



Patterns and predictors of sitting time over ten years in a large population-based Canadian sample: Findings from the Canadian Multicentre Osteoporosis Study (CaMos)

Klaus Gebel^{a,b,c}, Sarah Pont^d, Ding Ding^{c,a}, Adrian E Bauman^c, Josephine Y Chau^c, Claudie Berger^e, Jerilynn C Prior^{f,*}, for the CaMos Research Group:

^a Centre for Chronic Disease Prevention, College of Public Health, Medical and Veterinary Sciences, James Cook University, 14-88 McGregor Road, Smithfield, Queensland 4878, Australia

^b School of Allied Health, Australian Catholic University, 33 Berry St, North Sydney, NSW 2060, Australia

^c Prevention Research Collaboration, Sydney School of Public Health, University of Sydney, Level 6, The Charles Perkins Centre (D17), Sydney, NSW 2006, Australia

^d New South Wales Ministry of Health, 73 Miller St, North Sydney, NSW 2060, Australia

^e CaMos National Coordinating Centre, McGill University Health Center, 3801 University Street, Pavilion Ross R4-76, Montreal, Quebec H3A 2B4, Canada

^f Centre for Menstrual Cycle and Ovulation Research, Medicine/Endocrinology, University of British Columbia, The Gordon and Leslie Diamond Health Care Centre, Room 4111, 4th Floor, 2775 Laurel Street, Vancouver BC V5Z 1M9, Canada

ARTICLE INFO

Article history:

Received 22 November 2016

Accepted 23 January 2017

Available online 24 January 2017

Keywords:

Sedentary behavior

Cohort study

Population-based cohort

Predictor

Trend

ABSTRACT

Our objective was to describe patterns and predictors of sedentary behavior (sitting time) over 10 years among a large Canadian cohort. Data are from the Canadian Multicentre Osteoporosis Study, a prospective study of women and men randomly selected from the general population. Respondents reported socio-demographics, lifestyle behaviors and health outcomes in interviewer-administered questionnaires; weight and height were measured. Baseline data were collected between 1995 and 1997 ($n = 9418$; participation rate = 42%), and at 5- ($n = 7648$) and 10-year follow-ups ($n = 5567$). Total sitting time was summed across domain-specific questions at three time points and dichotomized into “low” (≤ 7 h/day) and “high” (> 7 h/day), based on recent meta-analytic evidence on time sitting and all-cause mortality. Ten-year sitting patterns were classified as “consistently high”, “consistently low”, “increased”, “decreased”, and “mixed”. Predictors of sedentary behavior patterns were explored using chi-square tests, ANOVA and logistic regression. At baseline (mean age = 62.1 years \pm 13.4) average sitting was 6.9 h/day; it was 7.0 at 5- and 10-year follow-ups (p for trend = 0.12). Overall 23% reported consistently high sitting time, 22% consistently low sitting, 14% decreased sitting, 17% increased sitting with 24% mixed patterns. Consistently high sitters were more likely to be men, university educated, full-time employed, obese, and to report consistently low physical activity levels. This is one of the first population-based studies to explore patterns of sedentary behavior (multi-domain sitting) within men and women over years. Risk classification of sitting among many adults changed during follow-up. Thus, studies of sitting and health would benefit from multiple measures of sitting over time.

© 2017 Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Research suggests that greater time spent in sedentary behavior (activities in a sitting or reclining posture requiring low energy expenditure) (Owen, 2012; Sedentary Behaviour Research Network, 2012), is associated with higher risk of type 2 diabetes, cardiovascular disease, and all-cause mortality (Biswas et al., 2015; Ekelund et al., 2016). Evidence suggests that the prevalence of sedentary behavior has increased, while physical activity has decreased in daily life, at work and outside of work; sedentary behavior is predicted to continue on these trajectories (Ng and Popkin, 2012).

For targeted interventions it is important to identify those people with consistently high or low levels of sitting time; that is high and low risk groups, respectively. Using data from time use surveys, repeated cross-sectional studies have examined trends in sitting time. Chau et al. (2012) reported a slight increase in overall non-occupational sedentary behavior in Australian adults between 1997 and 2006 and van der Ploeg et al. (2013) found that between 1975 and 2005 in the Dutch adult population the proportion of non-work related time spent sitting remained relatively constant. Both studies found that the percentage of sedentary leisure time spent with screen based activities increased significantly. Using data from the Eurobarometer study, Milton et al. (2015) reported a decrease in the prevalence of prolonged sitting (defined as ≥ 7.5 h/day) over three time points between 2002 and 2013 for 17 countries. For another 10 countries they had data for two time points (2005 and 2013) that showed the same trend. Systematic

* Corresponding author.

E-mail address: jerilynn.prior@ubc.ca (J.C. Prior).

