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ORIGINAL RESEARCH

Changes in Pediatric Movement Behaviors During the COVID-19 Pandemic by Stages of Lockdown in Ontario, Canada: A Longitudinal Cohort Study

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Background: Children's movement behaviors have been affected by the COVID-19 pandemic; however, little is known regarding movement behavior patterns over time by government-issued lockdowns. Our primary objective was to evaluate how children's movement behaviors changed by stages of lockdown/reopening in Ontario, Canada, from 2020 to 2021. ***Methods:*** A longitudinal cohort study with repeated measures of exposure and outcomes was conducted. The exposure variables were dates from before and during COVID-19 when child movement behavior questionnaires were completed. Lockdown/reopening dates were included as knot locations in the spline model. The outcomes were daily screen, physical activity, outdoor, and sleep time. ***Results:*** A total of 589 children with 4805 observations were included (53.1% boys, 5.9 [2.6] y). On average, screen time increased during the first and second lockdowns and decreased during the second reopening. Physical activity and outdoor time increased during the first lockdown, decreased during the first reopening, and increased during the second reopening. Younger children (<5 y) had greater increases in screen time and lower increases in physical activity and outdoor time than older children (≥5 y). ***Conclusions:*** Policy makers should consider the impact of lockdowns on child movement behaviors, especially in younger children.

Keywords: children, repeated measures, sedentary behavior, screen time

Healthy movement behaviors, including longer sleep duration, increased physical activity and outdoor time, and limited screen time, have been associated with favorable child health outcomes, including improved physical and cognitive development.[1–3] Lockdowns issued by governments to help curtail the spread of the COVID-19 pandemic have had substantial impacts on the daily lives of children and families. In Ontario, Canada, lockdown-related public health measures involved the closure of schools, nonessential businesses, parks, organized sports, and indoor and outdoor recreational facilities.[4–8] Daily COVID-19 cases in Ontario over time can be observed in the Ontario COVID-19 Data Tool, Public Health Ontario (https://www.publichealthontario.ca/en/data-and-analysis/infectious-disease/covid19-data-surveillance/covid19-data-tool?tab=summary).

Evidence suggests that child movement behaviors in Canada have changed during the pandemic compared with prepandemic as a result of public health preventative measures, including physical distancing, stay-at-home orders, and recreational facility closures, which may have served as barriers to healthy movement behavior.[9] A recent cross-sectional study found that parent-reported child physical activity levels and outdoor play times of Canadian children decreased, whereas screen time and sleep duration increased from before COVID-19 to during COVID-19.[10] They also found that the proportion of Canadian children meeting the 24-hour movement guidelines remained low from 4.8% in April 2020 to 4.5% in October 2020.[11] Similar patterns of changes in child movement behavior were observed in other Canadian[12–14] and international literature.[15] Family-level social determinants of health, including lower household income, have been associated with greater screen time[14,15] and lower physical activity,[15–17] outdoor time,[15,18] and sleep duration[15,19] during COVID-19. Sleep quality decreased more[15,20] and sleep duration increased more[15] for girls than boys during the pandemic. Most studies suggest greater physical activity in boys than girls during the pandemic,[10,15,17,19,21–25] whereas the findings on the effect of sex on screen time during COVID-19 are inconsistent.[10,15,24,26–29] Moreover, older children were found to engage in greater screen time,[15,24,27,28,30] be less physically active,[10,15,24,31] and spend less time outdoors[32] during COVID-19 compared with younger children.[10,15,33–35] Such trends have remained consistent since before the declaration of the pandemic.[36–40]

Most studies of children's movement behaviors during the pandemic have been cross-sectional without repeated-measure data and have not considered public health policies during this period. Further missing from the literature is a detailed examination of changes in child movement behavior across different age, income, and sex groups during COVID-19. Given the existing (>2 y) and

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projected longevity of the COVID-19 pandemic and impacts of its related lockdowns and public health restrictions, exploring child movement behavior over time by stages of government-issued public health restrictions is of paramount importance as it may inform future public health policy with a more targeted consideration of impacts on children's health and movement behaviors.

This study aimed to assess how children's movement behaviors (screen time, physical activity time, outdoor time, and sleep duration) changed during the COVID-19 pandemic by stages of lockdown and reopening. Secondary objectives included determining whether these trends were modified by child age, sex, and parent-reported annual household income and describing how children's movement behavior changed from before COVID-19 to during COVID-19. It was hypothesized that screen time and sleep duration increased during lockdowns and decreased during reopenings and that physical activity time and outdoor time decreased during lockdowns and increased during reopenings. It was further hypothesized that these changes would be more pronounced in older children (≥5 y), girls, and children from lower income families. It was also anticipated that screen time and sleep duration would have increased and that physical activity time and outdoor time decreased from before COVID-19 to during COVID-19.

