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Published in:
Applied Physiology, Nutrition, and Metabolism

DOI:
10.1139/apnm-2016-0026

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

NRC Research Press

ARTICLE

Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses[1]

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Abstract: The purpose of this study was to examine the relationships between movement behaviours (sleep duration, sedentary time, physical activity) and health indicators in a representative sample of children and youth using compositional analyses. Cross-sectional findings are based on 4169 children and youth (aged 6–17 years) from cycles 1 to 3 of the Canadian Health Measures Survey. Sedentary time (SB), light-intensity physical activity (LPA), and moderate- to vigorous-intensity physical activity (MVPA) were accelerometer-derived. Sleep duration was subjectively measured. Body mass index *z* scores, waist circumference, blood pressure, behavioural strengths and difficulties, and aerobic fitness were measured in the full sample. Triglycerides, high-density lipoprotein-cholesterol, C-reactive protein, and insulin were measured in a fasting subsample. The composition of movement behaviours was entered into linear regression models via an isometric log ratio transformation and was found to be associated with all health indicators ($p < 0.01$). Relative to other movement behaviours, time spent in SB or LPA was positively associated ($p < 0.04$) and time spent in MVPA or sleep was negatively associated ($p < 0.02$) with obesity risk markers. Similarly, LPA was positively associated ($p < 0.005$) and sleep was negatively associated ($p < 0.03$) with unfavourable behavioural strengths and difficulties scores and systolic blood pressure. Relative to other movement behaviours, time spent in SB was negatively associated ($p < 0.001$) and time spent in MVPA ($p < 0.001$) was positively associated with aerobic fitness. Likewise, MVPA was also negatively associated with several cardiometabolic risk markers ($p < 0.008$). Compositional data analyses provide novel insights into collective health implications of 24-h movement behaviours and can facilitate interesting avenues for future investigations.

Key words: physical activity, sedentary behaviour, sleep, obesity, fitness, metabolic syndrome, cardiovascular disease, compositional analysis, children, youth.

Résumé : Cette étude a pour objectif d'analyser la relation entre les comportements kinésiques (durée du sommeil, temps sédentaire, activité physique) et les indicateurs de santé dans un échantillon représentatif d'enfants et de jeunes en utilisant des analyses compositionnelles. Ces observations transversales sont basées sur 4169 enfants et jeunes (conclusions transversales sont basées sur 4169 enfants et les jeunes (âgés de 6–17 ans) des cycles 1 à 3 de l'Enquête canadienne sur les mesures de la santé. Le temps de sédentarité (« SB »), l'activité physique d'intensité légère (« LPA ») et l'activité physique d'intensité modérée à vigoureuse (« MVPA ») sont des mesures provenant d'accéléromètres. La durée du sommeil est mesurée subjectivement. Chez tous les jeunes, on mesure la cote *z* de l'indice de masse corporelle, le tour de taille, la pression sanguine, les forces et les faiblesses comportementales et la condition physique aérobie. Dans un sous-échantillon à jeun, on mesure les triglycérides, le cholestérol à lipoprotéines de haute densité, la protéine C-réactive et l'insuline. La composition des comportements kinésiques, insérée dans les modèles de régression linéaire par transformation log-ratio isométrique, est associée à tous les indicateurs de santé ($p < 0,01$). Comparativement aux autres comportements kinésiques, le temps de SB ou de LPA est positivement associé ($p < 0,04$) et le temps de MVPA ou le sommeil est négativement associé ($p < 0,02$) aux marqueurs du risque d'obésité. Tout autant, LPA est positivement associé ($p < 0,005$) et le sommeil est négativement associé ($p < 0,03$) à un score dommageable des forces et faiblesses comportementales et à la pression sanguine systolique. Comparativement à d'autres comportements kinésiques, le temps de SB est négativement associé ($p < 0,001$) et le temps de MVPA ($p < 0,001$) est positivement associé à la condition physique aérobie. Aussi, MVPA est négativement associé à plusieurs marqueurs de risque cardiométabolique ($p < 0,008$). L'analyse compositionnelle des données jette une nouvelle lumière sur les effets des comportements kinésiques durant toute une journée sur la santé globale et ouvre des voies pertinentes pour des études ultérieures. [Traduit par la Rédaction]

Mots-clés : activité physique, comportement sédentaire, sommeil, obésité, condition physique, syndrome métabolique, maladie cardiovasculaire, analyse compositionnelle, enfants, jeunes.

Received 13 January 2016. Accepted 7 March 2016.

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[1]This paper is part of a Special issue entitled Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep.

Introduction

From a movement perspective, time in a 24-h period is distributed among sleep, sedentary behaviour, and physical activity, and these behaviours range on a continuum from no/low movement to high movement. Traditionally, pediatric research has focused on the health implications of moderate- to vigorous-intensity physical activity (MVPA), the behaviour on the movement continuum that accounts for the smallest portion of the 24-h period even among those that are highly active (Chaput et al. 2014). A wealth of evidence has shown that 60 min of daily MVPA provides important benefits for body composition, cardiovascular and metabolic health, musculoskeletal health, mental health, and academic achievement among children and youth (Janssen and LeBlanc 2010; Poitras et al. 2016; Strong et al. 2005). A recent focus on the health implications of behaviours in the remaining waking hours of the day has resulted in an explosion of studies focusing on sedentary behaviour. Overall findings have been mixed, with screen-based sedentary behaviour, in particular television viewing, showing relatively consistent detrimental effects on health indicators but not total sedentary time among children and youth (Carson and Janssen 2011; Grydeland et al. 2012; Tremblay et al. 2011*a*; Veitch et al. 2012). Evidence is also growing on the health implications of light-intensity physical activity in children (LPA; e.g., activities of 1.5–3.9 METs), with preliminary findings showing some benefits, in particular for light-intensity activities at the higher end of the spectrum (Carson et al. 2013). When considering time outside of waking hours, short sleep duration has consistently been shown to be associated with obesity among children and youth, and evidence is growing for other health indicators (Chaput et al. 2016; Chen et al. 2008; Fatima et al. 2015).

