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Changes in physical activity among Canadian adults more than 6 months into the COVID-19 pandemic: a secondary analysis of the INTERACT cohort study

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ABSTRACT

Objective To estimate the effect of (a) the COVID-19 pandemic and (b) COVID-19 restriction stringency on daily minutes of device-measured moderate-to-vigorous physical activity (MVPA).

Design Physical activity data were collected from the INTerventions, Equity, Research and Action in Cities Team (INTERACT) cohorts in Montreal, Saskatoon and Vancouver before (May 2018 to February 2019, 'phase 1') and during the pandemic (October 2020 to February 2021, 'phase 2'). We estimated the effect of the two exposures by comparing daily MVPA measured (a) before vs during the pandemic (phase 1 vs phase 2) and (b) at different levels of COVID-19 restriction stringency during phase 2. Separate mixed effects negative binomial regression models were used to estimate the association between each exposure and daily MVPA, with and without controlling for confounders. Analyses were conducted on person-days with at least 600 min of wear time. Effect modification by gender, age, income, employment status, education, children in the home and city was assessed via stratification.

Setting Montreal (Quebec), Saskatoon (Saskatchewan) and Vancouver (British Columbia), Canada.

Main outcome measure Daily minutes of MVPA, as measured using SenseDoc, a research-grade accelerometer device.

Results Daily minutes of MVPA were 21% lower in phase 2 (October 2020 to February 2021) compared with phase 1 (May 2018 to February 2019), controlling for gender, age, employment status, household income, education, city, weather and wear time (rate ratio=0.79, 95% CI 0.69, 0.92). This did not appear to be driven by changes in the sample or timing of data collection between phases. The results suggested effect modification by employment, household income and education. Restriction stringency was not associated with daily MVPA between October 2020 and February 2021 (adjusted rate ratio=0.99, 95% CI 0.96, 1.03).

Conclusions Between October 2020 and February 2021, daily minutes of MVPA were significantly lower than 2 years prior, but were not associated with daily COVID-19 restriction stringency.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Accelerometer data was available for a relatively large sample of Canadian adults.
⇒ Data was collected during a similar period of calendar time before (May to February) and during the pandemic (October to February), reducing the risk that differences between the two periods were driven by seasonal trends.
⇒ There was a large decrease in daily wear time from phase 1 of data collection (before the pandemic) to phase 2 of data collection (during the pandemic).
⇒ Our measure of COVID-19 restriction stringency was not limited to policies that would be expected to influence physical activity levels.

INTRODUCTION

The WHO declared COVID-19 a pandemic on 11 March 2020, and, as of 12 January 2023, over 4.53 million confirmed infections and nearly 50 000 deaths had been reported in Canada alone.[1] COVID-19 restrictions implemented to control transmission of the virus[2] limited opportunities and spaces for physical activity. Regular physical activity is associated with reduced risk of all-cause mortality and chronic disease,[3–5] as well as improved mental health[6 7] and immune function.[8–10] Decreased physical activity may have public health consequences, particularly if reductions were sustained long-term.

Physical activity levels were significantly lower during initial COVID-19 lockdowns compared with before, both in Canada (eg, during April and early May 2020 compared with the weeks before the pandemic)[11 12] and elsewhere[13–18] (eg, between 31 January and 9 February 2020 in China,[13] January to March 2020 vs June 2020 in Brazil,[17] January to April 2020 vs January to April 2019 in Singapore[16]). Decreases in physical activity were largest in regions of Canada,[19] Germany[20] and Europe[21] where mitigation policies were strictest. A cross-sectional survey of over 11 000 adults from 11 countries found that the number and severity of public health measures, as summarised using the Oxford Coronavirus Government Response Tracker (OxCGRT) stringency index,[22 23] were associated with increased odds of engaging in no or low-levels of physical activity during the first few weeks of the pandemic, but not the odds of being less active relative to pre-pandemic levels.[22]

