results from multilevel mixed-effect regression models indicated that overall, daily average actual and feels-like temperature were positively associated with daily step count (Table 2). Students recorded 24 more steps/day with each degree Celsius increase in daily average feels-like temperature ($p = 0.04$), independent of their sex, weight status, day type, and parental socio-economic status. Students took, on average, 61 fewer steps/day with every unit increase in the daily average cloud coverage ($p = 0.002$). Compared to no precipitation, students took 1022 fewer steps/day ($p = 0.001$) on days with heavy precipitation (> 5 mm).

Multilevel mixed-effect regression models stratified by day type indicated that each degree Celsius increase in daily average actual and feels-like temperature was associated with 35 and 38 more steps/day, respectively, on school days ($p = 0.02$ and $p < 0.01$, respectively) and 65 and 60 more steps/day, respectively, on non-school days (both $p < 0.01$) (Table 3). Each unit increase in cloud coverage was associated with 170 fewer steps/day on non-school days ($p < 0.01$), and this association was not statistically significant ($p = 0.05$) on school days. Daily PA was negatively affected by heavy precipitation on both school and non-school days, with students taking 663 fewer steps/day on school days ($p = 0.01$) and 2427 fewer steps/day on non-school days ($p < 0.01$). When regression models were stratified by sex, girls' daily step count was affected by all weather conditions, whereas in boys, only heavy precipitation affected daily step count in a statistically significant manner ($p = 0.01$). The magnitude of the effect of most weather conditions on PA was also more pronounced in girls than boys, except for heavy precipitation that had a stronger effect in boys.

Discussion

The results show that changes in ambient temperature, cloud coverage, and total precipitation impact children's daily step count, regardless of their sex, day of the week, school region, and parental socio-economic status. Herewith, they contribute to the existing evidence that higher temperature and less precipitation increase PA levels among school-aged children (Katapally et al. 2015; Aibar et al. 2013; O'Neill et al. 2011; Duncan et al. 2008; Lewis et al. 2016; Bélanger et al. 2009).

While mean ambient temperature in Alberta can vary from – 25 °C or lower in winter to 35 °C in summer during the year (Environment and Climate Change Canada (ECCC) 2016), the data collection for this study took place from March to June. This time period is characterized by gradual increasing trend in temperature. Unlike the gradually increasing temperature, precipitation can vary greatly during spring months in Alberta. During this period, we observed that the average monthly temperature had increased by 27 °C. Since each degree increase in daily average actual temperature was associated with 22 more steps/day regardless of whether this was on a school day or non-school day, this means that participating students may have taken as many as 594 more steps/day (i.e., 27 Celsius degrees

Table 1 Characteristics of study participants, Alberta, Canada, 2013

	Girls ($n = 562$)	Boys ($n = 392$)	Total ($n = 972$)[a]
Age (years), mean (SD)	10.8 (0.4)	10.9 (0.4)[b]	10.9 (0.4)
BMI (kg/m^2), mean (SD)	19.4 (4.0)	20.2 (4.5)[b]	19.7 (4.2)
Weight status[c] (%)			
Normal	58.8	50.2[b]	54.2
Overweight (not obese)	21.7	20.0	20.6
Obese	19.5	30.0	25.2
Parent's education (%)			
Secondary or less	25.2	28.3[b]	26.4
College diploma	37.0	36.0	36.5
University or graduate	38.0	35.9	37.0
Household income (%)			
≤ $50,000	22.8	20.8[b]	22.0
$50,001–$75,000	13.8	12.5	13.3
$75,001–$100,000	16.0	14.3	15.2
≥ $100,001	47.5	52.3	49.5
School region (%)			
Rural	12.0	10.0	12.0
Urban	53.0	52.0	53.0
Metropolitan	35.0	35.0	35.0
Physical activity (steps/day)[d], mean (SD)			
Typical week[e]	10,413 (5135)	11,889 (6453)[b]	11,011 (5751)
School days	10,791 (4443)	12,520 (5581)[b]	11,483 (5008)
Non-school days	9586 (6315)	10,518 (7860)[b]	9953 (6974)
Meet MVPA recommendation[f] (%)			
School days	34.0	48.6[b]	40.0
Non-school days	28.7	33.0[b]	30.0

SD Standard deviation, *BMI* body mass index (kg/m^2), *MVPA* moderate-to-vigorous physical activity

[a] Includes participants with missing data for sex ($n = 18$), BMI ($n = 70$), parent's education ($n = 60$), and household income ($n = 389$)

[b] Difference between boys and girls is based on $p < 0.05$ of two-sample Student's t test for continuous variables and chi-squared test for categorical variables