URL: <http://www.cemcor.ca> (J.C. Prior).

reviews of correlates of sitting time found a positive relationship with age, body mass index, socio-economic status and smoking, an inverse relationship with physical activity and mixed results for neighborhood walkability and safety (O'Donoghue et al., 2016; Rhodes et al., 2012).

Nonetheless, to the best of our knowledge, only four large population-based cohort studies have examined patterns of sedentary behavior within individuals over time. An Australian cohort study examined effects of life events on sitting patterns in women in two age groups: work changes were related to increased, but retirement to decreased sitting in mid-aged women. For young women, return to work was related to increased sitting; having a baby, beginning work and decreased income were associated with decreased sitting (Clark et al., 2014). A Spanish cohort of older adults with two years of follow-up found that compared with consistently sedentary participants, those who were consistently non-sedentary were younger, more physically active, had a lower BMI, and had less chronic diseases (León-Muñoz et al., 2013). In post-menopausal women in the USA, those who maintained high levels of sitting or increased sitting over six years were more likely to be white, current smokers, and employed relative to those with consistently low or decreased sitting time (Lee et al., 2016). The Norwegian HUNT study found that adults with consistently high sitting time over 11 years tended to be middle-aged and men, university-educated, overweight or obese, do “light exercise” at least 1 h/week, do “hard exercise” up to 2 h/week, and have “good” or “very good” general health (Gruneit et al., 2017).

Using data from a large Canadian population cohort of women and men, this study examines 10-year patterns and predictors of sedentary behavior in adults over three time points as opposed to only two time points like in the four cohort studies mentioned above. This is a unique, Canada-wide, prospective 20-year population-based study of adult women and men whose primary purpose was to determine risks for osteoporotic fracture.

2. Methods

2.1. Participants

Data were from the Canadian Multicentre Osteoporosis Study (CaMos), a cohort study of non-institutionalized adults (2/3 women) aged 25 years and above, randomly selected from the general population living within 50 km of nine Canadian cities. Methods were previously published (Kreiger et al., 1999). Briefly, participants reported their socio-demographic information, lifestyle behaviors and disease history using interviewer administered questionnaires. Sitting information was available in 9418 participants at baseline (1995–1997), in 7648 participants at year 5 follow-up (2000–2002) and in 5567 participants at year 10 follow-up (2005–2007) (Fig. 1). CaMos was granted ethical approval by McGill University and each local institution. All participants provided signed informed consent.

2.2. Measures

2.2.1. Independent variables

Participants reported their date of birth, sex, ethnicity, education, employment, smoking, physical activity, sleep and self-rated health at baseline; height and weight were measured. Created time-dependent variables included employment status categorized as “continuously working”, “continuously retired”, “retired during follow-up”; BMI rated “consistently non-obese”, “obese to non-obese”, “non-obese to obese”, and “could not be classified”; self-rated health was classed as “good to excellent”, “consistently fair/poor”, “increasing”, and “decreasing”. Physical activity was classed as “consistently high” (≥ 7 h/week of moderate-to-vigorous physical activity), “consistently low” (< 7 h/week), “increasing”, and “decreasing”.