Physical activity increased when restrictions were relaxed in summer of 2020,[12 24–27] but few studies have assessed how activity changed when public health measures were re-introduced in the Fall of 2020. One study of Japanese workers reported decreased physical activity from June to November 2020, compared with the same period from 2019.[28] A cross-sectional survey of adults living in Europe found that physical activity levels in the fall lockdown (November to December 2020) were similar to the spring lockdown (March to April 2020) and significantly lower than before the pandemic or during the summer.[21] Additionally, a longitudinal study of 6540 Americans found an inverse association between state-level OxCGRT COVID-19 stringency index[23] and exercise frequency that was significant when stringency was high but insignificant once stringency dropped in January 2021.[29] To our knowledge, no study has described moderate-to-vigorous physical activity (MVPA) levels among Canadian adults during the second wave of the COVID-19 pandemic compared with a similar time period from before the pandemic, or assessed the impact of COVID-19 restriction stringency on activity levels during the Fall of 2020 and early 2021.

The purpose of this study was to estimate the impact of COVID-19 restrictions on physical activity among Canadian adults from October 2020 to February 2021. The first objective was to compare daily minutes of device-measured MVPA before (May 2018 to February 2019) and during (October 2020 to February 2021) the pandemic. The second objective was to estimate the association between daily COVID-19 restriction stringency and daily minutes of device-measured MVPA between October 2020 and February 2021.

METHODS

Study design

The INTerventions, Equity, Research and Action in Cities Team (INTERACT) is an open cohort study assessing the impact of urban change in Montreal, Saskatoon and Vancouver, Canada.[30] Participants gave informed consent to participate, completed online health surveys and were invited to wear a hip-worn SenseDoc accelerometer and integrated global positioning system (Mobysens) to collect device-based physical activity data for 10 consecutive days, except when showering. The accelerometer is manufactured by Analog Devices, which also produces the accelerometer in the ActiGraph GT3X device.[31] These data were collected during two periods: phase 1 between May 2018 and February 2019, and phase 2 between October 2020 and February 2021. The study sample differed between phases, since new participants were recruited for phase 2, while some phase 1 participants opted not to continue with the study; however, a subset of participants contributed data in both periods.[30] Differences in participant characteristics at the person and person-day levels are summarised in table 1.

Study population

INTERACT enrolled adults aged 18 or older, living in Montreal, Saskatoon or Vancouver, who did not plan on moving out of that city for at least 2 years and could read and write English (or French in Montreal) well enough to answer an online questionnaire.[30 32] Participants also needed to live near specific interventions of interest: within 3 km of the Arbutus Greenway in Vancouver; on the Island of Montreal, in Laval, or parts of the South Shore; or within 800 m of the proposed Bus Rapid Transit line and/or ride the bus at least monthly in Saskatoon. A convenience sample was recruited via social media, news media, partner communications, snowball sampling, newspaper advertisements and other efforts tailored for each city.[32]

Analytic sample

Previous accelerometer-based studies have found that a minimum of 600 min of wear time is required to generate a valid estimate of daily physical activity.[33–36] As such, we restricted the analysis to person-days with at least 600 min of accelerometer wear time (‘valid days’). Less active people tend to contribute fewer days of data overall,[34] so restricting to participants with a minimum number of valid days of data may introduce selection bias. To minimise this risk, all participants with at least one valid day of accelerometer data (600+ min) were retained for analysis. Studies using a 1-day threshold have generated similar estimates of daily sedentary time compared with those requiring 5 and 6 days of data from each participant,[37] and 95% of participants in a study by Colley *et al* had at least 1 day of data with 600 or more minutes of accelerometer wear time.[38]

Patient and public involvement

The INTERACT research team worked with community advocates and municipal staff in the study cities to craft research questions; design the recruitment strategy; interpret findings; and disseminate results. The general public was not involved in the design of the INTERACT study or this analysis specifically. The burden of participation was not assessed. INTERACT results are publicly available online.

Exposures

The two exposures of interest were the COVID-19 pandemic (before vs during pandemic) and the stringency of public health measures (during the pandemic).