Methods

Study Design and Participants

A longitudinal cohort study was conducted in The Applied Research Group for Kids (TARGet Kids!), a large primary care practice-based research network in Canada. Since 2008, TARGet Kids! has been enrolling healthy children, aged 0–5 years, from primary health care settings in the Greater Toronto Area, Kingston, and Montreal and has followed them into adolescence.[41] At each well-child visit (once every year), parents of participating children are invited to complete an age-specific questionnaire adapted from the Canadian Community Health Survey.[42]

In April 2020, TARGet Kids! launched the COVID-19 Study of Children and Families to understand the impact of the COVID-19 pandemic on children and families in the Greater Toronto Area. Parents in the Greater Toronto Area whose children were participants in the original TARGet Kids! longitudinal cohort study were invited to complete repeated biweekly questionnaires either online through research electronic data capture[43] or over the phone about their children's movement behaviors, school and daycare attendance, and sociodemographic information during COVID-19. Participating TARGet Kids! families provided informed verbal consent over the phone to participate. Parents could choose to complete as many or as few of the pre- and during COVID-19 questionnaires.

Exposure Variable

The exposure variable utilized in this study was time, categorized into 5 stages: a pre-COVID-19 stage from August 29, 2013 (beginning of study period), to March 16th, 2020 as well as 2 during COVID-19 lockdown stages and 2 during COVID-19 reopening stages in Ontario between March 17, 2020, and the end of the study period, August 30, 2021 (see Figure 1). First lockdown stage (March 17, 2020, to June 23, 2020): In Ontario, the first lockdown took place in March 2020 and involved the closure of schools, childcare centers, organized sports, and indoor and outdoor recreational facilities.[4,5,44] First reopening stage (June 24, 2020, to November 22, 2020): The province moved into the first phase of the reopening plan in June of the same year as the incidence of COVID-19 cases began to fall,[4,5] with the reopening of provincial parks, recreational facilities, and programs with limits on capacity and physical distancing restrictions.[5,44,45] Almost all public spaces and businesses were reopened by August 2020.[46,47] In September 2020, organized sports began to resume, and schools began to reopen for in-person instruction.[48,49] Second lockdown stage (November 23, 2020, to June 10, 2021): Ontario began to implement closures in October 2020,[50] and the second lockdown was implemented in November 2020.[6] This lockdown involved similar closures to the first lockdown. Second reopening stage (June 11, 2021, to the end of the study period, August 30, 2021): The province transitioned to the first phase of its reopening plan in early June 2021 and continued to ease restrictions throughout the summer of 2021 with similar lifting of restrictions as in the first reopening phase.[7,8,44] A 7-year study period (from August 29, 2013, to March 16, 2020) was chosen as the pre-COVID-19 stage to maximize the number of repeated measures in subjects before COVID-19 given that surveys were available to complete only once a year pre-COVID-19 instead of biweekly during COVID-19.

The exposure variables were measured using dates when the pre-COVID-19 and during COVID-19 parent-reported child movement behavior questionnaires were completed. Calendar date also captured time-varying external fluctuations, such as season and weather.

Outcome Variables

The outcome variables were parent-reported daily child screen time, physical activity, outdoor time, and sleep duration, using questions adapted from the Canadian Community Health Survey. All times were converted to minutes. Questionnaires containing the outcome variables were administered annually before COVID-19 and every 2 weeks during COVID-19. Outcome variables were calculated using the questions and formulas in Supplementary Material S1 (available online). Pre- and during COVID-19 screen time, physical activity time, and outdoor time observations were excluded if one of the subvariables used to calculate the overall movement behavior variable was greater than 24 hours per day or if the overall movement behavior variable was greater than 24 hours per day. Pre- and during sleep duration observations that were less than 4 hours or greater than 24 hours were excluded from analysis.

Covariates

Child age,[10,15,16,24,31,40] child sex,[10,15,17,19–29,40,51] maternal ethnicity,[39,52–55] and parent-reported annual household income[2,14–19,36–38] were included in all statistical models. The model involving screen time also controlled for the number of screen devices at home.[56] The models involving physical activity time and outdoor time also controlled for dwelling type (house or apartment)[57] and number of siblings.[58] Although many existing studies assessing physical activity over time adjust for seasonality by limiting data collection to one season[59] or controlling for it in the analysis,[60] per visual assessment of residual plots against calendar date, we did not find any evidence of additional nonlinearity by calendar date, hence did not adjust for seasonality.

The effect modifiers identified a priori included child age, child sex, and parent-reported annual household income.