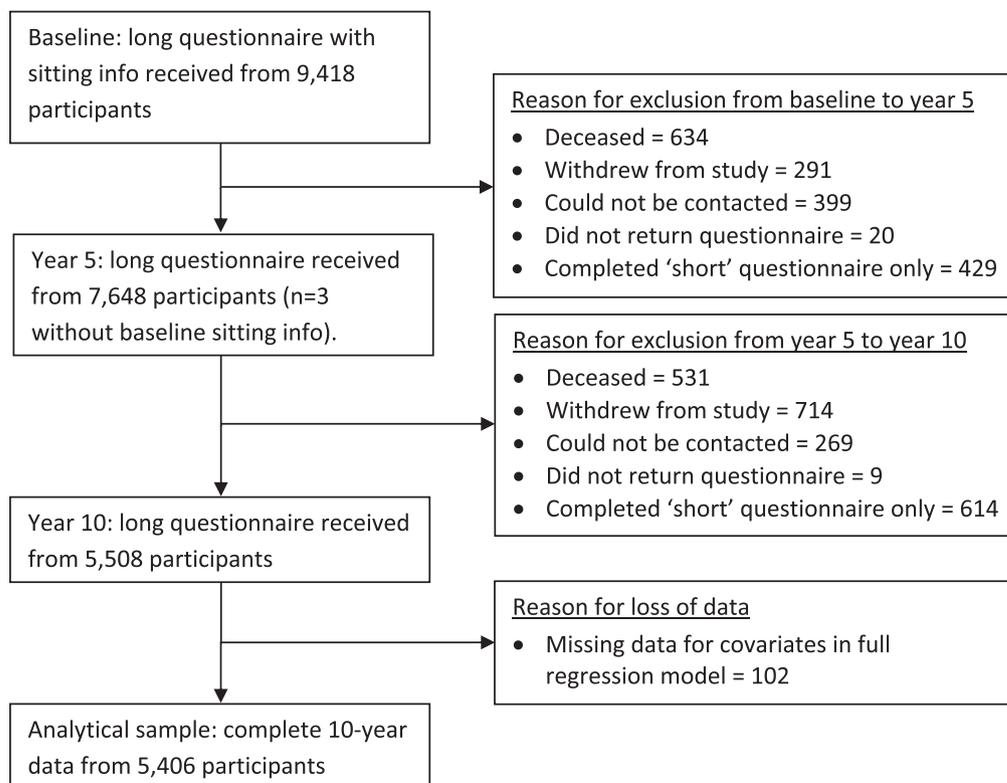


Fig. 1. Selecting the analytical sample, Canadian Multicentre Osteoporosis Study (CaMos), Canada, 1995–2007.

2.2.2. Dependent variables

Sedentary behavior was assessed at baseline, and years 5 and 10, using questions about time spent sitting in transit (car, bus etc.), at work, watching television, at meals, and in other sitting activities such as reading, playing cards and sewing. Response options were “never”, “<1 h”, “1–2”, “3–4”, “5–6”, “7–10”, and “11 h or more”. We took the mid-point of each possible response range (Armitage et al., 2001) and summed specific sitting times into overall sitting time. We then dichotomized overall sitting time into “high (>7 h)” and “low (≤7 h)” based on recent meta-analytical evidence on the risk threshold for sitting time and all-cause mortality (Chau et al., 2013). The mean age at baseline of our analytical sample was 58.8 years, so a large proportion of our study participants transitioned into retirement during the 10-year follow-up. Therefore, we think it is particularly informative to examine total sitting time including work-related sedentary behavior because it captures the change in occupational, respectively total sitting, as a result of changes in employment status.

To capture patterns of sitting over time, we categorized participants into five mutually exclusive groups: 1) “consistently low” sitting (low sitting time at all three time points), 2) “consistently high” (high sitting time at all three time points), 3) “increasing” (low sitting time at the first 1–2 time points, high sitting time at the last 1–2 time points, indicating an increase), 4) “decreasing” (high sitting time at the first 1–2 time points, low sitting time at the last 1–2 time points, indicating a decrease, and 5) “no clear pattern” over time.

2.3. Statistical analysis

We compared the characteristics of participants categorized into the five sitting groups using chi-square tests and Analysis of Variance (ANOVA). We used binary logistic regression to examine correlates of “consistently high” and “consistently low” sitting, the least and most healthy patterns of sitting, respectively.

3. Results

At baseline, 9418 respondents had available sitting information (mean age = 62.1 ± 13.4 years, 69% women) (Table 1). Of those, 7645 (81.2%) and 5567 (59.1%) provided data for 5 and 10-year follow-up measurements, respectively.

After excluding those with missing data for covariates, the average total sitting time for the analytical sample with ten-year follow-up data (n = 5406) was 6.96 (SD = 2.8) hours/day at baseline, 7.00 (SD = 2.7) hours/day at year 5 and 7.02 (SD = 2.7) hours/day at year 10 (p for trend = 0.12). At each of the three times, around half of the respondents were classified as ‘high sitters’ (i.e. ≥7 h of sitting per day [49% at baseline, 50.3% at year 5 and 51.5% at year 10]). Across the three times, 23% reported consistently high sitting time, 22% consistently low sitting time, 14% decreased sitting, 17% increased sitting, and 24% had mixed patterns.

3.1. Consistently high sitting levels

Multivariate models using baseline values of predictors (Table 2) showed that those with consistently high sitting time over ten years were more likely to be men, university educated, full-time employed, obese, have low physical activity levels, and fair or poor self-rated health. Baseline age, smoking and sleep were not associated with being a consistently high sitter.

In multivariate models based on change in predictors across the three times (Table 3), the odds of being a consistently high sitter were greater among men, those with university education; those consistently employed; those with consistently low or increasing activity levels; and among ‘obese to non-obese’ and ‘consistently obese’ categories. Similar to the models involving only baseline predictor values, age, smoking and sleep were not associated with the odds of being a consistently high sitter.

3.2. Consistently low sitting levels

By baseline predictors (Table 2) the likelihood of being a consistently low sitter was significantly greater among younger adults, women, high school vs. university educated, part-time, retired or others compared to full-time employed, previous or never smokers, high physical activity levels, and those with a healthy BMI. Baseline sleep and self-rated health were not associated with having consistently low sitting time over the 10-year period.

Ten-year changes in predictors showed that consistently low sitters were more likely to be younger, women, high school vs. university educated; continuously retired or other occupation vs. being consistently

Table 1
Participant characteristics, Canadian Multicentre Osteoporosis Study (CaMos), Canada, 1995–2007.