Until recently, research has examined relationships of movement behaviours, including sleep, sedentary behaviour, physical activity, with health indicators individually and in isolation of each other (Ferrar et al. 2013), ignoring the intrinsic and empirical interactions between these behaviours (Foti et al. 2011). In a review of sedentary behaviour studies, Pedisic (2014) found that most studies only partially adjusted for other behaviours on the movement continuum. Some studies still concluded that sedentary behaviour is an independent determinant of health (Pedisic 2014), but findings are equivocal. The lack of consistency in results, especially in the pediatric population (Carson et al. 2016), may be due to methodological issues, including the inability of current regression models to correctly adjust for all behaviours on the movement continuum, including LPA and sleep. As time within a 24-h period is finite, time spent in different movement behaviours are intrinsically collinear and codependent (Chastin et al. 2015; Pedisic 2014). Therefore, even if 2 movement behaviours are found to be uncorrelated using traditional statistics, Pearson warned in the case of such closed data, correlations are spurious and not to be trusted (Pearson 1896). In other words, collinearity indices might return values that suggest noncollinearity while the collinearity exists by nature. Consequently, adjusting for all these behaviours in a traditional regression model that assumes independence between variables will tend to produce inconsistent findings (Pearson 1896). These data analyses challenges prevent the understanding of the combined effects of sleep duration, sedentary behaviour, and physical activity on health, despite the increase in 24-h measurement procedures with devices such as accelerometers. Alternatively, compositional analyses allow for dealing directly with the fundamental nature of movement behaviour data, which are intrinsically compositional (Chastin et al. 2015; Pedisic 2014).

Though compositional data analyses have been used in other disciplines for years (Aitchison 1982), it has only recently been introduced for movement behaviour data (Chastin et al. 2015; Pedisic 2014). A concise guide has been published by Chastin et al. (2015), specifically focusing on sleep, sedentary behaviour, and physical activity research. Briefly, compositional analyses deal with data that is a proportion of a finite whole (e.g., 24 h) and can be used when all parts or just some parts of the finite whole have been measured (Chastin et al. 2015). Compositional data analyses use the correct geometry (i.e., closed space versus open space) for bounded data and findings are interpreted as the effects of a behaviour as a proportion relative to the other behaviours instead of a behaviour being independent of another behaviour (Chastin et al. 2015).

To date, compositional data analyses have been used to examine the health implications of sleep duration, sedentary time, and physical activity on the health of adults (Chastin et al. 2015). No study to date using such methodology has focused on the pediatric population. Therefore, the purpose of this study was to examine the relationships between movement behaviours (sleep duration, sedentary time, and physical activity) and health indicators in a representative sample of Canadian children and youth using compositional analyses.

Materials and methods

Participants

Participants for this cross-sectional study were from cycles 1 (2007–2009), 2 (2009–2011), and 3 (2012–2013) of the Canadian Health Measures Survey (CHMS; Tremblay and Connor Gorber 2007). All 3 survey cycles collected data from a nationally representative sample of 3 to 79-year olds (6- to 79-year olds in cycle 1) living in private households. Data collection for the 3 CHMS cycles consisted of a health interview administered in the participant's home and a physical health examination conducted at a mobile examination centre. Participants were randomly assigned to attend a fasting or nonfasting appointment at the mobile examination centre. The fasting appointment required participants to fast for at least 10 h (Statistics Canada 2015*a*). Participation was voluntary for all components of the CHMS. Ethics approval was obtained from Health Canada and the Public Health Agency of Canada Research Ethics Board (Day et al. 2007). The current study was conducted on a subsample of 6- to 17-year-old children and youth. For children aged 6–13 years, written informed consent was obtained from a parent or guardian, and written informed assent was obtained from the child. For youth aged 14–17 years, independent written informed consent was obtained. Detailed information about the CHMS is available elsewhere (Statistics Canada 2011, 2013, 2015*a*, 2015*b*). A total of 5217 CHMS participants aged 6–17 years were eligible for this study.

Movement behaviours

Sedentary time, LPA, and MVPA variables were measured using waist-worn Actical accelerometers (Philips Respironics, Ore., USA). Participants were given the accelerometer at the mobile examination centre and asked to wear it during waking hours for 7 consecutive days. Data were collected in 1-min epochs for 6- to 17-year olds. Nonwear time was defined as ≥60 consecutive minutes of zero counts, with allowance for 2 min of counts between zero and 100 (Colley et al. 2010). To be included in the analyses, participants were required to have 4 or more valid days, with ≥10 h of wear time (Colley et al. 2010). Sedentary time was defined as <100 counts per minute (cpm) (Wong et al. 2011), LPA as 100–1499 cpm, and MVPA as ≥1500 cpm (Puyau et al. 2004). Minutes per day of sedentary time, LPA, and MVPA were calculated.

Sleep was assessed as part of the in-home health interview. Participants (aged 12 to 17 years) or their parents/guardians (for those aged 6 to 11 years) were asked: "How many hours do you (your child) usually spend sleeping in a 24-hour period, excluding time spent resting." Responses were recorded to the nearest half hour. Minutes per night of sleep was calculated. Time spent in the

4 movement behaviours were summed and normalized to proportion of the total time, which summed to 1 (Chastin et al. 2015).

