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The association of physical activity, sleep, and screen time with mental health in Canadian adolescents during the COVID-19 pandemic: A longitudinal isotemporal substitution analysis

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A R T I C L E I N F O

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A B S T R A C T

Background: The impact of COVID-19 on adolescent mental health is a global concern. Increased screen time and reduced physical activity due to the lockdown measures have been linked to detrimental mental health outcomes; however, the literature remains limited by cross-sectional and retrospective designs, and consideration of behaviours in isolation. Prospective evidence is necessary to examine whether moderate-to-vigorous physical activity (MVPA), sleep and screen time influenced changes in mental health.
Method: Analyses used data from a prospective cohort study of secondary school students in Canada with baseline data from the 2018–2019 school year and linked follow-up data from online surveys completed during the initial COVID-19 outbreak (May–July 2020). Multilevel linear regression models were used to evaluate the within- and between-person isotemporal substitution effects of sleep, MVPA and screen time behaviours on depression, anxiety, subjective well-being, and trait emotional dysregulation.
Results: Linked longitudinal data from 2645 students attending 44 schools were available. Between-person effects indicated that individuals who engaged in more MVPA and sleep while minimizing screen time had lower depression scores, less severe emotional dysregulation, and better subjective well-being. While controlling for between-person effects, within-person year-on-year change suggests those who increased screen time while decreasing either MVPA or sleep experienced mental health decline on all outcomes.
Conclusion: MVPA and sleep were associated with youth mental health during the early COVID-19 lockdown. Increasing MVPA and sleep (or at least mitigating the increase of screen time) compared to the prior year was associated with better mental health during the early pandemic. A limitation to consider is that the screen time measure represents a combination of screen behaviours, and effects of replacing screen time may have varied if distinctions were made.

1. Introduction

The COVID-19 pandemic has resulted in several parallel health crises in addition to the primary infectious disease. Among them, the mental health and wellbeing of adolescents experiencing school closures has been highlighted as a particular concern due to accompanying feelings of social isolation and loneliness, less access to health promoting programs delivered through schools, and for some youth, increased time spent in problematic home environments (Armitage & Nellums, 2020; Choi, Heilemann, Fauer, & Mead, 2020; Clemens et al., 2020; Cooper et al., 2021; Golberstein, Wen, & Miller, 2020). Several reports from European and North American populations from the early stages of the pandemic have supported these concerns, indicating that, among youth, symptoms of internalizing and externalizing problems and rates of mental illnesses have increased (Bignardi et al., 2021; Cost et al., 2021; Hafstad, Sætren, Wentzel-Larsen, & Augusti, 2021; Hawes, Szenczy, Klein, Hajcak, & Nelson, 2021; Hawrilenko, Kroshus, Tandon, & Christakis, 2021; Loades et al., 2020; Luijten et al., 2021; Magson et al., 2021;

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Raw et al., 2021; Thorisdottir et al., 2021; Vizard et al., 2020; Zhou et al., 2020), while subjective well-being has decreased (Magson et al., 2021; Thorisdottir et al., 2021). However, at least one prospective analysis indicates that the year-on-year decline in mental health indicators for adolescents were no larger than pre-pandemic declines with age (Bélanger, Patte, Leatherdale, Gansaonré, & Haddad, 2021). Simultaneously, pre-pandemic patterns in movement behaviours such as moderate-to-vigorous physical activity (MVPA), sleep, and screen time in adolescents, were disrupted during periods of school closures and remote learning during initial lockdowns (Paterson et al., 2021). Prior to the emergence of COVID-19, addressing mental health issues and the adoption of healthy movement habits were primary targets of health promotion in youth as a method of reducing the burden of chronic illness across the lifespan. Given that movement behaviours have been consistently linked with mental health status in youth (Dale, Vanderloo, Moore, & Faulkner, 2019), changes in behaviours may be contributing to the mental health impacts of the pandemic.

Despite concerns (Armitage & Nellums, 2020; Choi et al., 2020; Clemens et al., 2020; Cooper et al., 2021; Golberstein et al., 2020) and evidence of declines (Magson et al., 2021; Thorisdottir et al., 2021), some youth appear to have experienced stable mental health or even benefitted during school closure periods of the early pandemic (Cost et al., 2021; Penner, Hernandez Ortiz, & Sharp, 2021; Soneson et al., 2022), and, at a population level average, the decline may be no worse than typical year-on-year change (Bélanger et al., 2021). Multiple factors may contribute to better outcomes during this period (Bruining, Bartels, Polderman, & Popma, 2021; Dvorsky, Breaux, & Becker, 2021). One study, aimed directly at identifying factors associated with improved mental well-being during COVID-19 related lockdowns, found that children who reported improved general happiness were more likely to report increased sleep and exercise compared to peers who had experienced a decrease or no change in mental health status (Soneson et al., 2022); however, changes in movement behaviours were evaluated retrospectively by asking participants to indicate on a Likert-type scale whether they were engaging in more or less exercise and sleep than before lockdown. Compared to prospective designs, retrospective assessments may lead to response bias when attempting to recall and report change, and categorical and ordinal scales may not quantify the degree of change depending on how items and responses are phrased. Additional cross-sectional studies examining concurrent movement behaviours and mental health status in youth during lockdown periods (Chi et al., 2021; Kang et al., 2021; Silk et al., 2022; Werneck et al., 2020; Zhang et al., 2020; Zhou, Yuan, et al., 2020) reported greater sleep (Zhou, Yuan, et al., 2020), MVPA (Alves, Yunker, DeFendis, Xiang, & Page, 2020; Chi et al., 2021; Kang et al., 2021; Morres, Galanis, Hatzigeorgiadis, Androutsos, & Theodorakis, 2021; Werneck et al., 2020; Zhang et al., 2020), and exercise (Zhou, Yuan, et al., 2020), and less screen/sedentary time (Alves et al., 2020; Morres et al., 2021; Werneck et al., 2020) were associated with better outcomes in terms of depression (Chi et al., 2021), anxiety (Alves et al., 2020; Chi et al., 2021; Werneck et al., 2020) or other indicators of mood, emotion (Alves et al., 2020; Kang et al., 2021; Werneck et al., 2020; Zhang et al., 2020), or subjective well-being (Morres et al., 2021). Two of these studies reported a null result for the relationship between sedentary time and mood state (Kang et al., 2021) and screen time and anxiety (Alves et al., 2020). Due to the rapid onset of the pandemic, it is of little surprise that much of the literature on how movement related lifestyle behaviours may be associated with mental health status has relied on cross-sectional samples (Marconcin et al., 2022). The lack of longitudinal studies makes it difficult to assess whether a temporal association exists, such that those who maintained or adopted healthier movement behaviours during lockdowns fared better than those who did not.