The COVID-19 pandemic exposure was operationalised as a binary indicator distinguishing data collected

Table 1 Participant characteristics, summarised at the person and person-day level, by phase and stringency index

	Exposure 1: COVID-19 pandemic (phase 1 vs phase 2)				Exposure 2: COVID-19 restriction stringency		
	Participants with at least one valid day of data, by phase		Valid person-days, by phase		Valid person-days in phase 2, by stringency index		
	Phase 1 n=386	Phase 2 n=65	Phase 1 n=3010	Phase 2 n=250	0–41 n=91	42–47 n=67	48–100 n=92
Minutes of wear time, mean (SD)			820.7 (101.4)	725.2 (87.3)	735.2 (85.0)	733.5 (103.7)	709.2 (74.1)
Minutes of moderate-to-vigorous physical activity, mean (SD)			43.5 (36.3)	35.2 (34.3)	36.0 (35.1)	28.9 (31.6)	38.9 (35.1)
Mean temperature (°C), mean (SD)			11.2 (11.8)	1.8 (8.8)	1.2 (8.1)	−1.4 (10.8)	4.8 (6.7)
Total precipitation (mm), mean (SD)			1.84 (4.8)	2.9 (5.7)	2.0 (5.7)	4.3 (6.6)	2.9 (4.8)
City, n (%)							
Montreal	158 (40.9)	19 (29.2)	1263 (42.0)	73 (29.2)	0 (0.0)	0 (0.0)	73 (79.3)
Saskatoon	81 (21.0)	18 (27.7)	555 (18.4)	68 (27.2)	47 (51.6)	21 (31.3)	0 (0.0)
Vancouver	147 (38.1)	28 (43.1)	1192 (39.6)	109 (43.6)	44 (48.4)	46 (68.7)	19 (20.7)
Gender, n (%)							
Man	131 (33.9)	22 (33.8)	1044 (34.7)	84 (33.6)	33 (36.3)	26 (38.8)	25 (27.2)
Woman	252 (65.3)	40 (61.5)	1940 (64.5)	150 (60.0)	55 (60.4)	41 (61.2)	54 (58.7)
Other	3 (0.8)	3 (4.6)	26 (0.9)	16 (6.4)	3 (3.3)	0 (0.0)	13 (14.1)
Age, n (%)							
18–29	55 (14.2)	10 (15.4)	426 (14.2)	24 (9.6)	6 (6.6)	7 (10.4)	11 (12.0)
30–49	142 (36.8)	30 (46.2)	1091 (36.2)	118 (47.2)	32 (35.2)	29 (43.3)	57 (62.0)
50–69	132 (34.2)	21 (32.3)	1036 (34.4)	90 (36.0)	37 (40.7)	29 (43.3)	24 (26.1)
70+	51 (13.2)	4 (6.2)	427 (14.2)	18 (7.2)	16 (17.6)	2 (3.0)	0 (0.0)
Missing	6 (1.6)	0 (0.0)	30 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Household income, n (%)							
<$50 000	81 (21.0)	7 (10.8)	574 (19.1)	15 (6.0)	8 (8.8)	7 (10.4)	0 0.0)
$50 000–$99 999	107 (27.7)	17 (26.2)	849 (28.2)	64 (25.6)	21 (23.1)	14 (20.9)	29 (31.5)
$100 000 or more	162 (42.0)	35 (53.8)	1300 (43.2)	148 (59.2)	55 (60.4)	33 (49.3)	60 (65.2)
Don't know/prefer not to answer	36 (9.3)	6 (9.2)	287 (9.5)	23 (9.2)	7 (7.7)	13 (19.4)	3 (3.3)
No children at home, n (%)	179 (46.4)	34 (52.3)	1402 (46.6)	127 (50.8)	52 (57.1)	32 (47.8)	43 (46.7)
Education, n (%)							
University or graduate degree	300 (77.7)	56 (86.2)	2389 (79.4)	224 (89.6)	80 (87.9)	61 (91.0)	83 (90.2)
Secondary school	27 (7.0)	3 (4.6)	167 (5.5)	6 (2.4)	2 (2.2)	4 (6.0)	0 (0.0)
Trade school or college	55 (14.2)	6 (9.2)	434 (14.4)	20 (8.0)	9 (9.9)	2 (3.0)	9 (9.8)
Don't know/prefer not to answer	4 (1.0)	0 (0.0)	20 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Employment, n (%)							
Employed	256 (66.3)	44 (67.7)	2000 (66.4)	166 (66.4)	55 (60.4)	49 (73.1)	62 (67.4)
Retired and not working	77 (19.9)	9 (13.8)	633 (21.0)	35 (14.0)	27 (29.7)	3 (4.5)	5 (5.4)
Unemployed	16 (4.1)	5 (7.7)	93 (3.1)	11 (4.4)	8 (8.8)	2 (3.0)	1 (1.1)
Other	37 (9.6)	7 (10.8)	284 (9.4)	38 (15.2)	1 (1.1)	13 (19.4)	24 (26.1)