Statistical Analysis

Differences between child movement behaviors before and during COVID-19 were estimated using linear mixed-effects models,

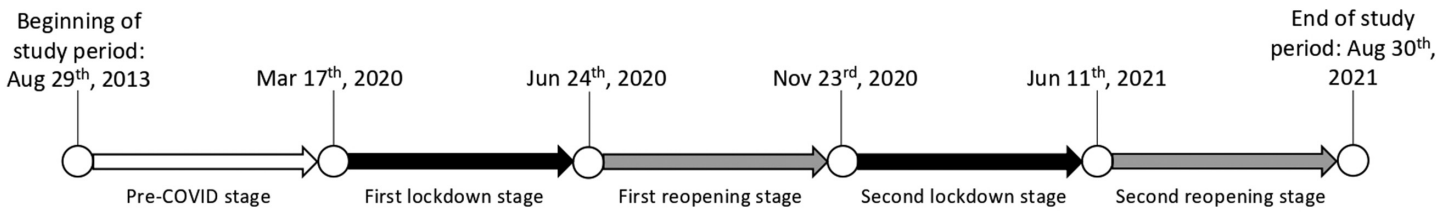

Figure 1 — Study timeline including pre-COVID-19, lockdown, and reopening periods.

adjusting for the aforementioned covariates. Dates corresponding with Ontario government-issued lockdowns and reopenings were included as knot locations in a piecewise linear spline model: March 17, 2020 (lockdown), June 24, 2020 (reopening), November 23, 2020 (lockdown), and June 11, 2021 (reopening). For the primary analyses, we fit linear mixed-effects models using repeated measures of exposure (calendar date with piecewise linear splines) and outcome (screen time, physical activity time, outdoor time, or sleep duration). Models for each movement behavior were fitted using the aforementioned covariates. To adjust for the correlation of observations from the same participant, we included random intercepts for participants. Likelihood ratio tests were performed to assess the evidence that child age, child sex, and parent-reported annual household income modified the associations between the exposure and the outcomes. This was done by comparing a model without the proposed interaction to a model with the proposed interaction over the entire study period.

Missingness for each covariate was under 11%. Multiple imputation using 10 imputed data sets was conducted using the R mice package to mitigate the bias introduced from the missing data.[61] All P values were 2-tailed, and statistical significance was set at $\alpha = .01$ (.05/5 stages) to adjust for multiple comparison bias and control for type 1 error inflation (ie, error rate for each outcome remained at approximately 5%). All statistical analyses were performed using R (version 4.0.2, R Project for Statistical Computing).[62]

Ethics Approval

This study obtained approval from the Research Ethics Board at The Hospital for Sick Children and Unity Health Toronto.

Results

This study included a total of 589 participants with 4805 observations (see Supplementary Material S2 [available online] for sample size flowchart). Participant characteristics are outlined in Table 1; 53.1% of the sample was boys, the mean age was 5.9 years, and 69.9% of the sample had a European maternal ethnicity. The mean number of observations per subject was 2.5 before COVID-19 and 5.7 during COVID-19 (Table 1). Compared with before COVID-19 (August 29, 2013, to March 16, 2020), on average, during COVID-19 daily screen time was 352.23 minutes greater (95% CI [confidence interval], 331.06 to 373.53), daily physical activity time was 116.12 minutes greater (95% CI, 100.09 to 132.15), outdoor time was 42.28 minutes greater (95% CI, 33.41 to 51.07), and sleep duration was 55.76 minutes lower (95% CI, –62.38 to –49.39; see locally estimated scatterplot smoothing (LOESS) curves from Figure 2).

Results of the adjusted primary analysis are presented in Table 2. There was insufficient evidence to suggest that the movement behaviors had statistically significantly changed during the pre-COVID-19 period (2013–2020). After adjusting for covariates, during the first lockdown, calendar date was associated with greater screen time by 3.47 minutes per day, on average (95% CI, 3.21 to 3.74; $P < .001$), with an average total increase of 343.5 minutes over this period of 99 days. The same direction was observed in the second lockdown ($\beta = 0.16$; 95% CI, 0.03 to 0.29; $P = .01$) with an average total increase of 32.6 minutes over this period. During the second reopening, calendar date was associated with lower screen time by −1.37 minutes per day, on average (95% CI, −1.85 to −0.89; $P < .001$). During the first lockdown, calendar date was associated with greater physical activity time by 1.61 minutes per day, on average (95% CI, 1.41 to 1.81; $P < .001$). In the first reopening, calendar date was associated with lower physical activity time by –0.53 minutes per day, on average (95% CI, –0.65 to –0.42; $P < .001$). In the second reopening, calendar date was associated with greater physical activity time by 1.58 minutes per day, on average (95% CI, 1.22 to 1.94; $P < .001$). Similar trends were observed in child outdoor time. During the first lockdown, calendar date was associated with greater outdoor time by 0.95 minutes per day, on average (95% CI, 0.84 to 1.05; $P < .001$). During the first reopening, calendar date was associated with lower outdoor time by –0.56 minutes per day, on average (95% CI, –0.62 to –0.50; $P < .001$). During the second reopening, calendar date was associated with greater outdoor time by 1.80 minutes per day, on average (95% CI, 1.61 to 2.00; $P < .001$). During the first lockdown, calendar date was associated with lower sleep duration by –0.28 minutes per day, on average (95% CI, –0.37 to –0.20; $P < .001$).