Few studies have simultaneously considered the impact of multiple movement behaviour changes on mental health status (Paterson et al., 2021), which may not adequately capture the effects of simultaneous changes across multiple behaviours (Pedišić, Dumuid, & Olds, 2017). Of the studies discussed, two studies assessed both sleep and exercise (Soneson et al., 2022; Zhou, Yuan, et al., 2020) and four assessed both MVPA and sedentary/screen time (Alves et al., 2020; Kang et al., 2021; Morres et al., 2021; Werneck et al., 2020). While all studies reported univariate relationships between behaviours and mental health status, four examined a multivariate relationship where the influence of both behaviours were included as predictors of mental health status (Alves et al., 2020; Morres et al., 2021; Werneck et al., 2020; Zhou, Yuan, et al., 2020), with sedentary/screen time occasionally dropping out of significance after adjusting for physical activity. Considering the health effects of multiple behaviours simultaneously may be particularly important during COVID-19, where preliminary evidence suggests that pandemic related restrictions (school closures and lockdowns) resulted in a decline in MVPA and increase in sleep (Paterson et al., 2021), which may counteract any deleterious effects of reduced MVPA (Dumuid et al., 2020). In general, the effects of replacing sleep with other movement behaviours on mental health has often been omitted from analyses (Grgic et al., 2018).

Two isotemporal modelling approaches have been suggested to evaluate the effect of exchanging time spent in one behaviour for another (Chastin, Palarea-Albaladejo, Dontje, & Skelton, 2015; Mekary, Willett, Hu, & Ding, 2009): in traditional or absolute isotemporal analysis the absolute time spent in reported behaviours are used directly as regressors in a model (Mekary et al., 2009), whereas in a compositional isotemporal approach the time spent in behaviours is treated as a composition of the given observation period (e.g. per day or per week) where the relative amounts of each behaviour are used as regressors (after a data transformation process to address collinearity) (Chastin et al., 2015). The merits and shortcomings of either approach are debated (see: Biddle, Edwardson, Henson, Rowlands, & Yates, 2019; Dumuid et al., 2019; Mekary & Ding, 2019), but represent mathematically similar models (Mekary & Ding, 2019).

The purpose of this study was to examine whether associations between time spent in movement behaviours of sleep, MVPA, and screen use were associated with symptoms of depression and anxiety, trait emotional dysregulation, and psychosocial well-being, which were mental health outcomes available in a prospective, population level data set prior-to and during the early outbreak of the COVID-19 pandemic in Canada. In-class instruction in Canada was suspended during this period. This study considered both whether individuals who are more active and accrued more sleep experienced better mental health on average, and the effects of behaviour change from baseline to follow-up during the pandemic. It was hypothesized that individuals who accrued more MVPA and sleep rather than recreational screen time would have better mental health status on average, and that those who limited year-on-year increases in screen time in favour of adopting more sleep or MVPA would experience additional mental health benefits. It was also hypothesized that individuals who tended to accrue less sleep in favour of more MVPA were expected to have worse mental health on average, and year-on-year decreases in sleep in exchange for more MVPA were expected to experience a greater decrease in mental health status.

2. Methods

2.1. Design & data collection

Data from the Cannabis, Obesity, Mental health, Physical activity, Alcohol, Smoking, and Sedentary behaviour (COMPASS) study were used. The COMPASS host study collects data annually (2012–2027) from a rolling cohort of students attending a convenience sample of secondary schools across Canada. Due to provincial variations in secondary education systems, analysis included only those in educational years corresponding with International Standard Classification of Education level 3 (Grades 9–12 in British Columbia and Ontario, *Secondaire 3–5* in Quebec). COMPASS is designed to track changes in multiple youth health behaviours and outcomes over time as a learning platform

(Leatherdale, Brown, et al., 2014), providing an optimal prospective design for evaluating change in response to COVID-19. Student-level linked data from the COMPASS study collected during the 2018–2019 (baseline) and 2019–2020 (follow-up) school years were used for analyses in the subset of students whose follow-up responses were collected after the World Health Organization declared the outbreak of COVID-19 a global pandemic on March 11th, 2020.

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 (Leatherdale, Brown, et al., 2014). 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, Battista, Bredin, Brown, and Leatherdale (2015)).

Baseline data were collected using a paper-based survey designed to collect student-reported data from full school samples during one classroom period. 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 (Thompson-Haile, Bredin, & Leatherdale, 2013; White, Hill, & Effendi, 2004). Recruitment methods are detailed further by Reel, Bredin, and Leatherdale (2018). From March 13th to 18th, 2020 school closures and states of emergency were declared in provinces with participating schools. Due to pandemic-related closures of in-person learning, follow-up COMPASS data collection 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. 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, Battista, and Leatherdale (2020). Students could decline to participate at any time.

2.2. Measures

2.2.1. Movement behaviours

2.2.1.1. Moderate-to-vigorous physical activity (MVPA). The COMPASS student questionnaire uses a MVPA measure used for national surveillance of youth (Wong, Leatherdale, & Manske, 2006). 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, response options range from 0 to 285 min in 15-min increments. Light PA is not assessed by the COMPASS student questionnaire due to poor quality self-report data in epidemiological surveys (Lee & Shiroma, 2014). 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 0.25 (Pearson's $r = 0.31$) with accelerometry derived measures of MVPA, and a 1-week test-retest ICC of 0.75 (Pearson's $r = 0.68$) (Leatherdale, Laxer, & Faulkner, 2014). MVPA data were classified as missing if there were no responses across all 7 days, otherwise non-responses were assumed to represent 0 min of activity.

2.2.1.2. 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/messaging/emailing. To align with Canadian 24h movement behaviour guidelines for children and youth (Tremblay et al., 2016) which only provides recommendations for recreational screen use, time spent watching television, playing video games, surfing the internet, and texting/messaging/emailing were summed as an indicator of recreational screen time with non-responses assumed to represent 0 min of 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 included in recreational screen time estimates and not analyzed in models. Previous evaluation of screen time items reported 1-week test-retest ICCs ranging from 0.54 to 0.86; when items were summed, the ICC with accelerometer derived sedentary behaviour was 0.15 (Pearson's $r = 0.20$) (Leatherdale, Laxer, & Faulkner, 2014).

