SLEEP DURATION, SEDENTARY BEHAVIOUR, PHYSICAL ACTIVITY, DEPRESSION, AND OTHER MENTAL HEALTH OUTCOMES AMONG CHILDREN AND ADOLESCENTS

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ABSTRACT

Mental health problems are the leading causes of disability in Canada. Nearly 70% of mental health problems have their onset during childhood or adolescence. Thus, identifying modifiable determinants of mental health problems in children and adolescents can inform future interventions intended to prevent them in this age group. Until recently, research has examined relationships of movement behaviours, including sleep, sedentary behaviour and physical activity mainly with physical health indicators (e.g., adiposity, cardiovascular disease risk factors, etc.). The few studies that have examined the relationships between movement behaviours and mental health indicators have considered the former individually and in isolation of each other, ignoring the intrinsic and empirical interactions between these behaviours. Adjusting for all these behaviours in a traditional regression model that assumes independence between variables has been shown to produce flawed and inconsistent findings.

The purpose of this doctoral dissertation is to examine how the combinations of physical activity, sedentary behaviour, and sleep duration are associated with depression and other mental health outcomes in children and adolescents, through a series of five research studies (one systematic review, 3 cross-sectional studies, and one longitudinal study). Empirical studies used data from 3 large and diverse samples of children and adolescents from Canada and the United States. Conventional regression models and structural equation modelling, and novel analytical techniques, including compositional data analysis were used to analyze the data.

The systematic review confirmed the paucity of existing research in this area and identified important research gaps to be filled. Collectively, the results from cross-sectional studies showed that meeting all three recommendations was associated with lower odds of depressive symptoms

and other mental health outcomes. However, this association appeared to be mainly driven by meeting the sleep duration recommendation, and to a lesser extent the screen time + sleep duration recommendations. There was a dose-response gradient from meeting none of the recommendations up to meeting two recommendations. Results from the longitudinal study using compositional data analysis provided further evidence suggesting that increasing sleep duration relative to the remaining behaviours (i.e. screen time and physical activity) was associated with lower depressive symptoms among all age/sex subgroups. Results further indicated that predicted changes in depressive symptoms were strongest and most beneficial when removing screen time while adding sleep duration. Finally, results from both cross-sectional and longitudinal analyses suggest that age and sex moderate the association between movement behaviour recommendations (individual or combined) and mental health indicators, depending on the type of movement behaviour and the type of mental health indicators.

The findings from this body of work have shed new light on the association between movement behaviours and mental health indicators in children and adolescents by demonstrating that meeting all three movement behaviour recommendations is associated with better mental health, and that sleep duration and screen time were more strongly associated with mental health compared with physical activity in our studies.

DEDICATION

This thesis is dedicated to the memory of my father, Felicien Bakwa Kanyinga. Thank you for teaching me that the secret to success is hard work and for encouraging me to always strive for excellence.

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LIST OF ABBREVIATIONS

ABCD	Adolescent Brain and Cognitive Development
ADHD	Attention Deficit Hyperactivity Disorder
ANOVA	Analysis of Variance
BDNF	Brain-Derived Neurotrophic Factor
BMI	Body Mass Index
CBCL	Child Behaviour Check List
CESD-R-10	Center for Epidemiologic Studies Depression Scale (Revised)−10
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CI	Confidence Interval
COVID-19	Coronavirus Disease 2019
DSM-5	Diagnostic and Statistical Manual of Mental Disorders
FIML	Full information Maximum Likelihood
GRADE	Grading of Recommendations Assessment, Development and Evaluation
HBSC	Health Behaviour in School-aged Children study
HPA	Hypothalamo-Pituitary-Adrenal
HRQoL	Health-Related Quality of Life
K6	Kessler 6-item Psychological Distress Scale
LPA	Light-intensity physical activity
MANOVA	Multivariate Analysis of Variance
METs	Metabolic equivalents
MFQ	Mood and Feelings Questionnaire

MVPA	Moderate-to-Vigorous Physical Activity
OR	Odds Ratio
OSDUHS	Ontario Student Drug Use and Health Survey
PICOS	Population, Interventions, Comparisons, Outcomes, and Study design
PR	Prevalence Ratio
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Ongoing Systematic Reviews
RMSEA	Root-Mean-Square Error of Approximation
SD	Standard Deviation
SE	Standard Error
SES	Subjective Socioeconomic Status
SRMR	Standardized Root Square Mean residual
TLI	Tucker-Lewis Index
US	United States
WHO	World Health Organization
YRBS	Youth Risk Behavior Survey

Chapter 1

INTRODUCTION

Good mental health is integral to human health and well-being. The World Health Organization (WHO) defines mental health as a "state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community" [1]. In line with this definition, mental health researchers increasingly acknowledge that the absence of mental illness does not necessarily imply a state of psychological well-being [2, 3]. Mental health problems account for 16% of the global burden of disease and injury in people aged 10–19 years [4], and they are a leading cause of disability worldwide [5, 6]. It is estimated that 10 to 20% of children and adolescents globally experience mental health problems [5]. Nearly 70% of mental health problems have their onset during childhood or adolescence [7]. However, mental health problems in childhood often track into adulthood [8].

Depression is one of the most common major psychiatric disorders to occur and frequently begins during adolescence [9]. The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) defines Major Depression by the presence of five or more symptoms within a 2-week period [10]. One of the symptoms should be either a depressed mood (or irritability in children) or anhedonia (loss of interest or pleasure in almost all activities) and at least three (for a total of at least five) of the following symptoms present most days: weight loss or change in appetite, insomnia or hypersomnia, psychomotor agitation or retardation, fatigue or loss of energy, feelings of worthlessness or excessive guilt, decreased concentration or indecisiveness, and recurrent

thoughts of death or suicide [10]. Depression is the second leading cause of years lived with disability and a leading cause of disability-adjusted life years [6]. It is well known to have adverse life-long consequences [11], impairing both physical and mental health and limiting opportunities to lead fulfilling lives as adults [4]. Research has shown that adolescent depression is associated with greater risk of depression, anxiety disorders, suicidality, and several psychosocial outcomes in adulthood [12, 13].

Approximately 1 in 5 children and adolescents has a mental health challenge in any given year [14-16]. A study using data collected in 2014 showed that 8% of Ontario adolescents aged 12 to 17 years self-reported major depressive symptoms [16]. A United States study in adolescents reported that the prevalence of depressive symptoms changed from 8.7% in 2005 to 11.3% in 2014 [17], suggesting that the prevalence of depressive symptoms has increased over the past years. In 2016, the number of adolescents aged 12 to 17 years in the United States who had at least one major depressive episode was estimated at 3.1 million, representing 12.8% of the United States population aged 12 to 17 years [18]. Moreover, approximately 60% of adolescents with major depressive episodes did not receive treatment [18]. Studies suggest that the full economic impact of mental health problems and illnesses in Canada is between $48.5 and $51 billion per year [19, 20]. These alarming data support the need for novel research to understand the determinants of depression and other mental health disorders among children and adolescents to inform ongoing and future prevention efforts. This is particularly important given the ongoing coronavirus disease 2019 (COVID-19) pandemic, which has had a tremendous impact on mental health of children and adolescents [21, 22]. This underscores the need to be doing more now than ever to improve the mental health of children and adolescents. Evidence has shown that promotion, prevention, and

early interventions will not only improve health and well-being, but will also produce significant cost benefits, particularly with children and adolescent programs [23, 24].

One target for prevention and intervention against mental health problems is lifestyle behaviours, particularly physical activity, screen time, and sleep [25, 26]. However, the role of these movement behaviours, and in particular their combined influence in the development of mental health problems in children and adolescents has received less attention than in adults. Thus, identifying healthy lifestyle choices that promote psychological well-being and reduce mental problems would be useful to prevent mental disorders. Along the same lines, the way school-aged children and adolescents spend their time over a 24-hour period has been suggested to have important mental health implications [27]. Poor lifestyle, such as physical inactivity, sedentary behaviour, and short sleep duration have been shown to be important determinants of mental health problems among children and adolescents [28-31].

1.1. Physical activity

Physical activity is often defined as any bodily movement produced by skeletal muscles that results in energy expenditure [32]. It is a multifaced behaviour that is usually described using its frequency, intensity, type, and duration. Physical activity could be seen as a continuum ranging from virtually no movement at all (e.g., sedentary behaviour or sitting time) through light physical activity (e.g., standing, slow walking) to moderate-to-vigorous physical activity (MVPA) (e.g., brisk walking, playing sports, cycling) [33]. Physical inactivity refers to not meeting physical activity guidelines of at least 60 minutes of MVPA per day for children and adolescents aged 5 to 17 years [34]. Indeed, MVPA is the most common form of physical activity intensity that is reported in the literature, mainly because it is related to guidelines and is easy to measure in

population surveys, particularly through self-reports. Children and adolescents engage in different types of physical activity, including outdoor active play (e.g., playing at recess, exploring nature), active transportation (e.g., walking or biking to school), curriculum-based physical activity (e.g., physical education), and organized sport (e.g., playing soccer or basketball). Physical activity can be measured using device-based (e.g. accelerometers, pedometers) and subjective (e.g. self-report, parent-report) tools.

Physical activity is vital to the physical, mental, social, and cognitive health of school-aged children and adolescents [31]. Insufficient physical activity is one of the 10 leading risk factors for death worldwide [35]. Physical inactivity has been identified as the fourth leading risk factor for global mortality (6% of deaths globally) [36, 37]. Approximately 3.2 million deaths each year are attributable to insufficient physical activity [38]. To derive health benefits, it is recommended that children and adolescents aged 5 to 17 years spend at least 60 minutes per day in MVPA [36]. However, globally, 81% of adolescents aged 11-17 years are not meeting this recommendation [35]. This is of greater concern given (1) the host of health benefits provided by regular physical activity; (2) physical activity constitutes an important tool in efforts to fight against childhood obesity; and (3) physical activity has potentially beneficial effects for reducing depressive symptoms in children and adolescents; however, the evidence base is limited.

In a large, nationally representative sample of nearly 3,000 adolescents from the Avon Longitudinal Study of Parents and Children, Wiles *et al.* [39] found that adolescents who were physically active had lower odds of depressive symptoms, but they did not find a significant association between the intensity of physical activity and depressive symptoms, once total physical

activity was taken into account. Belair *et al.* [40] showed that Canadian children and adolescents who reported engaging in leisure time physical activity less than 1 day per week were at higher risk for depressive and anxiety symptoms compared with those reporting at least 1 day of physical activity per week, suggesting that physical activity may be protective against depression. Two meta-analyses provided evidence suggesting that physical activity could be effective to reduce depressive symptoms among adolescents [41, 42]. A recent meta-analysis by Korczak *et al*. [43] indicated that physical activity in childhood or adolescence was associated with lower concurrent depressive symptoms, and the association with future depressive symptoms was weak. In their reviews of reviews conducted in 2010, Biddle and Asare [44] found very little evidence base for the potential benefits of physical activity on children and adolescent mental health indicators, including depression, anxiety, and cognitive functioning; however, research designs were often weak (many reviews include cross-sectional studies) and the effects were small to moderate. Eight years later, in their recently updated review of systematic reviews and meta-analyses on the association between physical activity and mental health in children and adolescents, Biddle *et al.* [45] found that, although there was an increase in research on physical activity and depression, self-esteem, and cognitive functioning, the strongest evidence for a causal association seems to be for cognitive functioning, and the evidence is partial for depression.

The mechanisms underlying the association between physical activity and mental health are biological and psychological. The biological mechanisms rely on energy expenditure resulting from physical activity, particularly MVPA which leads to an increase in the availability of monoamines, such as serotonin [46] and norepinephrine [47]. Physical activity also reduces physiological reactivity to stress via the hypothalamo-pituitary-adrenal (HPA) axis to contribute

to cortisol regulation. Physical activity increases endorphins and Brain-Derived Neurotrophic Factor (BDNF) which are linked to mood and depression [48]. Finally, physical activity increases hippocampal cell proliferation [49] and reduces levels of proinflammatory cytokines [50]. The psychological mechanisms underlying the association between physical activity and mental health rely on three main psychological hypotheses, including distraction, self-efficacy, and social interaction. The distraction hypothesis suggests that distraction from stressful stimuli results in an improved mood associated with exercise [51]. The self-efficacy hypothesis indicates that physical activity is a challenging activity that leads to an improved mood and self-esteem of individuals who are able to perform it on a regular basis [52]. According to the social interaction hypothesis, physical activity favours social relationships as well as a wide and supportive social network, which is beneficial to mental health [53]. Research has shown that physical activity participation also favours the satisfaction of feelings of autonomy, competence, and relatedness specific to the physical activity context [54, 55]. Nevertheless, a reverse-causal relationship is possible as individuals with better mental health could be more likely to engage in physical activity [56].

1.2. Sedentary behaviour

Sedentary behaviour is defined as any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining, or lying posture [57]. There are different types of sedentary behaviour, including TV viewing, using a computer, reading, writing and eating, which can be accumulated during different domains including work, transportation, and leisure time [58]. Screen time, such as social media use, TV viewing, and recreational computer use is the most common form of sedentary time among children and adolescents [59-61] (the present thesis will focus on screen time as a measure of sedentary behaviour). Public health

guidelines recommend that youth aged 5 to 17 years accumulate no more than 2 hours of recreational screen time per day [34]. However, research has shown that the majority of children and adolescents exceed this guideline [62-66]. For example, Janssen *et al.* [67] have indicated that 92% of Canadian children and adolescents aged 10 to 17 years do not meet the screen time recommendation. This is concerning because sedentary behaviour during childhood tends to continue into adolescence and into adulthood [68], and excessive sedentary time is associated with increased morbidity and mortality [69-71]. Sedentary time can be measured using device-based (e.g. accelerometers, inclinometers) and subjective (e.g. self-report, parent-report) tools.

Research studies have shown that children and adolescents spend excessive amounts of time being sedentary, mainly in the form of screen time behaviour, including but not limited to TV viewing, video gaming, and the use of electronic media devices [60, 61]. Indeed, the rapid advance of information and communication technology has made the Internet more accessible than ever. Consequently, electronic media devices, such as smartphones, tablets, computers, or gaming consoles have become omnipresent in the everyday life of most children and adolescents [72]. A recent report indicated that the majority of Ontario high school students use electronic devices for more than three hours a day in their free time [73]. Specifically, one-third (33.3%) of students use them for three to four hours, 17.7% use them for five to six hours, and 11.8% use them for seven hours or more per day. Only 1% report not using electronic devices each day in their free time [73]. Social media use is currently one of the main activities on electronic media devices among adolescents, with nearly 86% of middle and high school students reporting daily use of these web-based platforms [73].

Associations between sedentary behaviour and mental health problems among children and adolescents has been well-documented [74]. For example, a systematic review conducted by Hoare *et al.* [74] found strong consistent evidence suggesting that excessive recreational screen time is associated with high levels of depressive symptoms and psychological distress among adolescents. Similarly, in their systematic review and meta-analysis, Stanczykiewicz *et al.* [75] and Allen *et al.* [76] have found that higher levels of sedentary behaviours are associated with high levels of symptoms of anxiety among children, adolescents, and adults. Many publications have also underlined the association of social media use with mental health problems, such as depressive symptoms and suicidal ideation and attempts [62, 77, 78]. Moreover, research has indicated that the mental health effects of screen time can extend into adulthood. Longitudinal studies have shown that longer recreational screen time in adolescence is associated with depressive symptoms in adulthood [79-81].

The association between screen time and mental health problems could be direct and/or indirect. The direct effects of screen time on mental health can be related to the addictive nature of screen time and the nature of the content (e.g. violence, suicide, crimes, etc.) users are exposed to on these platforms. Indirectly, heavy screen time can reduce an individual's participation in more active or productive tasks, which in turn could impede their quality of life. This is often referred to as the displacement hypothesis [82]. Heavy screen time can also affect mental health via a third factor. Indeed, screen time has been associated with a wide range of risk behaviours [83], which in turn are associated with mental health problems in children and adolescents [84]. Social media use has been associated with social comparison [85], dissatisfaction with body mass [86], cyberbullying victimization [87], unhealthy eating behaviour [88], substance use [89, 90], short sleep duration

[91], and negative school outcomes [92], which are all linked to mental health problems. For example, in their systematic review, Seabrook *et al.* [78] found that negative interactions and social comparisons on social media were related to higher levels of depression and anxiety. Alternatively, a reverse-causal relationship is possible as individuals with mental health problems could be more likely to engage and spend more time using screen time as a possible coping strategy (as they are trying to escape from their experiences) or as a possible source of social support. For example, Frison and Eggermont (2015) have found that adolescents reported logging onto Facebook to receive social support to deal with their stress [93].

1.3. Sleep duration

Sleep is a physiological state that is generally defined as a naturally recurring state of body and mind characterized by altered consciousness, relatively inhibited sensory activity, inhibition of nearly all voluntary muscles, and reduced interactions with surroundings [94]. Sleep duration is the most common measure of children and adolescent sleep in the literature [95, 96], and the present thesis will focus on sleep duration as a measure of sleep. Sleep can be measured using device-based (e.g. polysomnography, actigraphy/accelerometry) and subjective (e.g. self-report, parent-report) measures.

Sleep is an essential component of healthy development and is required for physical and mental health. Sleep duration is often qualified as sufficient or insufficient (short sleep) based on the current public health guidelines [34, 95]. To maximize overall health benefits, it is recommended that children aged 6–13 years sleep between 9 and 11 hours per night, while adolescents aged 14–17 years should sleep 8–10 hours per night [34, 95]. However, research has shown that 68% of

children aged 10–13 years and 72% of adolescents aged 14–17 years sleep for the recommended amount per night when averaged across all days of the week [97]. With recent research indicating that nearly one-third of Canadian children and adolescents sleep less than recommended by public health authorities for optimal health [98, 99], short sleep duration has become endemic in modern societies. It is associated with daytime sleepiness and poor daytime functioning [100-102] and has been identified as a serious threat to the academic success, health, and safety of children and adolescents [101, 103]. In their systematic review of 76 studies on the functional consequences of sleep problems in adolescents, Shochat *et al.* [102] found that sleep disruption had a negative effect on psychosocial health, school performance, and risk-taking behaviours.

Evidence has shown that sleep problems are common symptoms of psychiatric disorders, such as depression and anxiety disorder [26]. More specifically, short sleep duration has been associated with mental health problems in children and adolescents [104]. For example, using a large sample of Chinese adolescents, Liu [105] found that short sleep duration was associated with greater odds of suicide attempts. Similarly, Fitzgerald *et al.* [106] found that short sleep duration was associated with suicidal ideation, plans, and attempts among United States high school students. Numerous longitudinal studies examining the directional relationship between sleep and depression among adolescents suggested that sleep problems constitute a precursor to the development of depression [107]. Moreover, sleep has been identified as an important factor in promoting mental health [108].

Physiologically, sleep is regulated by an interaction between the circadian clock and homeostatic mechanisms [109]. With the biological changes happening during adolescence, there is a biological shift in adolescents' circadian clock to a later point [110]. This delayed sleep phase is

often exacerbated by evening light exposure, early school start time, and social and school obligations [110]. On the pathological level, the association between short sleep duration and mental health problems could be direct and/or indirect. The direct path impacts upon the nervous system, whereas the indirect path is mediated by other factors, such as physical activity, screen time, cyberbullying, etc. Short sleep duration affects brain activity and neurochemicals that regulate mood and cognitive function [111]. It also increases stress reactivity via a dysregulation of the hypothalamic-pituitary-adrenal axis, thus increasing the risk of psychopathological disorders [112]. Short sleep impairs executive functions [113], such as inhibitory control and cognitive flexibility, that could result in increased irritability, impulsivity, anger, and aggression [114, 115]. Indirectly, short sleep duration results in daytime sleepiness, fatigue, and tiredness [100, 101], which in turn can make the maintenance of a healthy lifestyle (e.g., physical activity) more difficult, or render the concerned children and adolescents more vulnerable and perfect targets for bullying victimization [116]. It is noteworthy that there is a possibility of reverse causation in the relationship between sleep and mental health [117-119]. That is, students who have mental health problems may be more prone to short sleep duration than their healthy counterparts. For example, a systematic review and meta-analysis examining the relationship between sleep and depressive symptoms among adolescents found that depressed adolescents were more likely to experience more wakefulness in bed and lighter sleep, and they reported more subjective sleep disturbances [107].

1.4. Canadian 24-hour movement guidelines

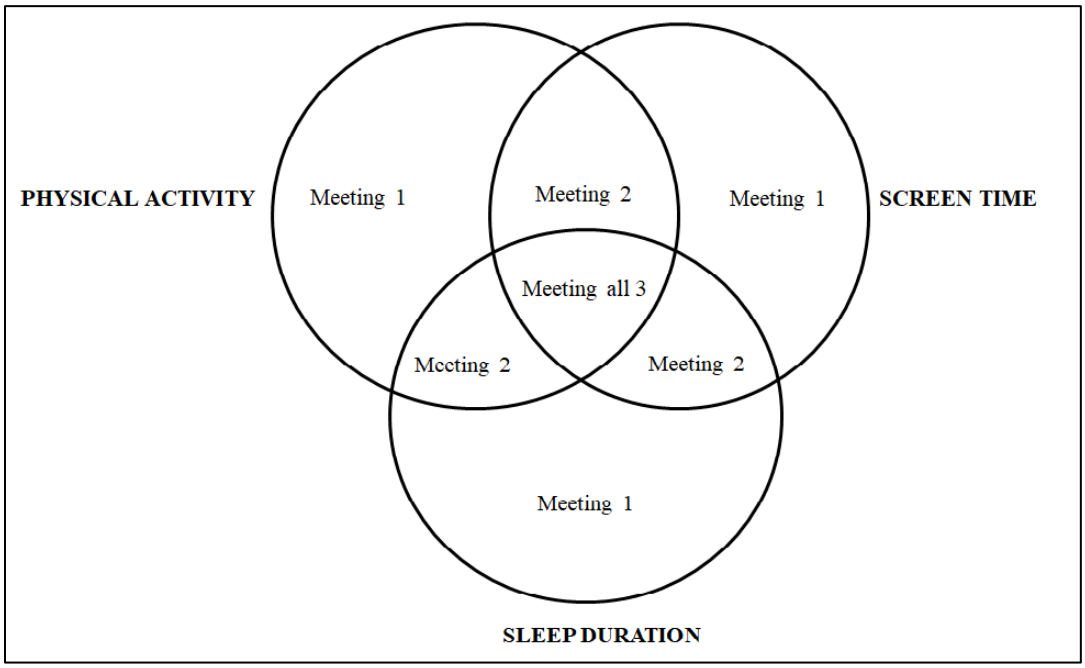
Public health recommendations for physical activity [37], screen time [120], and sleep duration [95] have long been considered separate and independent from each other. However, time spent in

these three behaviours are codependent because they are mutually exclusive, and time spent in all three behaviours across a day must collectively account for the entire 24-hour period [67]. Therefore, time spent in physical activity, screen time, and sleep duration should be considered simultaneously. The importance of an integrated approach that considers all behaviours across the movement continuum has been previously highlighted [34, 121, 122]. Canada was the first country to develop integrated guidelines that provide recommendations regarding the movement behaviours for children and adolescents aged 5 to 17 years. The *Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep* were released in June 2016. These guidelines provide specific recommendations on the amount of time during a typical 24-hour day that children and adolescents aged 5 to 17 years should spend engaged in MVPA (at least 60 minutes), recreational screen time (no more than 2 hours), and sleep (9 to 11 hours for 5- to 13-year-olds; 8 to 10 hours for 14- to 17-year-olds) [34].

