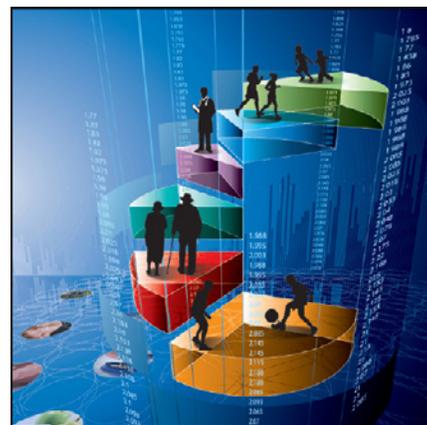


Health Reports

Reallocating time between sleep, sedentary and active behaviours: Associations with obesity and health in Canadian adults

by Rachel C. Colley, Isabelle Michaud and Didier Garriguet

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Reallocating time between sleep, sedentary and active behaviours: Associations with obesity and health in Canadian adults

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Abstract

Background: Moderate-to-vigorous physical activity (MVPA) and sleep are positively associated with adults' health, while the association with sedentary behaviour (SED) is negative. Light-intensity physical activity (LPA) is emerging as an independent predictor of improved cardiovascular health. The health impacts of each of these factors have been examined in isolation, but interest has increased in associations between health and movement behaviours collectively.

Data and methods: This analysis examines how reallocating time between movement behaviours is associated with obesity and with self-rated general and mental health. Data for 18- to 79-year-olds ($n = 10,621$) were collected from 2007 through 2015 as part of the Canadian Health Measures Survey. LPA, MVPA, and SED were measured using the Actical accelerometer. Body mass index (BMI) and waist circumference (WC) were directly measured. Sleep and general and mental health were self-reported.

Results: Reallocation of 30 minutes from SED, LPA or sleep to MVPA was associated with a lower BMI and smaller WC, particularly for older and overweight/obese individuals. Time reallocation from SED to LPA was associated with lower BMI and smaller WC in respondents who were aged 50 or older or who were overweight/obese. Time reallocated from SED to any other movement behaviour was associated with decreased odds of reporting poor/fair rather than excellent general health. Time reallocation from SED to LPA or to sleep, but not to MVPA, was associated with decreased odds of reporting poor/fair rather than excellent mental health.

Interpretation: These findings confirm previous research indicating a strong association between MVPA and markers of obesity and health, particularly among older and overweight/obese individuals. This study also provides evidence that increasing LPA is an important health promotion message for these two subpopulations.

Keywords: Accelerometer, isotemporal substitution, physical activity, regression

Moderate-to-vigorous physical activity (MVPA) and sleep are positively associated with adults' health,^{1,2} whereas the association with sedentary behaviour (SED) is negative.³ In addition, light-intensity physical activity (LPA) is emerging as an independent predictor of improved cardiovascular health.^{4,5}

While associations between each of these factors and health have been examined separately, interest in relationships between health and movement behaviours collectively has increased.^{6,7} This reflects an acknowledgement that participating in a specific intensity of movement means not participating in another. As noted by Mekary et al., "The benefits of different activities depend not only on the specific activity, but also on the activity it displaces."⁸

Isotemporal substitution is a statistical technique that allows associations between increasing a given movement intensity and a health outcome to be estimated while considering the intensity of movement being replaced.⁸ Research using isotemporal substitution has demonstrated that replacing SED with more intense movement is associated with improvements in cardiovascular disease risk⁹⁻¹⁵ and with reduced mortality.^{16,17} Stronger effects have been found for MVPA than for LPA.^{10,11,14-16,18} In two studies of healthy adults, no benefit was observed when substituting LPA for SED.^{12,14} However, in an older population, substituting LPA for SED was associated with better health, which suggests that LPA may be more beneficial for specific populations.¹⁹

Most studies using isotemporal substitution have examined physical health outcomes; only a few examined perception of health, which is an indicator of quality of life and an independent predictor of morbidity and mortality.²⁰ Generally, inactive people are more likely to report poor or fair health,^{21,22} and reallocation of time from SED to LPA has been associated with better general health in older adults.¹⁹

Associations between various movement intensities and mental health are less consistent. A strong association between SED and psychological distress was observed by Hamer et al.,²³ who also found a strong association between high LPA (but not MVPA) and reduced psychological distress.²³ Increasing MVPA and decreasing SED have been associated with lower odds of depression,²⁴ and in another study, replacing TV watching with brisk (but not slow) walking was associated with a lower risk of depression in women.¹⁸

This analysis uses isotemporal substitution regression models to examine how reallocating time among various movement intensities was related to indicators of obesity and self-rated general and mental health in a nationally representative sample of Canadian adults.

What is already known on this subject?

- Moderate-to-vigorous physical activity (MVPA) and sleep are positively associated with adults' health; the association with sedentary behaviour (SED) is negative; and light-intensity physical activity (LPA) is an independent predictor of improved cardiovascular health.
- The impact of each of these factors on health has been examined in isolation, but interest is growing in associations between health and movement behaviours collectively.
- Isotemporal substitution allows the effect of increasing a given movement intensity on a health outcome to be estimated while considering the intensity of movement being replaced.

What does this study add?

