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# Changes in Canadian Adolescent Time Use and Movement Guidelines During the Early COVID-19 Outbreak: A Longitudinal Prospective Natural Experiment Design

**Markus Joseph Duncan,[1] Negin Alivia Riazi,[1] Guy Faulkner,[2] Jenna Diane Gilchrist,[3] Scott Thomas Leatherdale,[3] and Karen Allison Patte[1]**

[1]Department of Health Sciences, Faculty of Applied Health Sciences, Brock University, St. Catharines, ON, Canada; [2]School of Kinesiology, The University of British Columbia, Vancouver, BC, Canada; [3]School of Public Health Sciences, University of Waterloo, Waterloo, ON, Canada

***Background:*** Comprehensive, prospective, longitudinal data are lacking on the effects of the COVID-19 outbreak on adolescents' movement behaviors (moderate to vigorous physical activity [MVPA], sleep, recreational screen use, and strengthening exercises). The purpose was to compare movement behavior changes among adolescents affected by the pandemic with controls. ***Methods:*** Survey data from 10,659 students at 82 Canadian secondary schools (aged 12–19 y) during the 2018–2019 and 2019–2020 school years were analyzed. One-year change in time spent in movement behaviors and likelihood of meeting Canadian 24-hour movement guidelines was compared between preoutbreak controls (October 2019–March 2020) and early outbreak respondents (May–July 2020) after controlling for sociodemographic factors. ***Results:*** Compared with controls, the early outbreak group reported a greater decrease in time spent in MVPA and greater increases in time spent in sleep and recreational screen use. The early outbreak group was less likely to meet MVPA and recreational screen time guidelines but more likely to meet guidelines for strengthening exercises and sleep duration. ***Conclusions:*** Findings for MVPA and screen time changes were in the same direction as retrospective reports from children and youth samples. Sleep adherence may have improved due to no longer having to commute to school. Strengthening exercises may represent physical activity that is easier to do in the home with minimal equipment leading to improved adherence during restrictions.

***Keywords****:* screen time, sleep, pandemic, youth

On March 11, 2020, the World Health Organization declared the outbreak of COVID-19 a global pandemic. To reduce the spread and rates of transmission, governments across the world imposed varying lockdown measures, mandating the closure of many schools, programs, facilities, and other community spaces with limitations on public use of outdoor spaces. The collateral public health consequences of these measures are evident. The impact of pandemic-related restrictions on the movement behaviors (physical activity [PA], screen time, and sleep) of children and youth is a case in point.[1] For children and youth, accruing more PA and sleep while minimizing screen time is associated with better mental and physical health status while facilitating long-term healthy physical and social development.[2–5] Additionally, maintaining positive movement-related habits into adulthood reduces the risk of several negative health outcomes, chronic diseases, and all-cause mortality.[6] The evidence of the benefits of movement behaviors for healthy growth and development is sufficiently compelling that Canada has released 24-hour integrated movement behavior guidelines for children and youth.[4] For children and youth aged 14–17 years, corresponding approximately to secondary school ages, the guidelines recommend ≥60 minutes per day of moderate to vigorous PA (MVPA) including muscle and bone strengthening activities ≥3 days per week, ≤120 minutes per day of recreational screen time, and 8 to 10 hours per night of sleep. Children and youth meeting movement recommendations have better cardiometabolic and mental health compared with peers not meeting guidelines.[7,8]

A recent scoping review systematically summarized the available literature investigating the relationships between the COVID-19 pandemic and movement behaviors (PA, sedentary behavior, and sleep) of school-aged children (aged 5–11 y) and youth (aged 12–17 y) in the first year of the COVID-19 virus outbreak.[1] One hundred and ten empirical studies were identified examining PA ($k = 79$), sedentary behavior/screen time ($k = 60$), and sleep ($k = 55$). Twenty-eight studies measured all 3 movement behaviors. Results from both prospective and cross-sectional studies consistently reported declines in PA time, increases in screen time, and total sedentary behavior; shifts to later bed and wake times, and increases in sleep duration have also been observed, but evidence is inconsistent. A national Canadian study of parents ($n = 1472$) with children and youth (5–17 y) examining changes in movement and play behaviors during the COVID-19 outbreak found that only 0.6% of youth 12–17 years old were meeting combined movement behavior guidelines during COVID-19 restrictions (individual guidelines: 13% MVPA, 72% sleep, and 6.6% screen time).[9] As

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Riazi https://orcid.org/0000-0002-0674-177X
Faulkner https://orcid.org/0000-0001-8898-2536
Gilchrist https://orcid.org/0000-0002-7323-0953
Leatherdale https://orcid.org/0000-0001-5926-3065
Patte https://orcid.org/0000-0002-5214-1943
Duncan (mduncan2@brocku.ca) is corresponding author, https://orcid.org/0000-0002-9190-7147

with the broader literature,[1] younger children experienced less change from their pre-COVID-19 movement behaviors compared with older youth, thus indicating a particular need to support adolescents in maintaining a healthy balance of movement behaviors during the ongoing recovery from the COVID-19 pandemic.

There remains a gap in understanding longer-term changes in movement behaviors and a need for longitudinal data to describe the change from prepandemic to during-pandemic behaviors.[1] Of the 20 longitudinal prospective studies identified by Paterson et al,[1] only 3 simultaneously examined changes in PA, sleep, and screen time/sedentary behavior[10–12]; however, the sample sizes were comparatively small (n = 9–291). Furthermore, despite clear recommendations for engaging in muscle and bone strengthening activities among school-aged children and youth,[4] no studies in the scoping review assessed changes in participation in these types of activities during the pandemic. Additionally, despite natural declines in PA with age in children and adolescents[13] and increases in sedentary behaviors,[14] longitudinal studies did not use a control group to evaluate whether changes were larger than what might be expected over a similar time span.

Given this gap and the absence of prospective longitudinal data tracking the impact of the pandemic on the movement behaviors of Canadian youth, the purpose of this study was to compare 1-year changes in MVPA, sleep, recreational screen time, and strengthening exercises among high-school aged adolescents who responded to a survey during the early COVID-19 outbreak across Canada to a control group who had responded prior to the of COVID-19 outbreak. Where appropriate, movement behaviors were examined as both the change in self-reported time spent engaging in each behavior as well as adherence to 24-hour movement behavior guidelines[4] for youth.