Previous research studies that examined the combinations between physical activity, sedentary behaviour, and sleep duration, as displayed in Figure 1 have mainly focused on their associations with physical health outcomes [123-125]. However, the effect of different combinations among physical activity, sedentary behaviour, and sleep duration on mental health in children and adolescents has received significantly less attention. Little is known about the extent of the gaps in the current literature regarding different combinations of physical activity, sedentary behaviour, and sleep in relation to mental health outcomes. It is also unclear whether some combinations among physical activity, sedentary behaviour, and sleep could be more beneficial than others in relation to mental health outcomes. Gaining the knowledge on which combinations of physical activity, sedentary behaviour, and sleep are most strongly associated with better mental health

outcomes is crucial, in order to design evidence-based interventions aimed at improving the health of children and adolescents.

Figure 1. Different combinations of adherence to the physical activity, screen time, and sleep duration recommendations



In one of the systematic reviews that were conducted as part of the process of creating comprehensive movement behaviour guidelines for school-aged children, Saunders *et al.* [126] examined how combinations of different levels of physical activity, screen time, and sleep were associated with health indicators among children and adolescents aged 5–17 years. Their results supported the possibility of synergistic benefits to achieving optimal levels for multiple movement behaviours [126]. More specifically, their results showed that school-aged children and adolescents who have the most ideal combination of movement behaviours (i.e. high physical activity/high sleep/low screen time) generally have more desirable measures of physical health

outcomes, when compared with those with the least ideal combination of movement behaviours (i.e. low physical activity/low sleep/high screen time) [126]. Furthermore, they found that children and adolescents who do well in any two movement behaviours (e.g. high physical activity/high sleep or high physical activity/low screen time) are also likely to experience health benefits, when compared with children and adolescents who do poorly in the same two movement behaviours (i.e. low physical activity/low sleep, or low physical activity/high screen time) [126].

Importantly, Saunders *et al.* [126] identified several important research gaps in the published literature to be addressed in future research, including but not limited to the following. First, research has examined relationships of movement behaviours with physical health indicators to a large extent (e.g., adiposity and cardio-metabolic disease risk factors) [122, 126]. Mental and psychosocial health indicators need to be considered in future studies. Second, the majority of studies compared only the best and worst combinations of behaviours (e.g., high physical activity/high sleep/low screen time vs. low physical activity/low sleep/high screen time), without directly comparing intermediate combinations. Thus, it is unclear how the health of children and adolescents who meet recommendations for 2 of the 3 movement behaviours compares with the health of children and adolescents who meet recommendations for a different combination of 2 movement behaviours.

With reports indicating a decline in physical activity and sleep duration and an increase of sedentary behaviour and mental health problems such as depressive symptoms across a lifespan, it is important to properly examine how physical activity, screen time, and sleep duration are associated with mental health among children and adolescents. First, childhood and adolescence

are critical periods where risk behaviours emerge and can extend into adulthood. Second, it is important to inform intervention programs, especially because childhood and adolescence are target age groups for intervention efforts before unhealthy behaviours become engrained. Third, physical activity, sedentary behaviour, and sleep duration are modifiable risk factors. Finally, there is a large body of literature (as discussed above) that suggests that these behaviours are each individually linked to mental health.

1.5. Research Objectives

The purpose of this doctoral dissertation is to examine how the combinations of physical activity, sedentary behaviour, and sleep duration are associated with depression and other mental health outcomes in children and adolescents using innovative statistical analyses. More specifically, this dissertation aims to answer the following research questions:

1. How are various combinations of physical activity, sedentary behaviour, and sleep duration related to depression and other mental health indicators among children and adolescents?
2. Is adherence to the Canadian 24-hour movement behaviour guidelines for children and adolescents associated with improved mental health?
3. How does movement behaviour composition relate to depression and other mental health indicators among children and adolescents?
4. Is replacing time spent in one type of movement behaviour with another associated with changes in mental health in children and adolescents using compositional data analyses?

1.6. Dissertation Organization and Outline

This dissertation is organized in an article format following the University of Ottawa dissertation guidelines. A brief overview of each chapter is provided below:

- Chapter 1 provides a brief introduction, overview, and justification of the dissertation topic.
- Chapter 2 is the first manuscript of this dissertation, entitled: Combinations of physical activity, sedentary time, and sleep duration and their associations with depressive symptoms and other mental health problems in children and adolescents: a systematic review. This manuscript is published in the *International Journal of Behavioral Nutrition and Physical Activity*.
- Chapter 3 is the second manuscript of this dissertation, entitled: 24-Hour Movement Behaviors and Internalizing and Externalizing Behaviors Among Youth. This manuscript is published in the *Journal of Adolescent Health*.
- Chapter 4 is the third manuscript of this dissertation, entitled: The Canadian 24-hour movement guidelines and psychological distress among adolescents. This manuscript is published in *The Canadian Journal of Psychiatry*.
- Chapter 5 is the fourth manuscript of this dissertation, entitled: 24-hour movement guidelines and suicidality among adolescents. This manuscript is published in the *Journal of Affective Disorders*.
- Chapter 6 is the fifth and final manuscript of this dissertation, entitled: Longitudinal association between movement behaviours and depressive symptoms among adolescents using compositional data analysis. This manuscript is currently under peer-review.

- Finally, Chapter 7 provides a general discussion, including a summary of the key findings, overall strengths and limitations of this thesis, and future implications of the dissertation results.

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Chapter 2

Combinations of physical activity, sedentary time, and sleep duration and their associations with depressive symptoms and other mental health problems in children and adolescents: a systematic review

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review. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 1-16." All Tables and figures were numbered using two digits, including chapter number followed by table or figure number to avoid confusion with those in other chapters. Additional supporting documents, including Database Search Strategy, PRISMA 2009 checklist, and ethical approval are included in appendices at the end of this chapter.

Online link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7273653/

Article preface: The objective of this systematic review was to examine how combinations of physical activity, sedentary time, and sleep duration relate to depressive symptoms and other mental health indicators among children and adolescents.

Contribution statement: I am the first author on this article. I was responsible for generating the study objectives and design, with guidance from my supervisor and co-authors. I conducted the literature search and reviewed all abstracts and full texts considered for inclusion in this study. I wrote the first draft of the manuscript, submitted the final version for publication, and addressed reviewer comments.

ABSTRACT

Background: For optimal health benefits, the Canadian 24-Hour Movement Guidelines for Children and Youth (aged 5–17 years) recommend an achievement of high levels of physical activity (≥60 minutes of moderate-to-vigorous physical activity), low levels of sedentary behaviour (≤2 hours of recreational screen time), and sufficient sleep (9-11 hours for children or 8-10 hours for adolescents) each day. The objective of this systematic review was to examine how combinations of physical activity, sedentary time, and sleep duration relate to depressive symptoms and other mental health indicators among children and adolescents.

Methods: Literature was obtained through searching Medline, EMBASE, PsycINFO, and SportDiscus up to September 30, 2019. Peer-reviewed studies published in English or French were included if they met the following criteria: population (apparently healthy children and adolescents with a mean age of 5-17 years), intervention/exposure (combinations of physical activity, sedentary time, and sleep duration), and outcomes (depressive symptoms and other mental health indicators). A risk of bias assessment was completed for all included studies using the methods described in the Cochrane Handbook. The Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework was used to assess the quality of evidence for each health indicator. Narrative syntheses were employed to describe the results due to high levels of heterogeneity across studies.

Results: A total of 13 cross-sectional studies comprised in 10 papers met inclusion criteria. Data across studies involved 115,540 children and adolescents from 12 countries. Overall, the findings indicated favourable associations between meeting all 3 recommendations and better mental health indicators among children and adolescents when compared with meeting none of the recommendations. There was evidence of a dose-response gradient between an increasing number

of recommendations met and better mental health indicators. Meeting the screen time and sleep duration recommendations appeared to be associated with more mental health benefits than meeting the physical activity recommendation. The quality of evidence reviewed was “very low” according to GRADE.

Conclusions: The findings indicate favourable associations between meeting all 3 movement behaviour recommendations in the 24-hour guidelines and better mental health indicators among children and adolescents. There is a clear need for high-quality studies that use robust measures of all movement behaviours and validated measures of mental health to increase our understanding in this topic area.

Key words: exercise, recreational screen time, sleep, depression, mental health, youth

INTRODUCTION

Depression is a serious public health issue worldwide [1]. It affects more than 300 million people of all ages around the world [2], with a low prevalence in children (less than 1%), and then increases significantly throughout adolescence [3]. Depression is one of the most common major psychiatric disorders to occur that frequently begins during adolescence [4, 5]. However, its negative impacts can extend into adulthood [6, 7]. Several longitudinal studies demonstrated that experiencing depression in early life is associated with a wide range of negative outcomes in adulthood, such as substance use, violent behaviour, and criminal outcomes [8-10]. Depression is the second leading cause of years lived with disability and a leading cause of disability-adjusted life years [11]. It is therefore important to identify modifiable factors that could prevent or alleviate depressive symptoms among children and adolescents.

Achieving high levels of physical activity, low levels of sedentary behaviour, and getting sufficient sleep have been individually associated with better mental health among children and adolescents [12-14]. However, the fact that physical activity, sedentary time, and sleep have been considered separately from each other is concerning, because research has shown that these three behaviours are codependent and should be considered simultaneously [15, 16]. Consequently, the Canadian 24-Hour Movement Guidelines for Children and Youth (aged 5 to 17 years) have been released in 2016 and recommend ≥60 minutes/day of moderate-to-vigorous physical activity (MVPA), ≤2 hours/day of recreational screen time, and 9 to 11 hours of sleep per day for 5- to 13-year-olds or 8 to 10 hours of sleep per day for 14- to 17-year-olds to support healthy development [17]. However, the prevalence of children and adolescents from different countries around the world

who meet all three recommendations contained within the guidelines varies between 3 to 10% [18-23]. Such low prevalence is concerning, so gaining a better understanding of how it relates to mental health is important to study from a public health perspective.

Previous studies looking at the 24-hour movement guidelines and health indicators have primarily focused on examining the associations between the combinations of physical activity, sedentary time, and sleep duration with physical health outcomes [12, 14, 24]. However, little is known about the extent of the gaps in the current literature regarding different combinations of physical activity, sedentary time, and sleep duration in relation to mental health indicators. It is also unclear whether some combinations of physical activity, sedentary time, and sleep duration could be more beneficial than others. Understanding which combinations are more strongly associated with better mental health is important to help design evidence-informed interventions aimed at improving the health of children and adolescents. This is particularly important given the developmental origins of depression and other mental health conditions begin in childhood and track into adulthood [25]. The systematic review by Saunders *et al.* [26] on the associations between different combinations of physical activity, sedentary time, and sleep duration with health indicators in children and adolescents is 5 years old and only included studies with objectively-measured physical activity. With the release of movement behaviour guidelines in 2016 [17], there has been a substantial increase in the number of studies investigating indicators of mental health and associations with specific combinations of movement behaviours. Therefore, it is necessary to have a better and current understanding of the combined influence of movement behaviours on mental health indicators. This knowledge will also help to inform and refine public health guidelines.

The purpose of this systematic review was to examine how combinations of physical activity, sedentary time, and sleep duration relate to depressive symptoms in children and adolescents, while secondary aims examined associations with a broader spectrum of mental health indicators. It was hypothesized that meeting all three movement behaviour recommendations would be associated with less depressive symptoms and better overall mental health compared to meeting two, one, or none of the recommendations.

METHODS

Protocol and registration

This review was registered *a priori* with the International Prospective Register of Ongoing Systematic Reviews (PROSPERO; submitted 25/11/2019, registration pending), and was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement for reporting systematic reviews and meta-analyses [27].

Eligibility criteria

The population, interventions, comparisons, outcomes, and study design (PICOS) framework [28] was followed to identify key study concepts in the research question *a priori*, and to facilitate the search process.

Population

Studies of apparently healthy school-aged children and adolescents (aged 5-17 years) were eligible. The mean age of eligible studies had to fall within the bracket of 5 to 17 years, regardless the study sample age range. For example, if the study sample ranged from 11 to 20 years and the

mean age was equal to 15 years, the study was included. Studies were excluded if they reported on a clinical sample (e.g., populations exclusively composed of adolescents with depressive symptoms) or if the behaviour (i.e., physical activity, sedentary time, and/or sleep duration) was not measured during the 5-17-year-old age boundaries for at least one time point.

Intervention (exposure)

Studies were included if they reported *all three* movement behaviours (i.e., physical activity, sedentary time, and sleep duration). Studies were included if they used (1) objective (actigraphy, accelerometry, heart rate monitors, pedometers, arm bands) or subjective (self/proxy-report) measures of physical activity; (2) objective (actigraphy, accelerometry, inclinometer) or subjective (self/proxy-report) measures of sedentary time; and (3) objective (polysomnography, actigraphy, accelerometry) or subjective (self-report, proxy-report) measures of sleep duration.

There are a few specifications worth mentioning here. Objective measures of physical activity can differentiate light-intensity physical activity (LPA) from MVPA, whereas subjective measures capture most often MVPA. For the sedentary component, objective measures report sedentary time, while subjective measures generally report screen time. Sedentary time is defined as the time spent for any duration (e.g., minutes per day) or in any context (e.g., at school or home) in sedentary behaviours, and a sedentary behaviour is any waking behaviour characterized by an energy expenditure ≤1.5 METs, while in a sitting, reclining or lying posture [29, 30]. Screen time refers to the time spent on screen-based behaviours. These behaviours can be performed while being sedentary or physically active [30]. Recreational screen time is the time spent in screen behaviours that are not related to school or work [17].

Comparison

Various levels and combinations of physical activity, sedentary time, and sleep duration. However, a comparator or control group was not required for inclusion.

Outcomes

Depressive symptoms represented our primary outcome (indicator) measure. Secondary outcomes (indicators) included other negative (e.g., anxiety, psychological distress, suicidal behaviour) and positive aspects (e.g., flourishing, pro-social behaviour) of mental health, substance use, behavioural problems or disorders (e.g., aggression, child behavioural disorder, child development disorder), and quality of life/well-being.

Study design

There was no restriction on the types of study designs eligible for inclusion. Only published or in press peer-reviewed articles were included. We excluded case studies and grey literature (e.g., book chapters, dissertations, conference abstracts). For longitudinal studies, any follow-up length was allowed as long as the exposure was measured before follow-up at least once during the identified age range (5-17 years). Follow-up measures of mental health outcomes could occur above this age.

Information sources and search strategy

The electronic search strategy was created by a research librarian with expertise in systematic review. The following databases were searched: MEDLINE (1946 to September 30, 2019), EMBASE (1947 to September 30, 2019), PsycINFO (1987 to September 29, 2019) using the Ovid

interface and SPORTDiscus (from inception to September 29, 2019) using the EBSCO platform. The searches looked for journal articles reporting on sleep, sedentary time and physical activity using previously developed and validated searches [12-14, 31]. Searches did not include terms pertaining to outcomes as this review examines outcomes that may be indexed or categorized in several different manners, and including outcome keywords in our search may lead to exclusion of studies that would meet eligibility criteria otherwise. There was no restriction by type of statistical analyses used. Searches were limited to articles published in English or French. The search strategies are presented in Additional file 1.

Study selection

After duplicate records were removed online, records retrieved by the electronic search were downloaded and imported into the Reference Manager Software (Thompson Reuters, San Francisco, California, USA) for additional removal of duplicate references. Titles and abstracts of potentially relevant articles were imported to Covidence (a secure, internet-based software; Evidence Partners, Ottawa, Ontario, Canada) where two reviewers screened them independently. Exclusion by both reviewers was required for a study to be excluded at level 1 (title and abstract) screening. At level 2, two independent reviewers performed full-text review of potentially eligible articles. Consensus was required for articles to be included; discrepancies between reviewers were resolved by discussion between them or with a third reviewer, if needed. Reference lists of included articles and relevant reviews were also checked for additional relevant studies.

Data extraction

Data extraction forms were created by the study coordinators, reviewed by study collaborators, and pilot tested by all reviewers. One reviewer completed the data extraction electronically in Microsoft Excel. A second reviewer independently extracted data from eligible articles and entered this information into the extraction form. Forms were compared afterwards, and discrepancies were resolved by consensus. Reviewers were not blinded to the authors or journals when extracting data. Results were extracted from the most fully adjusted models for studies that reported findings from multiple models.

Data items

Important study characteristics (e.g., publication year, study design, country, sample size, age and sex of participants, measure of physical activity, sedentary time, sleep, and mental health indicators, results, and confounders) were extracted.

Risk of bias and study quality assessment

A risk of bias assessment was completed for each outcome within each study using the methods described in the Cochrane Handbook [32]. Following the recommendations for observational studies, the risk of bias assessment identified methodological features of each study that could affect confidence in the overall estimate of effect for an outcome. More specifically, we assessed the risk of selection bias, performance bias, selective reporting bias, detection bias, attrition bias, and potential confounding [33]. Both exposures (i.e. physical activity, screen time, and sleep duration) and outcomes (i.e. depressive symptoms and other mental health indicators) were considered in the assessment of bias related to measurement. When the only source of bias was

performance bias due to selection bias due to convenience sampling, this was not considered "serious risk of bias". Risk of bias was assessed by one reviewer for all included articles, and then verified by another reviewer.

The overall quality of research evidence for mental health indicators was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework [33]. The GRADE framework categorizes the quality of evidence into four groups ("high", "moderate", "low", and "very low"). Evidence quality ratings start at high for randomized studies and at low for all other experimental and observational studies. The quality of evidence can be downgraded if there are limitations across studies in any of the five criteria, including risk of bias, imprecision, inconsistency, indirectness, and publication bias [33]. If there is no cause to downgrade, the quality of evidence can be upgraded if there is a large effect size, there is a dose-response gradient, or if all plausible confounders would decrease an apparent treatment effect. The quality of evidence assessment was evaluated by one reviewer and verified by the larger review team. Disagreements were resolved by discussion among the team members, if needed.

Data synthesis

Meta-analyses were planned if data were sufficiently homogenous with regards to methodological, statistical, and clinical characteristics. However, a meta-analysis was not possible due to heterogeneous data for the above characteristics. Therefore, a narrative synthesis was used to describe each health indicator.

RESULTS

Description of studies

A PRISMA flowchart summarizing the article selection process is displayed in Figure 1. A total of 1,217 records were identified during the electronic database search. Of these records, 677 were identified in Medline, 442 in EMBASE, 73 in SportDiscus, and 25 in PsycINFO. After duplicates were removed, a total of 885 records remained. After titles and abstracts were screened, 28 full-text articles were obtained for further review and 10 articles met the inclusion criteria (7 unique samples). Reasons for excluding articles were: not reporting a combination of physical activity, sedentary time, and sleep duration ($n = 10$), no measure of mental health indicators ($n = 6$), and ineligible age ($n = 2$). Some studies were excluded for multiple reasons.

Characteristics of the 10 included articles are summarized in Table 1. Data across studies involved 115,540 children and adolescents from 12 countries. All studies were cross-sectional, and were published in 2016 or later, with participants' age ranging from 6 to 20 years. The 10 articles comprised 13 studies because some papers had more than one mental health outcome. Of those, 3 reported on depressive symptoms [18, 19, 34], 3 on social and emotional health [35-37], 2 on health-related quality of life [38, 39], 1 on anxiety [34], 1 on substance use (including cigarette smoking, alcohol consumption, and cannabis use) [18], 1 on impulsivity [40], 1 on cognitive functions [20], and 1 on life satisfaction and prosocial behaviour [37]. Three studies reported on more than one mental health indicator [18, 34, 37]. The included articles used various statistical analyses (Table 1). Three papers used logistic regression analyses [18, 19, 34], 2 papers used compositional data analysis [36, 39], 2 papers used mixed linear models [20, 38], 2 other papers used standard linear regression [35, 37], and 1 paper used structural equation modelling [40].

Overall, the prevalence of depressive symptoms was 42.7% (unweighted) in a sample of more than 59,000 adolescents in the United States [18], 14.4% in a sample of nearly 4,000 adolescents in the United Kingdom [19], and 10.3% in a sample of more than 35,000 children and adolescents from the United States [34].

The prevalence of children and adolescents who met the physical activity recommendation in the included studies ranged from 4.1% to 40.5%, with the majority in the 33.3%-40.5% bracket; those who met the screen time recommendation ranged from 8% to 48.2%, with the majority in the 36.5%-48.2% bracket; and those who met the sleep duration recommendation ranged from 41.9% to 89.3%, with the majority in the 66.2%-89.3% bracket. The proportion of children and adolescents who met any one recommendation in the included studies ranged from 34.9% to 51.1%, those who met any two recommendations ranged from 18.4% to 37.0%, and those who met all three recommendations ranged from 2.6% to 17.1%.

Measurement of movement behaviours

Physical activity was measured with accelerometers in 5 studies from 3 unique datasets [19, 35, 36, 38, 39], and was either self-reported or parent-reported in the other studies [18, 20, 34, 37, 40]. Sedentary time was objectively measured using accelerometers in 3 studies [36, 38, 39], and self-reported in the rest of the studies [18-20, 34, 35, 37, 40]. Sleep duration was objectively measured in 2 studies [38, 39] and either self-reported or parent-reported in the other studies [18-20, 34-37, 40].

Depressive symptoms (primary outcome)

Depressive symptoms were reported in 3 studies [18, 19, 34], representing 3 unique datasets, and 84,004 individual participants with age ranging from 6 to 20 years (Table 2). All three studies had a combined measure of meeting all 3 movement behaviour recommendations (i.e., meeting all 3 vs. none). However, only one study examined different combinations of physical activity, sedentary time, and sleep duration (i.e., meeting 3, 2, 1 vs. none) [34]. Two studies stratified their results by sex [18, 19], while the other study stratified their analysis by age group (6–11 years old vs. 12–17 years old) [34]. Both of the studies that conducted sex-specific analyses found that depressive symptoms were associated with lower odds of meeting all 3 guidelines in both male and female adolescents [18, 19]. The study that conducted age-specific analyses found that meeting all three 24-hour movement guidelines was associated with lower odds for anxiety and depression among adolescents (i.e. 12–17 years old) compared to meeting none of the recommendations [34]. Meeting all three recommendations was associated with significantly lower odds of depressive symptoms among adolescents than meeting none, one, or any combination of two recommendations among adolescents [34]. However, among children (i.e. 6–11 years old), meeting the screen time recommendation alone, both the screen time and sleep duration recommendations, or both the physical activity and sleep duration recommendations was associated with lower odds of depressive symptoms than meeting none or all three guidelines [34].

Following the GRADE protocol, the quality of evidence for the three studies examining the association between the 24-hour movement guidelines and depressive symptoms began with a low-quality rating due to their observational design. Given that only one study used an objective

measure of physical activity and a reliable and valid measure of depression in children [19], the quality of evidence was downgraded from “low” to “very low” due to a serious risk of bias.