- Reallocation of 30 minutes from SED, LPA or sleep to MVPA was associated with a lower body mass index (BMI) and a smaller waist circumference (WC). The effect was greater for older and overweight/obese individuals.
- Reallocation of time from SED to LPA was associated with lower BMI and WC among people aged 50 or older and among those who were overweight/obese.
- Reallocation of time from SED to any other movement behaviour was associated with decreased odds of reporting poor/fair rather than excellent general health.
- Reallocation of time from SED to LPA or sleep, but not to MVPA, was associated with decreased odds of reporting poor/fair rather than excellent mental health

Data and methods

Data source

The Canadian Health Measures Survey (CHMS), an ongoing survey conducted by Statistics Canada, collects self-reported and measured health information from the household population aged 3 to 79. Residents of Indian Reserves, institutions and certain remote regions, and full-time members of the Canadian Forces are excluded. This analysis used data for adults aged 18 to 79 from the first four CHMS cycles: Cycle 1 (2007-to-2009), Cycle 2 (2009-to-2011), Cycle 3 (2011-to-2013), and Cycle 4 (2013-to-2015) (n = 10,621 respondents). Respondents answered an interviewer-administered questionnaire in their home and visited a mobile examination centre (MEC) to undergo physical measurements. Ethics approval for the CHMS was obtained from Health Canada's Research Ethics Board. Details about the CHMS are available elsewhere.²⁵⁻²⁸

Preparation of the dataset

Data from Cycles 1 to 4 were combined. Respondents aged 18 to 79 were included if they had valid accelerometer data and complete data for the outcome variables; 245 were deleted because of incomplete data for key variables.

Measurement of sleep, sedentary behaviour and physical activity

Sleep duration was self-reported as the number of hours respondents usually spend sleeping in a 24-hour period, excluding time spent resting.

Upon completion of the MEC visit, ambulatory respondents were asked to wear an Actical accelerometer (Phillips – Respironics, Oregon, USA) over their right hip on an elasticized belt during their waking hours for 7 consecutive days. A valid day was defined as 10 or more hours of wear time; a valid respondent was defined as a minimum of 4 valid days.³⁰ Wear time was determined by subtracting nonwear time from 24 hours. Nonwear time was defined as at least 60 consecutive minutes of zero counts, with allowance for 1 to 2 minutes of counts between 0 and 100.³⁰ Published

movement intensity thresholds were applied to the data to derive time spent in SED,³¹ LPA, and MVPA.³² A complete description of the accelerometer data reduction procedures is available elsewhere.^{25-28,30,33}

Health outcome variables

Body mass index (BMI) was calculated as measured weight in kilograms divided by measured height in metres squared (kg·m⁻²). Because of a change in the waist circumference (WC) measurement protocol after the first CHMS cycle, a correction factor³⁴ was applied to the Cycle 1 WC data to ensure comparability with subsequent cycles.

Perceived general and mental health were included as categorical variables and were based on the following questions:

- “In general, would you say your health is ...” (poor/fair/good/very good/excellent)
- “In general, would you say your mental health is ...” (poor/fair/good/very good/excellent)

Covariates

Age, sex, highest individual education, and household income were used as covariates in the regression models. Highest individual education was coded as: less than secondary school graduation, secondary school graduation, some postsecondary, and postsecondary graduation. Household income was imputed in all cases where it was not reported in the interview.²⁵⁻²⁸ Accelerometer wear time (sum of SED, LPA, MVPA) was included as a covariate in the single models, but not in the partition or isotemporal substitution models because of multicollinearity.

Regression model descriptions

For continuous outcome variables (BMI, WC), linear regression was used. For multi-categorical outcome variables (self-rated general and mental health), generalized multi-logistic regression was used. All movement variables (time spent on sleep, SED, LPA, MVPA) were divided by 30 before analysis to facili-

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tate interpretation of results. All beta coefficients represent the effect size of 30 minutes of a movement variable.

Single regression models were used to estimate the association between time spent at a given movement intensity with the outcome variables, while controlling for covariates (including wear time), but not for time spent at other movement intensities.

Partition regression models were used to estimate associations between time spent at a given movement intensity and the outcome variables, while controlling for the other movement variables and covariates (excluding wear time due to multicollinearity). Although the movement data were not complete (did not sum to 24 hours), inclusion of all movement variables in the same model raised multicollinearity concerns. Multicollinearity risk was assessed using correlation analysis and verifying variance inflation factors. MVPA was correlated with LPA ($Rho = 0.19, p < .0001$) and SED ($Rho = -0.12, p < .0001$). LPA was correlated with SED ($Rho = -0.22, p < .0001$) and sleep ($Rho = -0.064, p < .0001$). SED was correlated with sleep ($Rho = -0.051, p < .0001$). MVPA and sleep were not correlated. The variance inflation factors were all less than 2 using the “VIF TOL COLLINOINT” option in PROC REG in SAS. Despite the low variance inflation factors, four partition models were completed with one movement variable dropped each time to mitigate the multicollinearity risk. A final model including all variables was also completed:

- *Partition Model 1: LPA – MVPA – Sleep*
- *Partition Model 2: MVPA – Sleep – SED*
- *Partition Model 3: Sleep – SED – LPA*
- *Partition Model 4: SED – LPA – MVPA*
- *Partition Model 5: SED – LPA – MVPA – Sleep*

Isotemporal substitution models were used to estimate the effect of substituting a specified amount of time in one movement intensity for another,

while controlling for total time (SED + LPA + MVPA + sleep and covariates except wear time). For example, in the isotemporal model examining reallocation of SED to LPA or to MVPA, the model drops SED but includes LPA, MVPA, total time, and the other covariates. The beta coefficients for LPA and MVPA, therefore, represent the result of substituting 30 minutes of SED with LPA or MVPA, respectively. Additional isotemporal substitution models were run on a sample split by age [18 to 49 ($n = 5,990$) versus 50 to 79 ($n = 4,631$)] and by obesity status [underweight or healthy weight ($n = 3,985$) versus overweight or obese ($n = 6,636$)].

Analytical parameters

The data were analyzed with SAS 9.3 (SAS Institute, Cary, NC) and SUDAAN 11.0 using appropriate denominator degrees of freedom (46) for the full sample in the SUDAAN procedure statements. Survey and bootstrap weights²⁵⁻²⁸ were used in the variance estimations and calculation of confidence intervals to account for the survey design and to adjust for non-response (average response rate is about 40%).²⁹

Results

Descriptive characteristics

The analysis was based on 10,621 adults aged 18 to 79 (48% male), with relatively equal sample sizes by age group (Table 1). Average daily MVPA decreased with increasing BMI (Table 2) and was lower among individuals whose WC exceeded the threshold for metabolic syndrome (Table 2). Average daily MVPA rose as self-rated general health moved from poor/fair to excellent (Table 2). The average number of daily minutes of MVPA was stable across response categories of self-rated mental health (Table 2).