Health indicators

Health indicators were chosen to capture obesity risk, a range of cardiometabolic risk factors, fitness, and social and emotional health, and were based on availability of measures in the CHMS. Body mass index (BMI) *z* scores, systolic and diastolic blood pressure, and behavioural strength and difficulties measures from the full eligible sample were used. Height and weight were measured by a trained health measures specialist using a ProScale M150 digital stadiometer (Accurate Technology Inc., Fletcher, N.C., USA) and a Mettler Toledo VLC with Panther Plus terminal scale (Mettler Toledo Canada, Mississauga, Ont., Canada) following the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) 3rd edition protocols (Canadian Society for Exercise Physiology (CSEP) 2003). World Health Organization (WHO) growth standards were used to calculate age- and sex-specific *z* scores (de Onis et al. 2007). Systolic and diastolic blood pressures were measured by a trained health measures specialist using the BpTRU BPM-300 (BpTRU Medical Devices Ltd., Coquitlam, B.C., USA) following a new protocol developed by the CHMS (Bryan et al. 2010), which was informed by a previous report (Campbell et al. 2005). After 5 min of rest, 6 measurements were taken at 1-min intervals, and the last 5 measures were averaged.

The behavioural Strengths and Difficulties Questionnaire (Goodman 1997) was completed by a parent or guardian. Total behavioural strength and difficulties scores were calculated by adding responses from the emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and pro-social behaviour subscales. A lower score represented a more favourable behavioural strengths and difficulties score. Not all parents or guardians of 12- to 17-year olds were available to complete the strengths and difficulties questionnaire for their child, resulting in missing data for a proportion of the sample.

High-density lipoprotein (HDL) cholesterol, triglycerides, insulin, and C-reactive protein (CRP) measures from the fasting subsample were used. HDL-cholesterol, triglycerides, and CRP were measured in serum in all 3 cycles. Insulin was also measured in serum in all 3 cycles; however, different methods and instruments were used to measure insulin in cycle 1 compared with cycle 2 and 3, so a correction equation was applied to the data from cycle 1 (Dion 2013).

Waist circumference and aerobic fitness measures were only used from 2 out of the 3 cycles. Waist circumference was measured using the National Institute of Health (NIH) protocols in cycles 2 and 3 only (NIH 2000), which involves measuring the circumference at the level of the iliac crest. However, in cycle 1 waist circumference was measured using the WHO protocol only, which involves measuring the circumference at the midpoint between the last palpable rib and the iliac crest (WHO 2008). Aerobic fitness was measured in cycles 1 and 2 only using the modified Canadian Aerobic Fitness Test based on the 1981 Canada Fitness Survey (CSEP 2003; Stephens and Craig 1985). Only children 8 years and older were eligible for this test. See CHMS user guides for further details (Statistics Canada 2011, 2013, 2015*a*).

Covariates

Age, sex, and highest household education were considered as covariates. Highest household education was coded into 10 categories ranging from grade 8 or lower to university degree or certificate above bachelor's degree. For descriptive purposes, 4 categories of highest household education were created, including less than secondary school graduation, secondary school graduation, some post-secondary, and post-secondary graduation.

Statistical analyses

All statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, N.C., USA). Analyses followed the guide to compositional data analysis for physical activity, sedentary behaviour, and sleep research published by Chastin and colleagues (2015). Standard descriptive statistics were calculated for participant characteristics. Compositional descriptive statistics were calculated including compositional geometric means and a variation matrix for movement behaviours. The compositional geometric mean is a measure of central tendency and was derived by calculating the geometric mean of the time spent in each movement behaviour after the behaviours had been normalized to proportion of the total time (Chastin et al. 2015). The variance matrix is a measure of dispersion and was derived by calculating the variances of the logarithms of all possible pair-wise ratios (e.g., variance of ln(SB/MVPA)). Values closer to 1 indicated lower codependence and values closer to zero indicated higher codependence (Chastin et al. 2015). Compositional geometric mean bar plots were also calculated to display the relative movement behaviour profiles for select health indicators, including BMI *z* score, waist circumference, aerobic fitness, and insulin. For each movement behaviour, a log contrast was calculated between the compositional geometric mean of the entire sample and the compositional geometric mean of the health indicator subgroup (e.g., $\ln(SB_{subgroup}/SB_{totalsample})$) (Chastin et al. 2015). For BMI *z* score, subgroups included underweight, normal weight, overweight, and obese groups based on WHO growth standards (de Onis et al. 2007). For all other health indicators quartiles were used. Finally, 4 compositional linear regression models were conducted for each health indicator by sequentially rotating the sequence of the behaviours and then entering the composition of movement behaviours into the model via an isometric log ratio transformation. Models examined the combined effect of the relative distribution of all movement behaviours with each health indicator. Model *p* values indicated whether the composition of movement behaviours was significantly associated with the health indicator and model R^2 coefficient indicated what proportion of the variance was explained by the composition (Chastin et al. 2015). Model *p* values and R^2 coefficients were the same across all 4 linear regression models. Next, models examined the association between the time spent in each movement behaviour and each health indicator relative to the time spent in the other movement behaviours. The first coefficient and its *p* value for each rotated model was used to determine if the individual movement behaviour was significantly positively or negatively associated with each health indicator relative to the time spent in the other movement behaviours (Chastin et al. 2015). Finally, models examine the effect of displacing 10 min of time from 1 movement behaviour to the other (Chastin et al. 2015). Change prediction matrixes were derived by first calculating the inverse of the log ratio transformation of the first model and then contrasting time spent in 1 movement behaviour compared with other movement behaviours (Chastin et al. 2015). Effects were based on the average composition and were expressed as a percentage change in the health indicator around the sample mean. Waist circumference, systolic blood pressure, diastolic blood pressure, behavioural strengths and difficulties, triglycerides, CRP, and insulin required log-transformation to meet the assumption of normality of residuals in the regression models. All regression models were adjusted for age, sex, and highest household education.

