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Are one-year changes in adherence to the 24-hour movement guidelines associated with depressive symptoms among youth?

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Abstract

Background: There remains a need for prospective research examining movement behaviours in the prevention and management of mental illness. This study examined whether changes in adherence to the 24-h Movement Guidelines (moderate-to-vigorous physical activity [MVPA], sleep duration, screen time) were associated with depression symptoms among youth.

Methods: Conditional change models were used to analyze two waves of longitudinal questionnaire data (2016/17, 2017/18) from students in grades 9–12 ($N = 2292$) attending 12 schools in Ontario and British Columbia, Canada, as part of the COMPASS study. One-year change in adherence to the MVPA, screen time, and sleep duration guidelines were modeled as predictors of depressive symptoms, adjusting for covariates and prior year depressive symptoms. Models were stratified by sex.

Results: Continued adherence to sleep guidelines and transitioning from inadequate to sufficient sleep were associated with lower depressive symptoms than continued nonadherence, and continued adherence was associated with lower depression than transitioning from sufficient to short sleep. For screen time, transitioning from exceeding guidelines to guideline adherence was associated with lower depressive symptoms than continued nonadherence. MVPA guideline adherence was not associated with depression scores, when controlling for sleep and screen time guideline adherence change and covariates. When combined, meeting additional guidelines than the year prior was associated with lower depressive symptoms among females only.

Conclusions: Adherence to the sleep guidelines emerged as the most consistent predictor of depression symptoms. Promoting adherence to the Movement Guidelines, particularly sleep, should be considered priorities for youth mental health at a population level.

Keywords: Sleep, Physical activity, Screen time, Mental health, Adolescents, Sedentary behaviour

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Background

Depressive disorders are among the most commonly occurring mental illnesses that typically develop in adolescence [1]. Approximately one in ten adolescents will experience a major depressive episode (MDE) [2–4]. Another 18–40% of youth report subclinical depressive symptoms, which increase in frequency and severity over adolescence [5, 6], and are strong predictors of future clinical depressive episodes [7]. With each MDE and increased episode duration, reoccurrence becomes more likely and likelihood of remission declines [8, 9]. About three-quarters of youth experience another MDE within five years [10], and the elevated risk persists into adulthood [1, 11, 12]. Without effective intervention, depression has substantial health, social, and economic consequences [4, 12–14], as the leading global cause of years lived with disability, and second leading cause of disability-adjusted life years [15]. As chronic, reoccurring, and disabling conditions, prevention and early intervention of depressive disorders are critical.

Physical activity (PA) is proposed as a low-cost and undervalued strategy for the prevention and management of depression at the population level [16]. Substantial research has established PA as a first-line intervention for mild-to-moderate depression among adults [17, 18], and a lesser, but growing, evidence base supports the benefits of PA for youth with major depressive disorder (MDD) [19]. In a recent umbrella systematic review [19], increased PA was associated with decreased depression symptoms among children and youth in 12 of the 17 included reviews; however, many reviews were primarily cross-sectional studies, and larger effects tended to occur in clinical samples. Similarly, an updated review of reviews on PA and mental health in children and adolescents reported moderate effect sizes in intervention studies and small or null associations in observational studies [20]. Biddle et al. concluded there was currently insufficient evidence to support temporal sequencing [20]; hence, there is a continued need for prospective evidence of PA in the prevention of depressive disorders at a population level.

Distinct from physical inactivity, sedentary behaviour is defined as any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents, while in a sitting, reclining, or lying posture [21]. Screen-based activities, such as computer, television, video game, and mobile device use, represent common forms of sedentary behaviours in youth [22, 23]. Much debate has centered around the potential impact of screen use on youth mental health. Cross-sectional associations between screen time (ST) and depressive symptoms are well established [24–26]; however, longitudinal evidence has been more mixed [27, 28]. Several studies have suggested depressive symptoms predict increased sedentary

behaviour, or social media engagement, rather than the reverse [29–32]. Furthermore, a 2019 review of reviews identified most evidence as dated and not reflective of modern screen use, particularly mobile devices and computer/video games [33]. Other key critiques of the extant literature include the reliance on cross-sectional data [28, 34–36], the focus on physical health [35], and inadequate consideration of gender differences [28].