Single regression models

SED and MVPA were significantly associated with BMI and WC in the single regression models (Table 3). The effect size for MVPA was negative and of greater magnitude for BMI

($-1.36 \text{ kg}\cdot\text{m}^{-2}$) and WC (-1.57 inches) than for SED ($0.11 \text{ kg}\cdot\text{m}^{-2}$ and 0.17 inches). A 30-minute increment in SED was associated with an *increased* likelihood of reporting poor/fair rather than excellent general and mental health. A 30-minute increment in LPA or sleep was associated with a *decreased* likelihood of reporting poor/fair rather than excellent general and mental health. A 30-minute increment in MVPA was associated with a *decreased* likelihood of reporting poor/fair rather than excellent general, but not mental, health.

Partition regression models

MVPA was associated with BMI and WC in all partition models ($p < .001$) except Model 3 (sleep-SED-LPA), where it was the dropped variable (Table 3). The effect size remained stable across the various models (BMI range: -1.36 to $-1.37 \text{ kg}\cdot\text{m}^{-2}$; WC range: -1.56 to -1.58 inches). All movement variables were associated with a *decreased* likelihood of reporting poor/fair rather than excellent general health, except for SED, which was significant (in the opposite direction) only when LPA was excluded from the model (Model 2). SED was associated with an *increased* likelihood of reporting poor/fair rather than excellent mental health in all models. LPA and sleep were associated with a *decreased* likelihood of reporting poor/fair rather than excellent in all models. MVPA was not associated with mental health in any model.

Isotemporal substitution: BMI and WC

The isotemporal substitution models showed that reallocation of 30 minutes from SED, LPA or sleep to MVPA (increasing movement) was associated with a 1.28 to $1.38 \text{ kg}\cdot\text{m}^{-2}$ lower BMI ($p < .001$) (Figure 1). Results were similar for WC: a 30-minute reallocation from SED, LPA or sleep to MVPA was associated with a 1.49 - to 1.56 -inch smaller WC ($p < .001$). Time reallocations between sleep, SED and LPA yielded modest, non-significant results for BMI and WC (Figure 1).

Table 1
Descriptive characteristics of sample, by sex, household population aged 18 to 79, Canada excluding territories, 2007 through 2015

Characteristics	Both sexes (n = 10,621)			Men (n = 5,081)			Women (n = 5,540)		
	Mean	95% confidence interval		Mean	95% confidence interval		Mean	95% confidence interval	
		from	to		from	to		from	to
Age (years)	45.3	45.0	45.5	44.9	44.6	45.2	45.6	45.3	46.0
Annual household income (\$)	83,275	79,306	87,245	90,762	85,546	95,979	75,840	71,767	79,913
Education (%)									
Less than secondary school graduation	11.8	10.2	13.5	13.0	10.9	15.5	10.6	9.0	12.4
Secondary school graduation	20.1	18.3	21.9	20.0	17.9	22.4	20.1	18.0	22.4
Postsecondary degree/diploma	68.2	65.5	70.7	67.0	63.8	70.0	69.3	66.0	72.5
24-hour movement variables									
Moderate-to-vigorous physical activity (min·d ⁻¹)	23.6	22.2	24.9	26.5	24.6	28.3	20.6	19.1	22.2
Light physical activity (min·d ⁻¹)	226.7	221.8	231.7	233.7	226.9	240.5	219.8	215.1	224.4
Sedentary time (min·d ⁻¹)	503.0	497.3	508.6	498.1	491.5	504.7	507.8	501.2	514.4
Sleep time (hr·d ⁻¹)	7.1	7.1	7.2	7.1	7.0	7.1	7.2	7.1	7.2
Obesity variables									
Body Mass Index (BMI) (kg·m ⁻²)	27.3	27.0	27.6	27.6	27.3	27.9	26.9	26.5	27.3
Waist circumference (inches)	36.7	36.4	37.0	38.2	37.8	38.5	35.2	34.8	35.6
Self-rated general health (%)									
Excellent	14.4	13.2	15.7	15.0	13.4	16.8	13.8	12.1	15.7
Very good	38.9	37.1	40.7	38.7	36.6	40.9	39.0	36.4	41.7
Good	36.7	34.6	38.7	36.6	33.9	39.4	36.7	34.3	39.2
Poor/Fair	10.1	9.1	11.1	9.6	8.5	10.9	10.5	9.1	12.0
Self-rated mental health (%)									
Excellent	33.6	31.8	35.4	35.4	32.7	38.1	31.8	29.6	34.0
Very good	38.9	37.1	40.7	38.8	36.4	41.2	38.9	36.5	41.4
Good	21.6	20.2	23.0	20.5	18.5	22.7	22.6	20.5	24.8
Poor/Fair	6.0	5.0	7.2	5.3	4.2	6.7	6.7	5.2	8.6

Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

Table 2
Average minutes of moderate-to-vigorous physical activity (MVPA) per day, by sex, obesity markers (body mass index and waist circumference), and self-rated health, household population aged 18 to 79, Canada excluding territories, 2007 through 2015