Other mental health indicators (secondary indicators)

A total of 10 studies examined the association between the 24-hour movement guidelines and other mental health indicators, including 1 on anxiety [34], 3 on social and emotional health [35-37], 2 on health-related quality of life [38, 39], 1 on substance use (including cigarette smoking, alcohol consumption, and cannabis use) [18], 1 on impulsivity [40], 1 on cognitive functions [20], and 1 on life satisfaction and prosocial behaviour [37] (Table 3). All studies were cross-sectional, involving 111,641 participants aged 6 to 20 years from 6 unique datasets. These studies were consistent in showing better mental health indicators in participants who met all three recommendations compared to those who met none of the recommendations. While some studies found that meeting the recommendations for MVPA, screen time, and sleep duration each had a comparable strength of association with mental health indicators [34, 37], three studies found that meeting the screen time recommendation or the screen time + sleep duration recommendations could have more benefits to mental health [20, 38, 40]. Four studies [35, 36, 38, 39] from 2 unique datasets used objective measures of physical activity and only 2 studies [38, 39] used objective measures of sedentary time and sleep duration. Therefore, the quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias (i.e., most studies used a subjective assessment of physical activity, screen time, and sleep duration with no psychometric properties reported). Only two studies [35, 37] examined and documented a positive dose-response gradient between the number of recommendations met with mental health indicators (3>2>1>0), indicating

that a greater number of recommendations met was associated with a lower risk of mental health problems. However, other studies did not examine a possible dose-response gradient.

DISCUSSION

This systematic review synthesized peer-reviewed evidence from 13 studies examining the associations between combinations of physical activity, sedentary time, and sleep duration with depressive symptoms and other mental health indicators among children and adolescents aged 5–17 years. A total of 115,540 participants from 12 countries were represented in this review. All studies were published in 2016 or later, consistent with the release of the Canadian 24-Hour Movement Guidelines in 2016 [17]. The overall quality of evidence was rated as "very low" according to the GRADE framework [33]. Collectively, the findings indicate favourable associations between meeting all 3 recommendations and better mental health indicators among children and adolescents when compared with meeting none of the recommendations. In these studies, meeting the screen time and sleep duration recommendations seemed to be more strongly associated with mental health than meeting the physical activity recommendation. However, evidence in relation to each specific mental health indicator was limited. This comprehensive assessment of available evidence highlights the need for continued efforts to promote the 24-hour movement guidelines for overall mental health benefits in children and adolescents. It also highlights the need for higher quality research using longitudinal and experimental study designs, robust measures of movement behaviours, and validated measures of mental health indicators to increase our understanding in this topic area.

To our knowledge, this is the first time the relationship between 24-hour movement guidelines and mental health indicators in children and adolescents has been systematically reviewed since the release of aforementioned guidelines in 2016 [17]. Our findings are also of importance as they address the three important research gaps areas within the context of the *Canadian 24-Hour Movement Guidelines for Children and Youth* that have been previously identified in a systematic review on the health benefits of combined movement behaviours [26]. Indeed, Saunders *et al.* [26] highlighted first that existing evidence was mainly based on physical health indicators such as obesity, urging the need for mental and social health indicators to be considered in future studies. Second, it was unclear whether meeting a given specific recommendation was associated with more health benefits than meeting the others. Third, researchers have mainly compared meeting all 3 recommendations versus meeting none, ignoring potential influence of intermediate combinations. Unfortunately, to date, only 13 studies have examined mental health indicators in the context of the 24-hour movement guidelines among children and adolescents. These findings highlight the slow growth of new research on the 24-hour movement guidelines as they relate to mental health indicators in children and adolescents. Overall, our results provide some support that meeting all 3 recommendations is associated with better mental health among children and adolescents when compared with meeting none of the recommendations. Although previous evidence has shown that physical activity may prevent depression and/or alleviate its symptoms in children and adolescents [41-43], our results indicate that meeting the screen time and sleep duration recommendations were more strongly associated with fewer depressive symptoms and positive mental health than meeting the physical activity recommendation. These findings are interesting and warrant further investigations, along with potential mechanisms linking these lifestyle behaviours and mental health.

The mechanisms explaining the association between excessive screen time and mental health problems may be direct or indirect. Direct pathways could be observed through the content watched on screens, disrupted interpersonal relationships, or through direct cognitive effects, creating low emotional stability and impulsivity [44]. Indirect pathways could be observed through certain intermediate factors, such as insufficient sleep, unhealthy eating behaviours, dissatisfaction with body mass, cyberbullying victimization, etc. [45-48]. Moreover, excessive screen time could reduce physical activity time [49], thus limiting potential benefits of physical activity on mental health. Several possible mechanisms could explain the association between short sleep duration and mental health problems among children and adolescents. First, short sleep duration negatively affects levels of neurotransmitters that regulate mood and thinking [50]. It also impairs executive functions [51], including working memory, cognitive flexibility, and inhibitory control [52, 53]. Second, short sleep duration could be associated with heightened stress reactivity, which has been associated with the activation of the hypothalamic-pituitary-adrenal and the sympatho-adrenal-medullary axes, thus increasing the risk of mental health disorders [54]. Finally, short sleep duration can make the maintenance of healthy active living more difficult due to subsequent daytime sleepiness and fatigue [55, 56]. However, the possibility of reverse causation is not excluded, as excessive screen time may be a coping strategy for individuals who are already suffering from mental health problems [44]. It is also possible that mental health problems precede short sleep duration [57], suggesting that individuals with mental health problems could be more likely to sleep less.

In the current review, we found that the majority (80%) of papers used traditional regression models to examine the associations between 24-hour movement behaviours (sleep duration, sedentary time, and physical activity) and mental health indicators in children and adolescent. However, research has indicated that movement behaviours are codependent and require analyses that are sensitive to this collinearity [15, 16, 58]. Compositional data analysis has been suggested to represent the most appropriate analytical approach for understanding the association between 24-hour movement behaviours and health indicators, because time is finite over a period of 24 hours [59]. However, in the current review, only 2 studies used compositional data analyses [36, 39]. Indeed, the use of these novel statistical analyses in the context of 24-hour movement behaviours is still in its infancy, but it is growing. Future research including the use of compositional analyses is needed to examine the association between 24-hour movement behaviours and mental health indicators among children and adolescents.

To date, evidence addressing the third research gap area identified by Saunders *et al.* [26] is still limited. Only two studies have examined and documented a dose-response gradient between the number of recommendations met and mental health outcomes [35, 37], where a greater number of recommendations met was associated with a lower risk of mental health problems. These findings suggest that added mental health benefits may be derived from achieving optimal levels of multiple movement behaviours. For example, Janssen *et al.* [37] provided evidence for a dose-response gradient between the number of movement behaviour recommendations met and mental health indicators, and found that different intermediate combinations of the recommendations had similar influence on mental health indicators while the number of recommendations met was the same.

There is a need for more studies to clarify dose-response gradients and relationships (through intervention studies) between 24-hour movement behaviours and mental health indicators.

In this review, we focused on MVPA because it is included in the 24-hour movement guidelines and it is the most common indicator that could be measured both objectively and subjectively. Although 5 articles used objective measures of physical activity, light physical activity was also included in 2 articles that used compositional data analyses. None of the 10 papers included in the present systematic review have reported on vigorous-intensity physical activity apart from MVPA. Research has shown that different intensities of physical activity could differentially impact mental health outcomes in children and adolescents [60, 61]. For example, Goldfield *et al.* [62] found a dose-response relationship between intensity of physical activity and psychological distress whereby vigorous physical activity reduces phycological distress in adolescents compared to moderate and light physical activity. Likewise, the current review focused on sedentary time, particularly total recreational screen time, and did not look at the time spent in specific types of sedentary behaviours (e.g., watching television, using social media, playing games, reading, eating, travelling in a car). Research has shown that types of sedentary behaviour differentially impact upon mental health indicators [63]. Further research that simultaneously measures specific types of sedentary behaviour and different intensities of physical activity is needed to better understand the impacts of different combinations of sedentary behaviour and movement behaviours on mental health among children and youth.

Another measurement issue that is not considered within the context of 24-hour movement guidelines relates to different aspects of sleep, such as sleep efficiency, time to fall asleep, number

of awakenings, that may be associated with mental health. Indeed, the "sleep component" of the 24-hour movement guidelines focuses on sleep duration. However, different aspects of sleep have been associated with mental health problems among adolescents [64, 65]. Future research examining the association between the 24-hour movement guidelines and mental health indicators could account for other aspects of sleep health in their analyses to provide more insights into this important relationship.

Strengths and limitations

This systematic review has several strengths. First, it uses a comprehensive electronic search process that was created by an experienced research librarian, with the inclusion of a broad range of mental health indicators, comprising emotional, psychosocial, and cognitive health. Second, the review used a rigorous methodology following the PRISMA statement for reporting systematic reviews and meta-analyses [27] and GRADE framework [33]. Finally, to our knowledge, this is the first systematic review of the evidence regarding the associations between 24-hour movement guidelines and mental health indicators in children and adolescents since the release of the guidelines in 2016 [17].

Limitations of the included studies

The included studies are limited in several ways. First, the quality of evidence assessed using GRADE was of "very low" quality, mainly because of the cross-sectional nature of all included studies, and the use of subjective measures for physical activity, recreational sedentary time, and sleep duration with no psychometric properties reported, raising concerns about possibility of risk of bias. Second, many studies have used a single item measure of mental health problems (e.g.,

depressive symptoms) which could raise validity and reliability issues. Third, the cross-sectional design of all the included studies precludes temporality and causal relationships between combinations of physical activity, screen time, and sleep duration and mental health indicators. Thus, future studies using longitudinal or experimental designs are needed to confirm cause-and-effect relationships between movement behaviours and mental health indicators among children and adolescents.

Limitations of the systematic review

There are several limitations worth mentioning. First, only articles published in English or French were included in the present study. Therefore, we did not include any studies that may have been published in other languages. Second, the present systematic review is limited by the exclusion of grey literature, which was not included in the current systematic review because of its unconventional format and lack of standard indexing [66]. Third, a meta-analysis was not possible due to heterogenous data on the measurement of physical activity, screen time, sleep duration, and mental health indicators. Future research using standardized methodology is needed to address this limitation. Finally, the strength of our conclusions is limited by the small number of included studies and lack of longitudinal and intervention studies examining the associations between 24-hour movement guidelines and mental health indicators in children and adolescents.

Future directions

Research evidence is just beginning to emerge regarding the relationships between 24-hour movement guidelines and mental health outcomes among children and adolescents, and there is a clear need for future studies to use longitudinal designs, robust measures of movement behaviours,

and validated items for mental health indicators. Further research using high-quality study designs will be required to better inform the relationships between 24-hour movement guidelines and mental health among children and adolescents. It is also important for future studies to examine potential age and sex differences to inform the design of tailored prevention efforts.

CONCLUSION

We systematically reviewed studies that looked at combinations of physical activity, sedentary time, and sleep duration with depressive symptoms and other mental health indicators among children and adolescents. Our review provides supporting evidence that adherence to the 24-hour movement guidelines for children and adolescents is associated with better mental health status. These findings underscore the need to encourage children and adolescents to meet the 24-hour movement guidelines. It is important that all stakeholders including parents, schools, caregivers, health professionals, policymakers, and children and adolescents themselves be informed about the potential benefits of adherence to the 24-hour movement guidelines. However, the available evidence is of very low quality (using the GRADE framework), as it relies heavily on cross-sectional studies using self-reported measures of physical activity, screen time, and sleep duration. Higher quality research is desired to better determine whether a dose-response gradient exists between the number of movement behaviour recommendations met and mental health to better support the 24-hour guideline paradigm.

DECLARATIONS

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

HS, IC, GSG, IJ, JW, MST, TJS, MS, and JPC participated in the conception of the article. HS and IP screened the articles. HS extracted the data and IP checked the extracted data. HS wrote the first version of the manuscript. IC, GSG, IJ, JW, IP, MST, TJS, MS, and JPC provided comments related to the presentation of the findings and critically reviewed the manuscript. All authors read and approved the final manuscript.

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Table 1. Characteristics of included studies.

Authors and Study design	Year	Location	Age range (years)	N and statistical analysis	PA measure	SED measure	Sleep measure	Mental health outcome	Main Findings
Carson *et al.* [35] Cross-sectional	2017	Canada	6–17	4,157 (1239 fasting subsample) Linear regression	Accelerometer (Actical, Respironics) MVPA	Questionnaire (Parents/guardians for those aged 6 to 11 years and self-reported by participants aged 12 to 17 years). Screen time	Questionnaire (Parents/guardians for those aged 6 to 11 years and self-reported by participants aged 12 to 17 years). Estimated sleep duration in a 24-hour period.	Social and emotional health (Behavioral strengths and difficulties scores)	There was a dose–response pattern between the number of recommendations achieved and social and emotional health. Compared to meeting all three recommendations, meeting none, one, and two recommendations were associated with a higher behavioral strengths and difficulties score in a gradient pattern. Unstandardized beta coefficients and their 95% confidence intervals in parenthesis for meeting 3>2>1>0 recommendations were: 0 (reference group), 0.12 (0.01, 0.24), 0.23 (0.10, 0.37), and 0.34 (0.18, 0.50).
Carson *et al.* [36] Cross-sectional	2016	Canada	6-17	4,169 Compositional data analysis	Accelerometer (Actical, Respironics) LPA and MVPA	Accelerometer (Actical, Respironics) Sedentary time	Questionnaire (Parents/guardians for those aged 6 to 11 years and self-reported by participants aged 12 to 17 years).	Social and emotional health (Behavioral strengths and difficulties scores)	The composition of movement behaviours was found to be associated with all health indicators. LPA was positively associated with unfavourable behavioural strengths and difficulties scores, whereas sleep was negatively associated with unfavourable behavioural strengths and difficulties scores.

Authors and Study design	Year	Location	Age range (years)	N and statistical analysis	PA measure	SED measure	Sleep measure	Mental health outcome	Main Findings
							Estimated sleep duration in a 24-hour period.		
Dumuid *et al.* [39] Cross-sectional	2018	Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and United States	9-11	5,855 Compositional data analysis	Accelerometer (Actigraph GT3X+) LPA and MVPA	Accelerometry (Actigraph GT3X+) Sedentary time	Accelerometry (Actigraph GT3X+) Nocturnal sleep duration	Health-related quality of life (KIDSCREEN-10)	The relationship between children's health-related quality of life and their movement behaviors is moderated by their country's human development index. In the very high human development index strata alone, health related quality of life was significantly related to the movement behavior composition, with moderate-to-vigorous physical activity (relative to remaining behaviors) being positively associated with health-related quality of life.
Guerrero *et al.* [40] Cross-sectional	2019	United States	9-10	4,524 Structural equation modelling	Questionnaire MVPA	Questionnaire Daily average recreational screen time	Questionnaire (Reported by parents using the Parent Sleep Disturbance Scale for Children) Sleep duration on most night	Impulsivity (UPPS-P Impulsive Behavior Scale, Behavioral Inhibition System (BIS)/ Behavioral Activation System (BAS) Scale, and cash choice delay discounting task)	Adherence to individual movement behavior recommendations as well as combinations of adherence to movement behavior recommendations were associated with each dimension of impulsivity

Authors and Study design	Year	Location	Age range (years)	N and statistical analysis	PA measure	SED measure	Sleep measure	Mental health outcome	Main Findings
Janssen *et al.* [37] Cross-sectional	2017	Canada	10-17	17,000 Linear regression	Questionnaire MVPA	Questionnaire Average daily screen time	Questionnaire Average nightly sleep duration	Emotional problems, Life satisfaction (Cantril ladder), Prosocial behaviour	Achieving any given recommendation had preferable scores for the health outcomes compared with participants who did not meet the recommendations. There was a dose–response pattern between the number of recommendations achieved and the health outcomes. The adjusted mean and standard errors in parenthesis for meeting 3>2>1>0 recommendations were: 0.72 (0.04), 0.48 (0.03), 0.30 (0.04) and 0.08 (0.07) for emotional problems, −0.82 (0.05), −0.62 (0.05), −0.43 (0.05) and −0.29 (0.09) for life satisfaction, and −0.37 (0.05), −0.20 (0.05), −0.02 (0.06) and 0.11 (0.09) for emotional problems. When the number of recommendations achieved was the same, there were no differences in the health outcomes.
Knell *et al.* [18] Cross-sectional	2019	United States	13-20	59,397 Logistic regression	Questionnaire MVPA	Questionnaire Average daily screen time	Questionnaire Average nightly sleep duration	Depressive symptoms (2-week sadness), cigarette smoking, alcohol consumption, and cannabis use over the past 30 days	Meeting all 3 recommendations was associated with lower odds of depressive symptoms among males and females, alcohol consumption among females, and cannabis use among males compared to meeting none of the recommendations. Meeting the 3

Authors and Study design	Year	Location	Age range (years)	N and statistical analysis	PA measure	SED measure	Sleep measure	Mental health outcome	Main Findings
									guidelines was associated with greater odds of smoking cigarette among males compared with meeting none of the recommendations.
Pearson *et al.* [19] Cross-sectional	2019	United Kingdom	14	3,899 Logistic regression	Accelerometer (GENEActiv) MVPA	Questionnaire Screen time on typical weekday	Questionnaire Average nightly sleep duration	Depressive symptoms (Mood and Feelings questionnaire (MFQ))	Meeting all 3 recommendations was associated with lower odds of depressive symptoms among both males and females compared with meeting none of the recommendations.
Sampasa-Kanyinga *et al.* [38] Cross-sectional	2017	Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and United States	9-11	6,106 Linear mixed models	Accelerometer (Actigraph GT3X+) LPA (not included in statistical analyses) and MVPA	Accelerometry (Actigraph GT3X+) Sedentary time	Accelerometry (Actigraph GT3X+) Nocturnal sleep duration	Health-related quality of life (KIDSCREEN-10)	Children meeting the screen time recommendation, the screen time and sleep recommendation, and all three recommendations had significantly better HRQoL than children not meeting any of these guidelines.
Walsh *et al.* [20] Cross-sectional	2018	United States	9-10	4,524 Linear mixed effects models	Questionnaire MVPA	Questionnaire Daily average recreational screen time	Questionnaire (Reported by parents using the Parent Sleep Disturbance Scale for Children)	Global cognition (Youth NIH Toolbox)	There was a positive gradient between global cognition and each additional recommendation met. Meeting the screen + sleep or screen-only recommendations were the strongest predictors of superior cognition

Authors and Study design	Year	Location	Age range (years)	N and statistical analysis	PA measure	SED measure	Sleep measure	Mental health outcome	Main Findings
							Sleep duration on most night		compared to not meeting any recommendations.
Zhu *et al.* [34] Cross-sectional	2019	United States	6-17	20,708 Logistic regression	Questionnaire All intensities	Questionnaire Daily average recreational screen time	Questionnaire Average weeknight sleep duration	Anxiety and depression (parent- reports)	Meeting all three 24-hour movement guidelines was associated with lower odds for anxiety and depression among adolescents compared with meeting none of the recommendations.

PA: physical activity; SED: sedentary time; MVPA: moderate-to-vigorous physical activity; LPA: light-intensity physical activity.

Table 2. Combinations of physical activity, sedentary time, and sleep duration and their relationships with depressive symptoms.

No of studies	Design	Quality assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
3	Cross-sectional study[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	84,004	**MEETING ALL 3 RECOMMENDATIONS** [18, 19, 34] 3/3 studies found that meeting all 3 recommendations (compared with meeting none) was associated with lower odds of depressive symptoms among male and female adolescents [18, 19] but not children [34]. **DIFFERENT COMBINATIONS OF PHYSICAL ACTIVITY + SEDENTARY BEHAVIOUR + SLEEP** [34] 1/1 study found that meeting all three recommendations was associated with significantly lower odds of depression among adolescents compared with meeting none, one, or any combinations of two recommendations among adolescents. However, among children, meeting the screen time recommendation alone, both the screen time and sleep duration recommendation, or both the physical activity and sleep duration recommendations was associated with lower odds of depression than meeting none or all three guidelines.	VERY LOW

Note: Age ranged between 6 and 20 years, and all data collection was cross-sectional.

[a]Includes 3 cross-sectional studies [18, 19, 34].

[b]All studies used a subjective assessment of movement behaviours with no psychometric properties reported, except one study that measured physical activity by accelerometer [19]. Depression was measured differently across studies, with only one study that used a validated instrument [19]; one study [18] used an item that asked students if they felt sad or hopeless almost every day for two weeks or more in a row in the past year; another study [19] used the Mood and Feelings questionnaire (MFQ), a reliable and valid measure of depression in children, and another study [34] used parents' response ("currently have condition") to the question asking if they had ever been told by a health care professional that the child had the condition, and whether the child currently has depression. Therefore, the quality of evidence was downgraded from "low" to "very low" due to a serious risk of bias.

Table 3. Combinations of physical activity, sedentary time, and sleep duration and their relationships with other mental health indicators.

No of studies	Design	Quality assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
10	Cross-sectional study[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	111,641	**MEETING ALL 3 RECOMMENDATIONS** [18, 20, 34-40] 10/10 studies found that meeting all 3 recommendations was associated with lower odds of mental outcomes among children and adolescents compared with meeting none. **Anxiety** [34] Among children, meeting all three guidelines was associated with lower odds of anxiety compared to meeting the physical activity, and the screen time recommendations. Among adolescents, meeting all three guidelines was associated with lower odds of anxiety compared to meeting none of the recommendations. **Social and emotional health** [35-37] 3/3 studies found that participants achieving all 3 recommendations had preferable scores for the health outcomes compared with participants who did not meet the recommendations. **Health-related quality of life** [38, 39] 1/2 study found that the relationship between children's health-related quality of life and their	VERY LOW

No of studies	Design	Quality assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
								movement behaviors is moderated by their country's human development index [38]. 1/2 study found that meeting all three recommendations was associated with significantly better HRQoL than not meeting any of these guidelines [39]. **Substance use**[c] [18] 1/1 study found that compared with meeting none of the recommendations, meeting all 3 recommendations was associated with lower odds of alcohol consumption among females, and cannabis use among males. Meeting all 3 recommendations was also associated with greater odds of smoking cigarette among males. **Impulsivity** [40] 1/1 study found that meeting all 3 recommendations was associated with better impulsivity scores compared with meeting none. **Cognitive functions** [20] 1/1 study found that meeting all three recommendations was associated with superior global cognition compared with meeting none.	

No of studies	Design	Quality assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
								Life satisfaction and prosocial behaviour [37]. 1/1 study found that participants achieving all 3 recommendations had preferable scores for the health outcomes compared with participants who did not meet the recommendations. **DIFFERENT COMBINATIONS OF PHYSICAL ACTIVITY + SEDENTARY TIME + SLEEP** 9/10 studies assessed different combinations between movement recommendations and mental health outcomes [20, 34-40]. 3/10 studies found that meeting the screen time recommendation alone, and both the screen time and sleep duration recommendations, were consistently associated with better cognitive functions, impulsivity scores and HRQoL [20, 38, 40]. 2/10 studies found a dose-response relationship between the number of recommendations met and mental health outcomes [35, 37]. 2/10 studies used compositional data analyses and found that the composition of movement behaviours was associated with social and	

No of studies	Design	Quality assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
								emotional health [36] and with HRQoL [39]; whereas 8/10 used traditional methods [18-20, 34, 35, 37, 38, 40].	

HRQoL: health-related quality of life.