during phase 1 (May 2018 to February 2019) and phase 2 (October 2020 to February 2021) of the INTERACT study. Daily COVID-19 restriction severity was measured using a provincial stringency index calculated by The Institute for Research on Public Policy[39] using methods developed for the OxCGRT.[23] Briefly, the stringency index is the mean of several subindices, each of which summarises the severity of a specific public health measure in a given province on a given day, starting in March 2020. Severity was rated on a scale between 0 and 100, where 100 was the most severe, using a standardised codebook. Other studies have assessed COVID-19 restriction stringency using this methodology.[22 29]

Outcome

The primary outcome of interest was daily minutes of MVPA as assessed by SenseDoc accelerometers. Minutes of accelerometer data were classified as wearing or non-wearing,[40] and either sedentary, light, moderate or vigorous intensity using validated Actigraph activity count cut-points.[33] Non-wear minutes were removed, and both daily minutes of wear time and daily minutes of MVPA were calculated. Person-days with fewer than 600 min of wear time were excluded from the analysis.[33–36]

Covariates

The following variables were collected at the start of each phase: age (18–29, 30–49, 50–69 and 70+); gender (man, woman, trans man, trans woman, genderqueer/non-conforming; operationalised as man, woman or other gender for analyses due to small cell sizes for most categories); whether the participant had children in the home (yes/no); employment status (employed, retired and not working, unemployed, other); household income (<\$50 000, \$50 000 to \$99 999, \$100 000 or more, don't know/prefer not to answer); and education (secondary school, trade school or college, university or graduate degree, don't know/prefer not to answer). Values could vary between phases if respondents participated during both periods. Daily total precipitation and mean daily temperature in each city were accessed from the Government of Canada.[41] Daily wear time was calculated as the number of minutes during which the participant wore the SenseDoc device on a given date.[40]

Differences in physical activity between phase 1 and phase 2 or between days with different levels of COVID-19 restriction stringency could be confounded by changes in the cohort over time. As a result, models were run with and without adjusting for factors that were causally associated with device-measured physical activity (eg, age,[42] income, employment status, education,[43] gender and having children living at home[44]) that were unbalanced across phases or levels of restriction stringency, including daily minutes of wear time. We also hypothesised that both causal relationships could be modified by gender, age, household income, employment status, education level, having children living in the home and city. This was based on evidence that the pandemic had uneven impacts across different population groups[45 46] and differences in the pandemic response, activity culture and opportunities to remain active across the study cities.

Analysis

The analytic sample was created by removing person-days with fewer than 600 min of wear time. Descriptive statistics were used to characterise the sample at the person and person-day level, stratified by each exposure (table 1). The effect of the COVID-19 pandemic was estimated by running a mixed effects negative binomial model on daily minutes of MVPA, at the person-day level, with a random intercept per person and a fixed effect for data collection phase (phase 1 vs phase 2). The equation for the model is specified as follows: $\log(E[Y_{it}]) = \beta_0 + \beta_1 \cdot \text{Phase}_t + u_i$, where Y_{it} represents the daily minutes of MVPA for participant i on day t, Phase_t is a binary indicator distinguishing data from phase 1 and phase 2 of the INTERACT study (0 for phase 1/prepandemic, 1 for phase 2/during pandemic), β_0 is the intercept, β_1 is the coefficient for the phase/pandemic term, and u_i is the random intercept for participant i. The model was run with and without adjusting for day- and person-level predictors of physical activity that were unbalanced across levels of the exposure, leading to confounding (table 1). Balance across levels of the exposure (phase 1 vs phase 2) was assessed qualitatively, in alignment with current best practices for the reporting of observational studies.[47] This process was repeated to estimate the effect of COVID-19 restriction stringency on daily minutes of MVPA, but with a fixed effect for COVID-19 stringency index instead of phase. Only data from phase 2 was used for this analysis, as stringency index data was not available prepandemic. Balance was assessed by comparing the characteristics of person-days at different levels of COVID-19 restriction stringency. Participants were excluded from fully adjusted models if they were missing data for any identified confounders. A flow chart outlining the number of person-days included in each model is presented in online supplemental figure 1. Models were run using the glmer.nb function from the lme4 package in R V.4.1.1.