Accelerometer survey weights for combined cycles were used in all analyses. To account for survey design effects, standard errors and coefficients of variation were estimated with the bootstrap technique (Rao et al. 1992; Rust and Rao, 1996), using specific degrees of freedom outlined by the CHMS data user guide (Statistics Canada 2015*a*). Analyses that included participants from only 2 cycles (i.e., waist circumference and aerobic fitness) used 24 degrees of freedom

Table 1. Weighted participant characteristics of the 2007–2009, 2009–2011, and 2012–2013 Canadian Health Measures Survey.

Variables	Full sample, n = 4169	Fasting subsample, n = 1242
Age, y	11.4 (0.1)	12.4 (0.2)
Sex, %		
Male	51.3	48.3
Female	48.7	51.7
Highest household education, %		
Less than secondary school graduation	2.9	3.0‡
Secondary school graduation	10.2	9.3‡
Some post-secondary	4.0	2.4‡
Post-secondary graduation	82.9	85.3
Health indicators		
BMI z score	0.4 (0.04)	—
Waist circumference; cm; n = 2742*	67.2 (0.4)	—
Systolic blood pressure, mm Hg	94.5 (0.2)	—
Diastolic blood pressure, mm Hg	60.3 (0.3)	—
Behavioural strengths and difficulties; range: 0–32; n = 3924	4.6 (0.2)	—
Aerobic fitness; age: 8–17 y; fitness score; n = 2017†	505.3 (2.2)	—
HDL cholesterol, mmol/L	—	1.3 (0.02)
C-reactive protein, mg/L	—	0.4 (0.04)
Triglycerides, mmol/L	—	0.8 (0.02)
Insulin, pmol/L	—	59.9 (1.8)

Note: Data are presented as median (standard error) for continuous variables and percentage for categorical variables. BMI, body mass index; HDL, high-density lipoprotein cholesterol.

*Waist circumference includes participants from cycle 2 and 3 only.

†Aerobic fitness included participants from cycle 1 and 2 only.

‡Interpret with caution (coefficient of variation 16.6% to 33.3%).

Table 2. Geometric means for sedentary time, LPA, MVPA, and sleep duration in minutes/day.

Sample	Total, 6–17 y
Full sample, cycles 1 to 3	
SB	547.3
LPA	263.4
MVPA	50.7
Sleep	578.6
Fasting subsample, cycles 1 to 3	
SB	569.0
LPA	253.9
MVPA	48.4
Sleep	568.7
Waist circumference subsample, cycles 2 and 3 only	
SB	553.7
LPA	259.5
MVPA	49.3
Sleep	577.5
Aerobic fitness subsample; cycles 1 and 2 only; 8–17 y	
SB	565.1
LPA	256.1
MVPA	48.4
Sleep	570.4

Note: Movement behaviour variables have been normalized to 1440 min. Nonfasting outcomes: body mass index z score, systolic blood pressure, diastolic blood pressure, and strengths and difficulties. Fasting outcomes: triglycerides, high-density lipoprotein cholesterol, C-reactive protein, insulin. LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; SB, sedentary time.

Table 3. Pair-wise log-ratio variation matrix for sedentary time, LPA, MVPA, and sleep duration in minutes/day in the full sample.

	SB	LPA	MVPA	Sleep duration
SB	0	0.0002	0.0011	0.0001
LPA	0.0002	0	0.0009	0.0001
MVPA	0.0011	0.0009	0	0.0009
Sleep duration	0.0001	0.0001	0.0009	0

Note: LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; SB, sedentary time.

and analyses that included participants from all 3 cycles used 35 degrees of freedom. Statistical significance was set at $p < 0.05$.

Results

Of the 5217 eligible participants for this study, 4169 and 1242 participants in the full sample and in the fasting subsample, respectively, had complete data for the variables of interest. Participant characteristics for the full and fasting subsample are presented in Table 1. In the full sample, the average age of the sample was 11 years, and approximately half (49%) the sample were female.

The geometric means for sedentary time, LPA, MVPA, and sleep are shown in Table 2 for the full sample, fasting subsample, waist circumference subsample (cycles 2 and 3), and aerobic fitness subsample (cycles 1 and 2). In the full sample, the geometric means equate to participants spending 40% of the 24-h period in sleep, 38% in sedentary time, 18% in LPA, and 4% in MVPA. The variability of the data are displayed in Table 3 in the variation matrix. The smallest pair-wise log ratio variances were for sleep and sedentary time and sleep and LPA followed by sedentary time and LPA indicating high codependence between these variables. The largest pair-wise log ratio variances were all observed for MVPA, indicating less codependence between MVPA and the other movement behaviours.

Compositional geometric mean bar plots comparing the compositional mean of the entire sample with the compositional mean of BMI z score, log waist circumference, aerobic fitness, and log insulin subgroups for all movement behaviours are shown in Figs. 1–4. For BMI z score, the proportion of time spent sedentary was slightly higher and the proportion of time spent in MVPA was lower in the underweight and obese groups relative to the entire sample. Participants in the lowest log waist circumference quartile (Q1) spent less time sedentary and more time in LPA, MVPA, and sleep relative to the entire sample. The opposite was observed in the highest log waist circumference quartile (Q4). A similar pattern was observed for quartiles of log insulin. Participants in the lowest aerobic fitness quartile (Q1) spent more time sedentary and less time in LPA, MVPA, and sleep relative to the sample average. The opposite was observed for sedentary time, LPA, and MVPA in the highest aerobic fitness quartile (Q4).