Child age modified the associations with screen time, physical activity time, outdoor time, and sleep duration. Parent-reported annual household income modified the associations with screen time, outdoor time, and sleep duration. There was no evidence that child sex modified the association between date and any of the movement behavior outcomes. The results were stratified by annual income ($0–$79,999 or $80,000–$150,000+)[63] and age (<5 y or ≥5 y),[64] as planned a priori and described in Figure 3 and Supplementary Materials S3–S9 (available online).

Compared with older children (≥5 y), younger children had a greater increase in screen time during the first lockdown ($\beta = 3.44$; 95% CI, 3.14 to 3.74; $P < .001$) and second lockdown ($\beta = 0.35$; 95% CI, 0.14 to 0.56; $P < .001$) and a lower decrease in the second reopening ($\beta = -1.09$; 95% CI, −1.90 to −0.27; $P = .009$). Compared with younger children (<5 y), older children had a greater increase in physical activity time during the first lockdown ($\beta = 1.94$; 95% CI, 1.59 to 2.29; $P < .001$), a slightly greater decrease in the first reopening ($\beta = -0.62$; 95% CI, −0.74 to −0.50; $P < .001$), and greater increase in the second reopening ($\beta = 2.00$; 95% CI, 1.65 to 2.35; $P < .001$). Compared with older children, younger children had a slightly lower increase in outdoor time during the first lockdown ($\beta = 0.91$; 95% CI, 0.80 to 1.01; $P < .001$), a slightly greater increase during the second lockdown ($\beta = 0.08$; 95% CI, 0.01 to 0.16; $P = .02$), and a lower increase

Table 1 Participant Characteristics (N = 589)

	n (missing)	Mean (SD) or n (%)
Child sex[a]	589 (0%)	
Female		276 (46.9%)
Male		313 (53.1%)
Child age,[b] y	589 (0%)	5.9 (2.6)
Maternal ethnicity[a]	528 (10.4%)	
East Asian		50 (9.5%)
European		369 (69.9%)
Latin American		17 (3.2%)
Mixed ethnicity		27 (5.1%)
South Asian		35 (6.6%)
Southeast Asian		14 (2.7%)
Other		16 (3.0%)
Parent-reported annual household income[a]	581 (1.4%)	
$0–$39,999		21 (3.6%)
$40,000–$79,999		62 (10.7%)
$80,000–$149,999		189 (32.5%)
$150,000+		309 (53.2%)
Dwelling type[a]	537 (8.8%)	
Apartment		84 (15.6%)
House		453 (84.4%)
Number of siblings[a]	587 (0.3%)	1.4 (1.0)
Number of screen devices per household[a]	587 (0.3%)	8.2 (3.2)

		Before COVID-19	During COVID-19
Screen time, min/d	589 (0%)	143.6 (101.7)	499.5 (281.0)
Physical activity time, min/d	589 (0%)	222.4 (182.9)	255.8 (167.4)
Outdoor time, min/d	589 (0%)	107.3 (52.6)	143.7 (103.2)
Sleep duration, min/d	589 (0%)	740.0 (118.5)	628.0 (52.5)
Observations per subject		2.5 (1.5, range: 1–8)	5.7 (4.8, range: 1–22)

[a]Last measurement before COVID-19. [b]Age at which outcomes were first measured during COVID-19.

during the second reopening ($\beta = 0.87$; 95% CI, 0.58 to 1.16; $P < .001$). Compared with older children, younger children had a greater decrease in sleep duration during the first lockdown ($\beta = -1.01$; 95% CI, −1.16 to −0.88; $P < .001$).

Compared with children in the low-income group ($0–$79,999), children in the high-income group had a greater increase in screen time during the first lockdown ($\beta = 3.73$; 95% CI, 3.44 to 4.02; $P < .001$), a greater increase during the second lockdown ($\beta = 0.23$; 95% CI, 0.09 to 0.37; $P < .001$), and a greater decrease in the second reopening ($\beta = -1.49$; 95% CI, −2.00 to −0.98; $P < .001$). Compared with the low-income group, the high-income group had a greater increase in outdoor time during the first lockdown ($\beta = 0.97$; 95% CI, 0.85 to 1.09; $P < .001$) and a slightly lower increase during the second reopening ($\beta = 1.79$; 95% CI, 1.57 to 2.00; $P < .001$). Compared with the low-income group, the high-income group had a slightly greater decrease in sleep duration during the first lockdown ($\beta = -0.29$; 95% CI, −0.38 to −0.20; $P < .001$).