Another leading concern regarding youth screen use is the potential to delay and interrupt sleep. While improving, sleep is often regarded as an underrecognized and undervalued public health issue [37, 38]. Depression research has predominantly focused on sleep disturbance in clinical samples. At a population level, some evidence suggests sleep-related developmental changes partially mediate increases in depressive symptoms across adolescence [39, 40]. Indeed, the rise in depressive symptoms and depression onset over adolescence parallels declining sleep duration trajectories [39]. However, while cross-sectional associations between short sleep and depressive symptoms are well established [39, 41–44], a paucity of longitudinal population-level research exists and available prospective evidence is inconsistent. Some results suggest a bi-directional relationship or reverse causality [29, 31, 45], and others signify sex and gender differences, often with inverse associations between sleep duration and depressive symptoms in females only, and weaker or null effects in males [46, 47].

While prior research has often focused on one or two movement behaviours, researchers now recognize the need to consider all movement behaviours as codependent and distinct determinants of health [48]. Reflecting this shift, the *Canadian 24-h Movement Guidelines for Youth* provide integrated and evidence-based recommendations on PA, sedentary behaviours, and sleep across a day [21]. Based on these guidelines, youth aged 14–17 are recommended to engage in 60 min/day moderate-to-vigorous PA (MVPA; with vigorous PA and muscle and bone strengthening activities incorporated at least 3 days/week), accumulate no more than 2 h/day of recreational ST, and get an average of 8–10 h/night of uninterrupted sleep [21]. Alarming, only 6% of Canadian youth aged 12–17 are estimated to meet all three guidelines [49]. About two-thirds fail to meet MVPA guidelines, three-quarters exceed 2 h/day of ST, and at least one-third sleep less than 8 h/day [49, 50].

Recent studies have examined the physical health benefits of meeting combinations of the 24-h Movement Guidelines for Children and Youth [51, 52]; however, their associations with mental health and illness remain relatively unexplored. In the Canadian 2013/2014 Health Behaviour in School-aged Children study, participants meeting any given guideline had lower “emotional problems” scores than their peers not meeting that

recommendation [52]. Results were comparable regardless of which guideline or intermediate combination was met, with a dose-response pattern for the number of recommendations met. In a similar US representative study, youth meeting all three guidelines had lower depressive symptoms, but a dose-response pattern was not supported [53]. Also, higher depressive symptoms were associated with nonadherence to the sleep and MVPA guidelines, but not with weekday ST recommendations. Results of an Australian cross-sectional study point to differences by sex, with lower depressive symptoms associated with ST guideline adherence in females only, PA guideline adherence in males only, and adherence to the sleep guidelines among all youth [43]. Lastly, in a cohort study in Nova Scotia, Canada, meeting more lifestyle recommendations at age 10/11 predicted fewer mental illness-related physician visits over 8 years, with independent effects for ST and PA, but not for sleep guideline adherence [54]. Hence, while research tends to support mental health benefits of meeting more guidelines, evidence of the independent effects of MVPA, sleep, and ST guideline adherence is inconsistent.

Promoting adherence to the movement behaviours may offer a protective effect for mental health over adolescence; however, to best of our knowledge, only cross-sectional studies have been conducted on the combined 24-h movement behaviour guidelines and depression indicators, to date. Depressive symptoms can also lead to disturbed sleep, increased ST, and disengagement in PA [29–32, 55]. Moreover, to determine their independent effects, it is necessary to examine the movement behaviours simultaneously given potential confounding. The objective of this study was to examine if changes in adherence to the Canadian 24-h Movement Behaviour Guidelines were associated with depressive symptoms over one year among youth.

Methods

Sample and design

This study used linked student data from Year 5 (Y_5 [2016–2017]) and 6 (Y_6 [2017–2018]) of the COMPASS Study. COMPASS (2012–2021) collects hierarchical longitudinal data from students in grades 9–12 and the Canadian secondary schools they attend [56]. All students attending participating schools were invited to participate using active-information passive-consent parental permission protocols.