The combined effect of the movement behaviours on each health indicator is reported in Table 4. As indicated by the model p value, the composition of movement behaviours as a whole was significantly associated with all health indicators. As indicated by the model R^2, the portion of variance in health indicators explained by the composition of movement behaviours ranged from 1% to 44%. Greater than 10% of the variance was explained for 3 health indicators, including log waist circumference (44%), aerobic fitness (38%), and log insulin (12%).

The association between each movement behaviour and each health indicator relative to the other movement behaviours is also displayed in Table 4. Time spent in sedentary time relative to other movement behaviours was positively associated with BMI z score ($\gamma_{SB} = 0.58$; $p = 0.011$) and log waist circumference ($\gamma_{SB} = 0.09$; $p < 0.001$), and negatively associated with aerobic fitness ($\gamma_{SB} = -32.80$; $p < 0.001$). Time spent in LPA relative to other movement

Fig. 1. Compositional geometric mean bar plots comparing the compositional mean of the entire sample with the compositional mean of underweight, normal weight, overweight, and obese subgroups for sedentary time (SB), light-intensity physical activity (LPA), moderate- to vigorous-intensity physical activity (MVPA), and sleep. BMI, body mass index.

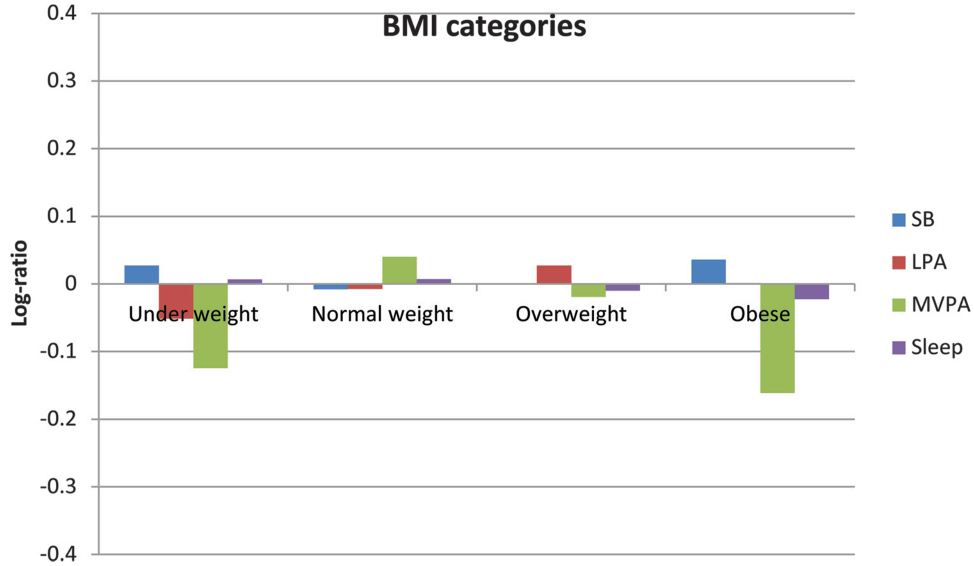
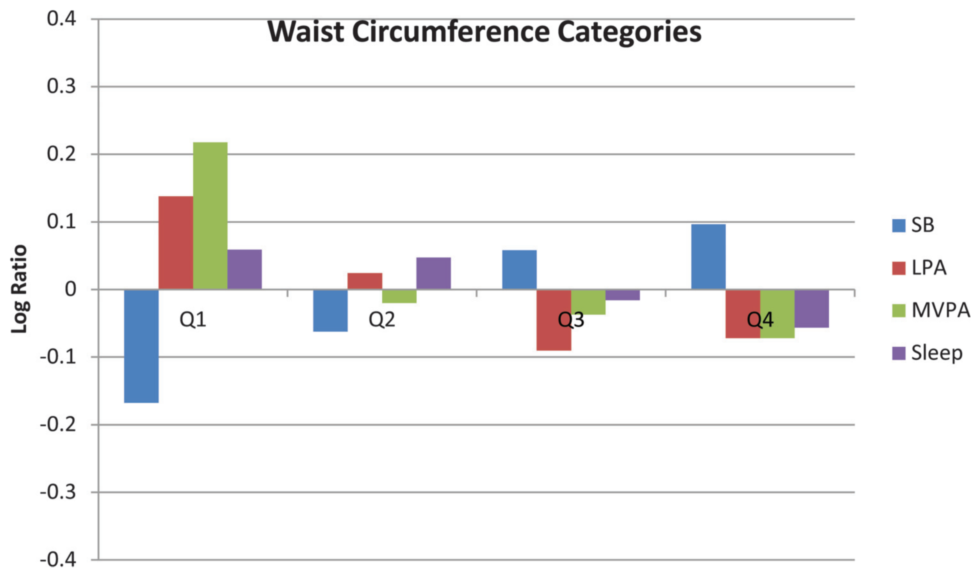


Fig. 2. Compositional geometric mean bar plots comparing the compositional mean of the entire sample with the compositional mean of waist circumference quartiles (Q) subgroups for sedentary time (SB), light-intensity physical activity (LPA), moderate- to vigorous-intensity physical activity (MVPA), and sleep.