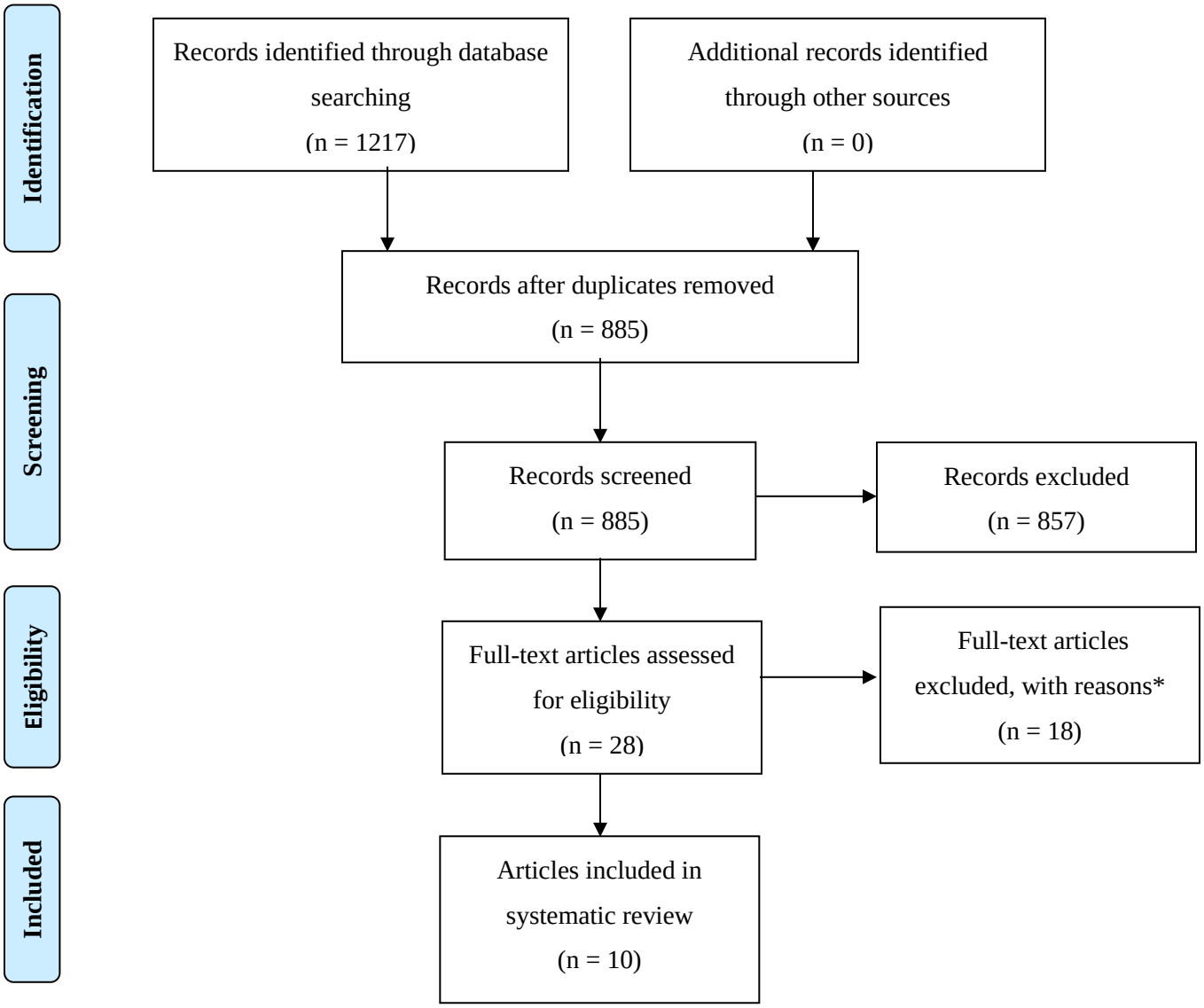
Note: Age ranged between 6 and 20 years, and all data collection was cross-sectional.

[a]Includes 10 cross-sectional studies [18, 20, 34-40].

[b]Four studies [35, 36, 38, 39] from 2 unique datasets used objective measures of physical activity and only 2 studies [38, 39] used objective measures of sedentary time and sleep duration. Therefore, the quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias (i.e., most studies used a subjective assessment of physical activity, screen time, and sleep duration with no psychometric properties reported).

[c]Including cigarette smoking, alcohol consumption, and cannabis use.

Figure 1. PRISMA flow diagram for the identification, screening, eligibility, and inclusion of studies



*Reasons for excluding articles were: not reporting a combination of physical activity, sedentary time, and sleep duration ($n = 10$), no measure of mental health indicators ($n = 6$), and ineligible age ($n = 2$).

Chapter 3

24-hour movement behaviours and emotional and behavioural problems among children

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documents, including additional analyses results and ethical approval are included in appendices at the end of this chapter.

Online link: https://pubmed.ncbi.nlm.nih.gov/33069581/

Article preface: The objective of this study was to examine the association of meeting different combinations of the 24-hour movement guidelines with internalizing and externalizing behaviours among children. This study tested the hypothesis that meeting the 24-hour movement guidelines would result in a lower risk of having high internalizing and externalizing behaviour scores.

Contribution statement: I am the first author on this article. I was responsible for generating the study objectives and design, with guidance from my supervisor and co-authors. I conducted the necessary statistical analyses, created all of the tables and figures, wrote the first draft of the manuscript, submitted the final version for publication, and addressed reviewer comments.

ABSTRACT

Purpose: The Canadian 24-Hour Movement Guidelines for Children and Youth (≥60 minutes of moderate-to-vigorous physical activity per day, ≤2 hours of recreational screen time per day, and 9-11 hours of sleep per night for 5-13 years old) are associated with better physical health, but less is known about how these behaviours are related to mental health. This study examined the association of meeting these guideline recommendations with internalizing and externalizing behaviours among children.

Methods: A large and broadly representative cross-sectional sample of 9- to 11-year-old U.S. children (N = 11,875) from the Adolescent Brain and Cognitive Development (ABCD) study was analyzed. Internalizing and externalizing behaviours were measured using the Child Behaviour Check List (CBCL). Associations were examined using negative binomial regression adjusted for several confounders.

Results: Compared to meeting none of the recommendations, meeting recommendations for screen time and sleep but not physical activity was associated with a lower prevalence ratio of total, internalizing, and externalizing behaviours. Meeting two or all three recommendations was more strongly associated with these outcomes than meeting one recommendation or none. The prevalence ratio (PR) of the group meeting all three recommendations was 0.77 (95% CI: 0.68-−0.86) for total problem scores, 0.78 (95% CI: 0.68−0.89) for internalizing problem scores, and 0.79 (95% CI: 0.68-0.91) for externalizing problem scores.

Conclusion: Meeting the 24-hour movement guidelines was associated with a lower risk of internalizing and externalizing behaviours in children. These associations were mainly explained by meeting the screen time and sleep duration recommendations.

Key words: physical activity; sedentary behaviour; sleep; internalizing behaviour; externalizing behaviour; epidemiology.

IMPLICATIONS AND CONTRIBUTION

This study found that children aged 9 to 11 years who met the 24-hour movement guidelines have less total problem behaviours as well as internalizing and externalizing problems. These associations were mainly driven by meeting the screen time and sleep duration recommendations.

INTRODUCTION

Mental health problems in children and youth are common. Nearly 10 to 20% of children and youth globally experience mental disorders [1]. Common symptoms of mental disorders tend to lie on two dimensions: internalizing (e.g., depression, anxiety, somatic complaints) and externalizing (e.g., aggression, delinquency). Thus, children can reveal their mental health problems on an emotional level or behaviourally [2]. Children's internalizing and externalizing behaviours have negative impacts on themselves, their family and society in the short- and long-term [3, 4]. Identifying modifiable factors associated with children's internalizing and externalizing behaviours could provide evidence that would inform intervention programs intended to enhance children's mental health.

Physical inactivity is associated with an increased likelihood of having several internalizing and externalizing behaviours [5] and the benefits of regular physical activity on children mental health are well known [6]. Physical activity enhances well-being, improves mood and can boost general self-esteem via improvements in skills and competence, body image, and physical fitness [7]. Physical activity is also associated with enhanced cognitive functioning, especially for tasks involving more complex executive functioning [8]. Importantly, physical activity is a potential therapy for internalizing and externalizing behaviours among children [9].

With rapid progress in information and communication technology, use of digital media has become ubiquitous in the everyday life of most children. Excessive screen time is associated with greater internalizing and externalizing behaviours [10]. Several possible mechanisms could

explain the association between screen time and problem behaviours among children. Screen time may adversely impact mental health through the content watched on screens, disrupted interpersonal relationships, or through more direct cognitive effects, creating low emotional stability and low self-control [11]. Moreover, the mechanisms by which excessive screen time may affect mental health may be indirect [11], via intermediate factors, such as displacing physical activity or sleep, unhealthy eating behaviour, dissatisfaction with body mass, and/or cyberbullying victimization [12-14]. Alternatively, excessive screen time may be a coping strategy for individuals who are already suffering from internalizing and externalizing behaviours [11].

Short sleep duration is increasingly widespread among children [15], and it could increase the risk of developing symptoms of internalizing and externalizing behaviours [10]. Short sleep duration affects brain activity and neurochemicals that regulate mood and cognitive function [16]. It impairs executive functions [17], such as inhibitory control and cognitive flexibility, that could result in increased irritability, impulsivity, anger and aggression [18, 19]. Short sleep duration can also make the maintenance of a healthy lifestyle (e.g., physical activity) more difficult because of subsequent daytime sleepiness, fatigue, and tiredness [20, 21]. Lastly, insufficient sleep duration could be associated with heightened stress reactivity within the hypothalamic-pituitary-adrenal axis, increasing the risk of psychopathological disorders [22].

However, previous research studies examining the associations of physical activity, screen time, and sleep duration with mental health indicators have considered these behaviours separately from each other, ignoring their codependence [23, 24]. This is concerning because these movement behaviours interact to influence health and should therefore be considered simultaneously. This

has motivated the development and promotion of the *Canadian 24-Hour Movement Guidelines for Children and Youth,* which are integrated recommendations intended to provide parents, caregivers, health professionals, and policymakers guidance on the quality and quantity of physical activity, sedentary behaviour, and sleep children need in a 24-hour period to achieve health benefits. These guidelines were released in 2016 and they recommend at least 60 minutes of moderate-to-vigorous physical activity per day, 2 hours or less of recreational screen time per day, and 9-11 hours of sleep per night for 5- to 13-year-olds and 8-10 hours per night for 14- to 17-year-olds [25]. The development of these guidelines followed a comprehensive, rigorous, and transparent process. It was informed by 4 systematic reviews and included consultation findings, compositional analysis findings, experts, different stakeholders, and end-users [25].

Research has shown that children who meet the 24-hour movement guidelines have better cognitive function [26], less impulsivity [27], better quality of life [28], improved emotional and psychosocial health [29], less depressive and anxiety symptoms [30], and better dietary patterns [31]. However, little is known about the association of different combinations of movement behaviour recommendations with internalizing and externalizing behaviours (as a more global measure rather than a single mental health indicator) in children. In a sample of over 500 Canadian children aged 3 years (i.e. preschoolers), Carson *et al.* [32] found that children who met more recommendations had lower internalizing and externalizing behaviours as measured by the Child Behavior Checklist (CBCL). They also found that physical activity and screen time, and screen time and sleep were the specific combinations of movement recommendations associated with internalizing and externalizing behaviours [32]. However, to the best of our knowledge, no previous study has specifically examined the association between the combinations of all 3

movement behaviour recommendations and the CBCL in later childhood (i.e. schoolchildren). It is also unclear if movement behaviours are differentially associated with internalizing versus externalizing problems in this age group. Gaining such knowledge is important to inform public health interventions and policies.

The purposes of this study were to examine the association of meeting different combinations of the 24-hour movement guidelines with internalizing and externalizing behaviours among children. We hypothesized that meeting the 24-hour movement guidelines would result in a lower risk of having high internalizing and externalizing behaviour scores. The results from these cross-sectional analyses should not be interpreted as being causal, but rather informative for future hypothesis generation.

METHODS

The cross-sectional data from 11,875 children aged 9–11 years was obtained from the Adolescent Brain Cognitive Development (ABCD) Study (release 2.0; www.abcdstudy.org), a longitudinal observational study that tracks children through adolescence across domains related to brain development and health over a 10-year period [33]. It is the largest long-term study of brain development and child health in the United States. The ABCD study uses probability sampling of public and private elementary schools within the catchment areas of 21 data collection sites across the United States resulting in a nationally diverse and geographically stratified sample [33]. Across recruitment sites, inclusion criteria included being in the desired age range (9–10 years of age) and able to provide informed consent (parents) and assent (child). Exclusions were minimal and were limited to lack of English language proficiency in the children, the presence of severe

sensory, intellectual, medical or neurological issues that would impact the validity of collected data or the child's ability to comply with the protocol, and contraindications to magnetic resonance imaging scanning. The data for this analysis were collected between September 1, 2016 and November 15, 2018. Detailed information on procedures, sampling, and recruitment for the ABCD study have been described previously [33]. All parents/guardians provided written informed consent and child assent was obtained prior to participation in the study. All procedures were approved by a central institutional review board and site-level institution research ethics boards.

Dependent variables

The Child Behavior Checklist/6-18 (CBCL) was used to assess problem behaviours over the past six months [34]. The CBCL is a parent-report measure that consists of 113 questions, each scored on a three-point Likert scale (0=absent, 1=occurs sometimes, 2=occurs often), and takes 15–20 minutes to complete. Responses were summed, with higher scores representing higher levels of emotional and behavioural problems. Raw scores (vs. standardized scores) were used for our data analyses following previous recommendations [35]. The CBCL/6-18 is made up of eight syndrome scales, including anxious/depressed, withdrawn/depressed, somatic complaints, social problems, thought problems, attention problems, rule-breaking behaviour, and aggressive behaviour. Scores on the CBCL have shown high validity and reliability (α= .78 to .94), and the eight-syndrome scale has displayed strong fit indices in 30 different societies [35]. Scores for total, internalizing, and externalizing problems were calculated. Total score includes all eight syndrome scales. Internalizing score comprises the following syndrome scales: anxious/depressed, withdrawn/depressed, and somatic complaints. The externalizing score comprises the rule-breaking and aggressive behaviour syndrome scales. In these data, internalizing and externalizing

scores have shown a good reliability of 0.87 and 0.90, respectively; the total scores had an excellent reliability of 0.95.

Independent variables

Physical activity was measured using questions from the Youth Risk Behavior Survey [36]. Participants reported the number of days that they were physically active for a total of at least 60 minutes per day in the past 7 days. Recreational screen time was measured using the Youth Screen Time Survey [37], which asked participants to report the number of hours spent on a typical weekday and weekend day performing a variety of recreational screen-based activities, including: 1) TV watching, 2) video watching (e.g., YouTube™), 3) video game playing, 4) texting on cellphone, tablet, or computer, 5) visiting social media sites, or 6) using video chat. Daily recreational screen time was calculated by taking a weighted average of weekday and weekend screen time, using the following formula: [(the sum of week day screen time in minutes x 5) + (the sum of weekend day screen time in minutes x 2)] / 7. Sleep duration was measured using one item from the Parent Sleep Disturbance Scale for Children [38], which asked parents to indicate the number of hours of sleep a child gets on most nights. The midpoint of each response option was used to provide a unique value for sleep duration in hours, as follows: 9-11 hours = 10 hours; 8-9 hours = 8.5 hours; 7-8 hours = 7.5 hours; 5-7 hours = 6 hours; < 5 hours: 2.5 hours. Children who reported being physically active 7 days per week, accumulating ≤2 hours of daily recreational screen time, and sleeping 9–11 hours per night were considered to be meeting the recommendations of the 24-hour movement guidelines [25].

Covariates

Covariates included age (years), gender (girls/boys), ethnoracial background (African-American/Asian/Caucasian/Hispanic/multiracial), household income (combined income in past 12 months from all sources before taxes and deductions), parental education (measured in years), and body mass index (BMI) z-scores. BMI was calculated from measured height and body mass, and age- and sex-specific BMI z-scores were calculated using reference data from the WHO [39].

Statistical analyses

Analyses were adjusted for the cluster effect of sites using STATA 14.1 (Stata Corp., College Station, Texas, USA) using svyset command. Descriptive statistics including means, standard deviations, and proportions were used to characterize the sample. The outcome variables of total, internalizing, and externalizing problems were treated as count variables and exhibited an over-dispersion (i.e., greater variances than means). Therefore, negative binomial regression analyses were used to examine the associations of meeting different combinations of movement behaviour recommendations with the three outcomes. Prevalence ratios (PR), their 95% confidence intervals, and p-values are presented. PR is a measure of association that quantify the strength of association between a given outcome and a suspected risk factor [40]. It indicates how large is the prevalence of the outcome in a group of exposed subjects (i.e. with suspected risk factor) relative to the group of unexposed subjects (i.e. without the suspected risk factor). Covariates included age, gender, ethnicity, family income, parental education, and BMI z-scores. Given that gender×meeting movement behaviour recommendations interaction was not significant for any of the outcomes, data for both genders were pooled to maximize statistical power. Missing data were handled using complete case analyses by outcome. Information regarding missing data is described in Table 1. Statistical inferences were based on p values <0.05 and confidence intervals.

RESULTS

The descriptive characteristics of the sample are shown in Table 1. The mean age of the 11,875 participants was 9.9 ± 0.6 years. Just over half (52.1%) were boys, 52.5% were Caucasian and 17.4% were of Hispanic ethnic background. Overall, the prevalence of meeting the physical activity, screen time, and sleep duration recommendations were 16.4%, 35.1%, and 47.4%, respectively (Figure 1). Different combinations of meeting the physical activity, screen time, and sleep duration recommendations are displayed in Figure 1. Overall, only 3.9% of the participants met all three movement behaviour recommendations, while 32.2% did not meet any of the recommendations. Boys were more likely than girls to meet the physical activity recommendation alone (6.7% vs. 4.8%), sleep duration recommendation alone (24.8% vs. 20.4%), or both (5.1% vs. 3.3%).

Results from negative binomial regression analyses examining the associations of meeting different combinations of movement behaviour recommendations with total, internalizing, and externalizing problems are summarized in Tables 2 to 4. Compared to children who met none of the recommendations, meeting any single movement behaviour recommendation or any combination of movement behaviour recommendations was associated with a lower risk of total problems, except for physical activity alone (PR: 1.06; 95% CI: 0.99 – 1.15). Meeting the sleep duration recommendation alone or any combination of movement behaviour recommendations was also associated with a lower risk of internalizing problems relative to children who met none of the recommendations. Meeting the screen time recommendation (PR: 0.85; 95% CI: 0.77 − 0.94), the sleep duration recommendation (PR: 0.86; 95% CI: 0.80 − 0.93), the screen time + sleep

duration recommendation (PR: 0.74; 95% CI: 0.67 − 0.81), and all 3 recommendations (PR: 0.79; 95% CI: 0.68 − 0.91) were associated with a lower risk of externalizing problems. In contrast, children who met the physical activity recommendation had a greater risk of externalizing problems than those who met none of the recommendations (PR: 1.18; 95% CI: 1.08 – 1.30). Meeting the physical activity + screen time (PR: 0.90; 95% CI: 0.78 − 1.04) or screen time + sleep duration (PR: 0.91; 95% CI: 0.78 – 1.07) recommendations were not significantly associated with externalizing behaviours. The multivariable associations between meeting different combinations of movement behaviour recommendations and each syndrome scales are outlined in Supplemental Table 1.

The associations of number of movement behaviour recommendations met with total, internalizing, and externalizing problems are summarized in Supplemental Table 2. There was a dose-response gradient from meeting none of the recommendations up to two recommendations, but not from two to three recommendations. Meeting all three recommendations had comparable strength of associations to meeting two recommendations for all three outcomes.

Given that 8.6% were dropped due to missing data on family income, a sensitivity analysis (where family income was removed from the multivariable models) was conducted and showed similar results (data not shown). Similarly, sensitivity analyses using multiple imputations provided similar results (data not shown).

DISCUSSION

This study examined the association between meeting different combinations of the 24-hour movement guideline recommendations and problem behaviours among children and tested if gender was a moderator of the associations. Our results showed that, compared to meeting no recommendations, meeting all 3 recommendations was associated with a lower risk of total, internalizing, and externalizing problems in a large and broadly representative sample of U.S. children, and these associations were mainly explained by meeting the screen time and sleep duration recommendations. Although boys were more likely than girls to meet the physical activity and sleep duration recommendations, the gender×movement behaviour recommendation interactions were not significant, suggesting that the association of meeting the movement behaviour combinations with internalizing and externalizing behaviours in children did not differ by gender.

Our results are consistent with previous studies that found that meeting all 3 movement behaviour recommendations is associated with lower emotional problems in children and adolescents, such as depressive and anxiety symptoms [30]. Similarly, in a large nationally representative sample of over 17 000 Canadians aged 10–17 years from the 2013/2014 cycle of the Health Behaviour in School-aged Children study (HBSC), Janssen *et al.* [29] found that meeting all 3 recommendations was associated with lower odds of emotional problems. However, children can manifest their mental health problems on an emotional level or in a more behavioural manner [2]. To our knowledge, we are the first to show that meeting all three movement behaviour recommendations is associated with a lower risk of behavioural problems, including rule-breaking behaviour and

aggressive behaviour, before and after adjusting for multiple confounders in a large and representative sample of children.

Contrary to Janssen *et al.* [29] who found a monotonic dose–response pattern between the number of recommendations achieved and emotional problems, indicating that the health outcome improved as more recommendations were achieved, our study identify a dose-response gradient from meeting none of the recommendation up to meeting two recommendations, but not from two to three recommendations. It is possible that differences in sample characteristics and outcome measures explain, at least in part, the discrepant findings. Indeed, our sample was comprised of children aged 9 to 10 years, whereas the HBSC data used by Janssen *et al.* [29] encompassed students aged 10 to 17 years. There are important variations between emotional/behavioural problems by age groups [41]. For example, the prevalence of depression is very low among prepubescent children (less than 1%), and then increases significantly throughout adolescence [42]. It is also possible that differences in the measures of movement behaviour explain these discrepancies. For example, Janssen *et al.* [29] added together the amount of MVPA participants did in their class time at school, in their free time (including organized sports and programs and active play), and time spent in active transportation. However, the ABCD has a particularly weak measure of physical activity using a single item measure. Moreover, emotional health in our study was measured using the CBCL [34], a well validated parent-reported measure. However, in the HBSC study, emotional health was measured using a 9-item self-report measure, which was constructed based on underlying theory and on factor and reliability analyses [2].

Our results further indicated that the significant associations between meeting all three recommendations and a lower risk of internalizing and externalizing behaviours were mainly driven by meeting the screen time and sleep duration recommendations. These findings are somewhat consistent with those from previous studies suggesting that meeting the physical activity recommendation is not as important as meeting the screen time and the sleep duration recommendations regarding mental health outcomes in the ABCD dataset. Indeed, Walsh *et al.* [26] found that meeting the screen + sleep or screen-only recommendations were the strongest predictors of superior cognition compared to not meeting any recommendations. Similarly, Guerrero *et al.* [27] found that children who met the sleep and screen time recommendations scored more favourably on all 8 dimensions of impulsivity than children who did not meet any recommendation. They also found that meeting the sleep duration + screen time recommendations had the strongest association with the impulsivity dimensions [27]. It is possible that the poor measure of physical activity (i.e., single item measure) in the ABCD explains, at least in part, the lack of association between physical activity and emotional and behavioural problems. However, in a sample of Canadian adolescents, Patte *et al.* [43] found no prospective association between meeting the physical activity recommendation and depressive symptoms. Future studies using objective measures of physical activity are needed to replicate these findings. Although meeting the physical activity recommendation was not associated with a lower risk of emotional and behavioural problems, active living should not be neglected due to its proven multiple health benefits in children and youth [6]. Research has further indicated that physical activity is a good treatment option for emotional problems, such as depression and anxiety [9].