During COMPASS Y_5 , new mental health measures were added to the COMPASS Student Questionnaire and piloted in 14 schools (5 British Columbia [BC], 9 Ontario) [57, 58]. The mental health measures were subsequently included in all COMPASS Student Questionnaires completed across the 124 schools participating in Y_6 of COMPASS. Of the 14 schools in the Y_5 pilot of

the mental health measures, 12 schools also participated in Y_6 ($N = 3173$), and 2356 (74.3%) students had depression scores at both Y_5 and Y_6 . One student was removed for not indicating sex, and 63 students were excluded for missing movement data (57 PA, 11 ST, 11 sleep). The resultant sample comprised 2292 participants (72.2% of total linked) (see Table 1 for sample descriptives). In each school, the COMPASS Student Questionnaire was used to collect whole-school samples during class time. The cover page contains measures to create a unique code for each respondent to ensure anonymity, while allowing student data to be linked over multiple years. Further details of recruitment and retention (~80%), linkage, the overall COMPASS methods (www.compass.uwaterloo.ca), and the mental health pilot study are available elsewhere [56–60].

Measures

Depression symptoms

The 10-item *Center for Epidemiologic Studies Depression scale Revised (CESD-R-10)* [61–63] was included among the COMPASS mental health measures to assess depressive symptoms. Items assess characteristics of clinical depression, including negative affect, anhedonia, and somatic symptoms, such as “I felt everything I did was an effort”, “I could not get ‘going’”, difficulty concentrating, and feelings of hopelessness. Students were asked how often they experienced each symptom within the last 7 days, with the response options: “None or less than 1 day”, “1–2 days”, “3–4 days”, or “5–7 days”. Responses were scored from 0 to 3, respectively, and summed. Higher total scores indicate greater depressive symptoms. Psychometric properties have been evaluated in adolescent and adult populations [61, 64, 65]. Internal consistency was good ($\alpha = 0.78$ Y_5 , 0.77 Y_6).

Movement guideline adherence

Sleep duration was assessed by asking students how much time they usually spend sleeping per day. Responses were classified according to adherence to the guidelines of 8–10 h/day [21].

ST was assessed by asking the amount of time per day they usually spend engaging in different forms of screen use (watching/streaming TV shows/movies, playing video/computer games, talking on the phone, surfing the internet, texting/messaging/emailing). The sum of all forms of ST was dichotomized based on adherence to the guideline of no more than two hours/day of total recreational ST [21].

To determine *MVPA*, two items were used to assess how many minutes of moderate (i.e., lower intensity activities such as walking, biking to school, and recreational swimming) and hard (i.e., jogging, team sports, fast dancing, jump-rope, and any other physical

Table 1 Descriptive statistics in the 2-year linked COMPASS Mental Health Pilot Sample (Year 5: 2016/2017; Year 6: 2017/2018)

		Females N = 1229	Males N = 1063	Chi-square <i>p</i> - value
		% (N)	% (N)	
Grade ^a	10	39.4 (484)	38.5 (409)	0.5238
	11	36.6 (450)	35.5 (377)	
	12	24.0 (295)	26.1 (277)	
Ethnicity	White	73.2 (900)	72.5 (771)	0.0684
	Black	2.0 (25)	2.0 (21)	
	Asian	8.2 (101)	8.7 (93)	
	Hispanic/Latin American	1.6 (20)	3.5 (37)	
	Other/Mixed	13.3 (164)	11.4 (121)	
BMI Classification	Underweight	1.1 (14)	1.6 (17)	0.0063
	“Normal-weight”	59.8 (735)	56.0 (595)	
	Overweight	12.3 (151)	15.2 (162)	
	Obesity	5.5 (68)	8.4 (89)	
	Missing BMI	21.2 (261)	18.8 (200)	
School-area household median income	\$50,001-75,000	38.6 (475)	35.1 (373)	0.0951
	\$75,001-100,000	55.3 (680)	57.2 (608)	
	>\$100,000	6.0 (74)	7.7 (82)	
Urbanicity	Large Urban	53.2 (654)	54.8 (583)	0.2601
	Medium Urban	16.2 (199)	13.7 (146)	
	Small/Rural	30.6 (376)	31.4 (334)	
Transition in Movement Guideline Adherence (Y ₅ -Y ₆) ^b				
MVPA	0-0	39.8 (489)	26.3 (280)	<.0001
	0-1	15.1 (186)	13.3 (141)	
	1-0	21.2 (261)	22.8 (242)	
	1-1	23.8 (293)	37.6 (400)	
ST	0-0	90.5 (1112)	94.3 (1002)	0.0005
	0-1	3.7 (46)	1.6 (17)	
	1-0	3.7 (45)	3.4 (36)	
	1-1	2.1 (26)	0.8 (8)	
Sleep Duration	0-0	50.2 (617)	48.0 (510)	0.4778
	0-1	11.6 (142)	11.0 (117)	
	1-0	17.3 (213)	17.5 (186)	
	1-1	20.9 (257)	23.5 (250)	
		Mean (SD)	Mean (SD)	T-test p-value
Transition in Total Guideline Adherence (Y ₆ -Y ₅)		0.77 (0.72)	0.88 (0.83)	0.0006
Depressive symptoms		10.53 (6.57)	8.03 (5.55)	<.0001

Note: MVPA: moderate-to-vigorous physical activity. ST: screen time

^a Covariates from Year 6 (Y₆:2017/2018).