# Methods

## Design and Data Collection

Student-level data linked from years 7 (Y7) and 8 (Y8) of the COMPASS study (collected during the 2018–2019 and 2019–2020 school year, respectively) were used for these analyses. COMPASS (2012–2021) collects hierarchical, longitudinal health data annually from a rolling cohort of students in grades 9 to 12 and *secondaire 1 to 5* (in Quebec) attending a convenience sample of secondary schools across Canada.[15] The primary purpose of the COMPASS study is to track changes in multiple youth health behaviors and outcomes over time, and allows for the evaluation of natural experiments by simultaneously tracking changes in school programs, policies, or built environment longitudinally.[15]

The COMPASS study has received ethics approval from the University of Waterloo Human Research Ethics Committee, Brock University Research Ethics Committee, and participating school boards. Additional details regarding study methods can be found online (www.compass.uwaterloo.ca), or in print.[15] The student questionnaire cover page includes items to create a unique code for each respondent to ensure anonymity, while allowing COMPASS researchers to link each student's data over multiple years (detailed by Qian et al[16]). All students attending participating schools were invited to participate using active-information passive-consent parental permission protocols, which are critical for collecting robust data among youth.[17,18] Students could decline to participate at any time. Recruitment methods are detailed further by Reel et al.[19]

Student-level data were collected using the COMPASS student questionnaire. Data during Y7 and Y8 prior to the 2020 outbreak of COVID-19 in Canada were collected using a paper-based survey designed to collect student-reported data from full school samples during one classroom period. Prior to the outbreak, participating schools were scheduled to participate in surveys at approximately the same time each year to facilitate comparison of year-on-year differences; Y7 data were collected from September 2018 to March 2019. Preoutbreak Y8 data were collected as scheduled from October 2019 to March 12, 2020. From March 13 to 18, 2020, school closures and states of emergency were declared in provinces with remaining participating schools; data collection for remaining participating schools shifted to an online survey. Schools emailed students an initial survey link and one reminder. For schools in Ontario and British Columbia, surveys were left open for 2 weeks, and 4 weeks for schools in Quebec; schools in Alberta opted not to participate in online survey administration. The earliest survey link was sent by a school on May 1, 2020; the last survey closed on July 6, 2020. Thirty-nine of 51 schools first emailed links in May, with the remainder sent in June. Additional details on the process of transitioning to online administration is described in detail by Reel et al.[20] To compensate for lower response rates, online responses were weighted within schools to achieve the same sex by age distribution in Y8 as Y7 and between schools such that schools contributed the same proportion of the overall sample in Y8 as they did in Y7.

## Measures

***Movement Behaviors.*** *Moderate to Vigorous Physical Activity:* The COMPASS student questionnaire uses a MVPA assessment tool used for national surveillance of youth.[21] The survey provides a definition and examples of MVPA and asks students to report activity time on each of the last 7 days (Monday–Sunday). For both moderate and vigorous PA intensities, participants were asked to indicate the number of hours and minutes of activity for each day. Response options for hours ranged from 0 to 4 in 1-hour increments, and options for minutes ranged from 0 to 45 in 15-minute increments. Thus, daily reported time in either moderate or vigorous PA could range from 0 to 285 minutes (ie, 0 h 00 min–4 h 45 min). Average daily MVPA was calculated by summing daily moderate PA and vigorous PA before averaging across 7 days. Previous validation data on COMPASS MVPA scores have reported an absolute agreement intraclass correlation coefficient (ICC) of .25 (Pearson $r = .31$) with accelerometry-derived measures of MVPA and a 1-week test–retest ICC of .75 (Pearson $r = .68$).[22] MVPA data were classified as missing if there were no responses across all 7 days, otherwise nonresponses were assumed to mean 0 minutes of activity. Average daily MVPA was used to classify participants based on Canadian movement guidelines, which recommend ≥60 minutes of daily MVPA for children and youth aged 5–17 years.

*Strengthening Exercise Guidelines:* The student questionnaire asks "On how many days in the last 7 days did you do exercises to strengthen or tone your muscles? (eg, push-ups, sit-ups, or weight-training)." Participants were classified as meeting Canadian movement guidelines for strengthening exercise guidelines if responses indicated 3 or more days.

*Sleep and Recreational Screen Time:* The student questionnaire asks for time usually spent per day sleeping, doing homework, watching television, playing video games, surfing the internet, and texting. Time spent watching television, playing video games, surfing the internet, and texting were summed as an indicator of recreational screen time with nonresponses assumed to represent 0 minutes of physical activity (unless all responses were missing, in which case recreational screen time data were classified as missing). Time reported doing homework was used to evaluate total reported time for sensitivity analyses but was not analyzed as an outcome. Previous evaluation of screen time items reported 1-week test–retest ICCs ranging from .54 to .86; when items are summed, the ICC with accelerometer-derived sedentary behavior was .15 (Pearson $r = .20$).[22] Canadian movement guidelines recommend 8 to 10 hours of sleep for youth aged 14–17 years and no more than 2 hours of recreational screen time.

Similar to MVPA items, participants were asked to indicate the number of hours and minutes of activity for each specific behavior. On the paper survey, response options for hours ranged from 0 to 9 in 1-hour increments, and responses for minutes ranged from 0 to 45 in 15-minute increments allowing for a range from 0 to 585 minutes (ie, 0 h 00 min–9 h 45 min) for each behavior. Due to fewer space constraints with online delivery and to allow surveys to capture oversleeping, students who completed the survey online during the outbreak had an expanded response options for 0 to 12 hours and 0 to 45 minutes, allowing for up to 765 minutes (ie, 12 h 45 min) to be reported for each behavior. However, for the purposes of this analysis, responses above 585 minutes were winsorized to match the response range possible on the paper survey. Among early outbreak respondents, 14.1% of responses on the sleep item were above 585 minutes; winsorizing reduced sleep scores >585 minutes by a mean (SD) of 44.5 (47.8) minutes. For screen behaviors, 0.7% to 2.1% of responses from the early outbreak were winsorized for being >585 minutes; affected scores were reduced by a mean (SD) of 86.5 (64.1) to 95.0 (63.6). For all behaviors, 600 minutes was the modal response among scores >585 minutes.

*Outliers and Time Use Constraints:* Previous analysis with the COMPASS data set classified <3 hours per day of sleep and >6 hours per day MVPA as data outliers[23]; the same criteria were applied to data for this analysis. Additionally, >21 hours per day of recreational screen time, as the maximum possible screen time assuming a minimum of 3 hours per day of sleep, was deemed an outlier. Primary analysis winsorized values above or below outlier thresholds, with sensitivity analyses performed excluding outliers instead. Regardless as to how outliers were handled, statistical tests and model comparisons resulted in the same conclusions and effect size were of a similar magnitude.[I] Results from winsorized data are reported.

In recognition of the constrained nature of time use, an additional sensitivity analysis was performed for all models, where participants were included only if they reported ≤24 hours of total time use with no behaviors missing. Results from both unconstrained and ≤24-hour constrained analysis of winsorized data are reported. Excluding outlier data again resulted in similar conclusions and effect sizes as winsorizing.

***Confounding Variables.*** Models controlled for Y7 demographics: sex (male/female), education year, race (responses were dichotomized as “White” if this was the sole racial identity selected or “Black, Indigenous, and other People of Color” for all other responses), province, urbanicity of the school region (large urban, medium urban, small urban, and rural), and weekly spending money ($0, $1–20, $21–100, >$100, and don’t know) as a proxy for socioeconomic status.[II] For education year, *secondaire 3 to 5* in Quebec were treated as equivalent to grades 9 to 11, respectively, where secondary education ends in Quebec; *secondaire 1 to 2* were excluded to align with typical North American “high school” years.