		Total baseline sample (N = 9418)	Analytical sample (N = 5406)	Not in analytical sample (N = 4012)	p-Value
Age (years)	Mean ± SD	62.1 ± 13.4	58.8 ± 12	66.5 ± 14	<0.0001
Sex	Women	6536 (69.4%)	3891 (72%)	2645 (65.9%)	<0.0001
Education	School (high school at most)	4855 (51.6%)	2496 (46.2%)	2359 (58.8%)	<0.0001
	Trade or at least some university	3044 (32.3%)	1885 (34.9%)	1159 (28.9%)	
	University degree	1518 (16.1%)	1025 (19%)	493 (12.3%)	
Employment status	Employed full time	2254 (23.9%)	1621 (30%)	633 (15.8%)	<0.0001
	Employed part time	746 (7.9%)	546 (10.1%)	200 (5%)	
	Retired	4263 (45.3%)	2074 (38.4%)	2189 (54.6%)	
	Other	2151 (22.9%)	1165 (21.6%)	986 (24.6%)	
Smoking status	Currently smokes	1466 (15.6%)	762 (14.1%)	753 (18.8%)	<0.0001
Physical activity (at all levels)	Low (<7 h/week)	3073 (32.6%)	1523 (28.2%)	1550 (38.6%)	<0.0001
	High (≥7 h/week)	6345 (67.4%)	3883 (71.8%)	2462 (61.4%)	
Sedentary behavior	Low (<7 h/day)	4780 (50.8%)	2755 (51%)	2025 (50.5%)	0.639
	High (≥7 h/day)	4638 (49.3%)	2651 (49%)	1987 (49.5%)	
Sleep	6 h or less	2713 (28.8%)	1451 (26.8%)	1262 (31.5%)	<0.0001
	7–8 h	5686 (60.4%)	3500 (64.7%)	2186 (54.6%)	
	9 h or more	1013 (10.8%)	455 (8.42%)	558 (13.9%)	
BMI	Underweight	147 (1.2%)	52 (1%)	95 (2.5%)	<0.0001
	Healthy weight	3231 (35.3%)	1914 (35.4%)	1317 (35.3%)	
	Overweight	3719 (40.7%)	2221 (41.1%)	1498 (40.1%)	
	Obese	2045 (22.4%)	1219 (22.6%)	826 (22.1%)	
Self-rated general health	Good, very good, or excellent	8373 (89%)	5030 (93%)	3343 (83.5%)	<0.0001
	Fair or poor	1035 (11%)	376 (6.96%)	659 (16.5%)	

Including baseline characteristics of all covariates in the full model and total sitting.

Table 2
Predictors of consistently high/low sitters (baseline predictors only), Canadian Multicentre Osteoporosis Study (CaMos), Canada, 1995–2007.

Predictor	Category	Sitting category							
		Consistently low				Consistently high			
		Univariate		Multivariate ^a		Univariate		Multivariate ^a	
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Age (years) ^b		1.00	0.99–1.00	0.98***	0.97–0.99	0.98***	0.97–0.98	1.00	0.99–1.00
Sex	Men (ref)	1.00		1.00		1.00		1.00	
	Women	1.45***	1.25–1.69	1.25**	1.06–1.48	0.56***	0.49–0.64	0.71***	0.61–0.83
Education	High school (ref)	1.00		1.00		1.00		1.00	
	Trade	1.00	0.86–1.15	0.96	0.82–1.11	1.06	0.92–1.23	0.95	0.82–1.11
	University	0.84	0.70–1.00	0.83*	0.68–1.00	1.61***	1.37–1.90	1.27**	1.07–1.53
Employment	Full-time (ref)	1.00		1.00		1.00		1.00	
	Part-time	1.91***	1.52–2.41	1.90***	1.49–2.41	0.44***	0.35–0.56	0.52***	0.41–0.66
	Retired	1.60***	1.35–1.89	2.19***	1.76–2.71	0.39***	0.34–0.45	0.46***	0.37–0.56
	Other	1.73***	1.43–2.08	1.86***	1.51–2.29	0.36***	0.30–0.43	0.44***	0.35–0.54
Smoking	Current (ref)	1.00		1.00		1.00		1.00	
	Previous	1.26*	1.02–1.56	1.34*	1.07–1.67	0.89	0.73–1.08	0.98	0.80–1.20
	Never	1.52***	1.24–1.87	1.51**	1.22–1.87	0.79*	0.66–0.95	0.93	0.76–1.13
Physical activity	High (ref)	1.00		1.00		1.00		1.00	
	Low	0.57***	0.49–0.67	0.62***	0.53–0.72	1.71***	1.50–1.96	1.50***	1.30–1.73
Sleep	≤6 h	0.92	0.79–1.06	0.96	0.82–1.12	1.11	0.96–1.28	1.14	0.98–1.32
	7–8 h (ref)	1.00		1.00		1.00		1.00	
	≥9 h	0.98	0.78–1.24	0.93	0.73–1.18	0.96	0.76–1.21	1.12	0.88–1.44
BMI	Underweight	1.29	0.71–2.34	1.24	0.68–2.29	0.94	0.47–1.89	1.11	0.54–2.26
	Healthy (ref)	1.00		1.00		1.00		1.00	
	Overweight	0.85*	0.73–0.98	0.90	0.78–1.05	1.13	0.97–1.31	1.08	0.92–1.26
	Obese	0.55***	0.46–0.66	0.55***	0.46–0.67	1.51***	1.28–1.79	1.58***	1.33–1.89
Self-rated general health	Good to excellent (ref)	1.00		1.00		1.00		1.00	
	Fair to poor	0.83	0.64–1.08	0.86	0.66–1.13	1.20	0.94–1.52	1.36*	1.06–1.75