^b Based on the Canadian 24-h Movement Guidelines (Tremblay et al., 2016)

activities that increase your heart rate and make you breathe hard and sweat) PA they accumulated on each of the last 7 days to calculate a daily average. Responses were classified according to whether they met the MVPA guideline of at least 60 min/day [21].

The PA and ST measures have been previously validated [66, 67].

Transition in total guideline adherence was determined by subtracting the number of guidelines that students adhered to in Y₅ from their total guideline

adherence in Y_6 . Possible scores ranged from -3 to 3 , with a positive score indicating that a student transitioned to meeting more Movement Guidelines (MVPA, ST, and/or sleep) in Y_6 than in Y_5 , and a negative score means a student met fewer guidelines in Y_6 than the previous year. Scores were treated as continuous variables.

Covariates

Student-level covariates included grade, ethnicity, and weight status (age- and sex-adjusted Body Mass Index [BMI; kg/m^2] WHO classifications using student-reported height and weight). Missing BMI was included as a category, given the quantity of unreported weight data. School postal codes were cross-referenced with Statistics Canada data to determine school-area median average household income and urbanicity.

Statistical analysis

Two conditional change models were conducted [68]. The first model tested change in adherence to the MVPA, ST, and sleep guidelines as predictors of Y_6 depression scores, adjusting for Y_5 depression and Y_6 covariates. The second model tested transitions in total guideline adherence as predicting Y_6 depressive symptoms at, adjusting for Y_5 depression and Y_6 covariates. Conditional change models are often used for two-wave panel data to take account of 'regression towards the mean' effects. Models were stratified by sex. Mixed models were used to account for school clustering by adding random intercepts at the school level. Analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC, USA).

Results

Sample Descriptives

See Table 1 for descriptive statistics. The majority of the sample identified as white (73.2% females; 72.5% males) and over half had BMIs in the 'normal-weight' range. The sample primarily attended schools in areas with median household incomes of \$50,000-100,000. Females had higher depressive scores than males ($p < .0001$).

One-year change in guideline adherence

Males were more likely to meet the MVPA guidelines in both years than females. About 40% of females did not meet MVPA guidelines in either year, in comparison to 26.3% of males; whereas 37.6% and 23.8% of males and females met MVPA guidelines in both years, respectively. Consistent with known age and grade trends [69], more students transitioned from being active to not meeting the MVPA guidelines over one year than the reverse.

Most students did not meet the guidelines for total ST in either year (90.5% females; 94.3% males). Only 2.1% of

females and 0.8% of males met the guidelines in both years.

About half of students reported sleep durations of less than 8 h in both, and approximately one-fifth reported sufficient sleep in both years. In line with known age trends over adolescence [50, 70], more students transitioned from adequate to short sleep than the reverse.

The mean difference in total of guideline adherence ($Y_6 - Y_5$) was higher among males ($p = .0006$), indicating more males transitioned to meeting additional guidelines at follow-up than females.

Conditional change models

See Table 2 for results modeling depressive symptoms by one-year change in adherence to the individual components (MVPA, ST, sleep) of the 24 h-movement guideline stratified by sex. Depression symptoms did not differ by changes in MVPA guideline adherence among females or males when controlling for prior year depression scores, covariates, and adherence transition to the other Movement Guidelines. For ST, females who transitioned from nonadherence to adherence reported lower depressive symptoms than students who continued to exceed guidelines. Results for continued ST guideline adherence in males and females, and for males transitioning from nonadherence to adherence for ST, were not interpreted due to the low frequency of students in these categories.

In both females and males, consistently meeting sleep duration guidelines was associated with lower depressive symptoms relative to individuals who consistently reported short sleep or those who transitioned from adequate to inadequate sleep. Also, females and males transitioning from inadequate to sufficient sleep reported lower depressive symptoms relative to their counterparts who consistently reported short sleep.