[c] Based on the WHO age- and sex-specific BMI z score cutoffs for children

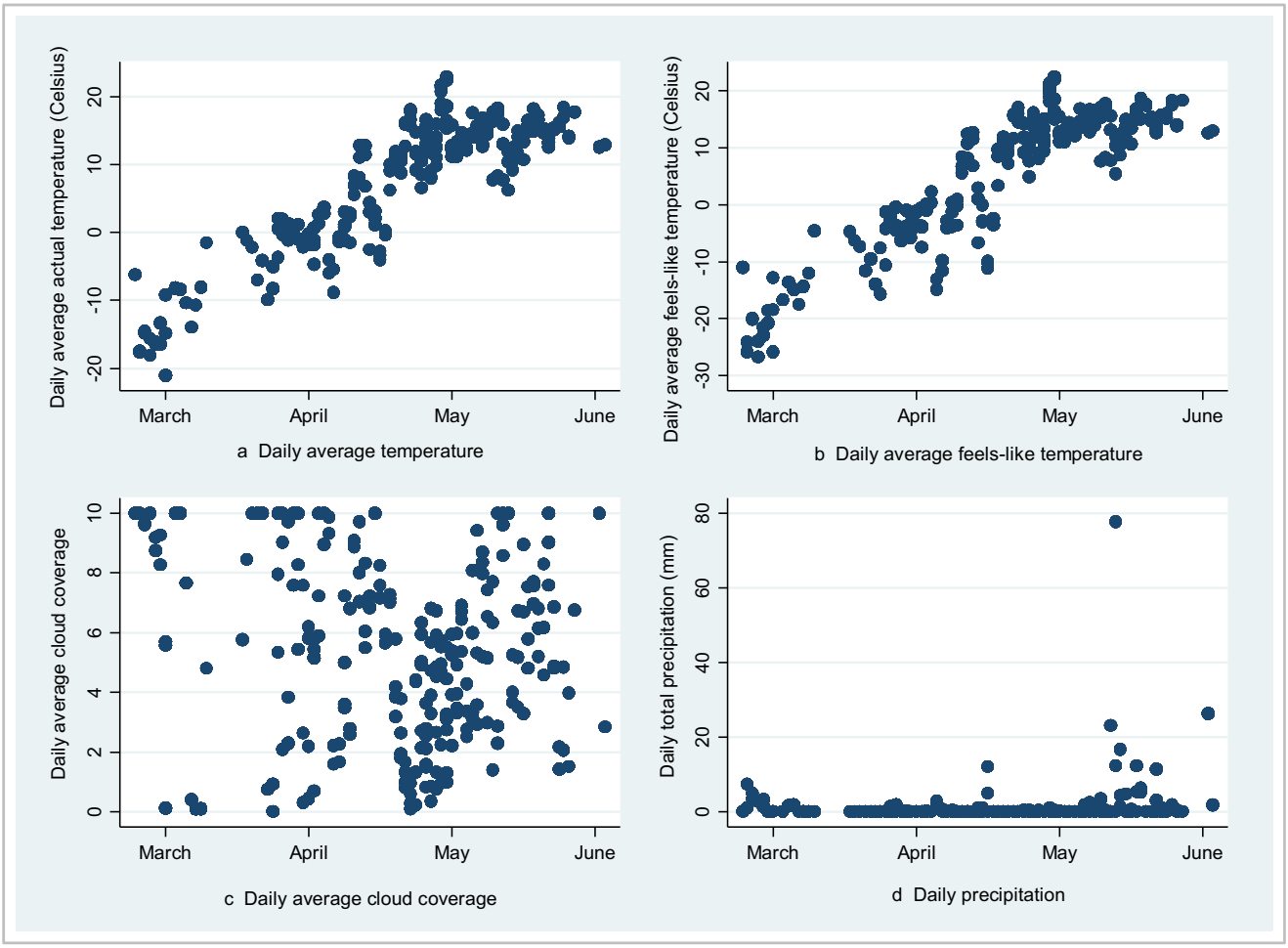
[d] Steps between 7:00 a.m. and 9:00 p.m. adjusted for non-wear time and missing data

[e] A typical week is defined as five school days and two non-school days. The average steps/day in a typical week for each participant was calculated as [(total steps/day on a school day × 5) + (total steps/day on a non-school day × 2)] / 7

[f] Based on 12,000 or more steps per day, which is approximately equivalent to 60 min of MVPA daily

times 22 steps). On non-school days, this would amount to 1755 more steps/day (i.e., 27 Celsius degrees times 65 steps). Likewise, a clear sky compared to overcast on a non-school day would yield a difference of 1700 more steps/day (i.e., 10 units times 170 steps). Moreover, a dry day compared to a day of heavy precipitation would make a difference of 2427 more steps/day. These are substantial differences in PA levels but are difficult to compare with findings of others because of diverse weather conditions across study sites as well as the time or season of data collection. Nonetheless, given that on a typical weekday, participating students took, on average, 11,000 steps/day, the associated increase in step count as a result of changes in the four weather conditions may be sufficient to attain the MVPA recommendation (i.e., ≥ 12,000 steps/day).