Discussion

The current study examined how children's movement behaviors changed during the COVID-19 pandemic in relation to government-issued lockdowns and reopenings. We found that daily screen time, physical activity time, and outdoor time changed by stages of lockdown and reopening in Ontario. Minimal changes were observed in sleep. Importantly, screen time experienced a rapid rise during the first lockdown and a decline during the second reopening but remained substantially increased overall compared with before pandemic. Physical activity and outdoor time seemed to increase during the first lockdown, decrease during the first reopening, and increase during the second reopening. Minimal changes in sleep duration were observed. Age and income were important modifiers, with different effects depending on the movement behavior. Younger children (<5 y) experienced more adverse changes to their movement behavior during the pandemic than older kids (≥5 y)—in particular, greater increases in screen time, greater decreases in sleep duration, and lower increases in physical activity and outdoor time. Children in the high-income group experienced greater increases in screen time during lockdowns and greater decreases in screen time during reopenings than children in the low-income group.

In line with existing literature[9,10,12–15,18,22,29,65–71] and our hypothesis, we observed an increase in screen time during lockdown and decrease during reopening. This may be attributable to the lack of alternative activities available during lockdown with

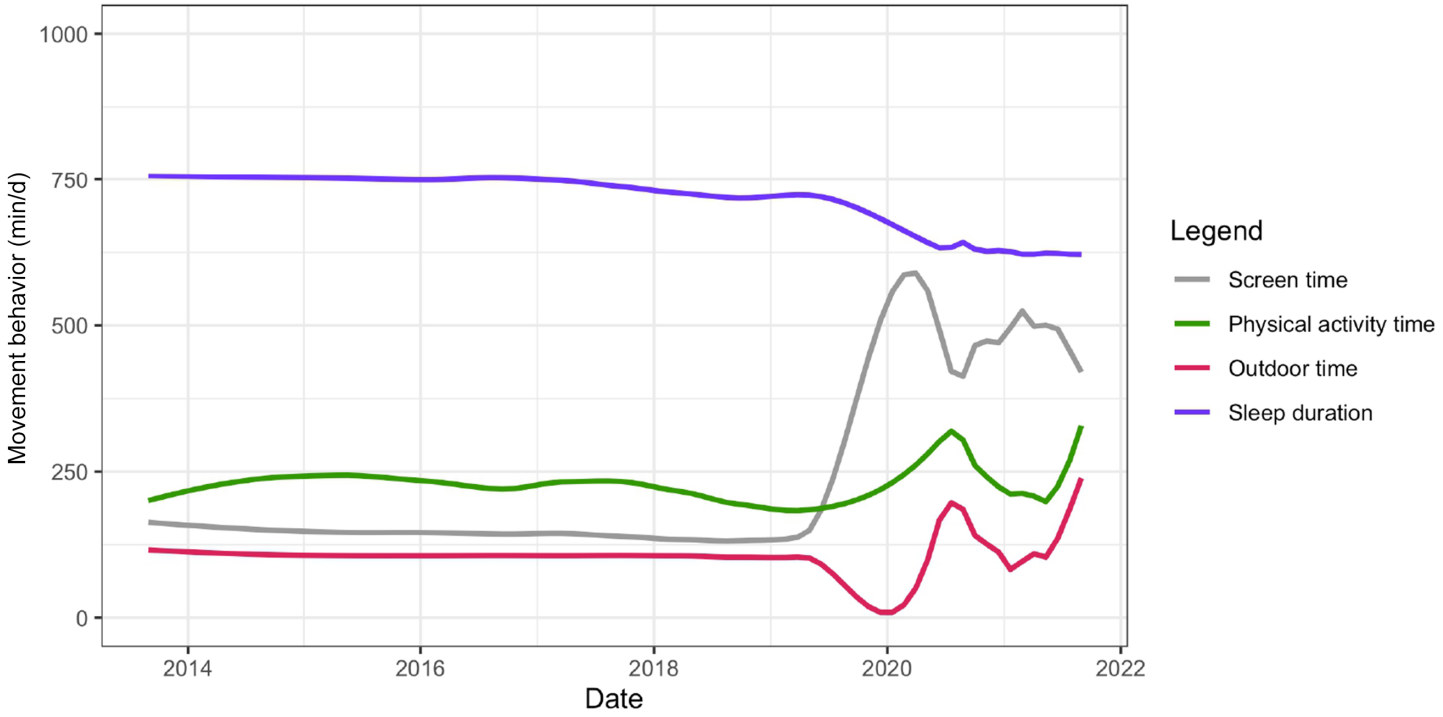

Figure 2 — Child movement behaviors over time using LOESS curves. For readers of the printed journal, the topmost line from the left represents sleep duration, the second top line from the left represents physical activity time, the third top line from the left represents screen time, and the bottommost line from the left represents outdoor time.