Table 3 presents results modeling depression scores as function of the difference in the total number of guidelines adhered to from the year prior. In females, meeting one or more guideline than the prior year was associated with lower depressive symptoms; however, transitions in total guideline adherence were not associated with depressive symptoms among males, when controlling for Y_5 depression and Y_6 covariates.

Discussion

The *Canadian 24-h Movement Behaviour Guidelines* [21] were developed based on systematic reviews demonstrating the physical, mental, and social benefits of sufficient MVPA [71], adequate sleep [72], and limited ST [73]; however, since their release, limited research has examined the combined and independent associations with mental health and illness symptoms, particularly over time. In a large sample of secondary school

Table 2 Conditional change model of depression symptoms by one-year change in movement guideline adherence among students the 2-year linked COMPASS Mental Health Pilot Sample

	Females (N = 1229)				Males (N = 1063)			
	Est.	SE	95% CI	p-value	Est.	SE	95% CI	p-value
Grade (ref: 10)								
11	0.27	0.33	-0.38, 0.92	.4148	-0.39	0.33	-1.04, 0.27	.2442
12	-1.11	0.38	-1.85, -0.38	.0031	-0.75	0.37	-1.47, -0.03	.0427
Ethnicity (ref: White)								
Black	0.35	1.02	-1.64, 2.35	.7281	0.23	1.03	-1.79, 2.25	.8263
Asian	-0.06	0.63	-1.29, 1.17	.9290	-0.06	0.56	-1.17, 1.05	.9162
Latin American/Hispanic	-0.08	1.14	-2.31, 2.15	.9451	0.66	0.79	-0.90, 2.22	.4059
Other/Mixed	0.16	0.43	-0.67, 1.00	.7017	0.84	0.46	-0.06, 1.73	.0671
BMI Classification (ref: "Normal-weight")								
Underweight	0.42	1.35	-2.23, 3.07	.7583	0.02	1.16	-2.25, 2.28	.9884
Overweight	0.50	0.45	-0.38, 1.38	.2637	-0.39	0.42	-1.21, 0.43	.3472
Obesity	0.41	0.64	-0.84, 1.66	.5217	-0.71	0.53	-1.75, 0.34	.1854
Missing	0.68	0.36	-0.03, 1.39	.0622	0.54	0.39	-0.24, 1.31	.1737
Median household income (ref: \$50,001-75,000)								
\$75,001-100,000	-0.04	0.67	-1.35, 1.27	.9516	0.94	0.49	-0.01, 1.90	.0535
> \$100,000	-1.34	0.92	-3.14, 0.46	.1454	0.50	0.62	-0.72, 1.72	.4243
Urbanicity (ref: Small/Rural)								
Medium Urban	-0.73	0.70	-2.11, 0.64	.2966	0.61	0.52	-0.40, 1.62	.2351
Large Urban	-0.44	0.66	-1.73, 0.86	.5097	-0.02	0.47	-0.93, 0.89	.9662
MVPA ^a								
0-1 vs. 0-0	-0.63	0.43	-1.47, 0.22	.1491	0.33	0.48	-0.61, 1.28	.4921
1-0 vs. 0-0	0.18	0.39	-0.58, 0.94	.6453	-0.17	0.41	-0.97, 0.63	.6779
1-1 vs. 0-0	-0.30	0.37	-1.03, 0.44	.4279	-0.54	0.37	-1.27, 0.20	.1516
1-1 vs. 1-0	-0.47	0.43	1.31, 0.36	.2679	-0.37	0.39	-1.12, 0.39	.3455
ST ^{ab}								
0-1 vs. 0-0	-1.63	0.76	-3.11, -0.15	.0315	-2.75	1.14	-4.99, -0.51	.0161
1-0 vs. 0-0	0.81	0.77	-0.70, 2.31	.2944	-0.36	0.79	-1.91, 1.19	.6511
1-1 vs. 0-0	-1.44	1.01	-3.41, 0.54	.1541	-2.63	1.66	-5.89, 0.63	.1143
1-1 vs. 1-0	-2.24	1.24	-4.67, 0.18	.0701	-2.27	1.83	-5.86, 1.32	.2157
Sleep Duration ^a								
0-1 vs. 0-0	-1.76	0.47	-2.68, -0.85	.0002	-1.11	0.48	-2.04, -0.17	.0210
1-0 vs. 0-0	0.34	0.40	-0.45, 1.14	.3981	0.05	0.40	-0.74, 0.84	.8958
1-1 vs. 0-0	-1.41	0.38	-2.15, -0.66	.0002	-1.62	0.37	-2.35, -0.90	<.0001
1-1 vs. 1-0	-1.75	0.46	-2.66, -0.84	.0002	-1.68	0.45	-2.57, -0.78	.0002