Response options for each behaviour range from 0 to 585 min in 15-min increments on the paper survey. Students who completed the survey online during the outbreak had expanded response options up to 765 min for each behaviour, however responses above 585 min were winsorized to match the response range possible on the paper survey. Among respondents, 14.1% of responses on the sleep item were above 585 min with a modal response of 600 min (n = 252, 9.5% of all responses); winsorizing reduced sleep scores >585 min by a mean (sd) of 44.5 (47.8) min. For screen behaviours 0.7%–2.1% of responses from the early outbreak were winsorized for being >585 min; affected scores were reduced by a mean (sd) of 86.5 (64.1) to 95.0 (63.6) min. For all behaviours, 600 min was the modal response among scores >585 min.

2.2.1.3. Outliers. Previous analysis with COMPASS data classified <180 min of sleep, >360 min MVPA, and >1260 min of recreational screen time as data outliers (Duncan et al., 2022; Gilchrist et al., 2021); the same criteria were applied to data for this analysis. Values outside outlier thresholds were winsorized; prior analysis with the COMPASS dataset comparing activity before and during the pandemic found similar changes regardless of whether outliers were winsorized or excluded (Duncan et al., 2022).

2.2.2. Mental health status indicators

2.2.2.1. Depressive symptoms. Depressive symptoms were self-reported by students on the 10-item Center for Epidemiologic Studies Depression scale Revised (CESD) (Andresen, Malmgren, Carter, & Patrick, 1994). Items asked for the frequency of depressive symptoms experienced within the last 7 days: "None or less than 1 day", "1–2 days", "3–4 days", or "5–7 days", scored from 0 to 3 respectively. Higher summed scores indicate greater depressive symptoms. Psychometric evaluation of the CESD suggests scores represent depression severity through evidence of correlation with external variables and internal structure in clinical and non-clinical populations including adolescents (Andresen et al., 1994; Björgvinsson, Kertz, Bigda-Peyton, McCoy, & Aderka, 2013; Bradley, Bagnell, & Brannen, 2010; Haroz, Ybarra, & Eaton, 2014; Van Dam & Earleywine, 2011) and demonstrate strict measurement invariance by grade and age in previous COMPASS data (Romano, Ferro, Patte, & Leatherdale, 2021). A score of ≥10 detects clinical depression with a sensitivity of 89%, and specificity of 47% (Andresen et al., 1994). Internal consistency was $\omega_{ordinal} = 0.86$ [0.86, 0.87]. Depressive symptom scores were analyzed as both a continuous score as well as a dichotomous presence of clinically relevant depressive symptoms (CESD ≥10).

2.2.2.2. Anxiety symptoms. Anxiety symptoms were self-reported using the 7-item Generalized Anxiety Disorder scale (GAD7) (Spitzer, Kroenke, Williams, & Löwe, 2006). Items asked respondents to indicate how frequently they experienced each symptom of anxiety in the last 2 weeks: "Not at all", "several days", "over half the days", or "nearly every day", scored 0–3 respectively. Higher summed scores indicate greater anxiety experienced. In clinical and non-clinical populations of adults and adolescents GAD7 scores correlate strongly with other measures of anxiety and poor emotional well-being (Löwe et al., 2008; Mossman et al., 2017; Spitzer et al., 2006; Tiirikainen, Haravuori, Ranta, Kaltiala-Heino, & Marttunen, 2019) and demonstrate strict measurement invariance by grade and age in previous COMPASS data (Romano et al., 2021). A score of 10 identifies the presence of generalized anxiety disorder with a sensitivity of 89% and specificity of 82% (Spitzer et al., 2006) and also identifies the presence of any anxiety disorder with a sensitivity of 68% and specificity of 88% (Kroenke, Spitzer, Williams, Monahan, & Löwe, 2007). Internal consistency was $\omega_{\text{ordinal}} = 0.93$ [0.93, 0.93]. Anxiety symptom scores were analyzed as both a continuous score as well as a dichotomous presence of clinically relevant anxiety symptoms (GAD7 $\geq$10).

2.2.2.3. Subjective well-being. Subjective psychosocial well-being was assessed using the 8-item Flourishing Scale (FS) (Diener et al., 2009, 2010). Items reflect feelings of competence, optimism, purpose, and success in personal relationships. FS scores correlate strongly with other measures of psychological and social well-being (Edmunds, Duda, & Ntoumanis, 2010). The COMPASS student questionnaire uses an abridged (Patte, Bredin, Henderson, Elton-Marshall, Faulkner, Sabiston, Battista, et al., 2017; Patte, Bredin, Henderson, Elton-Marshall, Faulkner, Sabiston, Ferro, et al., 2017) 5-point Likert-like scale ranging from "strongly disagree" to "strongly agree" scored 1–5; this scoring has shown measurement invariance in this sample (Romano, Ferro, Patte, Diener, & Leatherdale, 2020). Higher total scores represent greater positive well-being. FS scores correlate well with other measures of psychological and social well-being (Edmunds et al., 2010). Internal consistency was $\omega_{\text{ordinal}} = 0.93$ [0.93, 0.93].

2.2.2.4. Emotional dysregulation. Six items from the 36-item Difficulties in Emotion Regulation Scale (DERS) (Gratz & Roemer, 2004) were included in the COMPASS student questionnaire. Based on previous factor analyses conducted in youth samples (Neumann, van Lier, Gratz, & Koot, 2010; Perez, Venta, Garnaat, & Sharp, 2012; Weinberg & Klonsky, 2009), the highest loading items from each of six factors were selected: "I have difficulty making sense out of my feelings", "I pay attention to how I feel" (reverse scored), "when I'm upset, I have difficulty concentrating", "when I'm upset, I believe there is nothing I can do to make myself feel better", "I lose control over my behavior", and "when I'm upset, I feel ashamed for feeling that way". Response options ranged on a 5-point Likert-like scale from "almost never" to "almost always" and were scored 1–5. Total scores on this 6-item short form DERS ranged from 6 to 30 with higher scores indicating greater trait emotional dysregulation as conceptualized by Gratz and Roemer (Gratz & Roemer, 2004) (i.e. less ability to regulate emotional arousal and control behaviours when in a negative emotional state, and less self-awareness, understanding, and acceptance of one's own emotions). Internal consistency was $\omega_{\text{ordinal}} = 0.78$ (95% CI: 0.77 to 0.78).