To assess for effect modification, models adjusted for wear time were re-run stratified by gender, age, household income, employment status, education, having children at home and city. If the effect of a given exposure differed across strata, models were re-run controlling for other unbalanced factors and the interaction effects were plotted.

Differences in physical activity between phase 1 and phase 2 could be related to changes in who participated and/or when data was collected (May to February for phase 1, October to February for phase 2). As a sensitivity analysis, models were re-run on two subsamples: (a) participants who contributed at least 1 day of data in both phases; and (b) person-days collected between 3 October and 20 February, the period of calendar time for which data were available for both phases. For each subsample, covariate balance was re-assessed (online supplemental table 1), a fully adjusted model was fit and the results were compared with those from the primary analysis (online supplemental table 2).

RESULTS

At least one valid day of SenseDoc data (600+ min of wear time) was available for 416 of 465 participants overall (89%); 386 participants and 3010 person-days in phase 1 and 65 participants and 250 person-days in phase 2 (online supplemental figure 1). A subset of 35 participants contributed at least one valid day of data in both phases. Over 60% of participants were women (65.3% in phase 1, 61.5% in phase 2), more than three quarters had a university or graduate degree (77.7% in phase 1, 86.2% in phase 2) and approximately half had children living at home (53.6% in phase 1, 47.7% in phase 2) (table 1). Participants in phase 2 were younger (47.4% aged 50 or older in phase 1 vs 38.5% in phase 2), more likely to earn over $100 000 per year (53.8% in phase 2 vs 42.0% in phase 1), more likely to have an undergraduate or graduate degree (86.2% in phase 2 vs 77.7% in phase 1) and more likely to be unemployed (7.7% in phase 2 vs 4.1% in phase 1) (table 1). Mean daily temperature, total daily precipitation and the distribution of participants by city also differed between phases. Everything except daily wear time and education level was unbalanced across levels of COVID-19 restriction stringency (table 1).

On average, participants contributed two times as many valid days of data in phase 1 (mean 7.8 days, SD 2.1 days) compared with phase 2 (mean 3.8 days, SD 2.7). In phase 2, mean daily minutes of wear time were nearly 100 min lower (phase 1 mean: 820.7 min, SD: 101.4 min; phase 2 mean: 725.2 min, SD: 87.3 min) and mean daily minutes of MVPA were 8.3 min lower than phase 1 (phase 1 mean: 43.5 min, SD: 36.3 min; phase 2 mean: 35.2 min, SD: 34.3 min) (table 1; figure 1; online supplemental figure 2). Decreases in wear time (mean phase 1: 843.1 min, SD: 95.9 min; mean phase 2: 723.6 min, SD: 79.7 min) and MVPA (mean phase 1: 53.6 min, SD: 41.2 min; mean phase 2: 36.5 min, SD: 36.5 min) were also observed among the subsample of participants that contributed data in both phases.

Impact of COVID-19 pandemic on MVPA

Daily minutes of MVPA were 21% lower during the pandemic period (October 2020 and February 2021) compared with before (May 2018 to February 2019), adjusted for city, age, employment status, household income, education level, weather and daily minutes of wear time (rate ratio (RR)=0.79, 95% CI 0.69, 0.92) (table 2). The effect was similar, though more uncertain, when the sample was restricted to (a) participants that contributed data in both phases (adjusted RR=0.81, 95% CI 0.63, 1.03), and (b) data collected between 3 October and 20 February (the period of time represented in both phases) (adjusted RR=0.83, 95% CI 0.70, 0.99) (online supplemental tables 1 and 2).