Note: Model adjusted for prior year depressive symptoms and school clustering. MVPA: moderate-to-vigorous physical activity. ST: screen time. SE: Standard Error

^a Based on the Canadian 24-h Movement Guidelines (Tremblay et al., 2016)

^b Interpret ST results with caution given low frequency of students in 1-1 category (2.1% females; 0.8% males) and males in the 0-1 category (1.6%)

students from Ontario and BC, the current study examined one-year change in adherence to the 24-Hour Movement Behaviour Guidelines and depressive symptoms, adjusting for sociodemographic covariates and prior year depression scores. Adherence to the sleep guidelines emerged as the most consistent predictor of depression symptoms. Youth who consistently met sleep

recommendations over one year reported lower depressive symptoms in comparison to youth reporting short sleep across both years and those who transitioned from guideline adherence to nonadherence. This study also provides prospective evidence of a link between ST and depressive symptoms; where females who transitioned to meet ST guidelines had lower scores than those who

Table 3 Modeling depression symptoms (CESD-10-R) by one-year transition in total movement guideline adherence (MVPA, ST, sleep) among secondary school students the 2-year linked COMPASS Mental Health Pilot Sample

	Females (N = 1229)				Males (N = 1063)			
	Est.	SE	95% CI	p-value	Est.	SE	95% CI	p-value
Grade (ref: 10)								
11	0.37	0.33	-0.28, 1.02	.2642	-0.29	0.34	-0.95, 0.37	.3853
12	-0.99	0.38	-1.72, -0.25	.0085	-0.61	0.37	-1.33, 0.12	.1010
Ethnicity (ref: White)								
Black	0.21	1.02	-1.80, 2.21	.8408	0.32	1.04	-1.73, 2.36	.7626
Asian	0.19	0.62	-1.03, 1.41	.7583	0.12	0.57	-1.00, 1.23	.8352
Latin American/Hispanic	0.13	1.14	-2.10, 2.37	.9060	0.84	0.80	-0.73, 2.42	.2936
Other/Mixed	0.24	0.43	-0.60, 1.08	.5737	0.84	0.46	-0.07, 1.74	.0696
BMI Classification (ref: "Normal-weight")								
Underweight	0.45	1.36	-2.21, 3.11	.7392	0.15	1.16	-2.13, 2.43	.8996
Overweight	0.54	0.45	-0.34, 1.42	.2328	-0.23	0.42	-1.06, 0.59	.5798
Obesity	0.53	0.64	-0.73, 1.79	.4115	-0.48	0.53	-1.52, 0.57	.3719
Missing	0.65	0.37	-0.06, 1.37	.0736	0.73	0.39	-0.05, 1.50	.0658
Median household income (ref: \$50,001-75,000)								
\$75,001-100,000	-0.05	0.64	-1.30, 1.21	.9526	0.91	0.49	-0.06, 1.88	.0652
> \$100,000	-1.41	0.88	-3.13, 0.31	.1077	0.42	0.63	-0.81, 1.65	.5019
Urbanicity (ref: Small/Rural)								
Medium Urban	-0.81	0.67	-2.11, 0.50	.2251	0.59	0.52	-0.43, 1.61	.2593
Large Urban	-0.52	0.63	-1.75, 0.72	.4110	-0.07	0.47	-0.85, 0.99	.8826
Transition in total guideline adherence (Y ₆ -Y ₅) ^a	-0.71	0.17	-1.05, -0.37	<.0001	-0.22	0.18	-0.57, 0.13	.2205

Note: Model adjusted for prior year depressive symptoms and school clustering. MVPA: moderate-to-vigorous physical activity. ST: screen time. SE: Standard Error.
^a Difference in total adherence to the Canadian 24-h Movement Guidelines (MVPA, total ST, sleep) (Tremblay et al., 2016) from year prior (Y₆ total adherence minus Y₅ total adherence)

continued to exceed 2 h/day of total ST. However, no significant effect was found for one-year change in MVPA guideline adherence, when adjusting for the other guidelines, covariates, and prior year depression scores.