which children typically occupy their time, such as organized sports. We initially hypothesized that the increase in screen time during lockdown would be more pronounced in older children[15] as they may have been more affected by the transition to online school and typically have less parental control over and greater access to screen devices; however, we, instead, found a greater increase in the younger subsample. We can speculate that this may be because younger children have less independence and freedom than older children to occupy their time with unsupervised non-screen-based activities during lockdown. Although screen time has been associated with multiple adverse health outcomes in children of all ages, such as reduced sleep[65] and lower psychological well-being,[66] its detrimental effects may be more potent in very young children given their critical developmental stages.[72] In fact, the American Academy of Pediatrics recommends no screen time for children under 2 years.[67] Compounding our finding of a greater increase in lockdown screen time in younger children than older children, younger children were also found to experience a lower decrease in screen time during reopenings, suggesting that this subsample was more adversely affected by changes in screen time during the pandemic. We also found an unexpected greater increase of lockdown screen time and greater decrease of reopening screen time in the high-income group compared with the low-income group, despite adjusting for the number of screen devices per household. This may be because children from higher income households were enrolled in more extracurricular activities prior to COVID-19, hence were more affected by the lockdown-related recreational closures and openings and the consequent greater or lower use of screens to occupy their time, respectively. Our findings aligned with pre-COVID-19 literature demonstrating no sex-based differences in screen time between Canadian boys and girls.[40]

We observed an increase in physical activity time during the first lockdown. While this seems to contrast with much of the existing Canadian and international literature[10,12,15,21,22,29,33,35,68–71,73–79] and our hypothesis, it is in line with studies from Germany and Hong Kong, possibly related to the age of our study participants. Using data from children 4–17 years old, Schmidt et al found an increase in total daily physical activity from 142.2 minutes before COVID-19 lockdown to 167.80 minutes during the COVID-19 lockdown.[80] The study from Hong Kong, using data from preschool-aged children, found a 16% increase in moderate to vigorous physical activity during the COVID-19 lockdown.[81] We also observed an increase in outdoor time during the first lockdown. Although this contrasts with much of the existing evidence observing a decrease in outdoor time during lockdown,[10,15,18,81] it is consistent with Mitra et al,[16] who reported increases in outdoor time during COVID-19 in within-sample groups of children, specifically those with at least one sibling.[16] Consistent with our results, Mitra et al did not find any sex-based differences.[16] The observed increase in physical activity and outdoor time during the first lockdown and decrease during the first reopening could be attributed to having more free time for physical or outdoor activity during lockdown compared with reopening due to the cancelation of structured in-person activities, such as school. Differences between our results and the existing literature may be due to differences in public health guidelines with respect to recreational and public space closures within and across the different countries.[81] However, increases in physical activity and outdoor time were not observed in the second lockdown. We can speculate that this may be linked to the presence of greater pandemic fatigue, specifically exhaustion and demotivation during the second lockdown compared with the first lockdown that may have hindered physical activity and outdoor time.[82] We also found that the younger group experienced lower increases in physical activity and outdoor time than the older group. This may be because younger children have less independence and freedom to go

Table 2 Adjusted Linear Mixed-Effects Models Using Repeated Measures of Calendar Date and Movement Behaviors

N		Screen time[a]				Physical activity time[b]				Outdoor time[b]				Sleep duration[c]			
Subjects	Observations	Mean (SD), min	Slope estimate (95% CI), min/d	*P*	Average total change, min	Mean (SD)	Slope estimate (95% CI)	*P*	Average total change	Mean (SD), min	Slope estimate (95% CI), min/d	*P*	Average total change, min	Mean (SD), min	Slope estimate (95% CI), min/d	*P*	Average total change, min
Aug 29, 2013–Mar 16, 2020 (pre-COVID-19)																	
589	1476	143.6 (101.8)	0.01 (–0.01 to 0.03)	.31	25.1	222.4 (182.9)	–0.002 (–0.02 to 0.01)	.80	–4.3	107.3 (52.6)	–0.002 (–0.01 to 0.01)	.57	–5.0	740.0 (118.5)	–0.001 (–0.01 to 0.005)	.77	–2.1
Mar 17, 2020–Jun 23, 2020 (first lockdown)																	
189	346	505.4 (253.5)	3.47* (3.21 to 3.74)	<.001	343.5	301.3 (176.5)	1.61* (1.41 to 1.81)	<.001	159.4	167.6 (105.7)	0.95* (0.84 to 1.05)	<.001	93.7	632.7 (48.9)	–0.28* (–0.37 to –0.20)	<.001	–28.0
June 24, 2020–Nov 22, 2020 (first reopening)																	
372	1214	475.8 (283.2)	0.05 (–0.10 to 0.20)	.50	8.0	287.1 (174.5)	–0.53* (–0.65 to –0.42)	<.001	–80.7	167.4 (109.1)	–0.56* (–0.62 to –0.50)	<.001	–85.0	633.5 (57.9)	0.02 (–0.03 to 0.06)	.52	2.4
Nov 23, 2020–Jun 10, 2021 (second lockdown)																	
412	1321	526.70 (280.30)	0.16 (0.03 to 0.29)	.01	32.6	211.2 (150.9)	–0.04 (–0.13 to 0.06)	.44	–7.6	102.4 (73.4)	–0.005 (–0.06 to 0.05)	.86	–0.97	623.9 (48.3)	–0.02 (–0.06 to 0.03)	.47	–3.1
Jun 11, 2021–Aug 30th, 2021 (second reopening)																	
259	448	478.9 (290.5)	–1.37* (–1.85 to –0.89)	<.001	–111.0	267.10 (156.4)	1.58* (1.22 to 1.94)	<.001	128.0	182.5 (118.2)	1.80* (1.61 to 2.00)	<.001	145.8	621.4 (49.7)	0.01 (–0.14 to 0.17)	.86	1.1