2.2.3. Confounding variables

Regional median income and urbanicity (rural, small urban, medium urban, large urban) based on school postal codes were extracted from Statistics Canada (Statistics Canada, 2021). Public health region (based on school postal code) COVID-19 case rates (per 100,000 population (Statistics Canada, 2020)) averaged over the 7-days prior to the survey start date were extracted from provincial databases (BC Centre for Disease Control, 2020; Government of Ontario. (n.d.).; Institut national de santé publique du Québec, 2020); 7-day average COVID-19 case rates were used as an indicator of pandemic severity and risk for a given region at the time of response. Students self-reported gender ("*Female*", "*Male*", or Other ["*I describe my gender in a different way*", "*I prefer not to say*"]), race ("*White*" or if any other identities were reported: Black, Indigenous and People of Color), weekly spending money *($0, $1–5, $6–10, $11–20, $21–40, $41–100, >$100, Don't know*), and educational year (Grade 9/*Secondaire 3e*, Grade 10/*Secondaire 4e*, Grade 11/*Secondaire 5e*, Grade 12).

2.2.4. Analysis

Statistical analyses were performed in R v3.6.1 (R Core Team, 2020). Multivariate imputation by chained equations were performed using the *mice* package (van Buuren & Groothuis-Oudshoorn, 2011). Composite mental health scores and recategorized responses were calculated after imputation at the item level ("impute then transform") to reduce bias (van Buuren, 2018). The "lm.lmer" method from the *miceadds* package (Robitzsch, Grund, & Henke, 2019) was used to impute values measured at the individual level using predictive means matching, with schools set as a random intercept clustering factor, to preserve the hierarchical structure of data collection. The imputation model allowed within-participant baseline responses to inform imputed values at follow-up and *vice versa.* Multiple imputation in longitudinal data has been demonstrated to provide results similar to full-information maximum likelihood estimates (Ferro, 2014). All mental health outcomes, confounding variables, and movement behaviour variables were used in the imputation model. Based on missing data rates (see Table 1), guidelines (Graham, Olchowski, & Gilreath, 2007) suggest 10 imputations were likely sufficient. Convergence was inspected visually via trace plots and deemed acceptable with 50 iterations.

Mental health scores were modeled using a random effects within-between (REWB) approach (Bell, Fairbrother, & Jones, 2019) with students nested within schools as a random intercept. This method allows for the analysis of within-person effects of behaviour change on mental health outcomes while controlling for between-person differences in average behaviour and *vice versa.* For example, a 10-min reduction in daily average MVPA may have different effects in individuals who are accruing different levels of MVPA. To apply the REWB approach, time varying covariates (Education Year, Weekly Spending Money, COVID-19 case rates, MVPA, Sleep and Screen Time) were decomposed into between-persons (person mean of continuous variables; mean probability of dummy variables) and within-person effects (person mean centered for continuous variables; untransformed dummy variables) as described by Hoffman (Hoffman, 2015), both of which were included in models.

A traditional isotemporal substitution analysis was used to examine the effects of substituting 10 min/day of one reported behaviour for another (Mekary et al., 2009). An exchange of 10 min/day was chosen for reporting purposes, as it has historically been used to define a minimum length for a bout of MVPA that benefits physical health (Chastin et al., 2015). Traditional isotemporal substitution (Mekary et al., 2009) was chosen over compositional analysis (Chastin et al., 2015) as the total amount of time use per day reported by participants varied. This would lead to issues of interpretation when back transforming relative values into minutes when reporting results (e.g., a 1:5 ratio of MVPA to screen time may have represented 30min:150min for some but 20min:100min for others depending on how much total time was reported). To conduct isotemporal substitution analysis, several permutations of the model are performed each with a different behaviour replaced with a term representing the total reported time spent in movement behaviours (i.e., the sum of sleep, MVPA, and screen time); resultant parameters represent the effect of the remaining behaviours displacing the omitted behaviour. Thus, in the present REWB analysis, six models for each outcome were evaluated by sequentially omitting one of sleep, MVPA, or screen time for within-person components and then between-person components. Equations (1) and (2) provide an example of a formula estimating the effects of displacing within-person and between-person sleep (equations are simplified to exclude confounding variables and school level clusters).

$$\begin{aligned} Score = {} & \beta_0 + \beta_1 Time + \beta_2 Screen_{between} + \beta_3 MVPA_{between} + \\ & \beta_4 Sleep_{between} + \beta_5 Screen_{within} + \beta_6 MVPA_{within} + \\ & \beta_7 \sum (Sleep + Screen + MVPA) + u_{student} + e \end{aligned} \quad (1)$$

$$Score = \beta_0 + \beta_1 Time + \beta_2 Screen_{between} + \beta_3 MVPA_{between} + \beta_4 Screen_{within} + \beta_5 MVPA_{within} + \beta_6 Sleep_{within} + \beta_7 \sum (Sleep + Screen + MVPA) + u_{student} + e \quad (2)$$

Models from multiply imputed datasets were pooled using Rubin's rules. In order to determine whether a relationship existed between outcomes and movement behaviours, AIC and Analysis of Variance (ANOVA) using D2 pooled likelihood ratio tests (van Buuren, 2018) were used to compare a restricted model of confounding variables alone representing the null hypothesis to the full model which adds all movement behaviours. Wald tests were used to assess whether parameters representing specific time exchanges between behaviours were associated with significant differences in mental health outcomes.

Two sensitivity analyses were conducted where models were tested with subsets of the data. The first sensitivity analysis used only cases where 24h or less combined time use (sleep, screen time, MVPA and homework) was reported at both baseline and follow-up (n = 1885 in raw data, n = 2122 to 2133 in imputed data sets), which better adheres to the restricted nature of time use. The second sensitivity analysis was used to determine whether the process of aligning sleep response ranges between baseline and follow-up surveys by reducing high scores may have altered results given that responses greater than 600-min would be considered beyond Canadian movement guideline recommendations for sleep in youth age 14–17 (Tremblay et al., 2016); this analysis excluded individuals who reported greater than 585 min of sleep at follow-up (the upper bound available on the baseline survey, n = 758 excluded). Both sensitivity analyses concurred with the primary analysis in terms of tests results, as well as the direction and magnitude of effect sizes; results of primary analyses are presented.

3. Results

Sample characteristics (n = 2645, k = 44 schools) prior to multiple imputation are summarized in Table 1. Unadjusted pooled mean (sd) change in scores after multiple imputation were: 0.8 (5.6) for depression, 0.4 (5.1) for anxiety, 0.8 (5.1) for flourishing, and 0.5 (4.6) for emotional dysregulation. Pooled AIC and ANOVA model comparisons between restricted and full models are summarized in Table 2; lower AIC and significant test results for all mental health outcomes indicated that adding movement behaviours as predictors were an improvement over restricted models which included confounding variables alone.