## Statistical Analysis

Analyses were performed using R*Studio running R (version 3.6.3).[24] Mixed modeling approaches were used to account for school-level clusters ($k = 82$). Regressions were performed using the *lme4* package.[25] A conditional change model[26] was used for continuous data: change scores (Y8–Y7) were regressed on baseline (Y7) scores in addition to confounding and group variables. The conditional change approach results in identical interpretation as the analysis of covariance and residual differences approaches to evaluating change but with the advantage of predicted values being scaled to differences between Y8 and Y7 as opposed to the Y8 values or the residuals, respectively.[27] Diagnostic plots from mixed-model linear regression indicated divergence from the assumption of normally distributed residuals. Models were respecified using a generalized estimating equation (GEE) with a Gaussian distribution and exchangeable correlation structure for school-based clusters[28] using *geepack*.[29] GEE relaxes the variance distribution assumption so long as the distribution family is coherent with the scale of the dependant variable.[28] For adherence to movement behaviors guidelines and proportion of guidelines met, mixed-model logistic regressions with random intercepts for schools regressed Y8 behavior status against Y7 behavior, confounding variables and outbreak group.

For all dependant variables, 3 nested models were generated: (1) a restricted model with confounding variables and Y7 behavior, (2) a group difference model adding a group variable comparing preoutbreak to early outbreak responses to the restricted model, and (3) an interaction model with an interaction term added between the group variable and prior behavior to test whether the effect of the group variable was dependent on prior behavior (eg, whether the odds of meeting guidelines at Y8 in individuals previously meeting MVPA guidelines was affected by COVID-19 outbreak and associated restrictions more than those who had not been meeting guidelines). GEE models were compared sequentially using the Quasi-likelihood under the independence model criterion (QIC)—lower scores represent a better model while accounting for parsimony similar to the Akaike information criterion (AIC)—and the likelihood ratio test (LRT) implemented for GEE in the *geepack*.[29] Regression models were compared using AIC and LRTs. Models with the best fit indices were used to generate predicted group means after averaging over statistical controls (estimated marginal means) using the *emmeans* package.[30] When interaction effects were identified between categorical parameters, post hoc analysis compared preoutbreak with early outbreak groups within each prior movement category, reported $P$ values are adjusted for the false discovery rate using the Benjamini–Hochberg approach.[31]

# Results

## Participants

Data from 10,659 individuals from 82 schools were linked between Y7 and Y8 of the study. Table 1 summarizes Y7 demographics confounding variables and movement behavior data. At Y7, sample ages ranged from 12 to 19 years with a mean (SD) of 15.0 (0.9). While activity guidelines used to classify behaviors in this analysis are intended for children and youth age of 14–17 years, 98.3% of the sample was within this range at Y7. After winsorizing outliers, 8,719 (81.8%) individuals reported ≤24 hours of total time use across movement behaviors at both Y7 and Y8, and were included in sensitivity analyses.

## MVPA Time and Guidelines

Table 2 summarizes GEE model comparison statistics for all conditional change models of continuous movement behaviors.

**Table 1 Summary of Linked Sample Covariates and Behaviors**

| Descriptor | Preoutbreak | Early outbreak | |
|---|---|---|---|
| | | Unweighted | Weighted |
| Participants | 8014 | 2645 | |
| Schools | 38 | 44 | |
| Sex | | | |
| Female | 4192 (52.3%) | 1725 (65.2%) | 1445 (54.4%) |
| Male | 3794 (47.3%) | 917 (34.7%) | 1210 (45.5%) |
| Missing | 28 (0.3%) | 3 (0.1%) | 3 (0.1%) |
| Education year | | | |
| Grade 9/*secondaire 3e* | 3219 (40.2%) | 1102 (41.7%) | 1161 (43.7%) |
| Grade 10/*secondaire 4e* | 2987 (37.3%) | 1066 (40.3%) | 1049 (39.5%) |
| Grade 11/*secondaire 5e* | 1678 (20.9%) | 460 (17.4%) | 431 (16.2%) |
| Grade 12 | 130 (1.6%) | 17 (0.6%) | 17 (0.6%) |
| Province | | | |
| Alberta | 644 (8.0%) | 0 | 0 |
| British Columbia | 1290 (16.1%) | 207 (7.8%) | 197 (7.4%) |
| Ontario | 4094 (51.1%) | 1471 (55.6%) | 1401 (52.7%) |
| Quebec | 1986 (24.8%) | 967 (36.6%) | 1061 (39.9%) |
| Ethnicity | | | |
| White | 5744 (71.7%) | 1879 (71.0%) | 1956 (73.6%) |
| BIPOC or multiple ethnicities | 2270 (28.3%) | 766 (29.0%) | 702 (26.4%) |
| Weekly spending money | | | |
| $0 | 1448 (18.1%) | 494 (18.7%) | 502 (18.9%) |
| $1–20 | 1108 (13.8%) | 368 (13.9%) | 398 (15.0%) |
| $20–100 | 2823 (35.2%) | 938 (35.5%) | 905 (34.0%) |
| $101+ | 1158 (14.4%) | 388 (14.7%) | 415 (15.6%) |
| Don’t know | 1419 (17.7%) | 440 (16.6%) | 420 (15.8%) |
| Missing | 58 (0.7%) | 17 (0.7%) | 19 (0.6%) |
| Urbanicity | | | |
| Large urban | 3543 (44.2%) | 1638 (61.9%) | 1598 (60.1%) |
| Medium urban | 1197 (14.9%) | 115 (4.3%) | 154 (5.8%) |
| Small urban | 2815 (35.1%) | 799 (30.2%) | 870 (32.7%) |
| Rural | 459 (5.7%) | 93 (3.5%) | 35 (1.3%) |
| Y7 MVPA per day | 112.1 (76.4) | 97.2 (71.5) | 98.1 (74.3) |
| ≥1 h/d | 5790 (72.2%) | 1699 (64.2%) | 1679 (63.2%) |
| <1 h/d | 2104 (26.3%) | 908 (34.3%) | 932 (35.1%) |
| Missing | 120 (1.5%) | 38 (1.4%) | 47 (1.8%) |
| Y8 MVPA per day | 108.1 (76.3) | 81.0 (68.7) | 82.9 (70.4) |
| ≥1 h/d | 5637 (70.3%) | 1327 (50.2%) | 1351 (50.8%) |
| <1 h/d | 2263 (28.2%) | 1036 (39.2%) | 1011 (38.0%) |
| Missing | 114 (1.4%) | 282 (10.7%) | 296 (11.1%) |
| Y7 strength guidelines | | | |
| ≥3 d/wk | 3847 (48.0%) | 1104 (41.7%) | 1140 (42.9%) |
| <3 d/wk | 4044 (50.5%) | 1514 (57.2%) | 1489 (56.0%) |
| Missing | 123 (1.5%) | 27 (1.0%) | 29 (1.1%) |
| Y8 strength guidelines | | | |
| ≥3 d/wk | 3643 (45.5%) | 1204 (45.5%) | 1193 (44.9%) |
| <3 d/wk | 4276 (53.4%) | 1211 (45.8%) | 1222 (46.0%) |
| Missing | 95 (1.2%) | 230 (8.7%) | 243 (9.1%) |