In the total adherence models, meeting more guidelines than the year prior predicted lower depressive symptoms in females only. Research has generally supported a cumulative effect, where the more guidelines adhered to, the larger the mental health benefit [52–54]. When sex differences have been found in previous studies, significant effects have tended to occur among females only [46, 47]. Results are unsurprising given known variations in the manifestation of depressive symptoms and movement behaviour engagement. That is, females report higher levels of internalizing symptoms and depressive disorders [2–4] and are generally less likely to meet sleep and MVPA guidelines than males [50, 74, 75]. Overall, effect sizes for depressive symptoms were modest, similar to previous studies of healthy youth populations [52]. However, with few youth consistently meeting recommendations, promoting guideline adherence has potential to make a substantial population-level

impact on the prevention and early management of depressive symptoms [52, 76].

The independent associations for sleep, MVPA, and ST guideline adherence and depression vary across study. Similar to our results, an Australian cross-sectional study found sleep to be the only movement behaviour associated with depressive symptomatology in all youth, while inverse associations were found with ST guideline adherence in females and PA adherence in males [43]. In other cross-sectional research, Janssen et al. found adherence to each guideline had an inverse association with ‘emotional problem’ scores to an equivalent degree [52]; whereas, Zhu et al. found youth meeting recommendations for MVPA and sleep were less likely to have received a depression diagnosis, but no evidence of an association with ST [53]. Conversely, in a cohort study of children and youth, meeting ST and PA recommendations at age 10/11 predicted fewer mental illness-related physician visits over 8 years but meeting the sleep recommendations had no effect [54]. Methodology differences may contribute to inconsistent results, including cross-sectional versus prospective designs, types of ST included, and mental health indicators.

Hayward et al. used self-reported depressive symptoms, while Janssen et al. employed a composite score (including depressive and other symptoms), Zhu et al. assessed parental reports of physician-diagnosed depression, and Loewen et al. linked survey data to administrative healthcare records [43, 53, 54]. Further prospective research of large youth populations remains necessary to determine the independent associations of adherence to each movement behaviour recommendation for various mental health and illness outcomes; however, overall, evidence suggests benefits for youth meeting more recommendations.

Results bolster calls to give sleep the same attention traditionally devoted to PA and screen use. Our findings augment evidence of an inverse association between sleep and depressive symptoms [39, 41–43, 45, 52, 53] and conflict with studies that found no prospective effect [54, 77] or an effect in females only [46, 47]. Once considered a core symptom or comorbidity of depressive disorders, some now identify sleep problems as both a prodromal manifestation and an independent risk factor for subsequent episodes, predicting the occurrence and outcome of depressive disorders [78]. In fact, given the inadequacy of treatments for youth depression [79], sleep therapy has been suggested as an intervention for adolescent MDD [80]. In addition to symptom management, further consideration from a population prevention standpoint is warranted, particularly given the proportion of youth sleeping less than 8 h/night.

Developmental changes in sleep have been suggested to partly account for the emergence of depressive symptoms and MDD over adolescence [39]. A natural shift towards later sleep onset contributes to a steady decline in youth sleep durations, coinciding with growing school pressures, increased extra-curricular activities, and less parental monitoring. As a result, youth bedtimes become progressively later, yet early school start times prohibit compensating with delayed wake times [81–84]. Aligning school schedules to adolescent sleep patterns appears an effective public health strategy for promoting longer sleep. Evidence suggests even modest school start time delays predict increased sleep durations [74, 85] as well as improved mental health and fewer emotional problems [85]. In addition to developmental trajectories, evidence suggests a population shift towards shorter average sleep durations occurred over the past several years [75, 86, 87], parallel with increased reports of tiredness and difficulties sleeping [88, 89]. These trends coincide with increased reports of psychological distress and internalizing symptoms among youth [90] and further empathize the need to consider sleep in efforts to address youth mental health.