Obesity, waist circumference, self-rated general and mental health	Both sexes			Men			Women		
	MVPA (min·d ⁻¹)	95% confidence interval		MVPA (min·d ⁻¹)	95% confidence interval		MVPA (min·d ⁻¹)	95% confidence interval	
		from	to		from	to		from	to
Obesity status									
Underweight	29.8	22.9	36.6	37.0	24.9	49.2	27.5 ^E	17.8	37.3
Normal weight	28.8	27.0	30.6	34.1	31.0	37.2	25.2	23.2	27.1
Overweight	21.8	20.3	23.4	24.7	22.6	26.8	17.8	16.1	19.4
Obese, Class 1	20.2	17.4	23.0	21.4	18.4	24.3	18.7	14.3	23.0
Obese, Class 2	15.6	13.2	17.9	18.8	14.4	23.2	12.5	9.9	15.2
Obese, Class 3	13.0	10.1	15.9	18.7	12.2	25.1	10.3	7.5	13.0
Waist circumference status									
Below metabolic syndrome threshold	27.8	26.3	29.3	30.1	28.0	32.2	24.9	23.0	26.9
Above metabolic syndrome threshold	17.5	16.1	19.0	19.6	17.7	21.4	16.1	14.4	17.9
General health									
Poor/Fair	13.9	12.2	15.6	15.4	12.9	18.0	12.5	10.2	14.7
Good	21.1	19.6	22.6	24.8	22.4	27.3	17.4	15.5	19.2
Very good	26.1	24.0	28.2	27.7	25.3	30.1	24.5	21.5	27.5
Excellent	29.7	27.2	32.3	34.5	30.8	38.2	24.6	22.0	27.2
Mental health									
Poor/Fair	21.2	17.1	25.3	26.3	20.2	32.3	17.2	12.2	22.2
Good	21.1	19.1	23.0	24.3	21.8	26.9	18.1	15.6	20.6
Very good	24.3	22.8	25.9	27.1	24.7	29.5	21.6	19.3	23.9
Excellent	24.7	22.3	27.0	27.1	24.2	30.0	21.9	19.2	24.7

^E use with caution

Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

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Table 3
Beta coefficients and odds ratios relating single and multiple movement variables to obesity markers and self-rated health, household population aged 18 to 79, Canada excluding territories, 2007 through 2015

Outcome and movement behaviour (30 minutes)	Partition models																	
	Single models			Model 1			Model 2			Model 3			Model 4			Model 5		
	Beta	95% confidence interval		LPA-MVPA-sleep			MVPA-sleep-SED			Sleep-SED-LPA			SED-LPA-MVPA			SED-LPA-MVPA-sleep		
		from	to	Beta	from	to	Beta	from	to	Beta	from	to	Beta	from	to	Beta	from	to
Body mass index (kg/m²)																		
SED	0.11*	0.02	0.21	...	...	...	-0.01	-0.04	0.03	0.01	-0.04	0.06	-0.00	-0.04	0.04	-0.01	-0.05	0.04
LPA	-0.02	-0.11	0.07	0.01	-0.07	0.08	...	...	...	-0.03	-0.12	0.06	0.01	-0.07	0.09	0.00	-0.08	0.09
MVPA	-1.36**	-1.68	-1.05	-1.37**	-1.67	-1.07	-1.37**	-1.68	-1.07	...	...	...	-1.37**	-1.67	-1.07	-1.37**	-1.67	-1.08
Sleep	-0.09	-0.21	0.03	-0.09	-0.20	0.02	-0.09	-0.20	0.02	-0.09	-0.20	0.03	...	...	...	-0.09	-0.20	0.02
Waist circumference (inches)																		
SED	0.17**	0.08	0.26	...	...	...	0.00	-0.04	0.04	0.01	-0.04	0.06	-0.00	-0.04	0.04	-0.00	-0.05	0.04
LPA	-0.07	-0.17	0.02	-0.04	-0.12	0.04	...	...	...	-0.08	-0.17	0.02	-0.04	-0.12	0.05	-0.04	-0.13	0.04
MVPA	-1.57**	-1.87	-1.28	-1.56**	-1.84	-1.28	-1.58**	-1.86	-1.29	...	...	...	-1.56**	-1.85	-1.28	-1.56**	-1.84	-1.28
Sleep	-0.07	-0.18	0.03	-0.07	-0.18	0.03	-0.07	-0.17	0.03	-0.07	-0.18	0.03	...	...	...	-0.07	-0.18	0.03
Odds ratio																		
Report poor/fair rather than excellent general health																		
SED	1.23**	1.16	1.30	...	...	...	1.03*	1.00	1.06	1.02	1.00	1.05	1.02	0.99	1.04	1.01	0.99	1.04
LPA	0.85**	0.80	0.91	0.87**	0.82	0.92	...	...	...	0.86**	0.81	0.91	0.89**	0.84	0.94	0.87**	0.82	0.93
MVPA	0.33**	0.25	0.44	0.36**	0.27	0.47	0.34**	0.26	0.45	...	...	...	0.36**	0.27	0.48	0.36**	0.27	0.48
Sleep	0.86**	0.81	0.91	0.85**	0.80	0.90	0.86**	0.81	0.91	0.85**	0.80	0.90	...	...	...	0.85**	0.80	0.90
Report poor/fair rather than excellent mental health																		
SED	1.16*	1.07	1.27	...	...	...	1.08**	1.038	1.11	1.06**	1.03	1.09	1.06**	1.03	1.10	1.06**	1.03	1.09
LPA	0.86*	0.79	0.93	0.88*	0.81	0.95	...	...	...	0.90*	0.84	0.97	0.91*	0.85	0.98	0.90*	0.84	0.97
MVPA	0.85	0.62	1.16	0.90	0.66	1.23	0.93	0.68	1.26	...	...	...	0.94	0.70	1.27	0.94	0.70	1.27
Sleep	0.91*	0.83	1.00	0.90*	0.82	0.98	0.91*	0.84	1.00	0.90*	0.83	0.99	...	...	...	0.90*	0.83	0.99

... not applicable

* significant at p < 0.05

** significant at p < 0.001

SED = sedentary behaviour

LPA = light physical activity

MVPA = moderate-to-vigorous physical activity

Notes: Single models included the following covariates: age, sex, education, household income, and accelerometer wear time; partition models included age, sex, education, and household income.

Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

Isotemporal substitution: Self-rated general and mental health

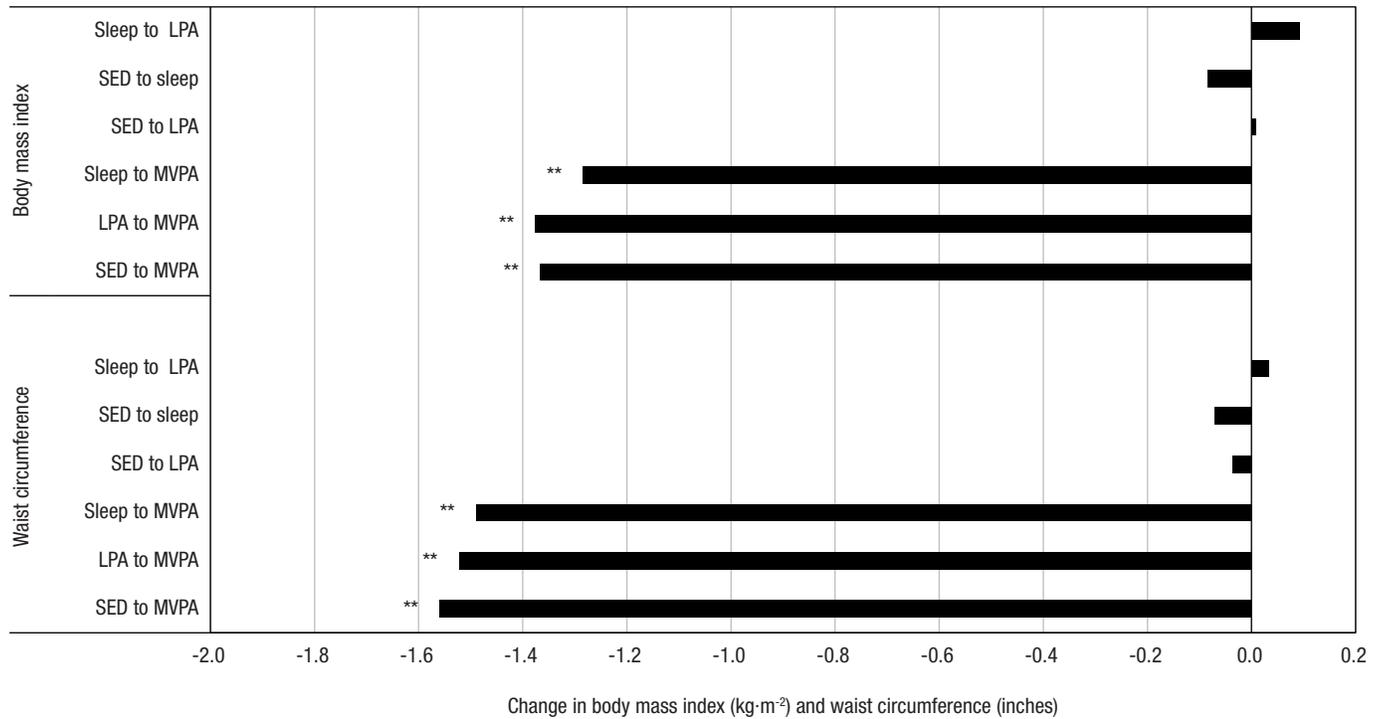
Reallocation of 30 minutes from SED, LPA or sleep to MVPA *decreased* the odds of reporting poor/fair rather than excellent general health (OR = 0.35 to 0.42, p < .001) (Figure 2). The odds were also *decreased* if SED was transferred to LPA or to sleep, but not as much as a transfer to MVPA (OR = 0.84 to 0.86, p < .001). Time reallocations to MVPA were not significantly related to self-reported mental health. However, a 30-minute transfer from SED to LPA or to sleep was associated with *decreased*

odds of reporting poor/fair rather than excellent mental health (OR = 0.85).

Isotemporal substitution by age: BMI and WC

Thirty-minute time reallocations to MVPA were associated with lower BMI and smaller WC, regardless of age or whether the time came from SED, LPA or sleep (p < .001) (Figure 3). In all time reallocations to MVPA, the effect size was 1.2 to 1.5 times greater for older (ages 50 to 79) than for younger (ages 18 to 49) adults.

Time reallocations from SED to LPA were significantly associated with a lower BMI and smaller WC among older (p < .05), but not younger, adults. Also, reallocations from sleep to LPA were significantly associated with a lower BMI and smaller WC only for older respondents (p < .05). Reallocations from SED, LPA or sleep to MVPA were associated with *decreased* odds of reporting poor/fair rather than excellent general health for both age groups; however, the magnitude was greater for older than for younger adults [OR_{SED to MVPA}: 0.487 (p < .0001) versus 0.203 (p < .0001);

Figure 1**Change in body mass index and waist circumference associated with 30-minute time reallocation between movement variables, household population aged 18 to 79, Canada excluding territories, 2007 through 2015**

** significantly different from 0 ($p < 0.001$)

SED = sedentary behaviour

LPA = light physical activity

MVPA = moderate-to-vigorous physical activity

Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

$OR_{LPA \text{ to } MVPA}$: 0.564 ($p < .05$) versus 0.244 ($p < .0001$) (data not shown). The effect size was relatively similar for the SED-to-LPA reallocation [$OR_{SED \text{ to } LPA}$: 0.864 ($p < .05$) versus 0.831 ($p < .0001$)] (data not shown). No notable differences by age were apparent for self-rated mental health.

Isotemporal substitution by obesity status: BMI and WC

Thirty-minute time reallocations to MVPA were all associated with a lower BMI and smaller WC, regardless of obesity status or whether the time came from SED, LPA or sleep (Figure 4). In time reallocations to MVPA, the effect size for BMI was 2.7 to 5.2 times greater for overweight/obese adults than for those who were underweight/healthy weight. The difference for WC was more

modest (1.6 to 2.3 times greater among those who were overweight/obese).