*(continued)*

**Table 1 *(continued)***

| Descriptor | Preoutbreak | Early outbreak | |
|---|---|---|---|
| | | Unweighted | Weighted |
| Y7 sleep per day | 432.0 (100.2) | 431.8 (94.6) | 432.5 (97.5) |
| 8–9.75 h | 3804 (47.5%) | 1184 (44.8%) | 1223 (46.0%) |
| <8 h | 4174 (52.1%) | 1456 (55.0%) | 1431 (53.8%) |
| Missing | 36 (0.4%) | 5 (0.2%) | 4 (0.2%) |
| Y8 sleep per day | 421.5 (97.0) | 471.3 (95.9) | 472.6 (94.3) |
| 8–9.75 h | 3185 (39.7%) | 1704 (64.4%) | 1716 (64.6%) |
| <8 h | 4804 (59.9%) | 845 (31.9%) | 833 (31.3%) |
| Missing | 25 (0.3%) | 96 (3.6%) | 109 (4.1%) |
| Y7 screen time per day | 377.2 (235.2) | 384.6 (238.0) | 386.3 (238.8) |
| ≤2 h | 642 (8.0%) | 199 (7.5%) | 205 (7.7%) |
| >2 h | 7336 (91.5%) | 2441 (92.3%) | 2449 (92.1%) |
| Missing | 36 (0.4%) | 5 (0.2%) | 4 (0.2%) |
| Y8 screen time per day | 406.6 (241.0) | 463.1 (251.4) | 466.2 (252.0) |
| ≤2 h | 486 (6.1%) | 89 (3.4%) | 94 (3.5%) |
| >2 h | 7503 (93.6%) | 2460 (93.0%) | 2455 (92.4%) |
| Missing | 25 (0.4%) | 96 (3.6%) | 109 (4.1%) |
| Y7 number of guidelines met | | | |
| 0 | 840 (10.5%) | 371 (14.0%) | 365 (13.7%) |
| 1 | 2115 (26.4%) | 822 (31.1%) | 808 (30.4%) |
| 2 | 2929 (36.5%) | 908 (34.3%) | 920 (34.6%) |
| 3 | 1721 (21.5%) | 448 (16.9%) | 457 (17.2%) |
| 4 | 187 (2.3%) | 37 (1.4%) | 40 (1.5%) |
| Missing | 222 (2.8%) | 59 (2.2%) | 69 (2.6%) |
| Y8 number of guidelines met | | | |
| 0 | 1008 (12.6%) | 217 (8.2%) | 198 (7.4%) |
| 1 | 2432 (30.3%) | 705 (26.7%) | 715 (26.9%) |
| 2 | 2928 (36.5%) | 844 (31.9%) | 838 (31.5%) |
| 3 | 1392 (17.4%) | 564 (21.3%) | 562 (21.1%) |
| 4 | 94 (1.2%) | 20 (0.8%) | 25 (1.0%) |
| Missing | 160 (2.0%) | 295 (11.2%) | 319 (12.0%) |

Abbreviations: BIPOC, Black Indigenous or other people of color; MVPA, moderate to vigorous physical activity; Y7, year 7; Y8, year 8. Note: Values represent n (%) for categorical data or mean (SD) for continuous data. Demographics are reported from Y7 of the COMPASS study. Movement behavior data are reported from Y7 and Y8. Means (SD) were calculated after winsorizing outliers (<3 h of sleep, >6 h of MVPA, and >21 h of recreational screen time). Weighted SDs were calculated using the "unbiased estimator" as this approach resulted in the same SDs for the preoutbreak group as when calculated without weights. Weighted counts are rounded to the nearest whole number. Percentages are calculated within groups (preoutbreak vs early outbreak).

Group difference models were a significant improvement on the restricted model and had a lower QIC. Adding a group by Y7 MVPA interaction further improved on the group difference model. Figure 1A illustrates the interaction effect where the difference between groups was more pronounced among the most active individuals. Averaged across statistical controls including Y7 MVPA, when total reported time was unconstrained, the interaction model predicted a mean (95% confidence interval) change of −23.1 (−29.5 to −16.7) minutes in the early outbreak group which differed significantly compared with a mean change of −5.2 (−9.2 to −1.1) minutes in the preoutbreak group. When movement behavior time data were constrained to ≤24 hours, model averages predicted a mean change of −20.9 (−27.1 to −14.8) minutes in the early outbreak group which differed significantly compared with a mean change of −5.4 (−9.1 to −1.7) minutes in the preoutbreak group. Models without an interaction predicted similar mean changes in MVPA.

Table 3 summarizes logistic mixed-model comparison statistics for adherence to behavior guidelines. For MVPA guidelines at Y8, the group difference model was an improvement on the restricted model, indicating significant differences in likelihood of meeting the guideline between early and preoutbreak groups. Adding a group by Y7 MVPA guideline adherence interaction did not improve the model. Figure 2A depicts the probabilities of meeting each behavior guideline, including MVPA, by group. Models predicted that the early outbreak respondents were significantly less likely to meet MVPA guidelines than preoutbreak respondents, for both unrestricted (adjusted odds ratio [AOR]: 0.58 [0.48 to 0.70]) and ≤24-hour restricted data (AOR: 0.58 [0.48 to 0.70]).

## Strengthening Exercise Guidelines

Strength guidelines was the only categorical dependent variable where conclusions from model comparisons differed depending on whether time use data were unconstrained or constrained to ≤24 hours reported. When data were unconstrained, the interaction model had the lowest AIC and was a statistically significant

**Table 2 Model Comparison Fit Indices and Likelihood Ratio Test Summary for Continuous Movement Behavior Change Variables**

| | Restricted | Group difference | | | Interaction (baseline behavior by group) | | |
|---|---|---|---|---|---|---|---|
| Model: behavior | QIC[a] | QIC[a] | $\chi^2$ (1) | *P* | QIC[a] | $\chi^2$ (1) | *P* |
| MVPA | | | | | | | |
| Unconstrained | 4.05 | 3.98 | 39.5 | <.001 | 3.96 | 17.8 | <.001 |
| ≤24 h constrained | 2.93 | 2.88 | 35.9 | <.001 | 2.87 | 4.7 | .030 |
| Sleep | | | | | | | |
| Unconstrained | 8.56 | 7.99 | 275.0 | <.001 | 7.98 | 5.1 | .025 |
| ≤24 h constrained | 6.66 | 6.244 | 246.0 | <.001 | 6.239 | 6.6 | .010 |
| Screen time | | | | | | | |
| Unconstrained | 40.57 | 39.563 | 51.5 | <.001 | 39.556 | 1.0 | .32 |
| ≤24 h constrained | 18.60 | 18.19 | 39.8 | <.001 | 18.17 | 9.2 | .003 |

Abbreviations: MVPA, moderate to vigorous physical activity; QIC, quasi-likelihood under the independence model criterion. Note: $\chi^2$ and *P* values correspond to likelihood ratio test comparing against the model to the left.