We found a somewhat counterintuitive finding of the association between meeting the physical activity recommendation and higher externalizing behaviour. It is possible that reverse causation explains these results. We cannot rule out this alternative given the cross-sectional nature of our study. These findings could also be partly due to measurement issue (i.e. single item measure of physical activity), but also children with behavioural disorders are more likely to be hyperactive (e.g. attention deficit hyperactivity disorder (ADHD)) and tend to act out more [41]. Children with behavioural disorders may be more attracted to physical activity, or their parents encourage physical activity as a means to dealing with behavioural issues. Indeed, physical activity has been identified as an effective means to manage ADHD symptoms and behavioural disorders [44, 45]. So in this context, the findings are not completely unexpected. As such, physical activity could constitute a result of people with externalizing symptoms. Longitudinal studies are therefore needed to confirm temporality between meeting the physical activity recommendation and higher externalizing behaviour among children.

Strengths and limitations

Strengths of this study include the use of a large and broadly representative sample of U.S. children, and the use of generalized linear models (negative binomial models) which are more appropriate for overdispersed response variables than general linear models. The present study is the first to examine the association between the combination of movement guidelines and internalizing and externalizing behaviour measured by CBCL in school aged children. Whereas, a previous study has examined these associations in preschoolers [32]. Other studies have focused on specific aspects of internalizing problems in adolescents, such as emotional health, anxiety and depressive symptoms, and suicidality among adolescents [29, 30, 46-48].

Our analyses adjusted for important covariates, which strengthen the validity of our findings. Nevertheless, this study had several limitations worth mentioning. First, the cross-sectional nature of the analyses precludes confirmation of causality between meeting the 24-hour movement guidelines and problem behaviours. Second, the data were self- (or parent-) reported and may be subject to recall and social desirability biases. However, the CBCL is a well validated tool [34] and single-item measures of sleep duration have been indicated to provide a reliable and valid assessment of sleep duration among children and adolescents [49]. Self-reported questions of physical activity and screen time tend to be modestly reliable and valid in children [50], suggesting that a fair amount of misclassification could still occur. Thus, the measure of effects reported in this study are likely underestimated (and to different extents for different movement behaviours). Third, the present study did not examine other characteristics of movement behaviour, such as type, intensity, and context of physical activity, type of screen use, and quality of sleep. The study did also not assess intermittent patterns of activity, multitasking or overlap in movement behaviours. Future research could account for these factors in the context of meeting the 24-hour movement guidelines and internalizing and externalizing behaviours. Finally, although our analyses adjusted for potential confounders, there is possibility of residual confounding by unmeasured variables.

CONCLUSION

This study shows that meeting the 24-hour movement guidelines was associated with a lower risk of total problem behaviours as well as internalizing and externalizing problems. These associations were mainly explained by meeting the screen time and sleep duration recommendations. These

findings can help to inform the development of early intervention efforts directed towards the improvement of the emotional and behavioural health of children. Increased awareness is needed among all stakeholders, including parents, caregivers, health professionals, policymakers, and children themselves on the benefits of meeting the 24-hour movement guidelines. Future research using experimental and longitudinal designs are needed to verify the relationships among 24-hour movement behaviours and internalizing and externalizing behaviours among children.

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Table 1. Descriptive characteristics of the sample.

Characteristics	**Sample N=11,875**	**Missing data (% of overall sample)**
	Mean (SD)[1]	**n (%)**
Socio-demographics and body mass		
Age (years)	9.9 (0.6)	0
[Min: 9.0, Max: 10.9]		
Gender, n (%)		6 (<1)
Girls	5,681 (47.9)	
Boys	6,188 (52.1)	
Ethnicity, n (%)		120 (1.0)
Caucasian	1,779 (52.5)	
African American	255 (15.1)	
Asian	6,176 (2.2)	
Hispanic	2,047 (17.4)	
Multiracial	1,498 (12.7)	
Parental education, years	16.6 (2.8)	20 (<1)
[Min: 1, Max: 21]		
Family income[2]	7.2 (2.4)	1,018 (8.6)
[Min: 1, Max: 10]		
BMI z-scores	0.7 (1.5)	46 (<1)
[Min: -14.1, Max: 7.5]		
Outcomes (CBCL)		
Total problems	18.2 (18.0)	0
[Min: 0, Max: 139]		
Internalizing problems	5.0 (5.5)	0
[Min: 0, Max: 51]		
Externalizing problems	4.2 (5.5)	0
[Min: 0, Max: 47]		
Exposures (movement behaviours)		
Meet the physical activity recommendation, n (%)		31 (<1)
No	9,896 (83.6)	
Yes	1,948 (16.4)	
Meet the screen time recommendation, n (%)		29 (<1)
No	7,684 (64.9)	
Yes	4,162 (35.1)	
Meet the sleep duration recommendation, n (%)		6 (<1)
No	6,241 (52.6)	
Yes	5,628 (47.4)	

SD = standard deviation. Data are shown as Mean (SD) unless otherwise specified.

[2]Combined income in past 12 months from all sources before taxes and deductions on a scale of 1=<US$5000; 2=$5000−11 199; 3=$12 000−15 999; 4=$16 000−24 999; 5=$25 000−34 999; 6=$35 000−49 999; 7=$50 000−74 999; 8=$75 000−99 999; 9=$100 000−199 999; and 10=≥$200 000.

Table 2. Association between meeting different combinations of movement behaviour recommendations and total problems.

	Univariable			Multivariable		
	PR	**95% CI**	***p***	**PR**	**95% CI**	***p***
24-hour movement guideline combinations (reference = meeting none)						
Only physical activity	1.04	0.96 − 1.12	0.334	1.06	0.99 − 1.15	0.108
Only screen time	0.81	0.74 − 0.89	<0.001	0.89	0.82 − 0.97	0.011
Only sleep duration	0.81	0.75 − 0.87	<0.001	0.86	0.81 − 0.92	<0.001
Physical activity + screen time	0.80	0.71 − 0.90	0.001	0.86	0.77 − 0.96	0.009
Physical activity + sleep duration	0.83	0.72 − 0.95	0.009	0.85	0.76 − 0.96	0.012
Screen time + sleep duration	0.68	0.63 − 0.72	<0.001	0.76	0.71 − 0.82	<0.001
Physical activity + screen time + sleep duration	0.70	0.61 − 0.80	<0.001	0.77	0.68 − 0.86	<0.001
Covariates						
Age	0.97	0.93 − 1.02	0.275	0.95	0.91 − 1.00	0.034
Gender (reference = girls)	1.24	1.19 − 1.29	<0.001	1.21	1.16 − 1.27	<0.001
Ethnicity (reference = Caucasian)						
African American	1.09	0.96 − 1.24	0.179	0.83	0.74 − 0.92	0.002
Asian	0.67	0.54 − 0.83	0.001	0.69	0.58 − 0.84	0.001
Hispanic	1.03	0.91 − 1.17	0.595	0.86	0.77 − 0.96	0.011
Multiracial	1.18	1.08 − 1.29	0.001	1.03	0.96 − 1.11	0.394
Family income	0.94	0.92 − 0.95	<0.001	0.94	0.92 − 0.95	<0.001
Parental education	0.96	0.95 − 0.98	0.001	1.00	0.99 − 1.01	0.817
BMI Z-scores	1.04	1.02 − 1.06	<0.001	1.02	1.00[a] − 1.03	0.041

PR: prevalence ratio; CI: confidence interval; BMI: body mass index.

Table 3. Association between meeting different combinations of movement behaviour recommendations and internalizing problems.

	Univariable			Multivariable		
	PR	**95% CI**	***p***	**PR**	**95% CI**	***p***
24-hour movement guideline combinations (reference = meeting none)						
Only physical activity	0.97	0.90 − 1.06	0.499	1.00	0.91 − 1.09	0.956
Only screen time	0.93	0.86 − 1.02	0.105	0.96	0.88 − 1.06	0.414
Only sleep duration	0.85	0.79 − 0.91	<0.001	0.87	0.81 − 0.93	<0.001
Physical activity + screen time	0.83	0.72 − 0.96	0.013	0.82	0.71 − 0.96	0.013
Physical activity + sleep duration	0.82	0.70 − 0.95	0.012	0.82	0.72 − 0.94	0.007
Screen time + sleep duration	0.80	0.75 − 0.85	<0.001	0.83	0.77 − 0.89	<0.001
Physical activity + screen time + sleep duration	0.76	0.67 − 0.87	<0.001	0.78	0.68 − 0.89	0.001
Covariates						
Age	1.02	0.97 − 1.07	0.433	1.01	0.96 − 1.05	0.728
Gender (reference = girls)	1.01	0.98 − 1.05	0.423	1.00	0.96 − 1.04	0.902
Ethnicity (reference = Caucasian)						
African American	0.88	0.78 − 1.00	0.044	0.69	0.62 − 0.77	<0.001
Asian	0.75	0.58 − 0.96	0.024	0.70	0.56 − 0.87	0.002
Hispanic	1.04	0.93 − 1.17	0.469	0.88	0.79 − 0.99	0.029
Multiracial	1.11	1.03 − 1.21	0.012	1.00	0.94 − 1.07	0.987
Family income	0.96	0.94 − 0.97	<0.001	0.94	0.93 − 0.95	<0.001
Parental education	0.98	0.97 − 0.99	0.002	1.01	1.00[a] − 1.02	0.033
BMI Z-scores	1.03	1.01 − 1.05	0.011	1.02	0.99 − 1.04	0.151

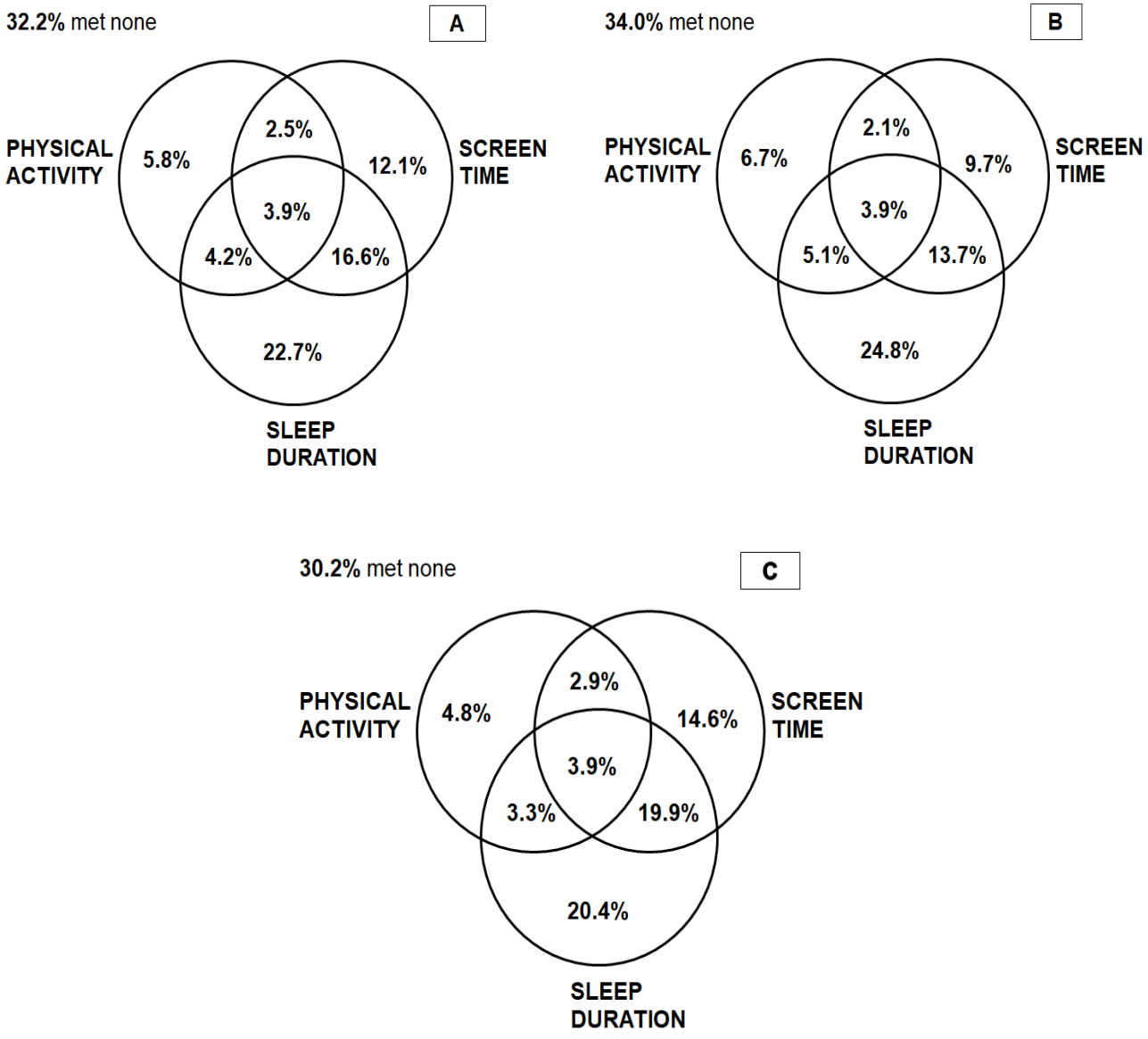
PR: prevalence ratio; CI: confidence interval; BMI: body mass index.

Table 4. Association between meeting different combinations of movement behaviour recommendations and externalizing problems.

	Univariable			Multivariable		
	PR	**95% CI**	***p***	**PR**	**95% CI**	***p***
24-hour movement guideline combinations (reference = meeting none)						
Only physical activity	1.13	1.03 − 1.24	0.010	1.18	1.08 − 1.30	0.001
Only screen time	0.73	0.65 − 0.82	<0.001	0.85	0.77 − 0.94	0.002
Only sleep duration	0.76	0.69 − 0.85	<0.001	0.86	0.80 − 0.93	0.001
Physical activity + screen time	0.78	0.67 − 0.91	0.004	0.90	0.78 − 1.04	0.153
Physical activity + sleep duration	0.84	0.70 − 1.01	0.056	0.91	0.78 − 1.07	0.233
Screen time + sleep duration	0.60	0.54 − 0.67	<0.001	0.74	0.67 − 0.81	<0.001
Physical activity + screen time + sleep duration	0.67	0.56 − 0.80	<0.001	0.79	0.68 − 0.91	0.002
Covariates						
Age	0.96	0.91 − 1.02	0.214	0.93	0.88 − 0.99	0.015
Gender (reference = girls)	1.36	1.31 − 1.42	<0.001	1.32	1.26 − 1.39	<0.001
Ethnicity (reference = Caucasian)						
African American	1.29	1.09 − 1.53	0.005	0.91	0.79 − 1.03	0.138
Asian	0.54	0.42 − 0.71	<0.001	0.64	0.49 − 0.85	0.003
Hispanic	1.04	0.90 − 1.19	0.592	0.82	0.71 − 0.93	0.004
Multiracial	1.23	1.10 − 1.38	0.001	1.03	0.94 − 1.14	0.482
Family income	0.91	0.88 − 0.94	<0.001	0.92	0.90 − 0.94	<0.001
Parental education	0.94	0.92 − 0.97	0.001	0.99	0.98 − 1.01	0.486
BMI Z-scores	1.05	1.03 − 1.08	<0.001	1.02	1.00 − 1.04	0.036

PR: prevalence ratio; CI: confidence interval; BMI: body mass index.

Figure 1. Venn diagram showing the number of children meeting no guidelines, the physical activity, screen time, and sleep duration recommendations, and various combinations of the recommendations in the total sample (Panel A, N=11,875), boys (Panel B, N=6,188), and girls (Panel C, N=5,681).



Note: p-value of difference between boys and girls was <0.001. Boys were more likely than girls to meet the physical activity and sleep duration recommendations.

Supplemental Table 1. Multivariable associations between meeting different combinations of movement behaviour recommendations and each syndrome scales.

	Univariable		
	PR	**95% CI**	***p***
INTERNALIZING PROBLEMS			
Anxious/depressed			
24-hour movement guideline combinations (reference = meeting none)			
Only physical activity	1.01	0.93 − 1.09	0.779
Only screen time	0.99	0.90 – 1.10	0.910
Only sleep duration	0.87	0.81 − 0.94	0.001
Physical activity + screen time	0.86	0.72 – 1.02	0.087
Physical activity + sleep duration	0.84	0.72 − 0.99	0.037
Screen time + sleep duration	0.87	0.79− 0.94	0.003
Physical activity + screen time + sleep duration	0.79	0.66 − 0.94	0.011
Withdrawn/depressed			
24-hour movement guideline combinations (reference = meeting none)			
Only physical activity	0.87	0.76 − 1.00	0.045
Only screen time	0.98	0.86 – 1.11	0.703
Only sleep duration	0.83	0.76 − 0.90	<0.001
Physical activity + screen time	0.73	0.56 − 0.97	0.031
Physical activity + sleep duration	0.62	0.50 − 0.78	<0.001
Screen time + sleep duration	0.76	0.71 − 0.83	<0.001
Physical activity + screen time + sleep duration	0.62	0.53 − 0.74	<0.001
Somatic complaints			
24-hour movement guideline combinations (reference = meeting none)			
Only physical activity	1.07	0.95 − 1.20	0.259
Only screen time	0.90	0.83 − 0.98	0.021
Only sleep duration	0.88	0.80 − 0.98	0.016
Physical activity + screen time	0.82	0.69 − 0.99	0.035
Physical activity + sleep duration	0.93	0.84 – 1.03	0.161
Screen time + sleep duration	0.80	0.74 − 0.87	<0.001
Physical activity + screen time + sleep duration	0.86	0.75 − 0.98	0.026

EXTERNALIZING PROBLEMS			
Rule-breaking			
24-hour movement guideline combinations (reference = meeting none)			
Only physical activity	1.19	1.06 − 1.34	0.005
Only screen time	0.77	0.71 − 0.84	<0.001
Only sleep duration	0.84	0.77 − 0.91	<0.001
Physical activity + screen time	0.86	0.68 – 1.08	0.172
Physical activity + sleep duration	0.91	0.75 – 1.11	0.342
Screen time + sleep duration	0.67	0.60 − 0.75	<0.001
Physical activity + screen time + sleep duration	0.74	0.62 − 0.88	0.002
Aggressive behaviour			
24-hour movement guideline combinations (reference = meeting none)			
Only physical activity	1.18	1.08 − 1.29	0.001
Only screen time	0.88	0.79 − 0.97	0.016
Only sleep duration	0.87	0.80 − 0.94	0.001
Physical activity + screen time	0.92	0.80 – 1.04	0.168
Physical activity + sleep duration	0.91	0.78 – 1.06	0.219
Screen time + sleep duration	0.76	0.69 − 0.84	<0.001
Physical activity + screen time + sleep duration	0.81	0.70 − 0.93	0.004

PR: prevalence ratio; CI: confidence interval

Models are adjusted for age, gender, ethnicity, family income, parental education, and BMI z-scores.

Supplemental Table 2. Multivariable associations of number of movement behaviour recommendations met with emotional and behavioural problems.

	Total problem behaviours			Internalizing behaviours			Externalizing behaviours		
	PR	**95% CI**	***p***	**PR**	**95% CI**	***p***	**PR**	**95% CI**	***p***
Number of recommendations met (reference = zero)									
One	0.90	0.85 − 0.95	0.001	0.92	0.86 − 0.97	0.007	0.91	0.85 − 0.97	0.007
Two	0.79	0.75 − 0.84	<0.001	0.83	0.78 − 0.87	<0.001	0.80	0.73 − 0.87	<0.001
Three	0.77	0.69 − 0.87	<0.001	0.78	0.68 − 0.89	0.001	0.80	0.69 − 0.92	0.003
Age	0.96	0.92 − 1.00	0.052	1.01	0.97 − 1.05	0.643	0.94	0.89 − 0.99	0.032
Gender (reference = girls)	1.22	1.16 − 1.28	<0.001	1.00	0.96 − 1.04	0.959	1.34	1.27 − 1.41	<0.001
Ethnicity (reference = Caucasian)									
African American	0.84	0.75 − 0.93	0.003	0.69	0.63 − 0.77	<0.001	0.92	0.81 − 1.05	0.224
Asian	0.69	0.57 − 0.83	<0.001	0.70	0.57 − 0.87	0.003	0.63	0.47 − 0.83	0.003
Hispanic	0.86	0.76 − 0.96	0.013	0.89	0.79 − 0.99	0.038	0.81	0.71 − 0.93	0.004
Multiracial	1.03	0.96 − 1.11	0.353	1.00	0.94 − 1.07	0.924	0.05	0.95 − 1.14	0.421
Family income	0.94	0.92 − 0.95	<0.001	0.94	0.93 − 0.95	<0.001	0.92	0.90 − 0.94	<0.001
Parental education	1.00	0.99 − 1.01	0.914	1.01	1.00 − 1.02	0.038	0.99	0.97 − 1.01	0.408
BMI Z-scores	1.02	1.00 − 1.03	0.030	1.01	0.99 − 1.04	0.150	1.02	1.00 − 1.04	0.026

PR: prevalence ratio; CI: confidence interval; BMI: body mass index.

Chapter 4

The Canadian 24-hour movement guidelines and psychological distress among adolescents

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including chapter number followed by table or figure number to avoid confusion with those in other chapters. Additional supporting documents, including a figure from confirmatory factor analysis and ethical approval are included in appendices at the end of this chapter.

Online link: https://pubmed.ncbi.nlm.nih.gov/33244994/

Article preface: The objective of this study was to examine the associations between meeting the recommendations from the 24-hour movement guidelines and psychological distress in a large and representative sample of adolescents. This study tested the hypothesis that adolescents who meet the recommendations of the 24-hour movement guidelines would have lower scores of psychological distress than those who meet some or none of the recommendations. In order to achieve the main objective, a confirmation of the factor structure of the Kessler 6-item psychological distress scale (K6) was undertaken.

Contribution statement: I am the first author on this article. I was responsible for generating the study objectives and design, with guidance from my supervisor and co-authors. I conducted the necessary statistical analyses, created all of the tables and figures, wrote the first draft of the manuscript, submitted the final version for publication, and addressed reviewer comments.

ABSTRACT

Objective: The Canadian 24-Hour Movement Guidelines for Children and Youth recommend at least 60 minutes of physical activity per day, 2 hours or less of recreational screen time per day, and 9-11 hours of sleep per night for 5-13 years old and 8-10 hours per night for 14-17 years old. This study examined the association between meeting these guidelines and psychological distress among adolescents.

Methods: The present cross-sectional sample included 6,364 students aged 11 to 20 years from the 2017 Ontario Student Drug Use and Health Survey. This provincially representative school-based survey is based on a 2-stage cluster design. A confirmatory factor analysis was first conducted to confirm the factor structure of the K6, and structural equation modelling adjusted for age, sex, ethnoracial background, subjective socioeconomic status, and body mass index z-score was used to investigate the association between meeting the 24-Hour Movement Guidelines and K6 factors among adolescents.

Results: The confirmatory factor analysis demonstrated that a two-factor model (representing anxiety and depressive symptoms) of the K6 fit the data well. The anxiety and depression items demonstrated a composite reliability (Cronbach's alpha) of 0.86 and 0.83, respectively, indicating a high level of internal consistency. Compared to meeting none of the recommendations, meeting all 3 movement behaviour recommendations was associated with lower anxiety ($\beta = -0.076$; $p=0.028$) and depressive symptoms ($\beta = -0.067$; $p=0.028$). Meeting the screen time + sleep duration recommendations had the strongest association with anxiety ($\beta = -0.157$; $p<0.001$) and depressive symptoms ($\beta = -0.139$; $p<0.001$), followed by meeting the sleep duration recommendation only for both anxiety ($\beta = -0.135$; $p<0.001$) and depressive symptoms ($\beta = -0.106$; $p<0.001$).