behaviours was positively associated with BMI z score ($\gamma_{LPA} = 0.66$; $p < 0.001$), log waist circumference ($\gamma_{LPA} = 0.05$; $p = 0.039$), log systolic blood pressure ($\gamma_{LPA} = 0.03$; $p = 0.004$), and log behavioural strengths and difficulties ($\gamma_{LPA} = 0.40$; $p = 0.001$). Time spent in MVPA relative to other movement behaviours was negatively associated with BMI z score ($\gamma_{MVPA} = -0.32$; $p < 0.001$), log waist circumference ($\gamma_{MVPA} = -0.03$; $p = 0.012$), log systolic blood pressure ($\gamma_{MVPA} = -0.02$; $p < 0.001$), log diastolic blood pressure ($\gamma_{MVPA} = -0.02$; $p = 0.007$), log triglycerides ($\gamma_{MVPA} = -0.16$; $p = 0.002$), log CRP ($\gamma_{MVPA} = -0.49$; $p < 0.001$), and log insulin ($\gamma_{MVPA} = -0.20$; $p = 0.002$), and was positively associated with aerobic fitness ($\gamma_{MVPA} = 21.95$; $p < 0.001$). Time spent in sleep relative to other movement behaviours was negatively associated with BMI z score ($\gamma_{sleep} = -0.93$; $p = 0.002$), log waist circumference ($\gamma_{sleep} = -0.11$; $p = 0.001$), log systolic blood pressure ($\gamma_{sleep} = -0.04$; $p = 0.027$), and log behavioural strengths and difficulties ($\gamma_{sleep} = -0.48$; $p = 0.001$).

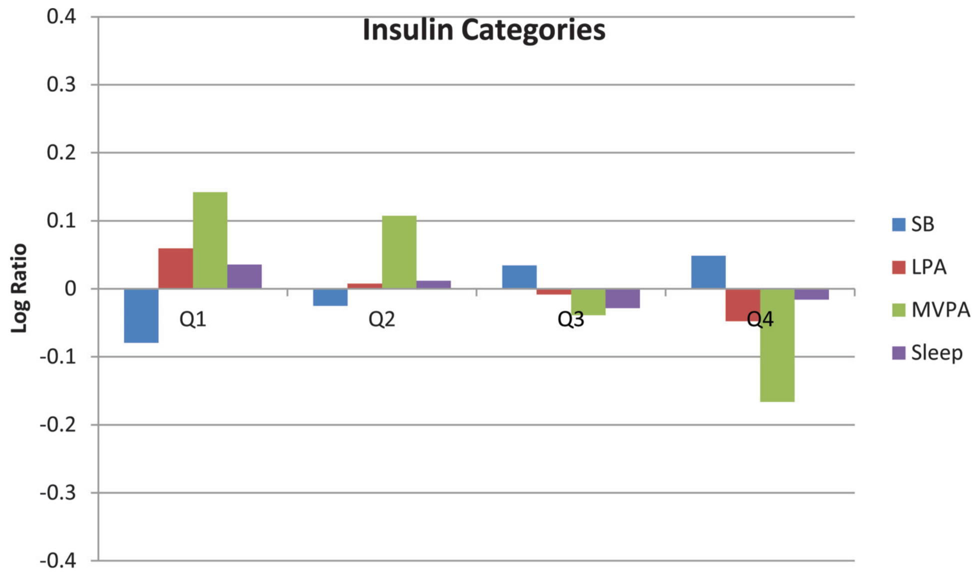
Change matrices of the effect of reallocating 10 min of time from one behaviour to another behaviour in the full sample are displayed in Table 5. The biggest effects seen across health indicators was observed when taking 10 min of MVPA and putting it into other behaviours, in particular into sedentary time. For example, taking 10 min away from MVPA and putting it into sedentary time, LPA, and sleep resulted in a 5.1%, 1.2%, and 1.1% increase in BMI z score, respectively; however, the effects were not symmetrical. For instance, taking 10 min away from sedentary time, LPA, and sleep and putting it into MVPA resulted in a less than 1% decrease in BMI z score.

Discussion

Compositional analyses provide an appropriate means statistically for understanding the collective health implications of finite, 24-h movement behaviours. To our knowledge, this is the

Fig. 3. Compositional geometric mean bar plots comparing the compositional mean of the entire sample with the compositional mean of fitness quartiles (Q) subgroups for sedentary time (SB), light-intensity physical activity (LPA), moderate- to vigorous-intensity physical activity (MVPA), and sleep.

Fig. 4. Compositional geometric mean bar plots comparing the compositional mean of the entire sample with the compositional mean of insulin quartiles (Q) subgroups for sedentary time (SB), light-intensity physical activity (LPA), moderate- to vigorous-intensity physical activity (MVPA), and sleep.



first study to use compositional analyses to examine these relationships in children and youth. Collectively, the findings of this integrated approach indicate that the composition of sleep, sedentary time, LPA, and MVPA within a 24-h period is important for optimal physical, social, and emotional health among children and youth. Based on statistical modeling, replacing MVPA with any other movement behaviour had the biggest negative effect on health.

Although this was the first study to use compositional analyses to examine the relationships between movement behaviours and health indicators in children and youth, the analyses modelled a previous study in a nationally representative sample of adults from the United States (Chastin et al. 2015). Similar with the present study, the composition of movement behaviours was significantly associated with a number of cardio-metabolic health indicators in adults (Chastin et al. 2015). Additionally, when focusing on obesity markers, MVPA and sleep duration, relative to other movement behaviours, also tended to be negatively associated with obesity markers and sedentary time and LPA, relative to other movement behaviours, also tended to be positively associated with obesity markers (Chastin et al. 2015). For American adults the positive coefficients were stronger for sedentary time compared with LPA. This was also the case for waist circumference but not BMI z score in the present study. This suggests that once adequate sleep and MVPA durations are met in a given day, spending more time in LPA compared with sedentary time may be less detrimental to health. In regards to the change matrices, asymmetric relationships were also observed in the adult sample (Chastin et al. 2015). More, specifically, taking time away from MVPA and replacing it with another movement behaviour also had the biggest effect on cardio-metabolic health indicators in adults (Chastin et al. 2015). As described by Chastin and colleagues

Table 4. Compositional behaviour model for health indicators for the proportion of the day spent in sedentary time, LPA, MVPA, and sleep duration.