[a] QIC statistics reported at 10 million unit scale ($\times 10^7$) and reported to the first differing decimal.

improvement on nested models (see Table 3), whereas when data were constrained, the group difference model had the lowest AIC and adding an interaction was not a statistically significant improvement.

For unconstrained analyses, the interaction model predicted that among individuals who had previously not met strengthening exercise guidelines, early outbreak respondents were more likely to meet guidelines than the preoutbreak respondents (AOR: 1.57 [1.17 to 1.97], $z = 10.0$, $P_{\text{adjusted}} < .001$), whereas among individuals who had previously met guidelines the difference the confidence interval crossed 1, indicating equivalence between groups (AOR: 1.17 [0.85 to 1.58], $z = 9.4$, $P_{\text{adjusted}} < .001$) despite achieving statistical significance.

Averaged across all other predictors, the model based on unrestricted data predicted that early outbreak respondents were significantly more likely to meet strengthening guidelines than the preoutbreak group (AOR: 1.35 [1.12 to 1.59]). The group difference model of ≤24-hour constrained data found a similar group difference (AOR: 1.56 [1.26 to 1.85]).

## Sleep Time and Guidelines

Like MVPA, QIC and LRTs indicated that among nested models, including a group by previous behavior interaction term was the best fit for change in reported sleep time (see Table 2). The interaction effect indicated that the group difference between the early outbreak compared with preoutbreak on changes in reported sleep time was greater for individuals who had previously been accruing less sleep than individuals previously reporting higher volume of sleep. Figure 1B illustrates the change in sleep as a function of previous sleep volume predicted by the interaction model.

Averaged across statistical controls including Y7 sleep, the interaction model predicted a mean change of 42.5 (35.4 to 49.7) minutes in the early outbreak group which differed significantly compared with a mean change of −4.9 (−9.5 to −0.4) minutes in the preoutbreak group when total reported time use was unconstrained. When movement behavior time data were constrained to ≤24 hours, model averages predicted a mean change of 38.6 (31.5 to 45.6) minutes in the early outbreak group which differed significantly compared with a mean change of −6.2 (−11.1 to −1.2) minutes in the preoutbreak group. Group difference models without interaction predicted similar mean changes in sleep time.

For sleep guidelines, the group by prior behavior interaction models was identified as the best fit for the data (see Table 3). Figure 2A illustrates the overall model predicted likelihood of meeting sleep guidelines by group averaged across statistical controls and prior behavior status; overall, early outbreak respondents were significantly more likely to meet sleep guidelines for both unrestricted (AOR: 3.59 [3.11 to 4.14]) and ≤24-hour restricted movement data (AOR: 3.59 [2.97 to 4.08]). The group difference model without an interaction resulted in similar overall predictions. Figure 2B illustrates the interaction effect by separating model predicted group probabilities based on prior guideline adherence. Individuals in the early outbreak group were always significantly more likely to meet sleep guidelines; however, the odds ratio between groups was significantly larger among those who had previously not met guidelines ($\text{AOR}_{\text{unrestricted}}$: 4.46 [3.59 to 5.55], $z = 17.7$, $P_{\text{adjusted}} < .001$; $\text{AOR}_{\text{restricted}}$: 4.36 [3.42 to 5.54], $z = 15.7$, $P_{\text{adjusted}} < .001$) than among those who had previously been meeting guidelines ($\text{AOR}_{\text{unrestricted}}$: 2.89 [2.24 to 3.73], $z = 10.7$, $P_{\text{adjusted}} < .001$; $\text{AOR}_{\text{restricted}}$: 2.78 [2.08 to 3.71], $z = 9.1$, $P_{\text{adjusted}} < .001$), suggesting that, in terms of sleep, individuals previously not meeting guidelines benefitted more from the changes associated with COVID-19-related restrictions than their peers who had already been getting sufficient sleep.

## Recreational Screen Time and Guidelines

Recreational screen time was the only continuous dependant variable where conclusions drawn from model fit comparisons differed depending on whether data were restricted or unrestricted to ≤24 hours. In the case of unrestricted data, QIC was slightly lower for the model including a prior behavior by group interaction; however, LRT found no significant improvement on the group difference model (see Table 2). The group difference model predicted a mean change in screen time of 101.4 (82.2 to 120) minutes among early outbreak respondents and 44.2 (28.8 to 59.6) minutes among preoutbreak respondents, representing a