Table 3 summarizes the specific parameter estimates of substituting movement behaviours; the *effectsize* package (Ben-Shachar, Lüdecke, & Makowski, 2020) was used to estimate the partial correlation between behaviour exchanges and continuous mental health status indicators based on parameter *t*-statistics and residual degrees of freedom of the models. Within-person behaviour change effects consistently found that after controlling for between-person behaviours, individuals who decreased screen time from baseline to follow-up in favour of increasing either MVPA or sleep reported better mental health outcomes across nearly all outcomes measured; the only exception being the exchange of screen time and MVPA on the likelihood of meeting the threshold for having clinically relevant symptoms of anxiety which was non-significant. The within-person effects of exchanging sleep and MVPA were non-significant for all outcomes except psychosocial well-being scores, where exchanging sleep for MVPA was associated with better psychosocial well-being scores. When statistically significant, the partial correlation coefficients between behaviour exchange and mental health status were generally small effects based on Cohen's (1988) guidelines.

While controlling for year-on-year within-person change of behaviour, between-person effects found a similar pattern regarding screen time, where individuals who averaged less screen time and reported more sleep or MVPA across the observations had better mental health outcomes on average, the only exception being the exchange of screen time and MVPA on anxiety scores and the likelihood of meeting the threshold for having clinically relevant symptoms of anxiety. However, contrary to the results from within-person effects, individuals who averaged more MVPA in lieu of sleep across both observation points had higher depression, anxiety, and emotional dysregulation scores on average and were more likely to meet clinically relevant thresholds for depression, anxiety, or both.

Table 1
Sample description.

Variable	Pre-Pandemic Baseline n (%)/mean ± sd	Follow-Up n (%)/mean ± sd
Race		
BIPOC	766 (29.0%)	
White	1879 (71.0%)	
Regional Median Income	65012.8 ± 13690.6	
Urbanicity		
Rural	93 (3.5%)	
Small Urban	799 (30.2%)	
Medium Urban	115 (4.4%)	
Large Urban	1638 (61.9%)	
Province		
BC	207 (7.8%)	
ON	1471 (55.6%)	
QC	967 (36.6%)	
Gender		
Female	1702 (64.4%)	
Male	913 (34.5%)	
Other	28 (1.1%)	
Missing	2 (0.0%)	
Weekly Spending Money		
$0	494 (18.7%)	493 (18.6%)
$1-5	171 (6.5%)	65 (2.5%)
$6-10	197 (7.5%)	92 (3.6%)
$11-20	339 (12.8%)	221 (8.4%)
$21-40	277 (10.5%)	213 (8.1%)
$41-100	322 (12.2%)	297 (11.2%)
>$100	388 (14.7%)	683 (25.8%)
Don't know	440 (16.6%)	495 (18.7%)
Missing	17 (0.6%)	86 (3.25%)
Education Year		
Grade 9/*Secondaire 3e*	1102 (41.7%)	24 (0.9%)
Grade 10/*Secondaire 4e*	1066 (40.3%)	1084 (41.0%)
Grade 11/*Secondaire 5e*	460 (17.4%)	1077 (40.7%)
Grade 12	17 (0.6%)	460 (17.4%)
Regional COVID-19 Cases	0 ± 0 per 100,000	1.47 ± 1.20 per 100,000
Depression	8.9 ± 6.0	9.7 ± 6.3
Change		0.9 (5.6)
≥10	941 (35.6%)	694 (38.1%)
<10	1408 (53.2%)	1616 (47.4%)
Missing	296 (11.2%)	383 (14.5%)
Anxiety	6.7 ± 5.5	7.2 ± 5.8
Change		0.5 (5.1)
≥10	670 (25.3%)	694 (26.2%)
<10	1808 (68.4%)	1616 (61.1%)
Missing	167 (0.6%)	335 (12.7%)
Anxiety or Depression		
≥10	1090 (41.2%)	1136 (43.0%)
<10	1257 (47.5%)	1135 (42.9%)
Missing	298 (11.3%)	374 (14.1%)
Flourishing	32.2 ± 5.5	32.0 ± 5.6
Change		0.2 (5.1)
Missing	96 (3.6%)	312 (11.8%)
Emotional Dysregulation	14.3 ± 4.7	14.8 ± 4.8
Change		0.5 (4.6)
Missing	127 (4.8%)	323 (12.2%)
MVPA	97.2 ± 71.5 min	80.9 ± 68.5 min
Missing	38 (1.4%)	282 (10.7%)
Sleep	431.8 ± 94.6 min	471.0 ± 96.0 min
Missing	5 (0.2%)	96 (3.6%)
Screen	384.6 ± 237.9 min	464.5 ± 252.1 min
Missing	5 (0.2%)	96 (3.6%)

Note: Time invariant variables are centered across observation periods; BIPOC = Black, Indigenous and People of Colour and includes all individuals who did not indicate "White" as their sole racial descriptor; Depression and Anxiety scores ≥10 were deemed to reach a clinically relevant threshold, frequencies above and below this threshold are reported. Change values for mental health scores are unadjusted difference of Follow-Up – Baseline.

Table 2
Pooled comparisons between restricted and full models after multiple imputation for mental health outcomes.

	Restricted Model		Full Model		D2-pooled Likelihood Ratio Test			
Outcome	Mean AIC	sd	Mean AIC	sd	F	df	p	RIV
Depression Score	32852.7	24.8	32577.9	22.7	46.4	6, 6196.7	<0.001	0.030
Anxiety Score	31852.3	29.4	31697.5	30.7	26.9	6, 5206.0	<0.001	0.033
Subjective Well-being Score	31575.2	38.2	31302.3	37.2	46.7	6, 22256.3	<0.001	0.016
Emotional Dysregulation Score	30459.4	37.1	30245.0	33.7	35.6	6, 1694.1	<0.001	0.059
CR Depression	6695.5	21.4	6528.0	19.2	28.9	6, 4905.5	<0.001	0.034
CR Anxiety	5731.0	25.4	5624.1	28.7	18.6	6, 1551.2	<0.001	0.062
CR Either	6722.9	23.7	6560.6	24.4	27.6	6, 2341.9	<0.001	0.050

Note: CR = Clinically relevant as determined by CESD/GAD7 scores ≥10. Restricted Models represent the null hypothesis with only confounding variables included as predictors, Full Models add movement behaviours (sleep, screen-time, and moderate-to-vigorous physical activity) to the Restricted Model; a lower AIC and significant Likelihood Ratio Test suggest Full Models to be a better fit than the Restricted Model. RIV = Relative Increase in Variance due to nonresponse.

Table 3
Effects of isotemporal time exchange in 10 minute/day increments.