Conclusion: Meeting the 24-hour movement guidelines was associated with lower anxiety and depressive symptoms among adolescents, and these associations appear mainly driven by meeting the sleep duration recommendation.

Key words: physical activity; sedentary behaviour; sleep; anxiety; depression**;** adolescents; epidemiology

INTRODUCTION

Adolescent mental health problems are common, disabling, and have long-term consequences for individuals, families, and communities [1, 2]. Psychological distress is often defined as a state of emotional suffering characterized by symptoms of depression and anxiety [3]. It is a risk indicator for common major psychiatric disorders such as depression and anxiety disorders [4]. Distress is common among adolescents; for example, the proportion of adolescents with moderate to high level of psychological distress was 24% in 2013 and increased to 39% in 2017 [5]. There is a need to identify correlates of anxiety and depressive symptoms that are amenable to intervention strategies in this population.

The way school-aged children and adolescents spend their time over a 24-hour period has important mental health implications [6]. Unhealthy lifestyle behaviours, such as lack of physical activity, excessive sedentary behaviour, and short sleep duration have been individually shown to be important determinants of anxiety and depressive symptoms among children and adolescents [7-11]. However, little is known on how these behaviours may concurrently relate to mental health problems among adolescents. Indeed, the importance of an integrated approach that considers all behaviours across the movement continuum has been previously highlighted [12-14]. The *Canadian 24-Hour Movement Guidelines for Children and Youth* were released in June 2016. These Guidelines provide specific recommendations on the amount of time during a typical 24-hour day that children and youth aged 5 to 17 should spend in moderate-to-vigorous physical activity (at least 60 minutes), recreational screen time (no more than 2 hours), and sleep (9 to 11 hours for 5- to 13-year-olds; 8 to 10 hours for 14- to 17-year-olds) [13]. Because physical activity,

sedentary behaviour, and sleep duration are modifiable risk factors, there is great desire to optimize the healthy active living behaviours of children and adolescents to improve their mental health. However, it is unknown whether meeting all or some combinations of the movement behaviour recommendations is more important to the mental health of children than meeting single behaviours. This information is important to inform future interventions and public health strategies aimed at promoting adolescent mental health.

The K6 scale is commonly used as a brief continuous scale of psychological distress [15-17]. However, the two-factor structure measuring anxiety and depressive symptoms, which represent the two most common forms of psychological distress [18, 19], has not been well established at the population level of adolescents. Although anxiety and depressive symptoms are highly correlated [20, 21], establishing if these represent different constructs in our data would provide important information to guide intervention. It is also unclear if movement behaviours may be differentially associated with symptoms of depression versus anxiety.

The purpose of this study was to examine the associations between meeting the recommendations from the 24-hour movement guidelines and psychological distress in a large and representative sample of adolescents. We hypothesized that adolescents who meet the recommendations of the 24-hour movement guidelines would have lower scores of psychological distress than those who meet some or none of the recommendations. In order to achieve our main objective, we sought to confirm the factor structure of the Kessler 6-item psychological distress scale (K6), information that would also be important to inform intervention strategies of youth struggling with emotional distress.

METHODS

The Ontario Student Drug Use and Health Survey (OSDUHS) is a population survey of Ontario students in grades 7 through 12 in publicly funded schools [22]. Out of scope groups are adolescents who dropped out of school, the homeless and institutionalized youths. Conducted biennially since in 1977, OSDUHS is the longest ongoing school survey in Canada and one of the longest in the world. The purpose of the OSDUHS is to identify epidemiological trends in student drug use, mental health, physical health, gambling, bullying, and other risk behaviours, as well as to identify risk and protective factors. The survey employs a stratified (region and school type), two-stage (school, class) cluster sample design. Within each stratum, schools are selected with probability-proportional-to-size, and within selected schools, classes are selected with equal probability.

The 2017 OSDUHS was approved by the Research Ethics Boards at the Centre for Addiction and Mental Health and York University, as well as 31 school board research review committees. Student participation required the consent/permission of several entities, including school boards, school principals, classroom teachers, parents for students aged under 18, and students themselves. The survey was self-administered, anonymous, and took approximately 30 minutes to complete. Four split ballot versions of the questionnaire were employed. This allowed researchers to include as many topics as possible in the survey, while minimizing the burden on students and schools to a fixed class period. As such, in each classroom, Form A and Form B were distributed alternatively (i.e., A, B, A, B) to achieve two near-equal random samples completing each form. In total, 11,435 students, from 764 classes, 353 schools, and 52 school boards participated in the survey.

Participation rates were 61% for students, 94% for classes, and 61% for schools. The response rates were above average for a survey of students requiring active parental consent [23]. Reasons for nonresponse among students included absenteeism (12%) and unreturned consent forms or parental refusal (27%). Analyses for the present study are restricted to the random half sample of students ($N = 6{,}364$) who completed form A, which contained questions regarding psychological distress. Detailed information on the survey design and methods is available elsewhere [22].

Dependent variable

The Kessler 6-item (K6) psychological distress scale assesses symptoms of depression and anxiety occurring over the most recent 4-week period [4, 24]. Responses were scored on a five-point ordinal scale reflecting how often of over the past month respondents had experienced 6 symptoms, such as "feeling tired out for no good reason" and "sad or depressed". The measure has five response categories ranging from 0 (none of the time) to 4 (all of the time). It has been widely used in research with adolescents [16, 25-27]. The psychometric properties of the K6 have been extensively examined among adolescents and young adults [15-17, 28]. Some investigators have confirmed a single factor using confirmatory factor analysis (CFA) [15-17], while others found that a two-factor model (representing anxiety and depression) fit the data best [28]. There is thus some uncertainty as to the true factor structure of the measure.

Independent variables

Physical activity was measured using the following item: "On how many of the last 7 days were you physically active for a total of at least 60 minutes each day? Please add up all the time you spent in any kind of physical activity that increased your heart rate and made you breathe hard

some of the time (some examples are brisk walking, running, rollerblading, biking, dancing, skateboarding, swimming, soccer, basketball, football). Please include both school and non-school activities." Response options ranged from 0 to 7 days. Screen time was measured using the following item: "In the last 7 days, about how many hours a day, on average, did you spend: watching TV/movies/videos, playing video games, texting, messaging, posting, or surfing the Internet in your free time? (Include time on any screen, such as a smartphone, tablet, TV, gaming device, computer, or wearable technology). Response options included none, less than 1 hour a day to 7 or more hours a day. Sleep duration was measured using the following item: "On an average school night, how many hours of sleep do you get?" Response options ranged from 4 hours or less to 11 or more hours. Students who reported being physically active 7 days per week, accumulating 2 hours or less of daily recreational screen time, and sleeping 9–11 hours per night for 11–13-year-olds; 8–10 hours per night for 14–17-year-olds, or 7–9 hours per night for those ≥18 years of age were classified as meeting the recommendations of the 24-hour movement behaviour guidelines [13]. Single-item measures of physical activity and sleep have been demonstrated to provide reliable and valid assessments of physical activity and sleep among children and adolescents [29, 30]. Self-report measures of sedentary behaviour have also been shown to have acceptable reliability and validity in children and adolescents [31, 32]. Although the 24-hour movement guidelines we are referring to in this study are relevant for children and adolescents aged 5 to 17 years, we have included in our analyses students aged 18 to 20 years (n=269) because they are still in high school and may still have most features of adolescent life. Regardless, we run a sensitivity analysis excluding students aged 18 to 20 years. Different combinations of movement behaviours examined in the current study include meeting none or any of the following recommendations: (1) physical activity only, (2) screen time only, (3) sleep

duration only, (4) physical activity + screen time, (5) physical activity + sleep duration, (6) screen time + sleep duration, and (7) physical activity + screen time + sleep duration.

Covariates

Covariates included age (years), sex (male/female), ethnoracial background (White/Black/East and South-East Asian/South Asian/Other), subjective socioeconomic status (SES), and body mass index (BMI) z-score. Subjective SES was measured using a modified version of the MacArthur Scale of Subjective Social Status [33]. BMI was calculated from self-reported measures of height and body mass, and age- and sex-specific BMI z-scores were calculated using reference data from the World Health Organization [34].

Statistical analyses

Analyses were conducted in Mplus 8.2 and were weighted and accounted for the complex sample design of the survey using TYPE=COMPLEX function. Descriptive characteristics of participants are presented using mean, standard deviation, counts, and proportions. Confirmatory factor analyses employing a weighted least squares means and variance-adjusted estimator were first carried out to examine the factorial structure of the Kessler 6 scale. Items were treated as continuous variables [4, 24]. We explored three competing models based on previous work [28], to determine which model was a better fit to the data and to be used in subsequent analyses. Specifically, Model 1 had all six items loading on a single factor representing psychological distress; Model 2 had the items loading on two correlated first-order factors representing depression and anxiety; and Model 3 had the items loading on two second-order factors

representing depression and anxiety and having a second-order structure representing psychological distress. Composite reliability estimates of latent variables were tested using Raykov composite reliability [35]. Lastly, structural equation modelling was used to examine both the measurement model and the hypothesized structural model. In the hypothesized structural model, anxiety and depression were modeled as latent variables, and movement behaviour combinations modeled as observed variables. Covariates included age, sex, ethnoracial background, subjective SES, and BMI z-scores. Maximum likelihood estimation with robust standard errors was used to account for possible nonnormality in responses. Data were missing completely at random, because there were no relationships between the missingness of the data and any values, observed or missing. Thus, missing data were handled through full information maximum likelihood (FIML). Goodness of fit for the measurement models was determined using the root-mean-square error of approximation (RMSEA), comparative fit index (CFI), Tucker-Lewis Index (TLI), and standardized root square mean residual (SRMR). Model fit was considered acceptable if RMSEA and SRMR are below 0.08 and a good fit if they are less than 0.06, CFI and TLI values of 0.90 or above are seen as acceptable and 0.95 or above are considered a good fit [36]. We did not rely on the chi-square test to examine model fit because current analyses used a large sample size, and chi-square is sensitive to sample size [37]. Statistical inferences were based on *P* values <0.05 and 95% confidence intervals (CIs).

RESULTS

Participant characteristics

Descriptive characteristics of the sample are provided in Table 1. The mean age of study participants was 15.1 ± 1.8 years. Half of the sample was male (51.7%) and of White ethno-racial background (52.5%). Participants who met the physical activity, screen time, and sleep duration

recommendations represented 21.3%, 33.8%, and 32.4% of the sample, respectively. We found that only 4.7% of participants met all three recommendations, whereas 38.9% met none of the recommendations.

Confirmatory factor analysis (CFA) and internal consistency

Results from the CFAs for three competing models are presented in Table 2. Model 1 had all 6 items loading on a single factor of psychological distress (Figure 1), whereas Model 2 had the 6 items loading on 2 correlated first-order constructs of anxiety and depression (Figure 2). Model 3 had two factors of anxiety and depression that have a second-order structure representing psychological distress (Supplemental Figure 1). While most of the indices were acceptable for Model 1, it showed a slightly high RMSEA value of 0.065. However, compared to the single factor model, the two-factor model was a better fit to the data, as defined in the Methods section (RMSEA = 0.041; CFI = 0.995; TLI = 0.991; SRMR = 0.018). The model fit indices of the second-order two-factor model (Model 3) of psychological distress indicated poor fit to the data. Therefore, the 2-factor model (Model 2) was retained for subsequent analyses. The anxiety and depression items demonstrated a Raykov composite reliability of 0.80 and 0.92, respectively, indicating a high level of internal consistency.

Meeting different movement behaviour combinations with anxiety and depressive symptoms

Results from structural equation modeling examining the associations of meeting different movement behaviour combinations with constructs of anxiety and depression are outlined in Table 3. Meeting all 3 recommendations was associated with lower anxiety ($\beta = -0.076$; $p=0.028$) and

depressive symptoms (β = −0.067; p=0.028) relative to meeting none. Moreover, compared to meeting none of the recommendations, meeting the sleep duration recommendation only (β = -0.135; p<0.001), physical activity + sleep duration (β = -0.084; p=0.001), and screen time + sleep duration (β = -0.157; p=0.035) were associated with fewer symptoms of anxiety. However, meeting the physical activity only, the screen time only, and the physical activity + screen time recommendations were not associated with anxiety symptoms. Meeting all intermediate movement behaviour combinations was also associated with fewer depressive symptoms, except meeting the physical activity only and the screen time only recommendations. Meeting the screen time + sleep duration recommendations had the strongest relationship with anxiety (β = −0.157; p<0.001) and depressive symptoms (β = −0.139; p<0.001), followed by meeting the sleep duration recommendation only for both anxiety (β = -0.135; p<0.001) and depressive symptoms (β = −0.106; p<0.001). Overall, any of the combinations that included meeting the sleep duration recommendation showed better mental health outcomes. The combinations that did not include meeting the sleep duration recommendation (e.g., physical activity only, screen time only, physical activity + screen time –except for depressive symptoms) were not associated with better mental health indicators.

Results also showed that being male and having a higher perception of socioeconomic status were associated with lower anxiety and depressive symptoms. Being older was associated with greater anxiety and depressive symptoms. Being of non-White ethnoracial background was associated with greater depressive symptoms (Table 3). Results of sensitivity analysis excluding students aged 18 to 20 years showed similar results (not shown).

DISCUSSION

This study examined the association between meeting the 24-Hour Movement Guidelines and anxiety and depressive symptoms, as measured by the K6 in a province-wide representative sample of Canadian students in grades 7 through 12. In order to achieve this objective, we first confirmed the factor structure of the K6 psychological distress scale. Our analysis suggested a two-dimensional structure of the K6 that assesses symptoms of depression and anxiety. We found that after adjusting for confounders, meeting all 3 movement behaviour recommendations was associated with lower anxiety and depressive symptoms. However, this association appeared to be mainly driven by meeting the sleep duration recommendation, and to a lesser extent recommendation for screen time + sleep duration. Meeting the sleep duration recommendation alone was as beneficial for the outcomes as meeting all 3 recommendations (i.e. getting sufficient sleep + sufficient physical activity + low screen time).

Our results are consistent with previous studies that showed that meeting all 3 movement behaviour recommendations is associated with lower risk of depressive symptoms. In a large and nationally representative sample of nearly 60,000 US adolescents from the 2011-2017 cycles of the Youth Risk Behaviour Surveillance Survey, Knell *et al.* [38] found that meeting all 3 movement behaviour recommendations was associated with lower odds of depressive symptoms among adolescents. Similarly, Pearson *et al.* [39] found that meeting all 3 movement behaviour recommendations was associated with lower odds of depressive symptoms in a sample of nearly 4,000 United Kingdom adolescents. These findings are in line with compelling evidence that accumulating sufficient physical activity [40], limiting recreational screen time [41], and getting

enough sleep [42] are beneficially associated with a variety of physical, mental, and social health indicators among school-aged children and youth, and provide further support to the 24-hour guidelines.

Previous studies have mostly examined the relationship between meeting all 3 recommendations only and depressive symptoms, whereas it is uncertain whether meeting a particular combination would be more strongly associated with depressive symptoms than others. There is only one study (by Zhu *et al.* [43]) we are aware of that has examined the relationship between different combinations of movement behaviour recommendations with anxiety and depressive symptoms among adolescents. Indeed, Zhu *et al.* [43] found that meeting all three recommendations was associated with significantly lower odds of depression and anxiety compared with meeting none of the recommendations among adolescents, which is consistent with our findings. They also found that meeting all 3 recommendations was always the best choice among adolescents compared to meeting any other combinations.

In contrast, our results showed that meeting the sleep duration recommendation, and to a lesser extent meeting the screen time + sleep duration recommendation, was as beneficial for the outcomes as meeting all 3 recommendations. Our findings are somewhat consistent with those of previous studies indicating that adherence to the screen time and sleep duration recommendations have generally more benefits for adolescent mental health than meeting the physical activity recommendation. Indeed, Walsh *et al.* [44] and Guerrero *et al.* [45] found that meeting the screen time and sleep duration recommendations were strongly associated with better cognitive function and less impulsivity in a representative sample of US children, respectively, while physical activity

was not. It is possible that other types of physical activity not measured in the OSDUHS nor the ABCD, such light physical activity be favourably associated with mental health outcomes. Regardless, physical activity should not be neglected, as it has proven to offer a variety of benefits on adolescent physical, mental, and social health [40]. Furthermore, previous evidence has shown that physical activity may prevent depression and/or alleviate its symptoms in children and adolescents [46-48]. Given that excessive screen time, particularly around bedtime, has been identified as an important contributor to short sleep duration among adolescents [49, 50], it is important to address both screen time and sleep duration for mental health benefits. Future research, particularly from longitudinal studies, is needed to disentangle these findings and to confirm if getting enough sleep would result in subsequent better mental health.

Sleep duration is the behaviour that plays a bigger role in the present study. This not surprising because sleep is well known as an essential component of healthy development and is required for optimal physical and mental health [51]. Our results suggest that adherence to the sleep duration recommendation could be a good behavioural target to prevent anxiety and depressive symptoms among adolescents. However, short sleep duration is increasingly widespread among adolescents [52]. This supports the need for effective sleep intervention programs such as school-based sleep programs, which have shown potential long-term benefits [53]. Several possible mechanisms could explain the associations of sleep duration with anxiety and depressive symptoms. Short sleep duration affects brain activity and neurochemicals that regulate mood and thinking [54]. It is associated with greater stress reactivity within the hypothalamic-pituitary-adrenal axis, thus increasing the risk of psychopathological disorder [55]. Finally, it can make the maintenance of a

healthy lifestyle, such as physical activity, more difficult because of subsequent daytime sleepiness, fatigue, and tiredness [56, 57].

Our results further indicated that being male and having a positive perception of socioeconomic status were associated with lower anxiety and depressive symptoms, whereas being older was associated with greater anxiety and depressive symptoms. These findings are consistent with the current literature indicating that females are more likely than males to have mental health problems [58], and that the latter increase with age [59]. The findings that having a positive perception of socioeconomic status was associated with lower anxiety and depressive symptoms is also consistent with previous research indicating that subjective SES is related to aspects of adolescent health and could play an important role in buffering the risk of mental health problems [60-62]. It is also possible that students who have good mental health tend to report higher levels of subjective SES. Finally, being of non-White ethnoracial background was associated with greater depressive symptoms. These findings are not surprising because research has shown that being of non-White ethnic background is associated with more mental health problems [63].

With regards to distress, although K6 consistently showed very good reliability (as measured by Cronbach's alpha) when treated as a simple continuous scale [4, 24], our results showed that a two-factor model (representing anxiety and depressive symptoms) of the K6 had a better fit. These findings are consistent with previous studies indicating that a two-factor model representing anxiety and depression fit the data best in young adults [28] and older adults [64]. The screening information derived from the two-factor structure allows one to ascertain whether anxiety and/or

depressive symptoms are elevated, thus providing richer information to guide intervention efforts compared to its traditional use as a continuous score of distress.

Strengths and limitations

Strengths of this study include the use of a large and representative sample of adolescents, and an assessment of the factor structure of the K6. While others have treated the K6 as a single scale as originally designed, our results showed that a two-factor model (representing anxiety and depression) of the K6 fit the data better in our sample, information that is important to guide intervention strategies. Our study also highlights the importance of assessing different combinations of recommendations within the 24-hour movement guidelines, whereas previous studies examining the relationship between meeting the 24-hour movement guidelines and depressive symptoms among adolescents have mainly included meeting all 3 movement recommendations [38, 39]. Lastly, the current study included a comprehensive set of covariates that statistically controlled for several confounding variables, strengthening the internal validity of the findings.

Our study has several limitations that should be recognized. First, the study is based on cross-sectional data and thus the temporal order of meeting the 24-hour movement guidelines and psychological distress cannot be determined. It is possible that anxiety and depressive symptoms may have preceded movement behaviours rather than the reverse. Longitudinal studies are necessary to confirm temporality. Second, analyses are based on self-reported measures, thus subject to desirability and recall biases. Third, because the OSDUHS is conducted among adolescents who are within the regular school system, it is possible that the excluded students,

mostly from private and alternative schools, differ from other adolescents with regards to movement behaviours and experiences of vulnerability to mental health problems. However, this is unlikely to be an important limitation because the vast majority of adolescents in Canada attend publicly funded schools, and our sample represents approximately 93% of students [22]. Fourth, the present study could not examine whether the observed associations varied with the severity of anxiety and depressive symptoms. This is an interesting research question that future research could answer. Fifth, it is worth mentioning that K6 measures anxiety and depressive symptoms, and it is not indicative of a diagnosed mental health disorder. Although they may indicate risk of a common mental disorder [24], future research using diagnosed mental disorders is needed to examine the role of different combinations of movement behaviours. Sixth, it is possible that strength of associations reported herein are underestimated because the survey excluded adolescents who dropped out of school, the homeless and institutionalized youths. These excluded groups are well known to have greater risk of engaging in health compromising behaviours and experiencing mental health problems [65, 66]. Finally, the possibility of residual confounding by unmeasured variable such as medication utilization that could influence both sleep duration and anxiety and depressive symptoms is not excluded.

CONCLUSION

To the best of our knowledge, the present study is among the first to demonstrate that meeting the 24-hour movement guidelines is associated with lower anxiety and depressive symptoms among adolescents. Our results further indicate that meeting the sleep duration recommendation could be the main driver of this association, and to a lesser extent meeting the screen time + sleep duration guidelines. Our findings provide further support for heightened efforts to encourage adolescents

to meet these guidelines, particularly to get adequate sleep as a possible means to promote adolescent mental health. It is important to intervene during adolescence because it is when many mental disorders emerge for the first time [67]. Further research using a longitudinal design is needed to confirm temporality and to elucidate the mechanisms linking sleep duration to mental health of adolescents. Future studies are also needed to confirm the validity of the 2- factor structure of the K6 in large and representative samples of youth.

DATA ACCESS

Our data cannot be made available in the manuscript, the supplemental files or a public repository due to the Centre for Addiction and Mental Health's and The Ontario Public and Catholic School Board's institutional Research Ethics Board agreements. Qualified, interested researchers may request access to the data at the Centre for Addiction and Mental Health.

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CONFLICTS OF INTEREST

Mark Ferro and JianLi Wang serve on the editorial board of the Canadian Journal of Psychiatry. The remaining authors have no conflicts of interest to declare.

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Table 1. Descriptive characteristics of the sample.

	Participants (N=6364)	
	Unweighted n (%)[1]	**Weighted %[2]**
Age (years)		
Mean (SD)	14.7 (1.8)	15.1 (1.8)
Missing	1 (<1)	<1
Sex		
Males	2754 (43.3)	51.7
Females	3610 (56.7)	48.3
Missing	0	0
Ethnoracial Background		
White	3624 (57.0)	52.5
Black	562 (8.8)	13.2
East/South-East Asian	555 (8.7)	8.2
South Asian	463 (7.3)	6.0
Other	1160 (18.2)	20.1
Missing	0	0
Subjective socioeconomic status		
Mean (SD)	7.0 (1.6)	6.9 (1.7)
Missing	155 (2.4)	4.3
BMI z-scores		
Mean (SD)	0.3 (1.1)	0.3 (1.2)
Missing	391 (6.1)	6.5
Meet the physical activity recommendation		
No	4,932 (77.5)	78.0
Yes	1,361 (21.4)	21.3
Missing	74 (1.1)	0.7
Meet the screen time recommendation		
No	4167 (65.5)	66.2
Yes	2197 (35.5)	33.8
Missing	0	0
Meet the sleep duration recommendation		
No	4173 (65.6)	65.9
Yes	2109 (33.1)	32.4
Missing	82 (1.3)	1.7
24-hour movement guideline combinations		
None	2417 (38.0)	38.9
Only physical activity	456 (7.2)	7.3
Only screen time	937 (14.7)	14.3
Only sleep duration	928 (14.6)	14.5
Physical activity + screen time	319 (5.0)	5.0
Physical activity + sleep duration	263 (4.1)	4.1
Screen time + sleep duration	593 (9.3)	8.8
Physical activity + screen time + sleep duration	308 (4.8)	4.7

Missing	143 (2.3)	2.3

SD = standard deviation.