ST is the most debated of the movement behaviours, in terms of prospective links with mental health and

illness. Some researchers have dismissed the effects as miniscule [28], while others argue a small risk of depression may result in substantial burden at the population level, considering the majority of youth exceed recommendations [76]. In the current study, so few youth reported ST guideline adherence that we are limited in interpreting results. Transitioning to meeting ST recommendations may have a modest effect on depressive symptoms in females. Several reviews have concluded research supports a positive relationship between leisure-time screen use and depressive symptoms, or internalizing symptoms more broadly, among adolescents [33, 34, 91–93]; however, much of this research has been cross-sectional. Proposed mechanisms for depression risk primarily focus on ST displacing more active, productive, or social activities. In this study, an association remained after adjustment for PA and sleep, suggesting depressive effects independent of their potential displacement; however, again, we are limited in interpretation. Other hypothesized mechanisms point to the context and content of ST engagement [76]. Sedentary behaviours often take place in solitude, potentially giving rise to rumination and feelings of isolation [76]; whereas PA typically occurs in the presence of peers among youth. The content itself could have a more direct effect, through social comparison or exposure to cyberbullying, for example. Further prospective research is needed exploring ways in which screens are used. Mixed findings in the literature may partially reflect inconsistencies in the form of ST assessed and included in determining guideline adherence, with prospective evidence varying by texting, computer, video game, or television time [24, 27, 76, 94].

Our MVPA results coincide with reviews of observational studies among largely healthy populations, in which prospective associations between PA and depression are typically small or null, as opposed to intervention studies among samples with clinically diagnosed depression [19, 20, 71, 95]. Only PA volume was examined, but the context likely has unique relationships with mental health [96–98]. Some evidence from young adults indicates MVPA is no longer associated with depressive symptoms when extracurricular activities such as team sports participation are accounted for [99], suggesting the mental health benefits relate more to positive social interaction and identity development. Many youth also report negative PA experiences, contributing to differences in PA and sports engagement by gender, body size, and age over adolescence [100–103]. Motives may also play a role. Appearance or weight loss PA motivations have been associated with negative psychosocial outcomes, as opposed to functional or enjoyment motivations [104]. Continued research is needed to explore various moderators in the relationship between PA and depression risk among youth.

Key strengths of this study include the linked data and adjustment for previous depression symptoms, as the reliance on cross-sectional evidence has been the most common criticism of previous research. The primary limitation pertains to self-report measures. As measures do not account for multi-tasking or for intermittent patterns of use, they likely overestimate total ST. The low frequency of students meeting ST guidelines may present power issues. Also, only two waves of linked data were available at time of this analysis. One-year change may not be optimal to understand effects over time. Lastly, COMPASS was not designed to be representative. The current sample was a pilot subsample of the larger study.

Conclusion

To our knowledge, this study is the first to examine change in the adherence to the 24-h Movement Guidelines and depression symptoms over time in a population sample of youth. Adherence to the sleep recommendations emerged as the most consistent predictor of depression symptoms. Promoting adherence to the movement guidelines, particularly for sleep, should be considered a priority in the prevention and management of youth depressive symptoms. The decline in sleep duration over adolescence [50, 70] has long been recognized yet remains undervalued in efforts addressing youth mental health, despite simultaneous increases in depressive symptoms and MDE onset [39]. Depression in adolescence is associated with problematic substance use, suicidality, poor physical health, reduced academic achievement, and elevated risk for future episodes or other mental disorders continuing into adulthood [4, 12]. Given the large burden of depression [13, 14] and low adherence to the Movement Guidelines, supporting youth in continuing to meet recommendations over adolescence appears a worthwhile public health investment, with clear benefits for multiple aspects of youth physical, mental, and social health [50, 51, 71].

Abbreviations

BC: British Columbia; COMPASS: The Cannabis use, Obesity, Mental health, Physical activity, Alcohol use, Smoking, and Sedentary behaviour study; MDE: Major depressive episode; MDD: Major depressive disorder; MVPA: Moderate-to-vigorous physical activity; PA: Physical Activity; ST: Screen Time

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Authors' contributions

KAP conceptualized the paper and lead the writing of the manuscript. GF contributed substantially to the conceptualization, interpretation of results, and revising drafts of the manuscript. WQ conducted the statistical analysis. MD wrote the original draft of the methods section. STL lead the COMPASS

host study, and KP lead the COMPASS Mental Health pilot study. All authors (KAP, GF, WQ, MD, STL) reviewed and provided feedback on drafts and approved the final manuscript.

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Availability of data and materials

COMPASS study data is available upon request through completion and approval of an online form: <https://uwaterloo.ca/compass-system/information-researchers/data-usage-application> The datasets used during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The University of Waterloo Office of Research Ethics (ORE#17264) and participating school boards approved all procedures. All students attending participating schools were invited to participate using active-information passive-consent parental permission protocols. Students could withdraw from the study at anytime.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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