Displaced:	Within-Person Effects						Between-Person Effects					
	Sleep (-10 min/day)			Screen (-10 min/day)			Sleep (-10 min/day)			Screen (-10 min/day)		
Outcome/ Substitute	*B*	$r_{partial}$	*p*	*b*	$r_{partial}$	*p*	*b*	$r_{partial}$	*P*	*b*	$r_{partial}$	*p*
Depression Score												
MVPA (+10 min)	−0.03 [-0.06, 0.01]	−0.02 [-0.05, 0.01]	0.18	−0.08 [-0.12, −0.05]	−0.07 [-0.09, −0.04]	**<0.001**	0.11 [0.07, 0.16]	0.07 [0.04, 0.10]	**<0.001**	−0.07 [-0.11, −0.04]	−0.05 [-0.08, −0.03]	**<0.001**
Sleep (+10 min)				−0.06 [-0.08, −0.03]	−0.07 [-0.09, −0.04]	**<0.001**				−0.18 [-0.21, −0.16]	−0.19 [-0.21, −0.16]	**<0.001**
Anxiety Score												
MVPA (+10 min)	−0.01 [-0.04, 0.02]	−0.01 [-0.03, 0.02]	0.587	−0.04 [-0.07, −0.01]	−0.04 [-0.07, −0.01]	**0.004**	0.11 [0.07, 0.15]	0.08 [0.05, 0.10]	**<0.001**	−0.02 [-0.05, 0.01]	−0.02 [-0.04, 0.01]	0.246
Sleep (+10 min)				−0.04 [-0.06, −0.01]	−0.05 [-0.07, −0.02]	**0.001**				−0.13 [-0.16, −0.11]	−0.14 [-0.17, −0.12]	**<0.001**
Emotional Dysregulation Score												
MVPA (+10 min)	0 [-0.03, 0.03]	0 [-0.03, 0.03]	0.905	−0.05 [-0.07, −0.01]	−0.04 [-0.07, −0.01]	**0.005**	0.07 [0.04, 0.11]	0.06 [0.03, 0.09]	**<0.001**	−0.05 [-0.08, −0.02]	−0.05 [-0.07, −0.02]	**0.001**
Sleep (+10 min)				−0.04 [-0.06, −0.02]	−0.06 [-0.09, −0.03]	**<0.001**				−0.12 [-0.14, −0.10]	−0.15 [-0.18, −0.13]	**<0.001**
Subjective Well-Being Score												
MVPA (+10 min)	0.04 [0.01, 0.07]	0.03 [0.01, 0.06]	**0.012**	0.07 [0.04, 0.10]	0.05 [0.03, 0.08]	**<0.001**	0.03 [-0.01, 0.07]	0.02 [-0.01, 0.05]	0.13	0.18 [0.15, 0.22]	0.15 [0.12, 0.17]	**<0.001**
Sleep (+10 min)				0.03 [0.01, 0.05]	0.04 [0.01, 0.06]	**0.002**				0.15 [0.13, 0.18]	0.17 [0.14, 0.19]	**<0.001**
	AOR		*p*	AOR		*p*	AOR		*P*	AOR		*p*
Clinical Depression												
MVPA (+10 min)	0.98 [0.95, 1.00]		0.091	0.96 [0.93, 0.98]		**<0.001**	1.03 [1.01, 1.06]		**0.003**	0.96 [0.94, 0.98]		**<0.001**
Sleep (+10 min)				0.98 [0.96, 0.99]		**0.002**				0.93 [0.92, 0.94]		**<0.001**
Clinical Anxiety												
MVPA (+10 min)	1.01 [0.98, 1.04]		0.587	0.98 [0.96, 1.01]		0.128	1.05 [1.02, 1.08]		**<0.001**	0.98 [0.96, 1.00]		0.057
Sleep (+10 min)				0.97 [0.96, 0.99]		**0.002**				0.93 [0.92, 0.95]		**<0.001**
Clinical Depression/Anxiety												
MVPA (+10 min)	0.99 [0.97, 1.02]		0.589	0.96 [0.94, 0.99]		**0.001**	1.05 [1.02, 1.07]		**<0.001**	0.97 [0.95, 0.99]		**0.002**
Sleep (+10 min)				0.97 [0.96, 0.99]		**<0.001**				0.93 [0.92, 0.94]		**<0.001**

Note: The effects of time exchange using the isotemporal substitution model are symmetrical, thus a 10-min increase in MVPA displacing sleep is of equal magnitude but in the opposite direction, as such only one exchange per behaviour pair is explicitly stated. Square brackets represent 95% Confidence Intervals. Within-person effects represent the effect of change in behaviour from baseline to follow-up within individuals while controlling for average behaviours (between-person effects) across both years, representing the between-person effects. Between-person effects represent the effect of average behaviour on mental health status while adjusting for change. For depression, anxiety, and emotional dysregulation scores positive parameter estimates (*b*) represent worse mental health, for psychosocial well-being positive parameter estimates represent better mental health. MVPA = Moderate-to-vigorous Physical Activity; $r_{partial}$ = partial correlation coefficient estimated based on t-statistic and regression model residual degrees of freedom; AOR = Adjusted Odds Ratio, values > 1 represent increased likelihood of meeting thresholds for Clinically relevant Depression and/or Anxiety symptoms, as determined by CESD/GAD7 scores ≥10.

4. Discussion

As hypothesized, when recreational screen time was reallocated to either sleep or MVPA this was associated with better mental health status for nearly all indicators. Partial correlation coefficients, a standardized indicator of association, suggested that the relationship between behavioural exchange and mental health status was small. However, unstandardized effect sizes were comparable to previous between-person effects from cross-sectional analysis prior to the pandemic (Gilchrist et al., 2021) and were on a similar scale to the unadjusted change in mental health scores observed in this sample; for example within-person effects of replacing 10-min screen time with MVPA is approximately equal to 1/25th of the change observed in anxiety scores at the lower end and nearly 1/5th to 1/4th of the mean change observed in emotional dysregulation and flourishing scores at the high end. The benefits of adding sleep at the cost of screen time were even greater, where for most outcomes increasing sleep by approximately 30 min would be roughly equivalent to the mean change in mental health scores. In the context of the early COVID-19 pandemic period, where literature has frequently found adolescents were, on average, reporting higher levels of depression (Bignardi et al., 2021; Cost et al., 2021; Hawrilenko et al., 2021; Magson et al., 2021; Thorisdottir et al., 2021; Zhou, Yuan, et al., 2020) and anxiety (Cost et al., 2021; Hawes et al., 2021; Luijten et al., 2021; Magson et al., 2021; Zhou, Yuan, et al., 2020), and worse subjective well-being (Magson et al., 2021; Thorisdottir et al., 2021). Under these circumstances, even small benefits may be valuable in mitigating mental health concerns throughout the pandemic or similar crises. However, difference-in-difference modelling from prospective analysis has suggested that the year-on-year change in depression, anxiety and flourishing reported by adolescents during the early COVID-19 pandemic were comparable to the decline in mental health typically observed as adolescents get older (Bélanger et al., 2021). One plausible explanation to emerge from the results from the current study is the adoption of healthier amounts of sleep may have offset some of the added burden of COVID-19 and lockdown related stress.