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

^a Multivariate models adjusted for age, sex, education, employment, smoking, physical activity, sleep, BMI, and self-rated general health.

^b Age was modelled as a continuous variable.

employed, previous or never smokers, having consistently high activity levels, and consistently non-obese (Table 3). Again, sleep and self-rated health were not associated with consistently low sitting over ten years.

4. Discussion

This is the first population-based nation-wide study in women and men to examine patterns and predictors of sedentary behavior within individuals with a long follow-up time. On average there was a small and non-significant increase in total sitting time over the three time points between 1995 and 2007; this is consistent with sedentary behavior trends observed in repeated cross-sectional studies with data up to 2006 from Australia (Chau et al., 2012), respectively up to 2010 from Denmark (Aadahl et al., 2013). However, repeated cross-sectional data from more recent years (up to 2013) from multiple countries in Europe showed a decline in high sitting time. This might be due to the recent increase in media reporting on the health effects of sedentary behavior which likely increased the public awareness and in turn may have led to a decline in sitting or more under-reporting of sitting (Milton et al., 2015).

While in the present study the mean change for sitting time for the whole sample was small, more than half of the study participants reported changes in sedentary behavior over the three time points (increases, decreases or mixed patterns). Most previous studies on sedentary behavior and health outcomes have used only a single measure of exposure at baseline (Biswas et al., 2015), assuming that sitting time would be relatively stable over time (León-Muñoz et al., 2013). This study indicates that a large proportion of people change sitting behaviors over time, consistent with previous cohort studies (Clark et al., 2014; Grunseit et al., 2017; Lee et al., 2016). This warrants studies on sedentary behavior that measure sitting at more than one point in time.

Participants that maintained high levels of sitting over time were men, more educated and employed, and less physically active.

Participants with consistently low sitting time were younger, women, had lower education, were retired and were highly physically active. These findings are in line with systematic reviews on correlates and determinants of sedentary behavior (O'Donoghue et al., 2016; Rhodes et al., 2012). However, these literature reviews were mainly based upon cross-sectional studies. The results for the cross-sectional baseline correlates in our study were similar to the determinants captured over time. The findings for gender and education as predictors of sitting showed the opposite associations to those seen for physical inactivity, suggesting that the stimuli for sedentary and physically inactive behavior are quite distinct (Bauman et al., 2012). This is likely due to a large proportion of the reported sitting time being from occupational sitting which is associated with educational levels (O'Donoghue et al., 2016). Recent systematic reviews suggest some promising strategies for reducing sitting at work (Neuhaus et al., 2014; Shrestha et al., 2016).

Our finding that baseline age and smoking were not associated with consistently high sitting levels was noteworthy. The literature suggests that smoking is associated with TV-viewing, time spent driving and with total sitting time (O'Donoghue et al., 2016) and so our results may be due to the measurement and operationalization of total sitting time in CaMos for the present analyses. While age is usually positively associated with sedentary behavior, almost all previous studies were based on single time point assessments of sitting time (Biswas et al., 2015; Rhodes et al., 2012). In the few studies that have examined associations between age and sitting patterns over two time points, the data show inconsistent directions. For example, in post-menopausal women in the USA, those with consistently low sitting time at 6-year follow-up were older than those with consistently high sitting (Lee et al., 2016); while in a Spanish cohort of older adults, those who were consistently non-sedentary over two years were younger than those who were consistently sedentary (León-Muñoz et al., 2013). Our findings thus contribute new information to the currently small body of literature about associations between age and sitting patterns over time.

Table 3

Predictors of consistently high/low sitters (based on changes in predictors), Canadian Multicentre Osteoporosis Study (CaMos), Canada, 1995–2007.