Stratified analyses were suggestive of effect modification by employment status, household income and education level. The impact of the pandemic on daily minutes of MVPA, adjusting for wear time, was largest for participants who earned <$50 000 per year (RR=0.41, 95% CI 0.22, 0.68), had only secondary school education (RR=0.38, 95% CI 0.16, 0.90) and were employed (RR=0.63; 95% CI 0.52, 0.74) (online supplemental table

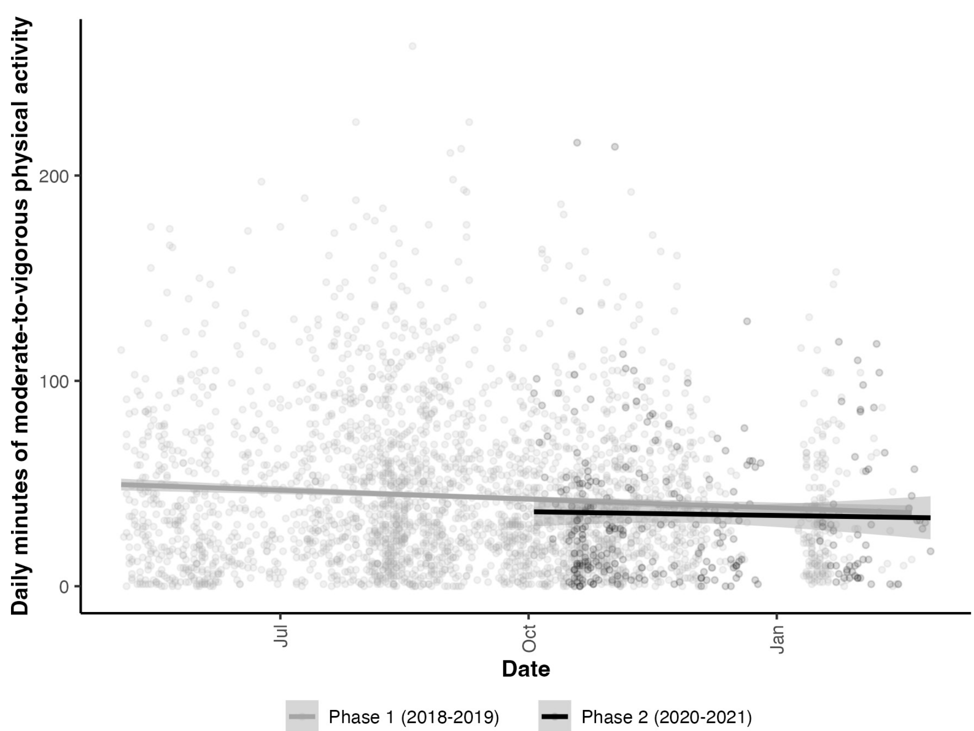

Figure 1 Trend in daily minutes of moderate-to-vigorous physical activity for each phase.

Table 2 Ratio of daily minutes of moderate-to-vigorous physical activity in phase 2 compared with phase 1 from multilevel negative binomial regression models, with and without adjusting for unbalanced factors

Covariates	Person-days		Rate ratio (RR)	95% CI
	Phase 1	Phase 2		
None (unadjusted)	3010	250	0.66	0.58, 0.75
Adjusted for unbalanced factors*	2893	249	0.79	0.69, 0.92

*City, age, employment status, household income, education level, mean daily temperature, daily precipitation, daily minutes of wear time.

Table 3 Rate ratios (RRs) of daily minutes of moderate-to-vigorous physical activity associated with a 10-unit increase in the stringency of COVID-19 restrictions, from multilevel negative binomial regression models

Covariates	Person-days	RR	95% CI
None (unadjusted)	250	1.01	0.98, 1.04
Unbalanced factors*	249	0.99	0.96, 1.03

*City, gender, age, household income, employment status, having children living at home, mean daily temperature, total daily precipitation.

3). The interaction between phase and each effect modifier, adjusted for age, city, employment status, household income, education level, mean daily temperature, total daily precipitation and daily minutes of wear time, is plotted in figure 2.

Impact of lockdown stringency on MVPA

Compared with the first few months of the pandemic, the stringency of COVID-19 restrictions was relatively low in all three provinces when phase 2 data collection started in October 2020 (online supplemental figure 3). Between October 2020 and February 2021, the stringency of COVID-19 restrictions remained relatively consistent in Saskatchewan but increased incrementally in Quebec and British Columbia (online supplemental figure 3). During this period, COVID-19 restriction stringency was highest in Quebec and generally lowest in Saskatchewan.