Reallocating time from SED to LPA was significantly associated with a lower BMI and smaller WC for overweight/obese adults ($p < .001$). Reallocations from sleep to LPA were significantly associated with a smaller WC for overweight/obese individuals ($p < .05$). Reallocations from sleep and SED to LPA exhibited a modest (0.06 to 0.08 $\text{kg}\cdot\text{m}^{-2}$), but statistically significant, increase in BMI among those who were underweight/healthy weight. Very little difference was observed between those who were overweight/obese and those who were not in their odds of reporting poor/fair rather than excellent general and mental health (data not shown).

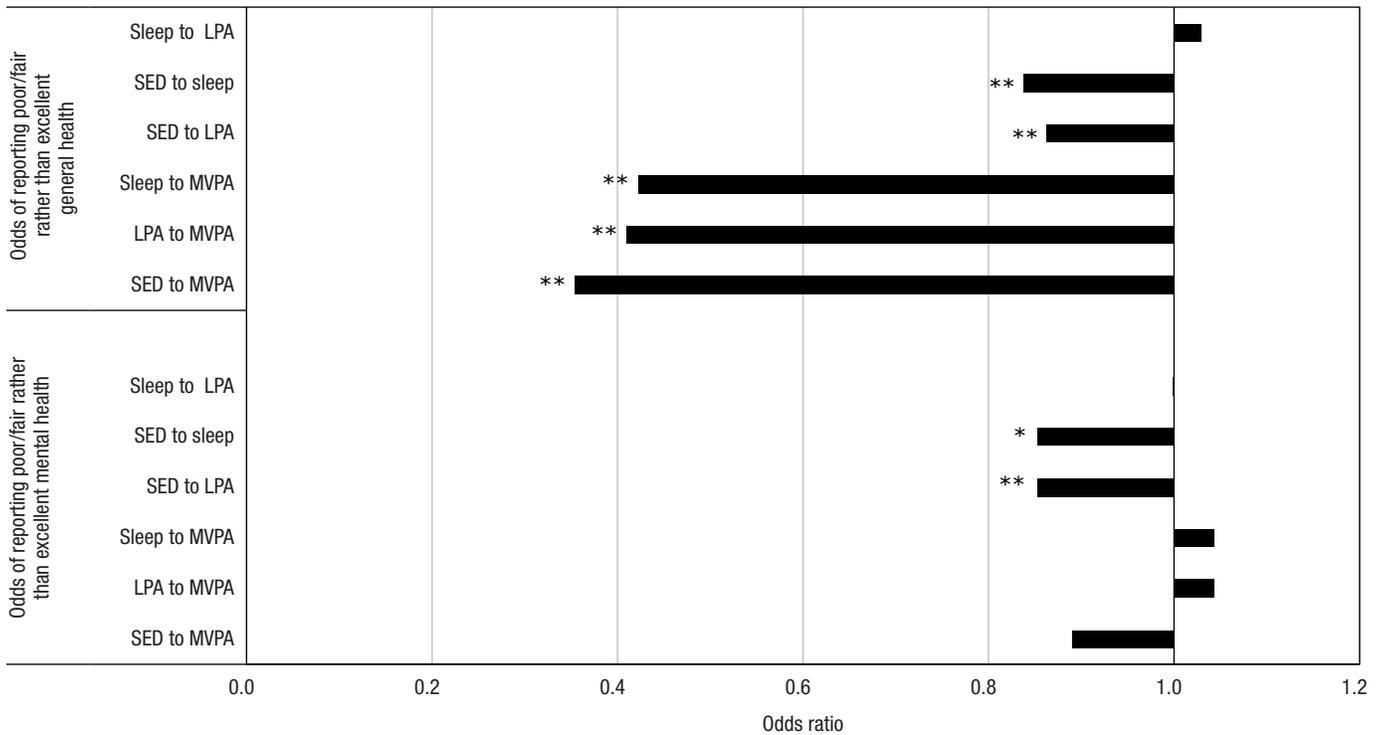
Discussion

Using isotemporal substitution, this study found that time reallocation from SED to MVPA was associated with improved obesity markers and a *decreased* likelihood of reporting poor/fair health, especially among older and overweight/obese individuals. Time reallocation from SED to LPA was significantly associated with improved obesity markers only for older and overweight/obese individuals.

A number of studies that employed isotemporal substitution have demonstrated an association between MVPA and a decrease in BMI and WC. In the present study, the result for BMI of replacing 30 minutes of SED with MVPA ($-1.4 \text{ kg}\cdot\text{m}^{-2}$) is similar to that observed in a group of healthy adults ($-1.2 \text{ kg}\cdot\text{m}^{-2}$),¹²

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Figure 2
Odds of reporting poor/fair rather than excellent general and mental health associated with 30-minute time reallocation between movement variables, household population aged 18 to 79, Canada excluding territories, 2007 through 2015



* significantly different from 0 ($p < 0.05$)
 ** significantly different from 0 ($p < 0.001$)

SED = sedentary behaviour
 LPA = light physical activity
 MVPA = moderate-to-vigorous physical activity

Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

more than that observed in a group of breast cancer survivors (-0.5 to -0.93 kg·m⁻²),³⁴ and less than that observed (-2.2 kg·m⁻²) in a group of adults with newly diagnosed type 2 diabetes.³⁵ The analysis of CHMS data found that reallocation of 30 minutes to MVPA was associated with a 1.6-inch smaller waist circumference, regardless of from where the time was reallocated, a finding similar to previous studies.^{34,35} The effect sizes observed in the present study differed little between single regression and partition models with various combinations of movement variables. The association with MVPA appears to be consistent regardless of whether other movement variables were included in the models.