Unlike temperature that gradually increased during the study period, precipitation and cloud coverage showed fluctuation that did not follow any trend. This day-to-day variability could underlie our finding of greater associations with precipitation than temperature since people can anticipate seasonal variation in temperature and plan activities accordingly. In contrast to changes in temperature, variation in the amount of precipitation happens more randomly, particularly during spring months, and this uncertainty is likely to negatively impact PA among children. This finding corroborates previous



*All weather conditions are considered as daily averages between 7:00am and 9:00pm, except precipitation which is total daily amount (mm)

Fig. 1 Variation in daily weather conditions between March and June 2013 across 23 regions in Alberta, Canada

evidence that variability in weather conditions is an important barrier to children's PA and that variability in precipitation affects children's PA levels to a greater extent compared to other weather conditions, particularly in regions with prolonged colder seasons (Brockman et al. 2011; Tucker and Gilliland 2007).

The association between weather conditions and PA was more evident on non-school days compared to school days. However, previous Canadian research in 9–11-year-old children from Ottawa, Ontario, reported that weather conditions, such as temperature and rainfall, collected between October 2012 and May 2013 had greater influence on children's MVPA and sedentary time on school days rather than non-school days (Lewis et al. 2016). Similar to our results, a study from New Zealand found greater association of mean ambient temperature with boys' PA levels on non-school days, compared to school days (Duncan et al. 2008). It is possible that spontaneous and unplanned activities that generally take place on weekends and non-school days are more likely to be affected by unexpected variations in weather conditions. Additionally, schools provide an environment to engage children in regular PA opportunities, both indoors and outdoors (Brazendale et al. 2017). Consistent with existing evidence (Vander Ploeg et al. 2012; Vander Ploeg et al. 2014), we found that PA levels and the proportion of students achieving the MVPA recommendations were higher on school days compared to non-school days. This difference could be the result of school policies and programs, such as physical education classes, mandatory recess periods, and a provincial curriculum requirement by Alberta Education of a minimum of 30 min of daily physical activity (DPA) for students in grades 1 to 9 (Canadian Fitness and Lifestyle Research Institute 2007). It is thus plausible that variation in daily weather conditions and unexpected changes in temperature have less impact on children's PA levels on school days. Nonetheless, inclement weather conditions might negatively impact PA levels when children are kept indoors during recess periods, with limited indoor activities or PA opportunities provided.

Table 2 Associations between daily weather conditions and physical activity (steps/day) in a typical week among 972 grade 5 students in Alberta, Canada in 2013

	Unadjusted model			Adjusted model[a]		
	β	95% CI	*p*	*β*	95% CI	*p*
Temperature (per 1 °C)						
Actual temperature	15	− 16, 44	0.3	22	− 7, 51	0.1
Feels-like temperature	23	− 1, 48	0.06	24	1, 48	0.04
Cloud coverage (per 1 unit)[b]	− 97	− 135, − 58	< 0.001	− 61	− 99, − 22	0.002
Total precipitation/day						
None (0 mm)	Ref.			Ref.		
Light (0.01–5 mm)	− 556	− 880, − 232	0.001	− 209	− 535, 116	0.2
Heavy (> 5 mm)	− 957	− 1500, − 416	0.001	− 1022	− 1557, − 487	< 0.001

All weather conditions are considered as daily averages between 7:00 a.m. and 9:00 p.m., except precipitation which is total daily amount (mm)

CI confidence interval

[a] Estimates for each of weather conditions are derived from separate models. Each model is adjusted for sex, weight status, parent's education, household income, day of the week, and school region. Weather conditions are not mutually adjusted

[b] Cloud coverage ranges from 0 to 10, with 0 being clear sky and 10 being overcast

Our finding that girls are more susceptible to the effects of weather conditions compared to boys, corroborates existing literature (Duncan et al. 2008; Lewis et al. 2016; Brodersen et al. 2005), although not all studies find this sex variation (Bélanger et al. 2009). One Canadian study based in Ottawa reported that a 10 °C increase in temperature during October 2012 and May 2013 was associated with 3400 more steps/day in boys and 2300 more steps/day in girls (Duncan et al. 2008). However, another Canadian study reported that maximum daily temperature was associated with similar MVPA increases in both girls and boys (Lewis et al. 2016). In adults, rainfall was reported to have a larger effect on daily PA levels in females than in males (Chan et al. 2006). While it is well established that overall, boys are more active than girls, as also observed in our data, there are many factors, including boys' greater self-efficacy, greater tolerance of injury (cautiousness), mastery of skill, and support from peers and parents, that may underlie these differences and help boys overcome environmental barriers to PA (Brodersen et al. 2005; Spence et al. 2010).