A 10-unit change in the stringency of lockdown measures was not associated with daily minutes of MVPA during phase 2 of data collection (unadjusted RR=1.01, 95% CI 0.98, 1.04; adjusted RR=0.99, 95% CI 0.96, 1.03) (table 3). The effect was unchanged after adjusting for city, gender, age, household income, employment status, having children living at home, daily mean temperature and total precipitation. In general, the results did not support effect modification due to wide CIs (online supplemental table 4).

DISCUSSION

We observed significant and meaningful reductions in physical activity between October 2020 and February 2021 compared with data from May 2018 to February 2019. The magnitude of the effect was not meaningfully impacted by differences in the sample or changes in the timing of data collection between phase 1 and phase 2. We also found preliminary evidence that the impact of the pandemic on daily physical activity was modified by household income, employment status and education. However, many strata contained a very small number of participants and results should be interpreted with caution.

The pandemic had a similar impact on daily MVPA in this study compared with others that have examined this association. We found that mean daily MVPA was 8.3 min lower during the pandemic compared with before, while other studies reported declines of between 3.7 and 25 min per day.[12 16 18 48 49] However, most other studies compared physical activity in the weeks immediately before and after the implementation of initial public health measures,[12 18 49] when the impact on behaviour was expected to be greatest.

The stringency of COVID-19 restrictions was not associated with daily minutes of MVPA in Vancouver, Montreal and Saskatoon from October 2020 to February 2021. This

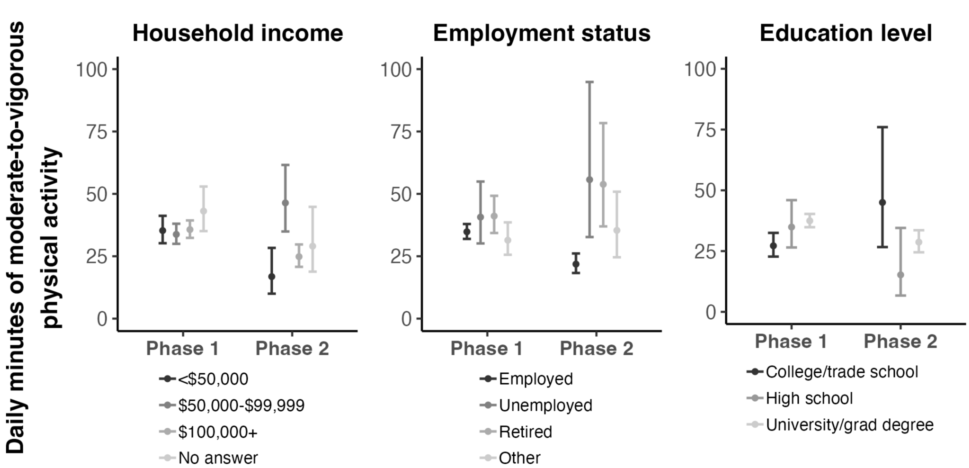

Figure 2 Daily minutes of moderate-to-vigorous physical activity by phase and across levels of identified effect modifiers.

may be related to a number of factors. First, the stringency index captures changes in a broad range of COVID-19 restrictions, many of which would not be expected to influence physical activity. Second, the stringency index was measured at the province-level and thus may not capture policy changes specific to the three cities. Third, changes in physical activity may lag changes in stringency, which was not assessed in our study. Finally, the relationship between stringency and physical activity observed early in the pandemic[19–21] may have diminished as people adapted and tired over time, or as they established new routines that were less effected by COVID-19 restrictions.