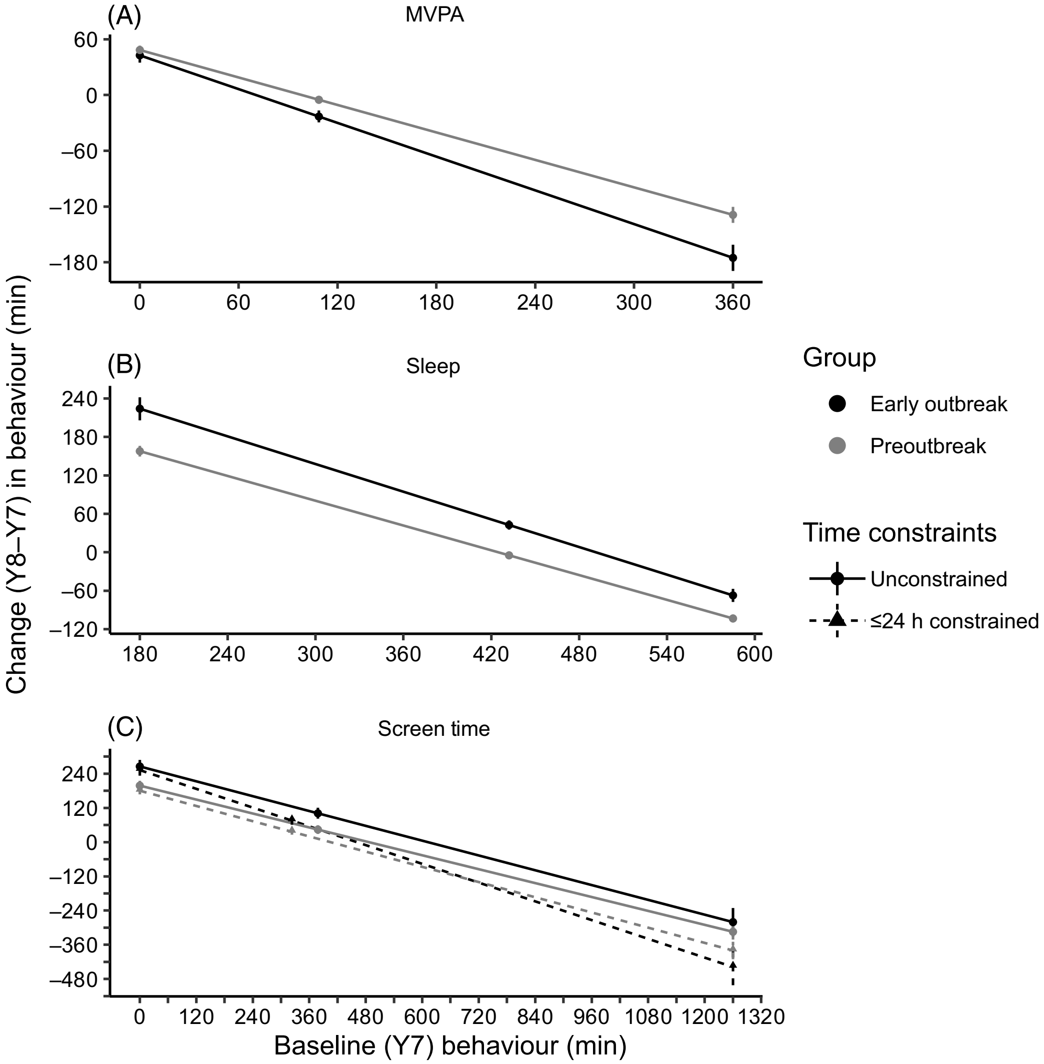

**Figure 1** — Comparison of model predicted 1-year change in movement behaviors between responses collected before or during early COVID-19 outbreak in Canada. Note: Depicted model predictions are based on interaction models as these were the best fit for data except for unconstrained screen time (see Table 2). Color denotes group based on when responses were collected (black = early outbreak and gray = preoutbreak). Points with 95% confidence intervals bars indicate model predictions at the minimum, mean, and maximum of time spent in that behavior at T1. Predictions from ≤24-hour constrained models are only illustrated for recreational screen time as there was no perceptible difference in predictions for other variables; for this graph point, shape and line-type differentiate unconstrained data (circle, solid lines) or ≤24-hour constrained data (triangle, dashed lines). MVPA indicates moderate to vigorous physical activity; Y7, year 7; Y8, year 8.

statistically significant difference between groups. The interaction model of unrestricted data predicted the same group differences at the mean of prior behaviors.

When movement data were restricted to ≤24 hours, QIC and LRT agreed that adding an interaction term resulted in a better fit of the data. Figure 1C illustrates the interaction model predictions for change in recreational screen time across reported screen time at Y7. At low levels of initial screen time, the early outbreak respondents increased recreational screen time more than preoutbreak respondents, whereas at higher levels of initial screen time a cross over is predicted with early outbreak respondents reducing screen time slightly more than the preoutbreak group. Averaged across statistical controls and prior behavior, the model predicted a mean change of 75.7 (61.0 to 90.5) minutes of recreational screen time in the early outbreak group and 36.4 (26.2 to 46.6) minutes in the preoutbreak group.

For recreational screen time guidelines, AIC and LRT tests found that the group difference model was an improvement over the restricted model, but adding an interaction term did not improve the model (see Table 3). Regardless of whether data were unrestricted (AOR: 0.59 [0.44 to 0.79]) or restricted to ≤24 hours (AOR: 0.60 [0.45 to 0.81]), the model predicted that individuals in the early outbreak group were significantly less likely to meet screen guidelines than preoutbreak respondents. Figure 2A illustrates the model predicted probabilities.

## Proportion of Movement Guidelines Met

After winsorizing movement data but before adjusting for statistical controls, 1.2% of preoutbreak respondents at Y8 met all Canadian movement guidelines (MVPA, strength, sleep, and recreational screen time) for youth, while 0.8% of early outbreak

**Table 3 Model Comparison Fit Indices and Likelihood Ratio Test Summary for Guideline Adherence at Follow-Up (Year 8)**

| | Restricted | Group difference | | | Interaction (baseline behavior by group) | | |
|---|---|---|---|---|---|---|---|
| **Model: behavior** | **AIC** | **AIC** | $\chi^2$ **(1)** | ***P*** | **AIC** | $\chi^2$ **(1)** | ***P*** |
| MVPA ≥ 1 h/d | | | | | | | |
| Unconstrained | 10,617 | 10,594 | 25.2 | <.001 | 10,593 | 2.6 | .11 |
| ≤24 h constrained | 9215 | 9192 | 24.6 | <.001 | 9192 | 2.4 | .12 |
| Strength exercise | | | | | | | |
| Unconstrained | 12,134 | 12,124 | 12.5 | <.001 | 12,118 | 7.6 | .006 |
| ≤24 h constrained | 10,232 | 10,214 | 19.2 | <.001 | 10,216 | 0.4 | .50 |
| Sleep ≥ 8 h/d | | | | | | | |
| Unconstrained | 11,855 | 11,727 | 130.0 | <.001 | 11,715 | 14.6 | <.001 |
| ≤24 h constrained | 9748 | 9635 | 116.0 | <.001 | 9625 | 11.7 | <.001 |
| Screen time ≤ 2 h/d | | | | | | | |
| Unconstrained | 3715 | 3704 | 12.5 | <.001 | 3705 | 0.6 | .44 |
| ≤24 h constrained | 3428 | 3419 | 11.2 | <.001 | 3421 | 0.1 | .78 |
| Proportion of guidelines met | | | | | | | |
| Unconstrained | 8882 | 8551 | 332.9 | <.001 | 8490 | 63.1 | <.001 |
| ≤24 h constrained | 7532 | 7258 | 276.1 | <.001 | 7210 | 49.3 | <.001 |

Abbreviations: AIC, Akaike information criterion; MVPA, moderate to vigorous physical activity. Note: $\chi^2$ and *P* values correspond to likelihood ratio test comparing against the model to the left.

respondents (1.0% weighted) met all guidelines (see Table 1). For guidelines related to time use[III] (MVPA, sleep, and screen time) at Y8, 2.0% (n = 160) in the preoutbreak group met time use guidelines, while 1.1% (n = 30; weighted: 1.4%, n = 37) in the early outbreak group met time use guidelines.

Logistic regressions assessed the proportion of movement behavior guidelines met. AIC and LRTs indicated that the interaction was an improvement on nested models (see Table 3). On average, the preoutbreak response group was predicted to meet 0.6 (0.5 to 0.7) guidelines, while the early outbreak group was predicted to meet 1.5 (1.4 to 1.7) guidelines; however, the interaction indicated that difference between groups was more pronounced among those who had previously been meeting fewer guidelines (0.1 [0.08 to 0.14] vs 0.8 [0.6 to 1.0] when 0 guidelines met at Y7) compared with those who had been meeting more guidelines (2.6 [2.4 to 2.8] vs 2.7 [2.4 to 2.9] when all 4 guidelines met at Y7).