This analysis applied isotemporal substitution models to different age groups to test whether the association

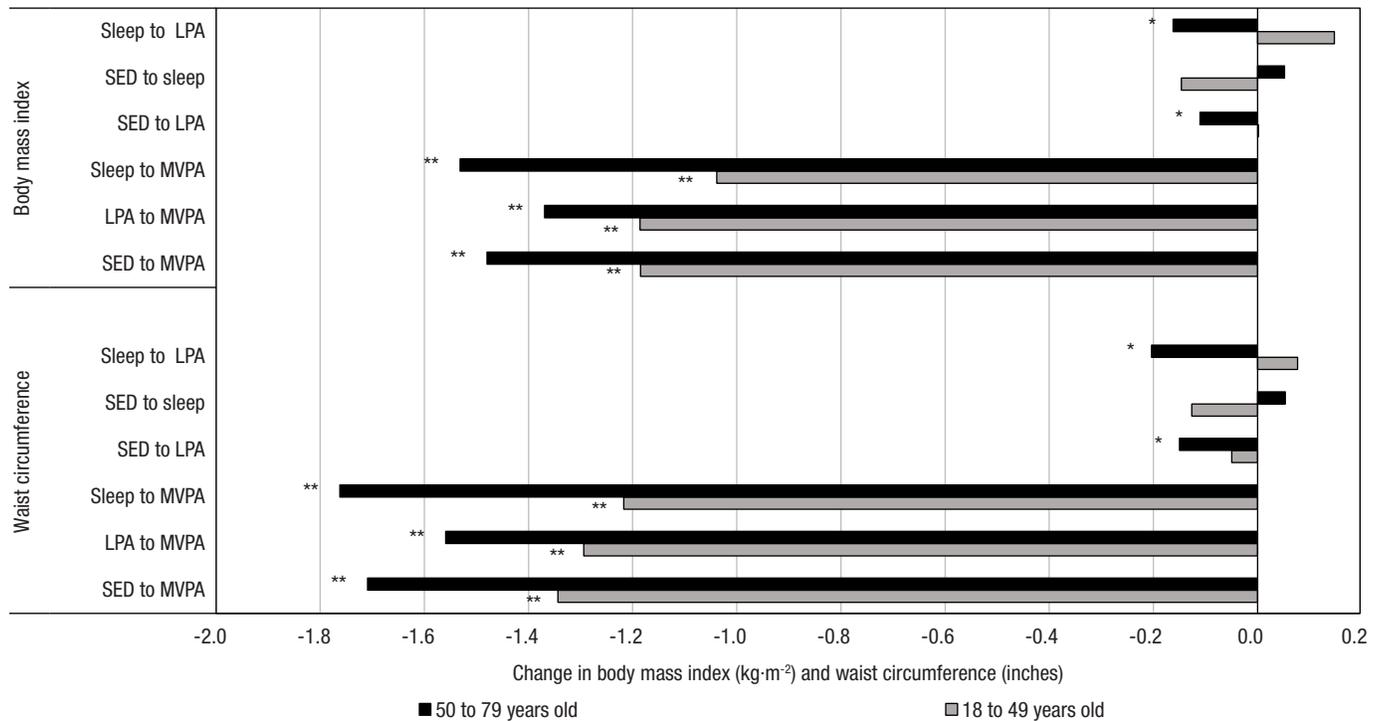
between MVPA and health differs by age.^{14,19} A greater effect size was found for reallocation of time to MVPA in older individuals and in those who were overweight/obese.

Time reallocation from SED or sleep to LPA was beneficial for older individuals and for those who were overweight/obese, but not for adults younger than 50 or for those who were not overweight/obese. These age-related differences may reflect decreased efficiency of movement at older ages.^{36,37} Similarly, obesity is associated with decreased gait efficiency and increased energy expenditure for a given task because of greater mass displacement.³⁸ Time reallocation from SED to LPA likely resulted in greater total daily energy expenditure among older and overweight/obese individuals, thus explaining why the SED-to-LPA tran-

sition was significantly associated with less obesity among these two subgroups.

The findings add evidence to previous research suggesting that LPA may be important for subpopulations who find exercise programs comprised largely of MVPA challenging to adopt and sustain.^{19,39} The results also lend support to criticism of current threshold-based guidelines that ignore proven health benefits of very modest doses and intensities of physical activity, especially in older populations.⁴⁰⁻⁴²

A shortcoming of population health surveys that use accelerometers is that the increased cost of movement for older and heavier people is not captured. This means that the energy expenditure of two people with equal minutes of MVPA could differ considerably. Physical activity levels of overweight/obese indi-

Figure 3**Change in body mass index and waist circumference associated with 30-minute time reallocation between movement variables, by age group (18 to 49 versus 50 to 79), household population aged 18 to 79, Canada excluding territories, 2007 through 2015*** significantly different from 0 ($p < 0.05$)** significantly different from 0 ($p < 0.001$)

SED = sedentary behaviour

LPA = light physical activity

MVPA = moderate-to-vigorous physical activity

Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

viduals tend to be lower than those of healthy weight people,³³ and the lack of information about actual energy expenditure at the individual level precludes a true understanding of how human movement relates to health.³⁸

While beyond the scope of the present analysis, future studies may be able to examine how much LPA would be required to equal the benefit of MVPA and determine how this differs by age and obesity status. Such information may contribute public health messaging in which MVPA may be the focus for some groups (for instance, young and healthy), while LPA or a combination of LPA and MVPA could be recommended for other groups (older and overweight/obese).