Predictor	Category	Sitting category							
		Consistently low				Consistently high			
		Univariate		Multivariate ^{a,b}		Univariate		Multivariate ^b	
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Age (years) ^c		1.00	0.99–1.00	0.99***	0.98–0.99	0.98***	0.97–0.98	1.01	1.00–1.01
Sex	Men (ref)	1.00		1.00		1.00		1.00	
	Women	1.45***	1.25–1.69	1.36**	1.16–1.60	0.56***	0.49–0.64	0.71***	0.61–0.83
Education	High school (ref)	1.00		1.00		1.00		1.00	
	Trade	1.00	0.86–1.15	0.94	0.81–1.08	1.06	0.92–1.23	0.97	0.83–1.13
	University	0.84	0.70–1.00	0.81*	0.67–0.98	1.61***	1.37–1.90	1.26*	1.05–1.52
Employment	Consistently employed (ref)	1.00		1.00		1.00		1.00	
	Became retired	0.86	0.69–1.07	0.93	0.73–1.18	0.34***	0.28–0.42	0.35***	0.28–0.43
	Stayed retired	1.24*	1.04–1.48	1.63***	1.28–2.07	0.31***	0.26–0.36	0.28***	0.22–0.36
	Other	1.32**	1.10–1.58	1.39**	1.11–1.72	0.29***	0.24–0.34	0.30***	0.24–0.37
Smoking	Current (ref)	1.00		1.00		1.00		1.00	
	Previous	1.26*	1.02–1.56	1.29*	1.03–1.61	0.89	0.73–1.08	0.99	0.80–1.21
	Never	1.52***	1.24–1.87	1.48**	1.19–1.83	0.79*	0.66–0.95	0.89	0.73–1.09
Physical activity	Consistently high (ref)	1.00		1.00		1.00		1.00	
	Consistently low	0.43***	0.34–0.54	0.48***	0.38–0.60	2.18***	1.82–2.62	1.97***	1.63–2.38
	Increasing	0.59***	0.48–0.72	0.62***	0.50–0.76	1.45***	1.21–1.75	1.32**	1.09–1.61
	Decreasing	0.67***	0.57–0.79	0.70***	0.59–0.82	1.13	0.96–1.33	1.17	0.98–1.40
Sleep	≤6 h	0.92	0.79–1.06	0.93	0.80–1.08	1.11	0.96–1.28	1.15	0.99–1.34
	7–8 h (ref)	1.00		1.00		1.00		1.00	
	≥9 h	0.98	0.78–1.24	0.95	0.75–1.21	0.96	0.76–1.21	1.14	0.89–1.46
BMI	Consistently not obese (ref)	1.00		1.00		1.00		1.00	
	Obese to not obese	0.57**	0.39–0.83	0.58**	0.39–0.84	1.26	0.91–1.73	1.44*	1.04–2.01
	Not obese to obese	0.78	0.60–1.00	0.83	0.64–1.07	1.27*	1.00–1.61	1.09	0.85–1.41
	Consistently obese	0.60***	0.50–0.73	0.61***	0.50–0.75	1.43***	1.21–1.69	1.45***	1.21–1.73
	Could not be classified	0.67**	0.51–0.87	0.68**	0.51–0.89	1.06	0.83–1.37	1.25	0.96–1.63
Self-rated general health	Good to excellent (ref)	1.00		1.00		1.00		1.00	
	Consistently fair/poor	0.89	0.62–1.27	0.97	0.67–1.40	1.26	0.91–1.76	1.48*	1.05–2.10
	Increasing	0.75	0.51–1.10	0.80	0.54–1.18	1.10	0.78–1.54	1.19	0.83–1.70
	Decreasing	0.79	0.59–1.04	0.88	0.66–1.17	0.78	0.59–1.04	0.91	0.68–1.22

* $p < 0.05$.** $p < 0.01$.*** $p < 0.001$.^a Four observations were deleted from the analytical sample due to missing values.^b Multivariate models adjusted for age, sex, education, and changes over time in employment, smoking, physical activity, sleep, BMI, and self-rated general health.^c Age was modelled as a continuous variable.

4.1. Strengths and limitations

Strengths of the study were the large population-based sample with interviewer administered questionnaires on 24-h activity and multiple sitting domains (work, commuting, eating, leisure), the prospective cohort design with three time points over ten years, adjustment for various potential confounders, and objectively measured height and weight. Single-item questions for overall sitting usually underestimate sedentary time (Healy et al., 2011) as do those using TV-viewing as a sedentary proxy (Sun et al., 2015). Despite being widely used as an indicator for sedentary behavior (Healy et al., 2011), TV-viewing may be an inadequate proxy of daily sitting due to its typical occurrence in leisure time and differential associations with health outcomes (Ekelund et al., 2016).