We observed large changes in wear time between the prepandemic and pandemic periods. In the current study, participants wore the data collection device on a similar number of days in both phases, but contributed half as many days with at least 600 min of movement data in phase 2 compared with phase 1. Reductions in wear time were also observed among individuals that contributed data in both periods, even though instructions regarding when to wear the device had not changed. At least one other study reported a statistically significant decrease in wear time during the pandemic compared with before, though the magnitude was smaller (52 min/day lower in June 2020 compared with January to March 2020) than observed among our sample.[17]

This decrease in wear time during the pandemic was an important limitation of our study. Even after restricting to valid person-days (600+ min of wear time), mean daily wear time was nearly 100 min lower in phase 2 compared with phase 1. As a result, the estimated effect of the pandemic term could be driven, in part, by lower daily wear time during phase 2. We mitigated this risk by also adjusting for daily wear time in our models. However, it is possible that the relationship between when an individual wore their device and when they were active changed during the pandemic. Additionally, if people who are more active tend to wear accelerometers for longer and on more days,[34] excluding person-days with less than 600 min of exercise may result in an overestimate of MVPA relative to the underlying population and thus an underestimate of the effect of the pandemic on activity levels. Future studies should aim to assess and account for this phenomenon.

The external validity of this study is limited by the representativeness of the sample. Our participants were highly educated, wealthy and primarily female. As a result, our results may not be generalisable to the underlying population. We expect that the impact of the pandemic on physical activity may be even greater among more marginalised individuals, particularly given our results showing larger reductions among participants with the lowest household incomes and education level. INTERACT participants may also be more active than the general population, and the effect of the pandemic on physical activity may vary depending on baseline activity level and/or exercise motivation. Future work should assess whether these factors, including whether a person met physical activity guidelines prior to the pandemic, predicted or modified the effect of either the pandemic and/or associated public health measures on daily MVPA.

Another important limitation was the change in sample composition between phases and over the course of phase 2, due to difficulties recruiting new and existing participants during the pandemic. In particular, characteristics of the sample differed greatly across levels of COVID-19 restriction stringency (table 1). For example, people without children were more likely to participate earlier in phase 2, when restriction stringency was relatively low (table 1; online supplemental figure 3). We addressed this by controlling for variables that impact physical activity and were unbalanced across levels of the exposure; however, the adjusted result may still be confounded by unmeasured factors. Future analyses should aim to recruit a larger and diverse sample, particularly for the purposes of assessing if and how the effect of the pandemic varied between population groups. Researchers with access to longitudinal physical activity data collected before and throughout the pandemic from a single cohort could extend our work by describing continuous trends in behaviour throughout this period.

Finally, many cities adopted policies in favour of physical activity during the pandemic.[50 51] While our models include city level fixed effects, they do not account for the temporal and spatial patterning of these policies in our study cities.

Conclusion

Daily minutes of MVPA were significantly lower between October 2020 and February 2021 compared with May 2018 to February 2019, but were not associated with daily COVID-19 restriction stringency. We provide preliminary evidence that the impact of the pandemic on physical activity differed depending on household income, employment status and education level. Some of the negative health impacts of pandemic restrictions may be reduced by simultaneously instituting policies that encourage physical activity and movement resiliency.

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Contributors DF, MW, YK and KS contributed to data collection and funding acquisition. SS and DF designed the current study. SS led the analysis, drafted the manuscript and revised the manuscript in accordance with coauthor feedback. DG, RM and SW supported the conceptualisation of the study. DF, DG, RM and SW

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Competing interests YK (NPI) holds shares in Mobysens Technologies Inc, a spin-off company that markets the SenseDoc 2.0, which is a multisensor device (SenseDoc 2.0) used to measure physical activity (accelerometer) in the INTERACT study. The SenseDoc was filed as an invention in 2013 at Univalor (www.univalor.ca), a company affiliated with Université de Montréal and Centre de Recherche du CHUM.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants. The INTERACT study received ethics approval from the ethics boards of Simon Fraser University (2017s0158, 2017s0531 and 2018s0127), the University of Saskatchewan (17-347), the Centre de Recherche du Centre hospitalier de l'Université de Montréal (CÉR CHUM 16.397) and Memorial University of Newfoundland (20180446). The current analysis was also approved by the Health Sciences Research Ethics Board at the University of Toronto (00041959). Participants gave informed consent to participate in the study before taking part.

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Data availability statement Data are available upon reasonable request. The datasets analysed in this study are not publicly available because they contain detailed data about participants, but can be made available by the corresponding author on request. The statistical analysis code for this study is available online (https://github.com/shelbysturrock/INTERACT-analysis).

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