The prevalence of reporting poor/fair general health was significantly lower when 30 minutes were reallocated from

SED to MVPA; however, this was not true for mental health. Previous studies have also had mixed or modest findings related to the association between physical activity and mental health in both cross-sectional^{23,24} and prospective randomized controlled trials.⁴³ As well, it is possible that a single question about mental health fails to capture the complexity of the issue, as “mental health” is more than the absence of mental illness.^{44,45}

Reallocation of time from SED to LPA or to sleep was associated with a decreased likelihood of reporting poor/fair rather than excellent mental health, which is consistent with research that supports the importance of sleep in maintaining mental health^{46,47} and the idea that reducing SED and engaging in LPA are also important.^{23,24}

Strengths and limitations

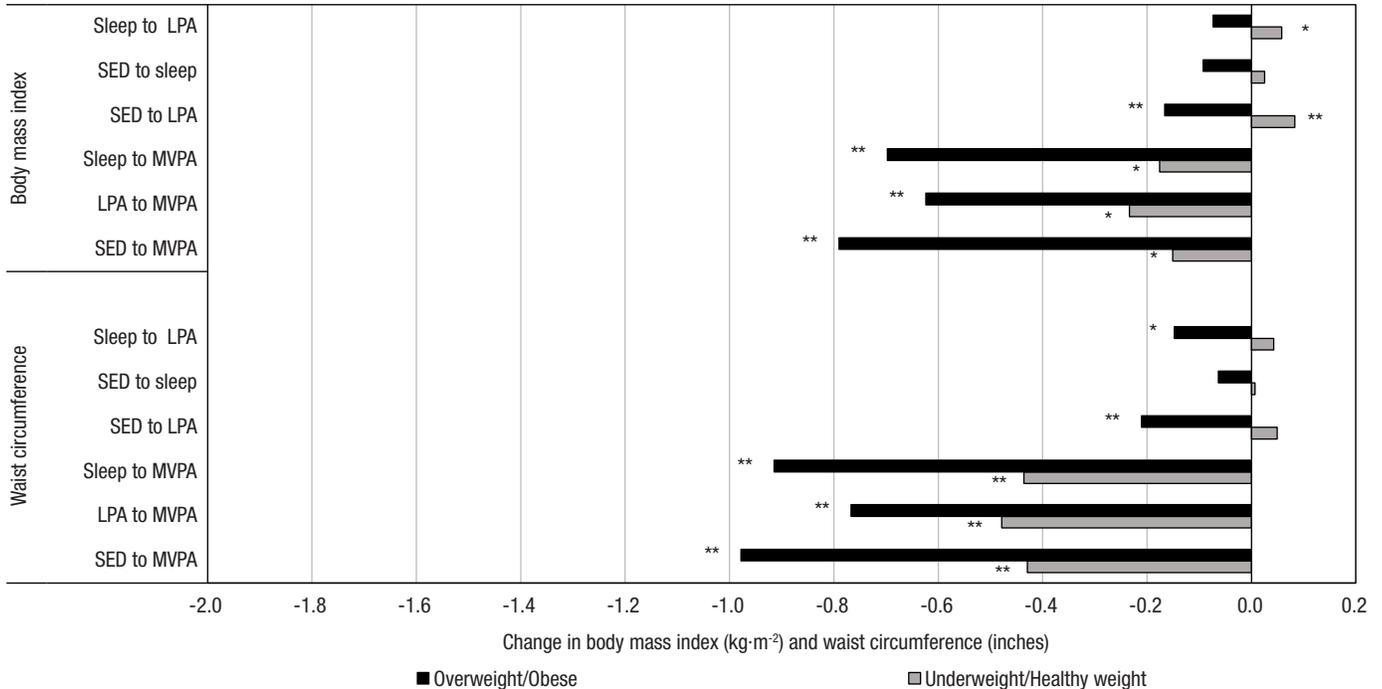
The study has several notable strengths. The sample is large and representative of Canadian adults. As well, SED, LPA, and MVPA were measured objectively by accelerometry.

However, accelerometers are limited in their ability to capture some types of movement such as swimming, cycling, and load-bearing. As well, CHMS respondents did not wear the accelerometers for 24 hours; therefore, sleep duration was derived from self-reported data.

Use of a single threshold for MVPA for adults of all ages in most population health surveys, including the CHMS, is a limitation because it assumes that the energy cost and health benefit of a given acceleration do not differ between people.

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Figure 4
Change in body mass index and waist circumference associated with 30-minute time reallocation between movement variables, by obesity status (overweight/obese versus underweight/healthy weight), household population aged 18 to 79, Canada excluding territories, 2007 through 2015



* significantly different from 0 (p < 0.05)
 ** significantly different from 0 (p < 0.001)
 SED = sedentary behaviour
 LPA = light physical activity
 MVPA = moderate-to-vigorous physical activity
 Source: Canadian Health Measures Survey, combined cycles 1 through 4 (2007 to 2015).

Adjustment of intensity thresholds is a method of overcoming this limitation and appears to be more effective at identifying survey respondents at increased health risk⁴⁸ and reducing discrepancies between reported and measured physical activity in overweight/obese individuals.⁴⁹ However, in the context of large population health surveys, adjustment of cut-points may be unrealistic.

Isotemporal substitution takes other movement behaviours into account when examining the effect of a given movement behaviour on a health outcome. Inclusion of multiple movement variables that theoretically add up to 24 hours makes controlling for accelerometer wear time in the regression models challenging. Wear time was controlled in the single models, but it could not be included as a covariate in the partition and isotemporal substitution models. SED was significantly associated with BMI and WC in

the single models when wear time was included, but not in any other models. This suggests that the true effect of SED is muted in the partition and isotemporal substitution models, which may be partially explained by wear time.

Another limitation of isotemporal substitution is its inability to provide an overall assessment of the association between the 24-hour movement profile and a health outcome. This has been challenging because of multicollinearity issues when all movement variables within a finite period (24 hours) are included in the same model. New techniques such as compositional data analysis are emerging to help address this limitation.^{50,51}

Finally, this analysis cannot assess cause-and-effect, because it was not a prospective intervention study in which outcomes were examined before and

after time was purposefully reallocated from SED to other activity intensities.

Conclusion

These findings confirm previous studies that found a strong association between MVPA and obesity and health. The beneficial effect of MVPA was greater in older and overweight/obese individuals. This analysis adds evidence to the idea that LPA is an important contributor to health, particularly for older and overweight/obese individuals.

Isotemporal substitution allows for a more comprehensive perspective to be taken on how all intensities of movement relate to health. This more inclusive approach confirms that sedentary behaviour, sleep and light-intensity movement should be considered alongside volitional exercise when developing strategies to improve health. ■

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