Abbreviation: CI, confidence interval.

[a]Adjusted for child age, child sex, maternal ethnicity, parent-reported annual household income, and no. of screen devices. [b]Adjusted for child age, child sex, maternal ethnicity, parent-reported annual income, dwelling, and no. of siblings. [c]Adjusted for child age, child sex, maternal ethnicity, and parent-reported annual income.

*$P < .01$ ($\alpha = .05/5 = .01$ for Bonferroni correction).

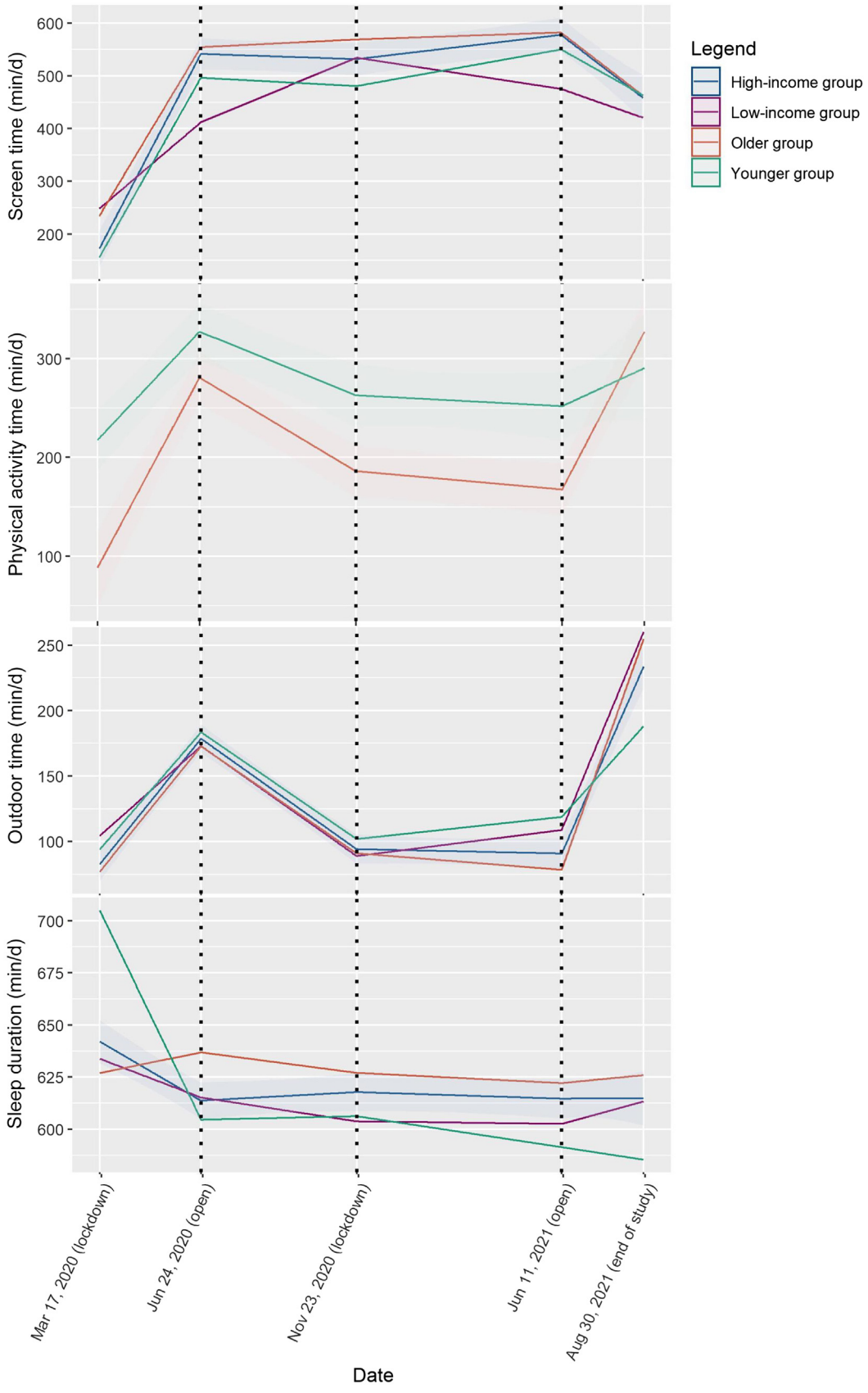

Figure 3 — Adjusted age- and income-stratified change in movement behaviors by stages of COVID-19 lockdown. For readers of the printed journal, in the screen time graph, the topmost line from the left represents the low-income group, the second top line from the left represents the older group, the third top line from the left represents the high-income group, and the bottommost line from the left represents the younger group; in the physical activity time graph, the topmost line from the left represents the younger group and the bottommost line represents the older group; In the outdoor time graph, the topmost line from the left represents the low-income group, the second top line from the left represents the younger group, the third top line from the left represents the high-income group, and the bottommost line from the left represents the older group; In the sleep duration graph, the topmost line from the left represents the younger group, the second top line from the left represents the high-income group, the third top line from the left represents the low-income group, and the bottommost line from the left represents the older group.

outside and be active than older children, which may have also contributed to the finding of a greater increase of lockdown screen time in the former group.

Our finding of decreased sleep duration during the first lockdown and minimal changes thereafter roughly aligns with an Italian longitudinal study of preschool children that found that sleep duration decreased in the early stages of the pandemic and then remained stable.[83] Much of the literature on child sleep duration changes during COVID-19 is mixed, with some studies reporting increases in sleep duration[10,15,29,33,69,70,79,81] from before COVID-19 to during COVID-19 and others reporting no overall change.[12,84]

This is one of the first studies to show how child movement behaviors fluctuate by stages of government-issued lockdowns and reopenings. The main strength of this study is the use of longitudinal, repeated measures of exposure and outcomes since 2013, which may have improved effect size estimates and increased statistical power. Moreover, we have adjusted for multiple covariates and examined data on 4 distinct child movement behaviors, providing a comprehensive insight into the impacts of the COVID-19 pandemic on child health. Our study was based on a sample of young children, a relatively unexplored population in existing studies on child movement behavior during COVID-19.

Limitations