## Discussion

Results were similar to existing literature on movement behavior change in children and youth during early outbreak/lockdown periods of 2020 and validate much of the existing retrospective cross-sectional data through a prospective, longitudinal design. Studies have consistently reported decreases in MVPA and increases in recreational screen time, with individuals less likely to meet both guidelines.[1] This study also expands on those previous reports by finding that, for time spent in MVPA, adolescents who were previously more active had a greater reduction in MVPA during the early outbreak than similarly active prepandemic controls. One plausible contributing factor may be that, prior to the COVID-19 outbreak, these active individuals were participating in school- or community-based programs and services (eg, clubs, intermural or competitive sports teams, community centers, and gyms), which provide opportunities to be more physically active; however, pandemic restrictions at the time of observation meant that many of these services were not operating and were not replaced with a different modality of MVPA, leading to a greater decrease in MVPA than the rate of disengagement observed in controls. Those individuals who do not spontaneously return to these programs and services when made available again may be a key demographic to target for additional health promotion to support returning to prior activities and a more optimal level of MVPA. Students who transitioned out of secondary school during pandemic-related restrictions may be particularly vulnerable to a premature decrease in activity if they have aged out or are otherwise no longer able to access of the services and programs that they had been previously using. Coaches, instructors, or other service providers should also recognize that those individuals who do return to prior activities may not be at the expected level of fitness due to an extended period with lower MVPA accrual, and should adapt programs and practice accordingly to avoid deterring youth from continued participation due to aversive experiences during bouts of vigorous PA or exercise.[32]

Previous literature has also suggested that while children and youth engaged in more total sleep time, the quality may have been negatively affected during the early outbreak.[1] The present study again found that, on average, adolescents during the early outbreak increased their sleep year-on-year more than the preoutbreak group, with individuals getting the least sleep showing the largest difference between groups. Remote delivery of school may have allowed individuals with the most time pressures (eg, longer commutes, after school activities and obligations, part time jobs) to allot more time toward sleep. The adoption of more sleep may be one positive outcome from restrictions designed to reduce the spread of COVID-19 and may mitigate some of the deleterious effects of accruing less MVPA and more recreational screen time. This finding reinforces the importance of considering multiple behaviors simultaneously when assessing the potential health consequences of changes in movement behaviors,[33] as benefits

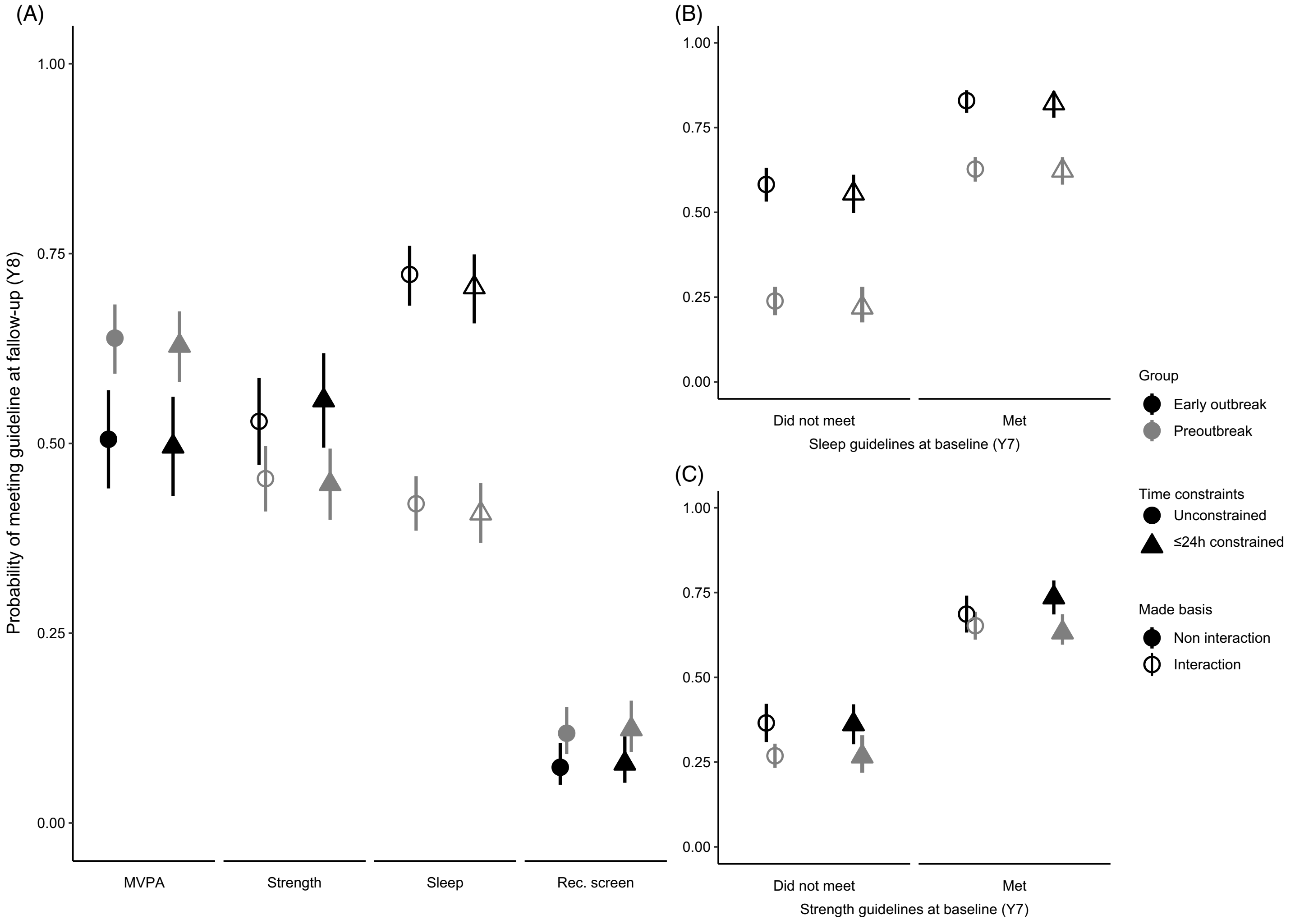

**Figure 2** — Comparison of model predicted probabilities of meeting guidelines at follow-up between responses collected before or during early COVID-19 outbreak in Canada. Note: Color denotes group based on when responses were collected (black = early outbreak and gray = preoutbreak). Point shape denotes whether models were based on unconstrained (circle) or ≤24-hour constrained data (triangle). When the interaction model was a better fit for data (see Table 3), probability point estimates are depicted unfilled as opposed to filled for the group difference models. Panel A illustrates the model predicted probabilities averaged over any interactions. The interactions between prior guidelines and outbreak group are depicted in panel B for sleep and panel C for strengthening exercise guidelines. MVPA indicates moderate to vigorous physical activity; Rec. screen, recreational screen; Y7, year 7; Y8, year 8.

to youth of accruing more sleep such as reduced adiposity and better emotional well-being[3] may be negated by simultaneously reducing MVPA.[5] Youth who have adopted better sleep (or other) behaviors during the pandemic would be well advised to maintain these habits after restrictions have been eased or lifted, while also being encouraged to return to prior physical activities. In fact, the adoption of sleep guideline adherence in the outbreak group was sufficiently large that, along with strength guideline adherence, individuals in the early outbreak were more likely to meet a larger proportion of the guidelines despite being less likely to meet MVPA and recreational screen guidelines. In that regard, this study is, to our knowledge, the first to examine strength-related guideline adherence during the pandemic, finding that adherence improved. It is certainly possible that strengthening exercises (eg, bodyweight, minimal equipment) were easiest to perform in the home to compensate for lost opportunities for aerobic MVPA through team sport and physical education facilities, as evidenced by widespread use in online physical education classes.[34] More research is warranted to explore potential benefits, risks, reasons, and determinants of strength-related exercise adoption during the pandemic.