Health indicator	Model p value	Model R^2	γ_{SB}	p	γ_{LPA}	p	γ_{MVPA}	p	$\gamma_{sleep\ duration}$	p
BMI z score	**<0.001**	0.05	**0.58**	**0.011**	**0.66**	**<0.001**	**–0.32**	**<0.001**	**–0.93**	**0.002**
Log waist circumference	**<0.001**	0.44	**0.09**	**<0.001**	**0.05**	**0.039**	**–0.03**	**0.012**	**–0.11**	**0.001**
Log systolic blood pressure	**<0.001**	0.09	0.03	0.053	**0.03**	**0.004**	**–0.02**	**<0.001**	**–0.04**	**0.027**
Log diastolic blood pressure	**<0.001**	0.01	0.03	0.153	0.01	0.513	**–0.02**	**0.007**	–0.02	0.383
Log strength and difficulties	**<0.001**	0.06	0.13	0.290	**0.40**	**0.001**	–0.06	0.403	**–0.48**	**0.001**
Log triglycerides	**0.001**	0.05	0.01	0.908	0.17	0.059	**–0.16**	**0.002**	–0.02	0.877
HDL cholesterol	**<0.001**	0.03	–0.10	0.211	0.03	0.576	0.04	0.126	0.03	0.766
Log C-reactive protein	**0.001**	0.04	–0.22	0.359	0.18	0.468	**–0.49**	**<0.001**	0.53	0.116
Log insulin	**<0.001**	0.12	0.27	0.059	0.14	0.295	**–0.20**	**0.002**	–0.21	0.227
Aerobic fitness (age: 8–17 y)	**<0.001**	0.38	**–32.80**	**<0.001**	7.22	0.451	**21.95**	**<0.001**	3.63	0.798

Note: All models are adjusted for age, sex, and highest household education. Statistically significant associations ($p < 0.05$) are highlighted in bold. Regression coefficients correspond to change in the log-ratio of the given behaviour relative to other behaviours. LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; SB, sedentary time.

(2015), 1 potential reason for this finding is taking 10 min of MVPA, which accounts for a small portion of the 24-h period, is a much larger change than taking 10 min away from sedentary time, which accounts for a large portion of the 24-h period. Additionally, as per the exercise physiology principles of reversibility and overload, significant decreases in metabolic and exercise capacity occur rapidly with physical inactivity; whereas, overloading the system with increased physical activity results in slower progressive gains (CSEP 2003). These findings suggest that maintaining MVPA levels as children age and transition into adolescents, where MVPA tends to decline (Colley et al. 2011; Dumith et al. 2011; Troiano et al. 2008), may be an important strategy for optimizing health. Furthermore, maintaining MVPA levels throughout the year during different seasons may also positively influence health. This is especially relevant in Canada and other countries or regions with similar climates where MVPA tends to be lower in the winter months (Carson and Spence 2010; Hjorth et al. 2013). Future longitudinal and intervention studies are needed to confirm these findings.

Interestingly, the similar findings observed for the present study in children and youth and the Chastin et al. (2015) study in adults when using a compositional paradigm do not mirror the scientific literature where movement behaviours have been studied in isolation. More specifically, positive relationships have consistently been observed between objectively measured total sedentary behaviour and cardio-metabolic risk among adults, in particular for type 2 diabetes markers (Brocklebank et al. 2015). In contrast, primarily null associations have been observed between objectively measured total sedentary behaviour and cardio-metabolic health in children and youth (Carson et al. 2016). Though methodological issues have been identified, this trend has resulted in a debate in the scientific community as to whether sedentary behaviour should be targeted in children and youth for health promotion (Chinapaw et al. 2015). However, when using compositional analyses, the present study found that the proportion of time spent sedentary was in fact positively associated with obesity markers and negatively associated with fitness, relative to the proportion of time spent in other movement behaviours. This finding emphasizes the importance of taking an integrated versus segregated approach when examining the health implications of movement behaviours. Future research in other samples of children and youth is needed to confirm these findings. Additionally, future research should examine whether health effects differ if sedentary behaviour is further divided into screen time and nonscreen time, given the large body of evidence on the negative health effects of screen time in the pediatric population (Carson et al. 2016; Tremblay et al. 2011*b*). Also, given the well-known misclassification of some sedentary time and LPA postures (e.g., sitting still vs. standing) when using an accelerometer, subdividing LPA into low-LPA and high-LPA (Carson et al. 2013; Howard et al. 2015) or using devices, such as inclinometers, that better classify postures (Ridgers et al. 2012) may shed additional insight on the collective health implications of movement behaviours, including the role of LPA relative to other movement behaviours in the pediatric population.

Unlike sedentary behaviour, findings of the present study do not dispute the abundance of evidence on the importance of regular MVPA (Janssen and LeBlanc 2010; Poitras et al. 2016) and adequate sleep in children and youth (Chaput et al. 2016; Chen et al. 2008; Fatima et al. 2015). However, the current findings also indicate that it may be misguided to continue to consider these behaviours in isolation of each other. Combining compositional analyses with increasing 24-h objective monitoring study procedures in observational studies can help support this paradigm shift. In terms of interventions, targeting a single movement behaviour, such as MVPA, is likely still advantageous; however, taking into account how other movement behaviours change when targeted movement behaviours increase or decrease may help to further guide interventions and improve intervention effects. Additional observational and experimental research that determine the most favorable composition for optimal health can help inform movement behaviour guidelines that go beyond the traditional MVPA or exercise recommendations for improving population health.