Several limitations apply. First, typical for large cohort studies, most variables were ascertained by self-report. Second, around 40% of the participants were lost during 10-year follow-up making the final analytical sample less representative although those that died or dropped out did not differ in sedentary behavior. Third, summing across ordinal sitting variables by using mid-points is an accepted method (Armitage et al., 2001), but may introduce bias. However, the potential measurement error is likely to be non-differential over time in this study, so unlikely to bias estimates of trend over time, or estimates of classification of maintained high sitters or the converse. Fourth, the reliability and validity of the sitting measures were not previously tested. Sedentary behavior is a relatively novel risk factor for chronic disease (Owen et al., 2009) and only in recent years new instruments and devices for measuring sitting time in population-based studies have been tested for validity

and reliability (Healy et al., 2011). Therefore, there have been few longitudinal studies that have measured sitting repeatedly over a long period of follow-up time. The baseline data for the present study were collected between 1995 and 1997, long before population-based sitting measures were widely used and validated. Although we acknowledge that the measure used in the current study was not validated against a more conventional instrument, which is an inherent limitation to an older study, it is surprisingly similar to more recent domain-specific and validated sitting questionnaires (Chau et al., 2011; Marshall et al., 2010). We also believe that our study has merits because of its repeated measures and long follow-up time. Finally, as the objective of this study was to quantify *change in sitting patterns* over time, rather than the prevalence of sedentary behavior, and given that the measurement instrument of sedentary behavior did not change across time points, it is unlikely that the instrument systematically biased sitting patterns over time.

5. Conclusion

Population studies with multiple measures of sitting are needed to examine time trends and thus characterize sitting-related risks and to assess the health associations with sedentary behavior. This research contributes to efforts to define target sub-groups for future sedentary-reducing interventions.

Conflict of interest statement

The authors declare that there is no conflict of interest.

CaMos Research Group

David Goltzman (co-principal investigator, McGill University, Montreal, Quebec, Canada), Nancy Kreiger (co-principal investigator, University of Toronto, Toronto, Ontario, Canada)

McGill University, Montreal, Quebec: Elham Rahme (biostatistician), J. Brent Richards (investigator), Suzanne N. Morin (investigator).

CaMos Coordinating Centre: Claudie Berger (study statistician), Suzanne Godmaire (research assistant), Silvia Dumont (research assistant).

Memorial University, St. John's Newfoundland: Carol Joyce (director), Christopher S. Kovacs (co-director), Minnie Parsons (coordinator).

Dalhousie University, Halifax, Nova Scotia: Susan Kirkland, Stephanie M. Kaiser (co-directors), Barbara Stanfield (coordinator).

Laval University, Quebec City, Quebec: Jacques P. Brown (director), Louis Bessette (co-director), GRMO, Jeanette Dumont (coordinator), Martin Després (imaging IT technician).

Queen's University, Kingston, Ontario: Tassos P. Anastassiades (director), Tanveer Towheed (co-director), Wilma M. Hopman (investigator), Karen J. Rees-Milton (coordinator).

University of Toronto, Toronto, Ontario: Robert G. Josse (director), Angela M. Cheung (co-director), Barbara Gardner-Bray (coordinator).

McMaster University, Hamilton, Ontario: Jonathan D. Adachi (director), Alexandra Papaioannou (co-director).

University of Saskatchewan, Saskatoon, Saskatchewan: Wojciech P. Olszynski (director), K. Shawn Davison (co-director), Jola Thingvold (coordinator).

University of Calgary, Calgary, Alberta: David A. Hanley (director), Steven K. Boyd (co-director), Jane Allan (coordinator and Coordinator's Representative to Executive Council).

University of British Columbia, Vancouver, British Columbia: Jerilynn C. Prior (director), Shirin Kalyan (co-director), Brian Lentle (investigator/radiologist), Bernice Liang (coordinator).

University of Alberta, Edmonton, Alberta: Stuart D. Jackson (medical physicist).

University of Manitoba, Winnipeg, Manitoba: William D. Leslie (investigator/nuclear medicine physician).

Acknowledgement

This work was completed while Sarah Pont was employed as a Trainee on the New South Wales Biostatistics Training Program, funded by the New South Wales Ministry of Health. She undertook this work while based at the Prevention Research Collaboration of the University of Sydney.

References

Aadahl, M., Andreasen, A.H., Hammer-Helmich, L., Buhelt, L., Jorgensen, T., Glumer, C., 2013. Recent temporal trends in sleep duration, domain-specific sedentary behaviour and physical activity. A survey among 25–79-year-old Danish adults. *Scand. J. Public Health* 41, 706–711.

Armitage, P., Berry, G., Matthews, J., 2001. *Statistical Methods in Medical Research*. fourth ed. Wiley-Blackwell, Malden, MS.

Bauman, A.E., Reis, R.S., Sallis, J.F., et al., 2012. Correlates of physical activity: why are some people physically active and others not? *Lancet* 380, 258–271.