Data are shown as unweighted count (unweighted percent)[1] or weighted percent[2] unless otherwise specified. The sample weights are applied to ensure that the data are representative of all Ontario students in grades 7–12 in publicly funded schools.

Table 2. Confirmatory factor analysis model fit indices.

	Criterion	**One Factor**	**Two Factor**	**Second-Order 2 Factor**
Chi square		245.812	91.608	1733.467
df		9	8	9
p	≥0.05	< 0.001	< 0.001	< 0.001
RMSEA	≤0.06	0.065	0.041	0.174
90% CI		0.058 to 0.072	0.033 to 0.048	0.167 to 0.181
p		< 0.001	0.978	< 0.001
CFI	≥0.95	0.986	0.995	0.901
TLI	≥0.95	0.977	0.991	0.835
SRMR	≤0.06	0.028	0.018	0.079

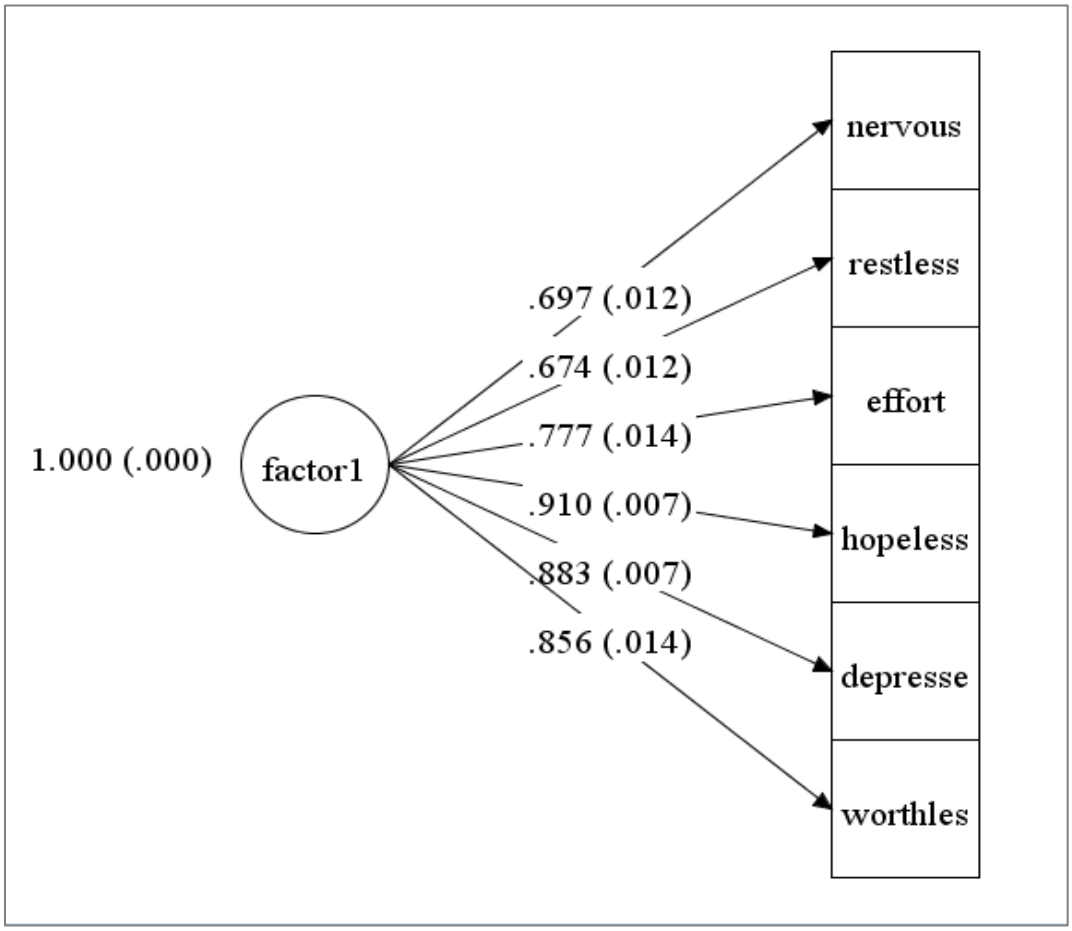
df: degrees of freedom; RMSEA: root mean square error of approximation; CI: confidence interval; CFI: comparative fit index; TLI : Tucker–Lewis fit index; SRMR: standardized root mean square residual. *p <0.001.

Table 3. Standardized path coefficients between combinations of movement behaviour recommendations and anxiety and depressive symptoms (N =6,364).

Path	β	SE	P	95% CI	R^2, %
Anxiety					20.7
24-hour movement guideline combinations					
Only physical activity	0.010	0.027	0.705	-0.03 to 0.06	
Only screen time	-0.042	0.037	0.256	-0.10 to 0.02	
Only sleep duration	-0.135	0.024	**<0.001**	-0.17 to -0.10	
Physical activity + screen time	-0.045	0.022	0.141	-0.08 to 0.01	
Physical activity + sleep duration	-0.084	0.026	**0.001**	-0.13 to -0.04	
Screen time + sleep duration	-0.157	0.024	**<0.001**	-0.20 to -0.12	
Physical activity + screen time + sleep duration	-0.076	0.035	**0.028**	-0.13 to -0.02	
Covariates					
Age	0.190	0.032	**<0.001**	0.14 to 0.24	
Sex (reference = females)	-0.268	0.027	**<0.001**	-0.31 to -0.22	
Ethnoracial background (reference =White)	0.058	0.032	0.068	0.01 to 0.11	
Subjective socioeconomic status	-0.156	0.024	**<0.001**	-0.20 to -0.12	
Body mass index z-score	-0.009	0.029	0.767	-0.06 to 0.04	
Depressive symptoms					17.9
24-hour movement guideline combinations					
Only physical activity	0.001	0.030	0.978	-0.05 to 0.05	
Only screen time	-0.031	0.036	0.382	-0.09 to 0.03	
Only sleep duration	-0.106	0.025	**<0.001**	-0.15 to -0.07	
Physical activity + screen time	-0.054	0.017	**0.001**	-0.08 to -0.03	
Physical activity + sleep duration	-0.073	0.020	**<0.001**	-0.11 to 0.04	
Screen time + sleep duration	-0.139	0.025	**<0.001**	-0.18 to -0.10	
Physical activity + screen time + sleep duration	-0.067	0.031	**0.028**	-0.12 to -0.02	
Covariates					
Age	0.150	0.040	**<0.001**	0.08 to 0.22	
Sex (reference = females)	-0.244	0.025	**<0.001**	-0.29 to -0.20	
Ethnoracial background (reference =White)	0.078	0.029	**0.007**	0.03 to 0.13	
Subjective socioeconomic status	-0.176	0.028	**<0.001**	-0.22 to -0.13	
Body mass index z-score	-0.008	0.028	0.783	-0.05 to 0.04	

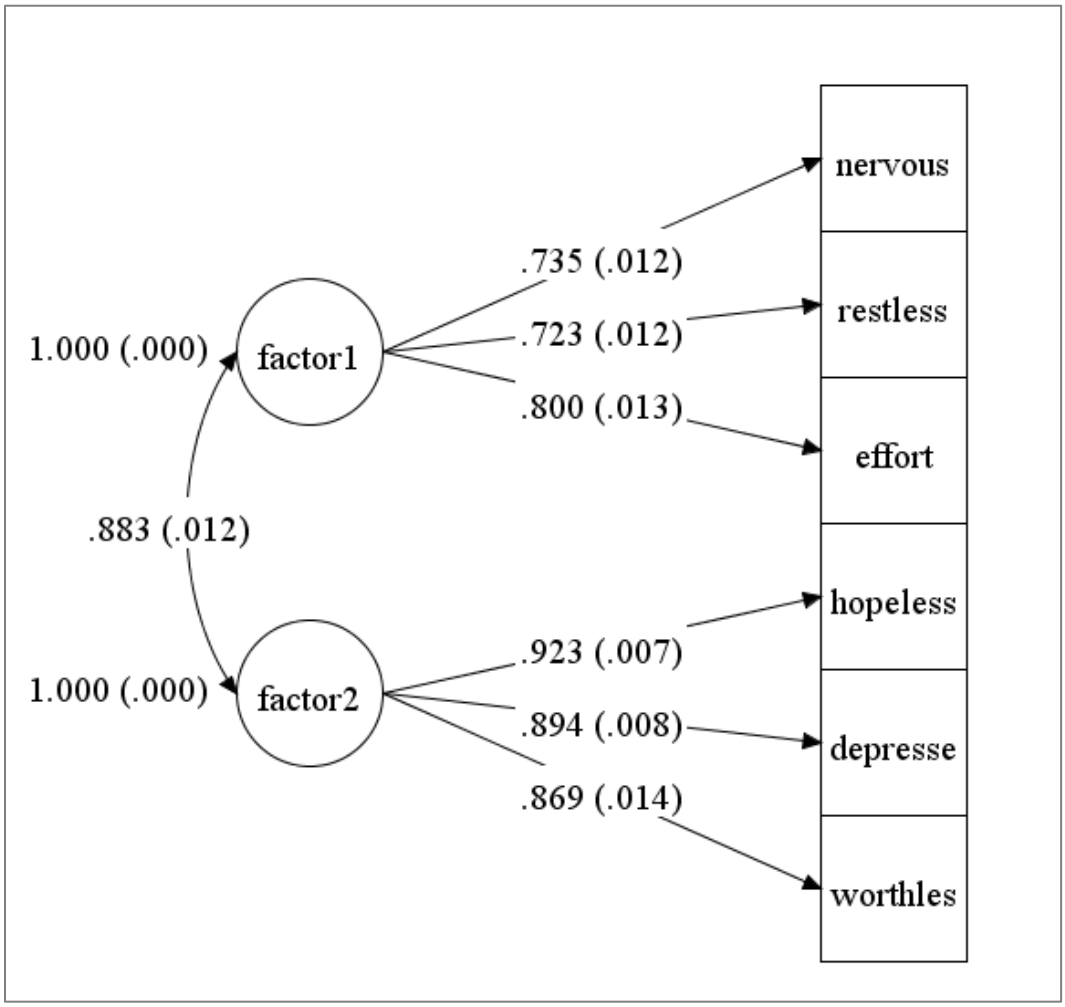
SE: standard error; CI: confidence interval. Meeting none of the recommendations represents the reference group.

Figure 1. Confirmatory factor analysis of one-factor model of psychological distress (N =6,364).



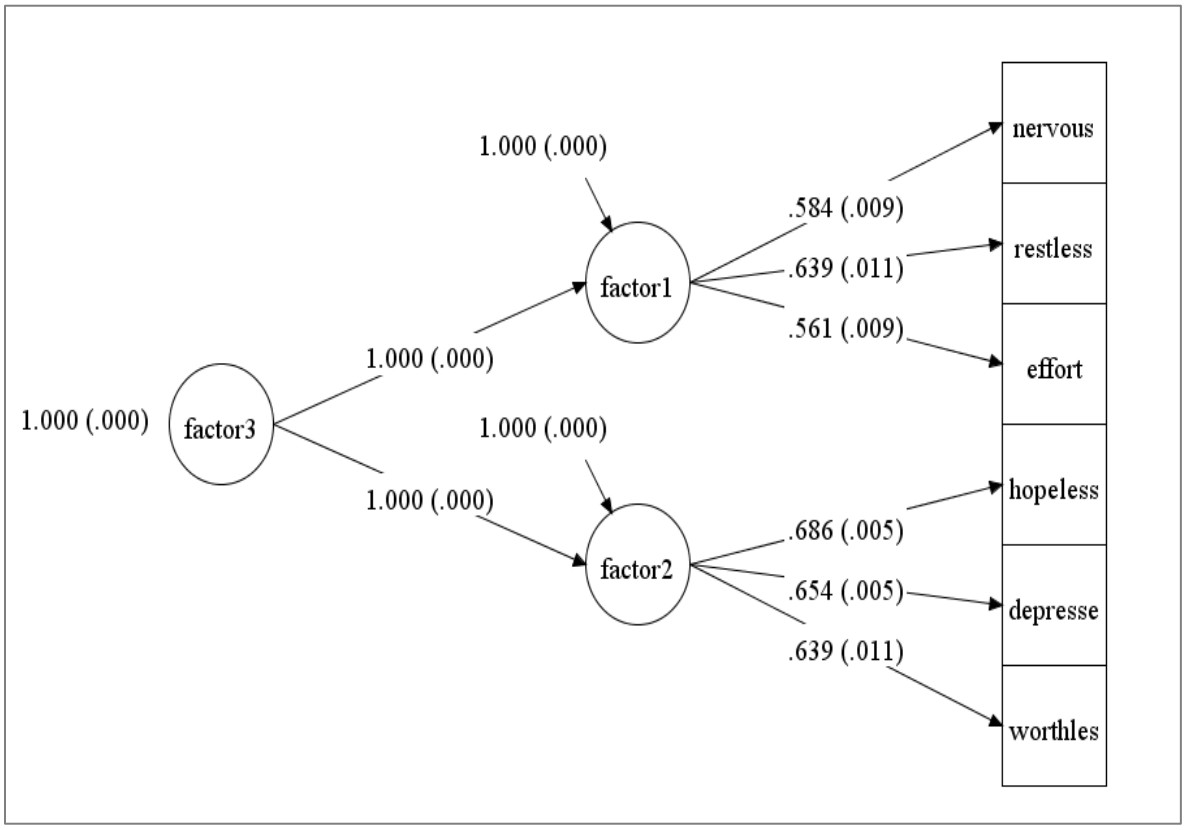
Factor 1 = Psychological distress

Figure 2. Confirmatory factor analysis of two-factor model of depression and anxiety (N =6,364).



Factor 1 = Anxiety; Factor 2 = Depression.

Figure 3. Confirmatory factor analysis of second-order two-factor model of psychological distress by depression and anxiety (N =6,364).



Factor 1 = Anxiety; Factor 2 = Depression; Factor 3 = Psychological distress.

Chapter 5

24-hour movement guidelines and suicidality among adolescents

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Strategy, PRISMA 2009 checklist, and ethical approval are included in appendices at the end of this chapter.

Online link: https://pubmed.ncbi.nlm.nih.gov/32469829/

Article preface: The objectives of this study were to examine the associations between meeting combinations of the 24-hour movement guidelines and suicidal ideation and suicide attempts in adolescents, and test whether age and gender moderate these associations. This study tested the hypotheses that adherence to a greater number of recommendations would be associated with lower odds of suicidal ideation and suicide attempts among adolescents, and that age and gender may moderate these associations.

Contribution statement: I am the first author on this article. I was responsible for generating the study objectives and design, with guidance from my supervisor and co-authors. I conducted the necessary statistical analyses, created all of the tables and figures, wrote the first draft of the manuscript, and submitted the final version for publication. I have also responded to all comments arising from the peer review process.

ABSTRACT

Background: The 24-hour movement guidelines for children and youth recommend ≥60 min/day of moderate-to-vigorous physical activity, ≤2 h/day of screen time, 9-11 h/night of sleep for 11-13 years and 8-10 h/night for 14-17 years. The objectives of this study were to examine the associations between meeting combinations of the recommendations contained within the 24-hour movement guidelines for children and youth and suicidal ideation and suicide attempts, and test whether age and gender moderate these associations.

Methods: Data on 10,183 students were obtained from the 2015-2017 Ontario Student Drug Use and Health Survey, a representative cross-sectional survey of Ontario students in grades 7-12 (mean [SD] age, 15.2 [1.8] years).

Results: Suicidal ideation and suicide attempts were reported by 13.1% and 3.3% of students, respectively. Meeting individual recommendations or combinations of recommendations were differentially associated with suicidal ideation and suicide attempts between adolescent boys and girls and younger and older (three-way interactions statistically significant for both outcomes). Meeting all 3 recommendations was associated with lower odds of suicidal ideation (OR: 0.24, 95% CI: 0.09 – 0.69) and suicide attempts (OR: 0.08, 95% CI: 0.02 – 0.41) among boys aged 15 to 20 years, but not those aged 11 to 14 years nor girls in both age groups.

Limitations: The cross-sectional nature of the data precludes causal inferences and there is possibility of bias related to self-reports.

Conclusion: These findings suggest that adherence to the 24-hour movement guidelines among adolescents is related to lower odds of suicidality in older boys.

Keywords: Physical activity; sedentary behaviour; screen time; sleep; suicide; teenagers

INTRODUCTION

Suicide is the third leading cause of death globally for adolescents aged 15 to 19 years [1]. It is the second leading cause of death in this age group in Canada [2]. Current epidemiological evidence indicates that the prevalence of adolescent suicide in Canada is increasing [3]. Rates of suicide and suicidality differ by age and gender among adolescents [4, 5]. Suicidality increases with age and there is a gender paradox [4, 5], in that girls have higher rates of suicidal ideation and suicide attempts, but deaths by suicide are more common among boys than girls. Several factors contribute to youth suicidality, including but not limited to mental disorders, previous suicidal ideation and attempts, a family history of suicidal behaviours, exposure to childhood maltreatment, and peer victimization [6-9]. Factors that could protect children and adolescents from suicidality are numerous [5, 10], and a better understanding of these determinants can inform the development of effective interventions to reduce suicidality. Physical inactivity, excessive screen time, and short sleep duration have previously been identified as factors associated with depressive symptoms [11-13] and suicidality among adolescents [14-17]. However, the associations between mental health and physical activity, screen time, and sleep duration are dominated by clinical samples. It is therefore important to examine these associations in population-based studies of adolescents. Furthermore, previous studies have considered these factors individually [18], ignoring how these behaviours may concurrently relate to suicidality among adolescents.

The Canadian 24-hour movement guidelines for children and youth were released in 2016 [19]. These guidelines integrate physical activity, sedentary behaviour, and sleep across the 24-hour period and represent a paradigm shift in thinking about daily movement behaviours. These guidelines recommend that during a typical 24-hour day children ages 5 to 17 years accumulate a

minimum of 60 minutes of moderate-to-vigorous physical activity, no more than 2 hours of recreational screen time, and 9 to 11 hours of uninterrupted sleep per night for those aged 5 to 13 years and 8 to 10 hours for those aged 14 to 17 years [19]. Researchers have started to examine the relationship between adherence to the recommendations contained within the 24-hour movement guidelines and health outcomes. Children who meet all 3 recommendations have better cognitive function [20], less impulsivity [21], lower odds of obesity [22], better dietary patterns [23], enhanced quality of life [24], and fewer depressive symptoms [25-27] than children who do not meet any of the recommendations. In a cohort study of over 3000 students (aged 10–11 years) in Nova Scotia (Canada) on various lifestyle behaviours and physician visits for mental illness, Loewen *et al.* [28] found that meeting 7 to 9 lifestyle behaviour recommendations was associated with fewer physician visits for mental illness during follow-up. However, their exposure (i.e. adherence to various lifestyle behaviours) conflates the 24-hour movement guidelines to six recommendations regarding diet. To our knowledge, the association between combinations of physical activity, screen time, and sleep duration with suicidal ideation and suicide attempts among adolescents has yet to be explored. As such, it is largely unknown whether adhering to all or certain combinations of guideline recommendations is associated with less suicidal ideation and fewer suicide attempts among adolescents. Gaining such knowledge can help inform and improve adolescent mental health promotion efforts.

Recent research has documented important age and gender differences in adherence to the 24-hour movement guidelines among children and adolescents [24, 29, 30]. Younger children are more likely than older children to meet the 24-hour movement guidelines [29]. Among younger children, boys are more likely than girls to meet all 3 recommendations; however, among adolescents, there

is no sex-differences in meeting all 3 recommendations.[29] With respect to individual components of the 24-hour movement guidelines, adolescent boys are more likely than girls to meet the physical activity recommendation, while females are more likely to meet the screen time recommendation than their male counterparts [29]. Given the above-mentioned gender differences in suicidality, and that rates of suicidality increase dramatically in early adolescence [8, 31], it is possible that the relationship between 24-hour movement behaviours and suicidality differs between younger and older students, and between boys and girls. Thus, using data from the 2015 and 2017 Ontario Student Drug Use and Health Surveys (OSDUHS), the objectives of the current study were to examine the associations between meeting combinations of the 24-hour movement guidelines and suicidal ideation and suicide attempts in adolescents, and test whether age and gender moderate these associations. We hypothesized that adherence to a greater number of recommendations would be associated with lower odds of suicidal ideation and suicide attempts among adolescents, and that age and gender may moderate these associations.

METHODS

Participants

The OSDUHS is a provincially representative survey of Ontario students in grades 7 to 12 attending publicly funded schools [32]. The survey excludes about 9% of the Ontario student population, including those in schools on military bases, in First Nations communities, hospitals and other institutions, and private schools. Students in special education classes and English as a Second Language (ESL) classes were also excluded from selection. The OSDUHS is a repeated cross-sectional survey that has been conducted every two years since 1977. The survey uses a stratified (region by school level) two-stage (school, class) cluster design. A total of 10,426

students drawn from 43 school boards, 220 schools, and 750 classes participated in the 2015 cycle of the survey. Completion rates were 94% and 59% for classes and students, respectively. In 2017, the OSDUHS surveyed 11,435 students in grades 7 through 12 in 764 classes and 214 schools from 52 English and French public and Catholic school boards. Sixty-one percent of randomly selected schools, 94% of selected classes, and 61% of eligible students in those classes completed the survey. Participation was considered above average for a student survey where active consent from a parent or guardian was necessary [33, 34]. Non-response among students for both cycles was due to absenteeism and lack of parental consent or unreturned consent forms. Pooled data for 2015 and 2017 OSDUHS represented a total of 21,861 students. However, the present study was restricted to a subsample of 11,767 eligible students who were offered one of the two randomly distributed questionnaires containing the mental health items. Further details regarding the study design and methods are available elsewhere [32, 35]. Ethics approval was obtained from the Research Ethics Boards of the Centre for Addiction and Mental Health, York University, and relevant school boards. In addition to parental consent, all students also provided their own assent.

Measures

Independent variables

Physical activity, screen time, and sleep duration were measured using items from the Centre for Disease Control's Youth Risk Behavior Survey (YRBS) [36]. *Physical activity* was measured by asking students to report the number of days during which they were physically active for ≥60 min/day in the last 7 days. They were asked to add up all the time spent on any form of physical activity that increased their heart rate and made them breathe hard some of the time, such as brisk walking, running, rollerblading, biking, dancing, skateboarding, swimming, soccer, basketball,

and football. Response options ranged from 0 to 7 days, and "7 days" corresponded to students that met the physical activity guideline recommendation [19]. Response options of 0 day through 6 days were collapsed to represent students that did not meet the physical activity guideline recommendation. *Screen time* was assessed using a question that asked students to report the average number of hours per day of the last 7 days that they spent watching TV/movies, playing video/computer games, chatting on a computer, emailing, or surfing the Internet. Response options were "none," "≤1 h/day," "1-2 h/day," "3-4 h/day," "5-6 h/day," and "≥7 h/day." Responses of ≤2 h/day corresponded to students that met the screen time guideline recommendation [19]. Remaining response options were collapsed to represent students that did not meet the recommendation. *Sleep duration* was measured using an item that asked students how many hours of sleep on an average school night they usually get. Response options ranged from "4 hours or less" to "10 or more hours". For analysis, a dichotomous variable was constructed to represent respondents who had a sleep duration that met the recommended range (9–11 h per night for 11–13-year-olds; 8–10 h per night for 14–17-year-olds, or 7–9 h per night for those ≥18 years of age) compared to those who did not get the minimum amount of recommended sleep [19, 37]. Single-item measures of sleep and physical activity have shown moderate to strong criterion validity with accelerometry-assessed sleep and physical activity among children and adolescents [38, 39]. Self-report methods of quantifying screen time have also been reported to have acceptable reliability and validity in children and adolescents [40, 41].