Consistent with cross-sectional and retrospective literature among youth (Chi et al., 2021; Kang et al., 2021; Silk et al., 2022; Soneson et al., 2022; Werneck et al., 2020; Zhang et al., 2020; Zhou, Yuan, et al., 2020), our findings provide more robust evidence that during the early lockdown period more sleep and MVPA and less screen time were associated with better mental health status. The findings that between-persons differences in overall activity as well as within-individual changes from baseline were related to mental health status suggests dual benefits to accruing and maintaining sleep and MVPA rather than screen time. Taken together this study provides evidence that, during the early lockdowns, mental health benefits for adolescents were accrued both when individuals maintained higher amounts of MVPA and sleep across both years, as well as when individuals adopted more MVPA and more sleep in their routine.

It is also relevant to consider that during the early stages of the pandemic, global reports suggested that youth were engaging in less MVPA and more recreational screen time (Paterson et al., 2021); when considering this overall trend, perhaps one of the best ways to ensure more healthful behaviours during pandemics and similar crises is to continue efforts to encourage MVPA and adequate sleep before crises arise in hopes that even when habits change for the worse, adolescents are still engaging in a least some healthful behaviours. Additionally, prior behaviour may influence later mental health as well; longitudinal evidence indicates that engaging in more physical activity earlier in life is associated with reduced risk of later depression (Mammen & Faulkner, 2013) and dementia (Blondell, Hammersley-Mather, & Veerman, 2014). It is certainly plausible that neurobiological factors such as the potential neurotrophic and neurodevelopmental effects of physical activity and sleep (Jan et al., 2010) may contribute to better mental health under similar circumstances; it may also be that sport and physical activity provide opportunities for skill development that help youth face unprecedented challenges (Madsen, Hicks, & Thompson, 2011). While the modelling approach used in the present analysis did not directly address prior behaviour as a predictor (i.e., with a lag term), the between-persons terms as a person-mean across years inherently capture some of this prior behaviour in so much that accruing more sleep and MVPA at baseline will increase the person mean, especially when the effects of year-on-year change are held constant in the model.

While this study demonstrates a temporal association between mental health and movement behaviour change, the relationship may be bidirectional: those who experienced less change in their mental health status may be best equipped to maintain their movement habits or maintaining movement habits may have helped mitigate the general decline in mental health observed in youth during the early pandemic. As well, external factors such as resiliency (Dvorsky et al., 2021), supportive family life (Penner et al., 2021; Raw et al., 2021), and better socio-economic status (Penner et al., 2021; Raw et al., 2021) may have contributed to both movement behaviour and mental health maintenance. However, evidence from randomized control trials and longitudinal studies suggest that sleep and MVPA support positive mental health status (Dale et al., 2019). It may be beneficial to devise evidence-based resources to help families cope with pandemic-related restrictions and support 24-h movement guideline adherence among the whole family (ParticipACTION, 2020, p. 2020). Additionally, a re-envisioning of opportunities for PA is necessary. In their qualitative study of parental perceptions of the impact of the first lockdown on their child's physical activity, Riazi and colleagues (Riazi et al., 2021) emphasized that some online physical education and physical activities, much of which were fitness-based (e.g., squats, push-ups), were not of interest to children and youth. Practitioners and researchers need to rethink how to deliver engaging online physical education and activities in addition to providing resources for families that enable healthy movement behaviours during such periods of in-person learning restriction (Riazi et al., 2021). The pandemic also highlights calls for greater attention to physical literacy in the context of public health (Cairney, Dudley, Kwan, Bulten, & Kriellaars, 2019). Defined as 'the motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engagement in physical activities for life' (International Physical Literacy Association, 2017), enhancing physical literacy may buffer the impact when typical structures, such as in-person physical education classes and opportunities for active transportation, are no longer available.

While there was little surprise that less screen time in favour of more MVPA and sleep was broadly beneficial both from a between-person perspective and at the level of change within-persons, the effects of exchanging sleep with MVPA were less consistent. Interestingly, between-persons, those who accrued less sleep, in favour of MVPA, had worse scores on depression, anxiety, and emotional dysregulation scales but no difference in psychosocial well-being. Previous literature has been mixed regarding the relationship between psychosocial well-being and exchanging sleep and MVPA. One cross-sectional study reported several non-significant between-persons effects of exchanging of sleep with MVPA time and multiple indicators of psychosocial well-being in adolescents (Brown & Kwan, 2021) whereas another cross-sectional study reported that replacing sleep with MVPA was associated with higher well-being scores (Gilchrist et al., 2021). Additionally, the negative mental health effects of exchanging sleep and MVPA may vary based on whether individuals are getting guideline recommended $\geq$8h of sleep (Brown & Kwan, 2021; Gilchrist et al., 2021). Stratifications based on meeting sleep guidelines were not performed for the current analyses as classifying participants across multiple time points would have led to several stratifications or would otherwise need to account for individuals moving into and out of guideline adherence. Contrary to the observed between-person effects, year-on-year decreases in sleep when replaced with MVPA were associated with an increase in psychosocial wellbeing scores, but no other indicators. Given the evidence for a bi-directional role between sleep and emotion where emotional distress can disrupt sleep and lack of sleep can impair emotional processing and enhance sensitivity to stressors (Vandekerckhove & Wang, 2018), it is unsurprising that accruing more MVPA on average at the cost of sleep is associated with worse mental health status on indicators related to mood and emotion – especially when habitual. Null findings for the within-person exchange of sleep and MVPA for depression, anxiety and emotional dysregulation may suggest that habitual tendencies are more important when considering the impacts of exchange of sleep and MVPA. The reverse findings for psychosocial well-being are however puzzling. The within-person effects of exchanging MVPA for sleep on psychosocial well-being had the smallest effect size based on partial correlation and highest p-value of any relationship deemed statistically significant, and thus may represent a Type I error, especially given that the between-persons effect size was similar in magnitude but did not achieve statistical significance. Alternatively, if the observed effects are genuine, MVPA may offer slightly more benefits towards feelings of competence, optimism, and maintaining social relationships during the pandemic than sleep.