Limitations in this study include the use of parent-reported movement behavior data and potential desirability bias, possibly contributing to our observed increases in physical activity and outdoor time. Moreover, generalizability may be limited as over 50% of our sample were of European ethnicity and had an annual household income of over $150,000 and, therefore, may not be representative of the general population. Missing exposure and outcome data due to the required repeated completion of questionnaires may have lowered the sample size and introduced selection bias. However, the descriptive characteristics of the children included in the analysis (n = 589) were similar to those of the initial cohort of children (n = 1168; Supplementary Material S10 [available online]). If outcomes were related to the probability that parents completed forms, even after adjusting for covariates, the results may be biased. Another limitation of our study was that time spent on online school was factored into total screen time only during COVID-19, not before, and, therefore, may have resulted in an increase of increase in screen use. Furthermore, naptime was not factored into total sleep time before or during COVID-19, possibly resulting in an underestimation of sleep time, especially in the younger (<5 y) subsample.

Conclusions

This study presents initial insight into the patterns and fluctuations of children's movement behaviors throughout the stages of government-issued lockdowns and reopenings in Ontario, Canada, in relation to COVID-19. In particular, screen time was observed to rapidly increase during the first lockdown and decline during the second reopening but remains substantially increased overall compared with before the pandemic, and physical activity and outdoor time seemed to increase during the first lockdown, decrease during the first reopening, and increase during the second reopening. These findings were particularly pronounced among young children. The results suggest that as the COVID-19 pandemic continues, policy makers, health care providers, schools, and families should consider the impact of public health-mandated lockdowns on child movement behaviors, especially sedentary behavior in the form of screen time and, by extension, their overall health and well-being. When developing restrictions, policy makers should seek to limit barriers to healthy movement behavior, such as by ensuring safe access to play spaces and parks, and encourage maximizing time spent outdoors and on physical activity to offset the time for screen use. Parents can also adopt harm reduction approaches to encourage healthful screen time.[85] The observed greater increases in sedentary behavior in the younger children coupled with the increased developmental risk for excessive screen use among this young population[72] and high malleability of their health behaviors at these ages suggest that these interventions should include a focus on younger children. Furthermore, longitudinal studies on outcomes related to child movement behaviors and health outcomes, by lockdown and reopenings, are needed to better inform public health policy and practice.

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