Table 3 Associations between daily weather conditions and physical activity (steps/day) according to day of the week and sex in 972 grade 5 students in Alberta, Canada in 2013

	School days (*n* = 4089)			Non-school days (*n* = 1869)			Girls (*n* = 562)			Boys (*n* = 392)		
	β[a]	95% CI	*p*	*β*[a]	95% CI	*p*	*β*[b]	95% CI	*p*	*β*[b]	95% CI	*p*
Temperature (per 1 °C)												
Actual temperature	35	5, 65	0.02	65	16, 114	< 0.01	54	25, 82	< 0.01	11	− 36, 57	0.6
Feels-like temperature	38	14, 63	< 0.01	60	20, 101	< 0.01	50	26, 73	< 0.01	13	− 25, 52	0.5
Cloud coverage (per 1 unit)[c]	− 12	− 50, 25	0.5	− 170	− 267, − 73	< 0.01	− 69	− 115, − 22	< 0.01	− 45	− 112, 22	0.2
Total precipitation/day												
None (0 mm)	Ref.			Ref.			Ref.			Ref.		
Light (0.01–5 mm)	− 423	− 793, − 53	0.02	− 232	− 422, 886	0.5	− 623	− 1015, − 231	< 0.01	327	− 241, 896	0.26
Heavy (> 5 mm)	− 663	− 1177, − 148	0.01	− 2427	− 3884, − 969	< 0.01	− 769	− 1410, − 128	0.02	− 1194	− 2154, − 234	0.01

All weather conditions are considered as daily averages between 7:00 a.m. and 9:00 p.m., except precipitation which is total daily amount (mm)

CI confidence interval

[a] Estimates for each of weather conditions are derived from separate models. Each model is adjusted for sex, weight status, parent education, household income, and school region. Weather conditions are not mutually adjusted

[b] Estimates for each of weather conditions are derived from separate models. Each model is adjusted for weight status, parent education, household income, school region, and day of the week. Weather conditions are not mutually adjusted

[c] Cloud coverage ranges from 0 to 10, with 0 being clear sky and 10 being overcast

The key strength of this study is measured PA using time-stamped pedometers, with step count adjusted for non-wear time and missing data based on daily activity logs completed by students (Vander Ploeg et al. 2014; Masse et al. 2002). This allowed activities that were not recorded by the pedometers to be incorporated in order to provide a more accurate estimate of actual activity levels. Other strengths include the use of accurate and reliable meteorological data for the province, the use of individual repeated measures that better capture children's PA in a typical week, and the use of multilevel mixed-effect models to account for clustering of students within schools and schools within regions across Alberta.

Several limitations warrant consideration. The sample of students included in the current study is not representative of the provincial population, as the schools were not randomly selected, thus limiting the generalizability of study findings. PA and meteorological data were available for a limited timeframe between March to June 2013, and the observed relationships may not hold over an extended period of observation or different seasons (e.g., increasing PA levels being hampered by summertime high temperatures). The set of four meteorological variables provided by TWNCS hinders conclusions about the full set of weather conditions, including wind speed, sunshine duration, and other factors, that may affect PA levels. Also, precipitation reported in meteorological data included both snowfall and rainfall. Although these two conditions could have a different impact on children's PA levels, it was not possible to distinguish between the two. Finally, as with other observational studies, there is a possibility of residual or unmeasured (e.g., immigrant status, ethnic background, parental attitudes toward outdoor play in adverse weather conditions) confounding.

Conclusion

Successful promotion of PA in children requires both individual-level and population-level interventions. The latter is of particular importance, as even a small shift in a population can result in major public health benefits. Our finding that weather conditions have a substantial effect on children's PA levels on non-school days that is almost double the effect on school days supports the fact that parents and the home environment play an important role in shaping healthy lifestyle behaviours (Spence et al. 2012). In summary, developing weather-appropriate and indoor physical activity opportunities for wet and colder days will help minimize the impact of unfavourable weather conditions on children's PA and prevent a transient weather-induced decline in PA levels. Additionally, structured physical education classes and sex-focused interventions and programs may help promote PA equally among girls and boys (Sarkin et al. 1997).

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