Understanding the determinants of who adopted or maintained more healthful movement behaviors during COVID-19 restrictions may help inform efforts to get children and youth to move more, accrue sufficient sleep, and sit less during recreation beyond the pandemic. For example, delaying school start times for youth has been suggested as a modifiable factor to encourage more sleep accrual.[35] While the current study was not able to examine whether wake times had shifted during the early outbreak, it is likely that much of the increased sleep time accrued by the early outbreak group replaced time spent getting ready for or commuting to school. Unfortunately for those who actively commuted to school, this may have simultaneously reduced time spent in PA. Providing opportunities to both accrue more sleep before school as well as actively commute would be more optimal; delaying school start times appears to be one potential approach. The reduction in time spent in MVPA when existing supports are removed reinforces the need to develop more competence, knowledge, and understanding to value and engage in physical activities among youth—key aspects of physical literacy,[36] especially in a population nearing the transition to adulthood and will age out of existing programs and services. In particular, developing physical literacy surrounding muscle and bone strengthening exercises that are both enjoyable and can be done at home or community may be particularly useful to mitigate time constraints or financial and environmental barriers.

A key limitation of the data was the use of self-report measures as opposed to device-based methods of quantifying movement (eg, accelerometers). While the self-report scores available in COMPASS correlate with accelerometry-derived measures about as well as other self-report measures,[22] in general, self-report scores of MVPA[37,38] and sedentary behavior[39] appear to be less accurate as a measure of time use when compared with device-based scores. However, when self-report scales are used to assess whether youth and adolescents meet guidelines, agreement with accelerometry varies (72%–88%),[40–42] but appears to be better than using scores as a measure of minutes. While caution should be taken when interpreting results from *all* self-report data on movement behaviors, both categorical and continuous approaches to data analysis performed in our analysis widely agreed and should increase the confidence in the findings (even if exact minutes of activity may be somewhat inaccurate). Additionally, even with device-based approaches, supplemental self-report data collection would be necessary to differentiate recreational screen time from other sedentary behaviors to align with the Canadian guidelines. Given the circumstances, the trade-off of using self-report is likely necessary to understand the effect of the pandemic on the movement behaviors of youth.[1] Only one prospective study used device-based measures to assess PA change during COVID-19-related lockdowns by leveraging baseline data from 66 primary school children (7–12 y old) enrolled in a registered controlled trial,[43] which highlights the unfeasibility of device-based population-level measurement of movement behaviors in these circumstances.

The specific self-report questions posed some additional limitations. Paper-based student surveys limited responses on the sleep item to <10 hours, thus we could not detect changes in sleep that may put individuals over the guideline recommended 8 to 10 hours for this age group. Additionally, the way recreational screen time data is collected allows for values over 30 hours per day before winsorizing data; even with winsorizing, this can lead to greater than 24 hours of total activity per day. This issue may arise from screen time activities not being mutually exclusive from other activities (eg, watching TV while doing MVPA on treadmill) which may explain why test results were similar regardless of whether the 24-hour total time reported constraint was applied to data for all variables *except* screen time. Similarly, some screen time behaviors may be erroneously classified as recreational (eg, “surfing the internet” for homework; texting to discuss a group project). Finally, while models were run with a 24-hour constraint to align data better with daily activities, without measures of light PA and time spent in sedentary behavior for nonrecreational purposes—most notably, time spent in online delivery of lessons—the calculated total time used to accomplish this represents an underestimation.

The shift to online data collection may result in inherent biases in the data collection process, despite using a weighting approach to reduce biases associated with a lower response rate. For example, no data were collected from Alberta during the early outbreak. It is also plausible that responding at home compared with in the classroom may also have affected response biases, for example, students may have been more likely to respond in a socially desirable manner in one environment contributing to the observed differences between groups. Additionally, data collection was delayed for early outbreak respondents compared with a typical school year, as a result, any seasonal effects on movement behaviors may not have been controlled for to the same extent as the preoutbreak group. The generally more amenable weather of May/June in Canada compared with March/April when the surveys for the affected schools were originally to be administered may have led to underestimation of the change in MVPA and recreational screen time.

Despite these limitations, this analysis is among the most comprehensive and high-quality evidence quantifying movement behavior change in adolescents during the early COVID-19 outbreak thus far. Only 3 prospective studies have simultaneously examined changes in PA, sleep, and screen time/sedentary behavior[10–12]; however, they included comparatively small sample sizes (n = 9–291), did not include a control comparison group despite natural declines in PA with age in children and adolescents,[13] and generally used researcher constructed items to assess movement behaviors rather than established questionnaires with validation studies.[1] Only the smallest study (n = 9) examined behavior change in a North American (United States) context and was limited to individuals with Autism Spectrum Disorder.[10] Given the varied nature of global lockdown, mitigation, and COVID-19 transmission rates, it is optimal to have geopolitically regionalized data. Despite this, few reports using longitudinal prospective movement data from North American youth exist compared with Europe and Asia[1]; PA and sedentary behaviors in 211 children aged 5–13 years in the United States were assessed by Dunton et al,[44] and 2 international studies assessed sleep in adolescents aged 15–18 years living in the United States and/or Canada (n = 3078 and 1142, respectively)[45,46] but did not break data down by region. The analyses presented addresses a need for a large, prospective, North American study in adolescents that assesses multiple movement behavior domains simultaneously.

In conclusion, there is little surprise that the COVID-19 pandemic and early outbreak mitigation strategies have negatively impacted the MVPA and recreational screen usage of adolescents in Canada. The impact of such health behavior changes, and how they interact with the inherent stress of living through a pandemic, requires additional research. However, results from this study are an important reminder to consider the impact of multiple movement behaviors on health simultaneously, as compensatory increases in sleep may represent a protective mechanism.

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## Notes

[I] Due to the nature of outliers being defined at only one extreme, the overall proportion of participants meeting sleep and screen guidelines was inflated, and meeting MVPA guidelines was deflated when excluding outliers rather than winsorizing; however, the relative probabilities between groups (ie, odds ratios) were unaffected.

[II] Spending money and regional median income based on the school postal code were tested in models together as well as apart. Logistic regression models failed to converge when regional median income was included as a term, and model indicators (AIC/QIC) were also best when spending money alone was used.

[III] Reported for comparability with studies where only guidelines related to time use are evaluated, for example Moore et al.[9]

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