Strengths of this study include the novel analytical approach to deal with 24-h data, the large representative sample of children and youth, the range of included health indicators, and the objective measures of physical activity and sedentary time. However, objective measures of sleep were not available. Additionally, accelerometers may not be sensitive to distinguish between some sedentary time and LPA postures (Ridgers et al. 2012), and this misclassification may have impacted study findings. Also, with the focus of the analyses on duration of movement behaviours, other important aspects of sleep, such as sleep quality, were not included in the analyses. Moreover, diet was not adjusted for in the regression analyses. Further, all CHMS cycles include cross-sectional data; therefore, causal inferences cannot be made regarding study findings. Finally, given this study was the first to use compositional analyses to examine health outcomes of movement behaviours in the pediatric population, we were interested in identifying relationships for the whole population. Future work using the compositional analyses paradigm is needed to ascertain whether associations differ between subgroups (e.g., males vs. females or children vs. youth).

Table 5. Change matrices of the effect of reallocating 10 min of time from the behaviour in columns to the behaviour in rows in the full sample.

BMI *z* score

	SB	LPA	MVPA	Sleep
SB		1.129	5.072	0.048
LPA	−0.026		1.230	0.011
MVPA	−0.036	−0.119		−0.007
Sleep	−0.053	−0.571	1.088	

Diastolic blood pressure

	SB	LPA	MVPA	Sleep
SB		0.006	0.017	0.000
LPA	−0.000		0.001	−0.000
MVPA	−0.000	−0.000		−0.000
Sleep	−0.000	0.001	0.005	

HDL cholesterol

	SB	LPA	MVPA	Sleep
SB		−0.074	−0.093	−0.001
LPA	0.002		0.047	0.001
MVPA	0.001	−0.004		0.000
Sleep	0.001	−0.042	−0.015	

Aerobic fitness

	SB	LPA	MVPA	Sleep
SB		−0.059	−0.050	−0.001
LPA	0.001		0.018	0.001
MVPA	0.001	−0.004		0.000
Sleep	0.001	−0.041	−0.027	

Waist circumference

	SB	LPA	MVPA	Sleep
SB		0.022	0.070	0.001
LPA	−0.001		0.008	0.000
MVPA	−0.001	−0.001		−0.000
Sleep	−0.001	−0.005	0.004	

Strength and difficulties

	SB	LPA	MVPA	Sleep
SB		0.072	0.636	0.007
LPA	−0.002		0.250	0.003
MVPA	−0.005	−0.024		−0.001
Sleep	−0.008	−0.171	0.087	

CRP

	SB	LPA	MVPA	Sleep
SB		−0.369	−0.885	0.018
LPA	0.008		0.019	0.021
MVPA	0.006	−0.002		0.015
Sleep	−0.018	−0.985	−2.423	

Systolic blood pressure

	SB	LPA	MVPA	Sleep
SB		0.005	−0.022	0.000
LPA	−0.000		0.005	0.000
MVPA	−0.000	−0.001		−0.000
Sleep	−0.000	−0.002	0.006	

Triglycerides

	SB	LPA	MVPA	Sleep
SB		−0.068	−2.064	0.001
LPA	0.001		−0.975	0.002
MVPA	0.013	0.088		0.014
Sleep	−0.001	−0.110	−2.172	

Table 5 (*concluded*).

Insulin

	SB	LPA	MVPA	Sleep
SB		0.067	0.213	0.001
LPA	−0.001		0.024	−0.000
MVPA	−0.001	−0.002		−0.001
Sleep	−0.002	0.015	0.084	

Note: Effects are based on the average composition and are expressed as percent change in the health indicator around the sample mean (BMI *z* score =0.5 SD, log waist circumference = 4.2 cm, log systolic blood pressure = 4.6 mm Hg, log diastolic blood pressure = 4.1 mm Hg, log strength and difficulties = 1.7, log triglycerides = −0.2 mmol/L, HDL-cholesterol = 1.4 mmol/L, log CRP = −0.6 mg/dL, log insulin = 4.1 mmol/L, aerobic fitness score = 502.3). CRP, C-reactive protein; HDL, high-density lipoprotein; LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; SB, sedentary time.

Conclusion

Compositional data analyses provide novel insights into collective health implications of 24-h movement behaviours and facilitate interesting opportunities for innovation in the years to come. Our findings continue to support the importance of MVPA for optimal health in children and youth, especially to maintain it. However, our findings also support the importance of the time spent in other movement behaviours outside of MVPA for health benefits. Consequently, future guidelines and subsequent messaging aimed at optimizing health in pediatric populations should consider an integrated movement behaviour approach.

Conflict of interest statement

The authors have no conflicts to declare.

Acknowledgements

This study has been made possible through funding from the Canadian Society for Exercise Physiology, Conference Board of Canada, Healthy Active Living and Obesity Research Group at the Children's Hospital of Eastern Ontario Research Institute, and the Public Health Agency of Canada. The research was supported by funds to the Canadian Research Data Centre Network (CRDCN) from the Social Sciences and Humanities Research Council (SSHRC), the Canadian Institutes of Health Research (CIHR), the Canadian Foundation for Innovation (CFI), and Statistics Canada. V.C. is supported by a CIHR New Investigator Salary Award. Although the research and analyses are based on data from Statistics Canada, the opinions expressed do not represent the views of Statistics Canada.

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