Limitations arise from how movement behaviours were assessed. Foremost, no data were collected as to quality or consistency of sleep and wake times, which may be important factors to consider in addition to quantity. Furthermore, the self-report tool did not measure sleep greater than 10-h at baseline, which is the upper limit of Canadian 24h movement behaviour guidelines for youth age 14–17 (Tremblay et al., 2016); any potential negative associations between oversleep and mental health could not be detected. However, sensitivity analysis found that the process of winsorizing responses above 585 min at follow-up had little impact compared to excluding these responses. Nevertheless, had baseline data with a wider response range been available, higher amounts of sleep may have been found to be negatively associated with mental health status given that excess sleep is a possible symptom of clinical depression (American Psychiatric Association, 2013). The COMPASS student questionnaire does not collect an indicator of light PA which is now one component of Canada's 24-Hour Movement Guidelines for children and youth (Tremblay et al., 2016). This would have been a useful behaviour to assess for the impact on mental health, especially in the context of reduced opportunities for incidental movement during school closures (e.g. no walking between classrooms, no commuting). However, a systematic review of observational studies (k = 4) suggests light PA may have little to no impact on mental health status in youth (Felez-Nobrega et al., 2021); had an indicator of light PA been available the impact on the present findings may be minimal but this behaviour would have been worth assessing nonetheless.

Additionally, the measures of screen time were assumed to represent mutually exclusive, recreational screen use, which respondents may not have intended when responding to items (e.g., watching TV while doing MVPA at home, performing multiple screen behaviours simultaneously, or "surfing the internet" for homework rather than recreation). Winsorizing total reported screen use values greater than >1260 min was undertaken in part to address the isotemporal substitution assumption of mutually exclusive behaviours but represents an imperfect solution. As a result of this data censoring approach and the lack of confidence in the mutually exclusive nature of reported screen time (Jago, Sebire, Gorely, Cillero, & Biddle, 2011; Thomas et al., 2022), isotemporal models attempting to distinguish the effects of replacing different screen behaviours were not conducted and we chose to align the analysis of screen time to the Canadian 24-Hour Movement Guidelines for children and youth (Tremblay et al., 2016) which currently does not distinguish between active or passive activities. However, an emerging interest in screen time and sedentary behaviour research is the differentiation between cognitively or socially active screen use and passive screen use or sedentary behaviours which appear to have differential and diverse associations with mental health outcomes in children and youth (Hallgren et al., 2020; Kandola, Owen, Dunstan, & Hallgren, 2021, 2022; Sweetser, Johnson, Ozdowska, & Wyeth, 2012). Given the widespread reports of greater screen use (Paterson et al., 2021) and public health recommendations to engage in online social interactions with friends and family outside of the household during the early COVID-19 outbreak, data that can differentiate the mental health effects between various screen use and sedentary behaviours would be beneficial, but may require a more extensive list of specific behaviours (e.g. social media use, video calls) than the items used here to estimate recreational screen time. It is possible that the mental health benefits associated with replacing more cognitively or socially active screen behaviours for MVPA would be smaller than the current results which amalgamates all recreational screen time and treats all screen behaviours equally.

As a final limitation, while the self-report scores of movement behaviours used by COMPASS have been shown to correlate with accelerometry derived measures as well as other self-report measures (Leatherdale, Laxer, & Faulkner, 2014), in general, self-report scores of MVPA (Galfo & Melini, 2021; Lee, Macfarlane, Lam, & Stewart, 2011) and sedentary behaviour (Prince et al., 2020) appear to be less accurate as a measure of time use when compared to device-based scores. However, among prior studies during COVID-19 related lockdowns, movement behaviour change were frequently assessed using an ordinal or dichotomous scale (Alves et al., 2020; Chi et al., 2021; Kang et al., 2021; Morres et al., 2021; Silk et al., 2022; Soneson et al., 2022; Werneck et al., 2020; Zhang et al., 2020; J. Zhou, Yuan, et al., 2020); while this may be appropriate given potential accuracy issues with self-reported movement behaviours (Galfo & Melini, 2021; Lee et al., 2011; Prince et al., 2020), continuous self-report approaches are better able to quantify changes in daily behaviour, even if imperfect. Prospective studies with a device-based indicator of movement behaviours are likely to be rare in the context of COVID-19 related lockdowns (Paterson et al., 2021). Device-based measures would also not have resolved issues of distinguishing recreational screen time from other sedentary behaviour without supplemental questionnaires. As such COMPASS data represents one of the few prospective data sets where continuous measures of adolescent movement behaviour change can be connected to mental health indicators at a population-level.

In addition to presenting a large population-level sample of prospectively collected data, this analysis methodology presents several strengths. First, missing data, which is common for both mental health and movement behaviours data was multiply imputed through multivariate imputation by chained equations to reduce bias. Secondly, the analyses used an isotemporal substitution approach to estimate the effects of specific behaviour displacement and substation combinations across sleep, MVPA, and screen time; such approaches are particularly appropriate when considering the effects of movement behaviour time use which is inherently constrained (Pedišić et al., 2017). Furthermore, we adapted the isotemporal substitution approach to the REWB modelling framework (Bell et al., 2019), which we believe this to be a novel contribution to movement behaviour research methodology. Existing methodology papers are based on applying isotemporal paradigm to cross-sectional data (Chastin et al., 2015; Mekary et al., 2009) leading to a heterogenous mix of approaches to assessing prospective data, despite a call for more longitudinal analyses (Grgic et al., 2018). The REWB approach offers a generalized approach to modelling panel data that separates and adjusts for within- and between-effects for time varying variables, rather than assuming equivalent effects (Bell, Jones, & Fairbrother, 2018, 2019).

In conclusion, this study provides evidence from a large Canadian sample that during the early stages of the pandemic minimizing recreational screen time in favour of accruing sleep or MVPA was associated with better psychosocial-wellbeing and lower depression, anxiety, and trait emotional dysregulation scores in adolescents. While more MVPA and sleep were better on average, increasing MVPA and sleep (or at least mitigating the increase of screen time) compared to the prior year was associated with better mental health during the early pandemic. It may be important to develop resources for families to stay healthy and active during future pandemic situations such as 24-h movement behaviour contingency plans (Riazi et al., 2021). Future research that can differentiate between screen behaviours is essential to improving public health recommendations regarding screen use, but will need to account for the issue of simultaneous multiple screen use (Thomas et al., 2022) if evaluating the effects isotemporal exchanges in behaviour.

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Conflicts of interest

The authors have declared no conflicts of interest.

Data availability

Data will be made available on request.

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