Biswas, A., Oh, P.I., Faulkner, G.E., et al., 2015. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann. Intern. Med.* 162, 123–132.

Chau, J.Y., van der Ploeg, H.P., Dunn, S., Kurko, J., Bauman, A.E., 2011. A tool for measuring workers' sitting time by domain: the Workforce Sitting Questionnaire. *Br. J. Sports Med.* 45, 1216–1222.

Chau, J.Y., Merom, D., Grunseit, A., Rissel, C., Bauman, A.E., van der Ploeg, H.P., 2012. Temporal trends in non-occupational sedentary behaviours from Australian Time Use Surveys 1992, 1997 and 2006. *Int. J. Behav. Nutr. Phys. Act.* 9, 76.

Chau, J.Y., Grunseit, A.C., Chey, T., et al., 2013. Daily sitting time and all-cause mortality: a meta-analysis. *PLoS One* 8, e80000.

Clark, B.K., Peeters, G.M.E.E., Gomersall, S.R., Pavey, T.G., Brown, W.J., 2014. Nine year changes in sitting time in young and mid-aged Australian women: findings from the Australian Longitudinal Study for Women's Health. *Prev. Med.* 64, 1–7.

Ekelund, U., Steene-Johannessen, J., Brown, W.J., et al., 2016. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet* 388, 1302–1310.

Grunseit, A., Chau, J., Rangul, V., Lingsaas-Holmen, T., Bauman, A., 2017. Patterns of sitting and mortality in the Nord-Trøndelag Health Study (HUNT). *Int. J. Behav. Nutr. Phys. Act.* 14, 8.

Healy, G.N., Clark, B.K., Winkler, E.A.H., Gardiner, P.A., Brown, W.J., Matthews, C.E., 2011. Measurement of adults' sedentary time in population-based studies. *Am. J. Prev. Med.* 41, 216–227.

Kreiger, N., Tenenhouse, A., Joseph, L., et al., 1999. Research notes: the Canadian Multicentre Osteoporosis Study (CaMos): background, rationale, methods. *Can. J. Aging* 18, 376–387.

Lee, J., Kuk, J.L., Ardern, C.I., 2016. The relationship between changes in sitting time and mortality in post-menopausal US women. *J. Public Health* 38, 270–278.

León-Muñoz, L.M., Martínez-Gómez, D., Balboa-Castillo, T., López-García, E., Guallar-Castillón, P., Rodríguez-Artalejo, F., 2013. Continued sedentariness, change in sitting time, and mortality in older adults. *Med. Sci. Sports Exerc.* 45, 1501–1507.

Marshall, A.L., Miller, Y.D., Burton, N.W., Brown, W.J., 2010. Measuring total and domain-specific sitting: a study of reliability and validity. *Med. Sci. Sports Exerc.* 42, 1094–1102.

Milton, K., Gale, J., Stamatakis, E., Bauman, A., 2015. Trends in prolonged sitting time among European adults: 27 country analysis. *Prev. Med.* 77, 11–16.

Sedentary Behaviour Research Network, 2012. Letter to the Editor: standardized use of the terms "sedentary" and "sedentary behaviours". *Appl. Physiol. Nutr. Metab.* 37, 540–542.

Neuhaus, M., Eakin, E.G., Straker, L., et al., 2014. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. *Obes. Rev.* 15, 822–838.

Ng, S.W., Popkin, B.M., 2012. Time use and physical activity: a shift away from movement across the globe. *Obes. Rev.* 13, 659–680.

O'Donoghue, G., Perchoux, C., Mensah, K., et al., 2016. A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach. *BMC Public Health* 16, 163.

Owen, N., 2012. Sedentary behavior: understanding and influencing adults' prolonged sitting time. *Prev. Med.* 55, 535–539.

Owen, N., Bauman, A., Brown, W., 2009. Too much sitting: a novel and important predictor of chronic disease risk? *Br. J. Sports Med.* 43, 81–83.

Rhodes, R.E., Mark, R.S., Temmel, C.P., 2012. Adult sedentary behavior: a systematic review. *Am. J. Prev. Med.* 42, E3–E28.

Shrestha, N., Kukkonen-Harjula, K.T., Verbeek, J.H., Ijaz, S., Hermans, V., Bhaumik, S., 2016. Workplace interventions for reducing sitting at work. *Cochrane Database Syst. Rev.* 3, CD010912.

Sun, J.W., Zhao, L.G., Yang, Y., Ma, X., Wang, Y.Y., Xiang, Y.B., 2015. Association between television viewing time and all-cause mortality: a meta-analysis of cohort studies. *Am. J. Epidemiol.* 182, 908–916.

van der Ploeg, H.P., Venugopal, K., Chau, J.Y., et al., 2013. Non-occupational sedentary behaviors: population changes in the Netherlands, 1975–2005. *Am. J. Prev. Med.* 44, 382–387.