Outcomes

Suicidal ideation and suicide attempts were measured using two items that asked: "In the last 12 months, did you ever seriously consider attempting suicide?" and "In the last 12 months, did you

ever actually attempt suicide?" Response options to both questions were "yes" or "no". Both questions are from the Centre for Disease Control's YRBS and have demonstrated good reliability and validity among students [42].

Potential Moderators

Age (in years) and gender (boy/girl) were self-reported by students. For age comparisons, participants were grouped into 11- to 14-year-olds (n = 4,719) and 15- to 20-year-olds (n = 5,464) categories. The cut-point that differentiated the younger and older age groups was based on Statistics Canada age groups [43]. Age was also treated as a continuous variable ranging from 11 to 20 years.

Covariates

Age and gender were treated as covariates in those instances where there was no evidence that they were moderators. Other covariates included ethnicity (White/Black/East and South-East Asian/South Asian/Other), subjective socioeconomic status (SES), and body mass index (BMI) z-score. Subjective SES was measured using a modified version of the MacArthur Scale of Subjective Social Status [44]. Students were presented with a 10-rung ladder, where increasing rungs represented higher perceived status in Canadian society in terms of money, education, and occupation. They were asked to select the rung that best represented their family. BMI was calculated using students self-reported height and body mass, as weight divided by the square of height (kilograms/metres^2). Overweight and obesity were defined using the WHO's sex- and age-specific BMI cut-points established for children and youth [45] and the International Classification

for students over 19 years (n=2). A binary variable was constructed to indicate the presence of "overweight or obesity" vs. not.

Statistical Analysis

All analyses were conducted using Stata 14.1 (Stata Corporation, College Station, TX, USA). Design-based survey commands were used to adjust for the complex survey sample design of the OSDUHS. The estimation model was based on a design with 39 strata (region by school level) and 401 primary sampling units (schools). Population weights were included to adjust for the unequal probability of selection. Missing data were handled through listwise deletion, which reduced the sample size from 11,767 to 10,183 students. Excluded participants comprised significantly more students in junior grades (e.g. 21.3% vs. 11.7% in grade 7) and of other ethnic background (21.7% vs. 16.0%) compared with those included in the present analytical sample. There were no differences in suicidal ideation, suicide attempts, and movement behaviours between excluded participants and those included in our analyses. Prevalence and means were used to describe the sample. Differences among 11- to 14-year-old boys, 11- to 14-year-old girls, 15- to 20-year-old boys, and 15- to 20-year-old girls were assessed using an adjusted Wald test for continuous measures and a Pearson's χ^2 test that was adjusted for survey design and transformed into F-statistics for categorical data. Given that two-way gender interactions (gender X movement behaviours), two-way age interactions (age X movement behaviours), and three-way gender and age interactions (gender X age X movement behaviours) were statistically significant ($p<0.05$), analytical analyses were stratified by gender and age groups. Logistic regression analyses were used to examine the associations between meeting individual and combinations of the 24-hour movement guidelines for MVPA (≥60 minutes/day), screen time (≤2 hours/day), and sleep

duration (9-11 hours/night for 5-13 years and 8-10 hours/night for 14-17 years) with suicidal ideation and suicide attempts. Confounding variables included age, ethnicity, subjective SES, and BMI z-score. Adjusted odds ratio (OR) and their 95% confidence intervals (CI) are presented. The *marginsplot* command in Stata was used after *margins* to visualize age-related interaction effects stratified by sex.

RESULTS

Sample characteristics

Descriptive characteristics of the sample are provided in Table 1. About 49% of the sample were girls, 57% were White, and 29% were classified as having overweight or obesity. The prevalence of suicidal ideation and attempts were 13.1% and 3.3%, respectively. A total of 48.3% of students met the sleep duration recommendation, 35.4% met the screen time recommendation, and 22.1% met the physical activity recommendation. There were no differences in adherence to the sleep duration recommendation among 11- to 14-year-old boys, 11- to 14-year-old girls, 15- to 20-year-old boys, and 15- to 20-year-old girls; however, a greater proportion of 11- to 14-year-old boys met the physical activity and screen time recommendations. On the other hand, it was 15- to 20-year-old girls who had the highest prevalence of suicidal ideation and suicide attempts.

The prevalence of students who met recommendations for individual movement behaviours and different combinations of movement behaviours are displayed in Figure 1. Overall, 5.2% of students met all three recommendations while 27.7% did not meet any. The prevalence of meeting all three recommendations significantly differed across age and gender ($p<0.001$), with 11- to 14-year-old boys being the group that had a greater proportion of adherence to all 3 recommendations

(9.6%), followed by 15- to 20-year-old boys (5.8%). The lowest proportion of meeting all three recommendations was seen among 15- to 20-year-old girls (2.4%).

Combination of guideline recommendations and suicidality

Meeting all three recommendations was associated with lower odds of suicidal ideation (OR = 0.24; 95% CI: 0.09 – 0.68) and suicide attempts (OR = 0.08; 95% CI: 0.02 – 0.68) among 15- to 20-year-old boys, but not their younger (i.e. 11- to 14-year-old) counterparts (Table 2). Meeting the physical activity recommendation only (OR = 0.17; 95% CI: 0.04 – 0.74) and sleep duration recommendation only (OR = 0.34; 95% CI: 0.12 – 0.97) were associated with lower odds of suicide attempts among 15- to 20-year-old boys.

Among 11- to 14-year-old girls, participants meeting the screen time recommendation only had lower odds of suicidal ideation (OR = 0.38; 95% CI: 0.22 – 0.67) and suicide attempts (OR = 0.23; 95% CI: 0.06 – 0.89). Those who met both the physical activity and screen time recommendations had lower odds of suicidal ideation (OR = 0.41; 95% CI: 0.17 – 0.98). Among 15- to 20-year-old girls, meeting both the screen time and sleep duration recommendations was associated with lower odds of suicidal ideation (OR = 0.55; 95% CI: 0.35 – 0.86). However, meeting the physical activity recommendation only was associated with greater odds of suicidal attempts (OR = 2.90; 95% CI: 1.21 – 5.83) in this latter group.

Number of guideline recommendations met and suicidality

Figure 2 shows the interactions between the number of guideline recommendations met and age stratified by sex for suicidal ideation (Figure 2A) and suicide attempts (Figure 2B). The

interactions were statistically significant for age by meeting all 3 recommendations for both suicidal ideation and attempts among boys, but not girls. At average age, adolescent boys who meet all 3 recommendations had lower odds of suicidal ideation (OR=0.66, 95% CI: 0.48 – 0.89) and suicide attempts (OR=0.52, 95% CI: 0.30 – 0.88). The probability of suicidal ideation among adolescent boys who met all 3 movement guidelines significantly decreased with age. Results further indicate that at younger ages, there was no difference in boys' odds of suicidal ideation and suicide attempts between meeting all 3 recommendations and none of the recommendations. However, at older ages, boys who meet all 3 recommendations had lower odds of suicidal ideation and suicide attempts compared to those who meet none of the recommendations.

DISCUSSION

In this large, population-based sample of Ontario secondary students, meeting recommendations for physical activity, screen time, and sleep duration was associated with a lower risk of suicidality among older boys. Our results are somewhat consistent with those from previous studies suggesting that adherence to a combination of recommendations is associated with lower reports of mental health problems [25, 26]. In a large, representative sample of over 17,000 children and adolescents from the 2013/2014 cycle of the Health Behaviour in School-aged Children study (HBSC), Janssen *et al.* [46] found that meeting the recommendations for MVPA, screen time, and sleep duration on their own and in different combinations were associated with better physical, mental, and social health indicators. For the most part, meeting the recommendations for MVPA, screen time, and sleep duration had a comparable strength of associations with health indicators.

Janssen *et al.* [46] also found a dose-response relationship between the number of guideline recommendations met and health indicators, and that different intermediate combinations of the recommendations had similar influence on health indicators while the number of guideline recommendations met was the same [46]. Recent studies have also shown that meeting all 3 movement behaviour recommendations is associated with lower odds of depressive symptoms among adolescents [25-27]. However, those studies found no gender differences in the association between meeting all 3 recommendations and depressive symptoms. Zhu *et al.* [27] found that the association between meeting all 3 recommendations and depressive symptoms significantly varied between children and adolescents. To the best of our knowledge, the present study is the first to examine the relationship between adherence to the movement behaviour recommendations and suicidality among adolescents. We have provided evidence that adherence to the movement behaviour recommendations is associated with lower odds of suicidality differentially across age and gender. The strongest associations (i.e. lowest risk) were observed in older adolescent boys meeting all 3 movement behaviour recommendations and with both outcomes of suicidal ideation and attempts.

Although 11- to 14-year-olds were more likely than 15- to 20-year-olds to meet all three recommendations, our results showed that meeting all 3 recommendations in the 24-hour movement guidelines was associated with lower odds of suicidal ideation and suicide attempts among 15- to 20-year-old boys. Given the novelty of the findings, it is difficult to speculate what factors could explain the observed age differences. It is possible that meeting all 3 recommendations in the 24-hour movement guidelines influences mental health via known protective factors for adolescent suicidality, such as positive coping strategies, efficacious

problem-solving skills, and general life satisfaction [47-49], that are less well established in 11- to 14-year-olds. Previous studies have also suggested that lifestyle behaviours could operate via substance use disorders to decrease risk of suicidal behaviour among adolescences [50]. This mechanism could be more present in 15- to 20-year-olds due to increased prevalence of substance use and suicidality in this age group [4, 5]. Future research is needed to examine the mediating role of substance use on the association between adherence to movement guidelines and suicidality among adolescents.

Our results further showed that the probability of suicidal ideation and suicide attempts among students who met all 3 movement guidelines significantly decreased with age. At younger age, there was no difference in risk of suicidal ideation and suicide attempts between students who meet all 3 recommendations and none of the recommendations. However, at older age, students who meet all 3 recommendations have lower odds of suicidal ideation and suicide attempts than those who meet none of the recommendations. These findings are interesting and deserve further investigation. However, it is difficult to explain the mechanism that could explain the observed age differences given the novelty of our findings. It is possible that the absence of differences between meeting all 3 recommendations versus none in regard to suicidality at younger age could be explained by the lack of statistical power due to lower prevalence of suicidal ideation and suicide attempts among younger adolescents. Indeed, research has shown that younger children are more likely than older children to meet the 24-hour movement guidelines [29], and are less likely to experience suicidal ideation and suicide attempts than their older counterparts [4, 5]. Regardless, findings from this study suggest that older adolescent boys are more likely than

younger ones to be protected against suicidal ideation when meeting all 3 guideline recommendations.

The observed gender differences, particularly the lack of an association between meeting all 3 guidelines and suicidality among girls, may be explained by the fact that a small proportion of girls meet all three recommendations and, in our study, meeting the physical activity recommendation was surprisingly strongly associated with greater odds of attempts in older girls only. These findings are consistent with those from a previous study involving over 74,000 South Korean adolescents, which found that meeting the physical activity recommendations for vigorous, moderate and light physical activity was associated with increased suicidal ideation and suicide attempts [51]. It is possible that adolescents who attempted suicide engaged in physical activity as a coping strategy or a resiliency factor. However, we cannot confirm this because of the cross-sectional nature of the survey. Research has shown that physical activity can be used as a therapy for depressive symptoms [52], which include suicidal thoughts. It is also possible that residual confounding by unmeasured factors such as eating disorders or disordered eating may explain the findings of girls meeting the physical activity recommendation having greater odds of suicide attempts. Future research using longitudinal data is needed to determine temporality among meeting the physical activity guidelines and suicide attempts among older female adolescents.

In the same light, we found that meeting the screen time recommendation alone or the sleep duration recommendation alone were often strongly associated with lower odds of suicidal ideation and suicide attempts, particularly among girls. Our results are somewhat consistent with previous findings indicating that adherence to the screen time and sleep duration recommendations have

generally more incremental benefits to adolescent mental health indicators than meeting the physical activity recommendation. Indeed, Walsh *et al.* [20] and Guerrero *et al.* [21] found that meeting the screen time and sleep duration recommendations were strongly associated with better cognitive function and less impulsivity in a representative sample of US children, respectively, while physical activity was not. In contrast, Zhu *et al.* [27] found that meeting all 3 recommendations was always the best choice among adolescents compared to meeting any other combinations. Similarly, Janssen *et al.* [46] found that for the most part, meeting the recommendations for physical activity, screen time, and sleep duration had a comparable strength of associations with health indicators. They also found a dose-response relationship between the number of guideline recommendations met and health indicators, and that different intermediate combinations of the recommendations had similar influence on health indicators while the number of guideline recommendations met was the same [46]. The observed discrepancies may be explained, at least in part, by methodological differences across studies. Future research is needed to explore the dose-response gradient between the number of recommendations met and suicidality among adolescents.

This study has several limitations worth mentioning. First, all measures were self-reported and may be at risk of recall and desirability bias. Second, given the cross-sectional nature of the data, we are not able to confirm temporality between adherence to 24-hour movement guidelines and suicidality. For example, suicidal thought is a symptom of depression [53], and another symptom of depression is difficulty in sleeping [54], implying that some adolescents may not meet sleep recommendations due to their suicidal thought rather than the other way around. Future studies using longitudinal data are needed to establish temporality and confirm causality. Third, the survey

did not measure the intensity of physical activity nor the types of physical activity performed by participants (competitive sport or leisure time physical activity). Research has shown that sports that are more social (i.e., team sports) have more beneficial effects on mental health than individual sports [55]. This information could have helped further explore the positive association between adherence to the physical activity recommendation and suicide attempts documented among girls. Fourth, we were unable to examine this association in relation with different types of screen time, which vary between girls and boys [56]. For example, screen use by girls tends to be higher in social media use [57], while for boys it tends to be higher in computer gaming [56]. Social media use has been linked to both risks (e.g., social comparisons and cyberbullying victimization) and benefits (e.g. social connections) related to mental health [58, 59]. Fifth, the screen time measures do not account for multi-tasking or intermittent patterns of screen use (e.g., youth texting while watching television). As such, we may have overestimated screen time; however, research has shown that self-reported screen time has acceptable reliability and validity in children and adolescents [60]. Another limitation is that the strength of the association between movement behaviours and suicidality reported herein may be underestimated because those who have dropped out of school may have particularly high rates of suicidal ideation and suicide attempts [61]. Finally, the student participation rate was relatively low (nearly 60%) and may have negatively affected the internal validity of the results. However, the data did not show evidence of appreciable nonresponse bias [32].

CONCLUSION

This study provides evidence that adherence to the 24-hour movement behaviour recommendations is associated with lower odds of suicidal ideation and attempts, especially

among older adolescent boys. Future research using a longitudinal design is needed to replicate these novel findings, disentangle the observed gender and age differences, and confirm whether promoting adherence to the 24-hour movement guidelines among adolescents reduces the risk of suicidality during a critical period of development.

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Table 1. Sample characteristics, 2015 and 2017 Ontario Student Drug Use and Health Survey.

	TOTAL SAMPLE (N = 10,183)	**11- to 14- year-old boys (N = 2,104)**	**11- to 14- year-old girls (N = 2,615)**	**15- to 20- year-old boys (N = 2,416)**	**15- to 20- year-old girls (N = 3,048)**	**p-value†**
Age (years)						
Mean (SD)	15.2 (1.8)	13.2 (0.9)	13.2 (1.0)	16.4 (0.9)	16.3 (1.0)	
Ethnic background						
White	57.2	59.4	52.5	59.5	56.1	0.469
Black	9.8	9.3	10.5	9.4	10.2	
East/South-East Asian	9.6	9.3	9.4	8.6	11.0	
South Asian	7.4	7.2	9.0	7.5	6.5	
Other	16.0	14.8	18.7	15.0	16.3	
Subjective socioeconomic status						
Mean (SD)	6.9 (1.7)	7.2 (1.6)	7.2 (1.9)	6.9 (1.5)	6.8 (1.7)	<0.001
Body mass index						
Normal	71.0	70.0	73.7	67.6	73.8	0.062
Overweight/obese	29.0	30.0	26.3	32.5	26.2	
Physical activity						
Not meeting	78.0	64.1	81.6	75.3	87.0	<0.001
Meeting	22.1	35.9	18.4	24.8	13.0	
Screen time						
Not meeting	64.6	55.8	62.1	68.7	67.0	<0.001
Meeting	35.4	44.3	38.0	31.3	33.0	
Sleep duration						
Not meeting	51.7	52.6	48.0	51.1	53.9	0.187
Meeting	48.3	47.5	52.0	48.9	46.1	
Suicidal ideation						
No	86.9	94.7	85.2	89.7	80.3	<0.001
Yes	13.1	5.3	14.9	10.3	19.7	

Suicide attempts						
No	96.7	98.7	95.6	97.7	94.9	<0.001
Yes	3.3	1.3	4.4	2.3	5.1	

Data are shown as weighted column %, unless otherwise indicated. SD: standard deviation.

†p value of difference across age and gender was assessed using an adjusted Wald test for continuous measures and a Pearson's χ^2 test that was adjusted for survey design and transformed into F-statistics for categorical data.

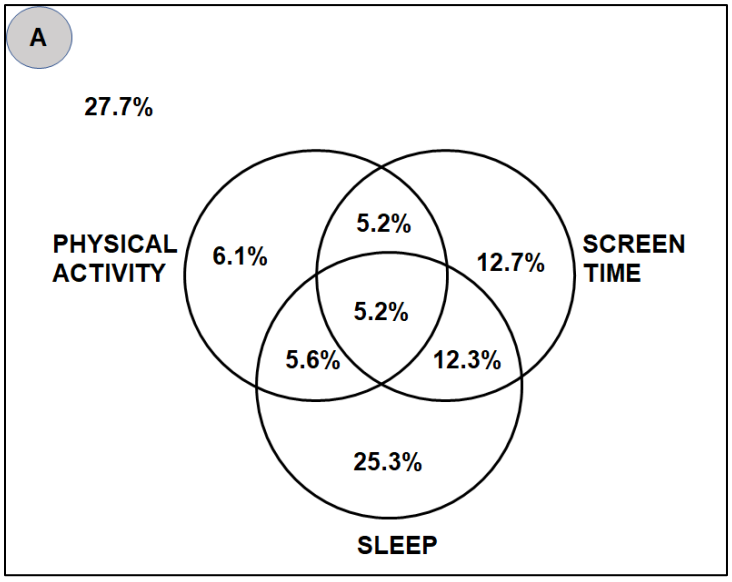
Table 2. Association between combinations of adherence to movement behaviour recommendations and suicidal ideation and suicide attempts.

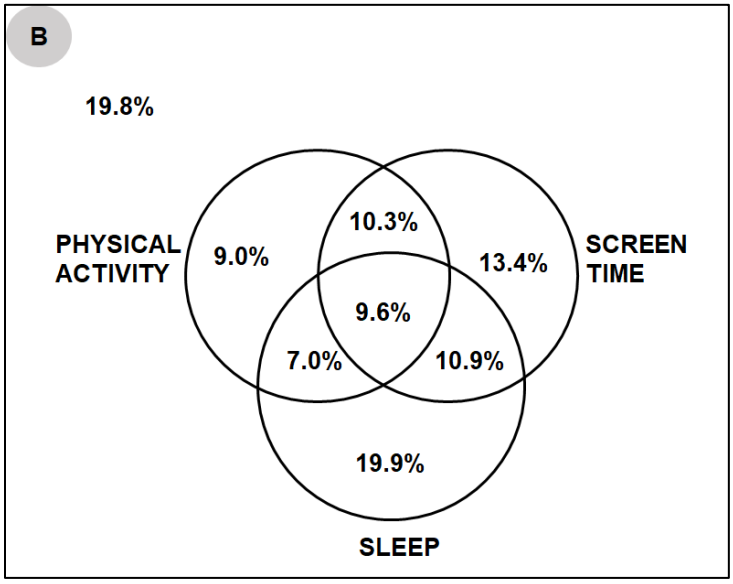
	BOYS (N = 4,520)		**GIRLS** (N= 5,663)	
	Suicidal ideation (n=378)	Suicide attempts (n=88)	Suicidal ideation (n=972)	Suicide attempts (n=256)
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
11- to 14-year-olds (N = 4,719)				
Neither (n=1,140)	1	1	1	1
PA only (n=329)	1.44 (0.65 – 3.18)	3.93 (0.69 – 22.24)	0.65 (0.33 – 1.27)	0.83 (0.28 – 2.42)
ST only (n=612)	0.84 (0.31 – 2.25)	1.93 (0.30 – 12.41)	**0.38 (0.22 – 0.67)**	**0.23 (0.06 – 0.89)**
Sleep only (n=1,078)	2.00 (0.86 – 4.68)	0.44 (0.08 – 2.34)	0.93 (0.56 – 1.55)	1.23 (0.50 – 2.99)
PA & ST only (n=350)	0.47 (0.16– 1.35)	1.13 (0.20 – 6.39)	**0.41 (0.17 – 0.98)**	0.57 (0.14 – 2.28)
PA & sleep only (n=283)	1.54 (0.55 – 4.35)	1.43 (0.22 – 9.43)	0.42 (0.16 – 1.06)	1.49 (0.36 – 6.25)
ST & sleep only (n=584)	1.04 (0.34 – 3.18)	2.98 (0.39 – 22.87)	0.44 (0.16 – 1.20)	1.26 (0.23 – 7.05)
Meeting all 3 (n=343)	1.84 (0.72 – 4.71)	0.70 (0.13 – 3.75)	1.03 (0.32 – 3.32)	0.86 (0.17 – 4.23)
15- to 20-year-olds (N = 5,464)				
Neither (n=1,735)	1	1	1	1
PA only (n=264)	1.00 (0.49 – 2.05)	**0.17 (0.04 – 0.74)**	0.80 (0.35 – 1.82)	**2.90 (1.21 – 5.83)**
ST only (n=741)	0.83 (0.42 – 1.67)	0.74 (0.25 – 2.24)	0.79 (0.58 – 1.08)	0.89 (0.37 – 2.18)
Sleep only (n=1,418)	1.27 (0.61 – 2.65)	**0.34 (0.12 – 0.97)**	1.05 (0.79 – 1.40)	0.90 (0.44 – 1.83)
PA & ST only (n=209)	0.58 (0.19 – 1.83)	0.40 (0.05 – 3.53)	0.62 (0.27 – 1.45)	1.63 (0.65 – 4.06)
PA & sleep only (n=282)	1.28 (0.51 – 3.20)	2.92 (0.91 – 9.34)	0.86 (0.36 – 2.06)	1.68 (0.62 – 4.51)
ST & sleep only (n=615)	1.54 (0.64 – 3.69)	0.55 (0.12 – 2.43)	**0.55 (0.35 – 0.86)**	0.72 (0.28 – 1.87)
Meeting all 3 (n=200)	**0.24 (0.09 – 0.68)**	**0.08 (0.02 – 0.41)**	0.49 (0.18 – 1.39)	0.68 (0.10 – 4.47)

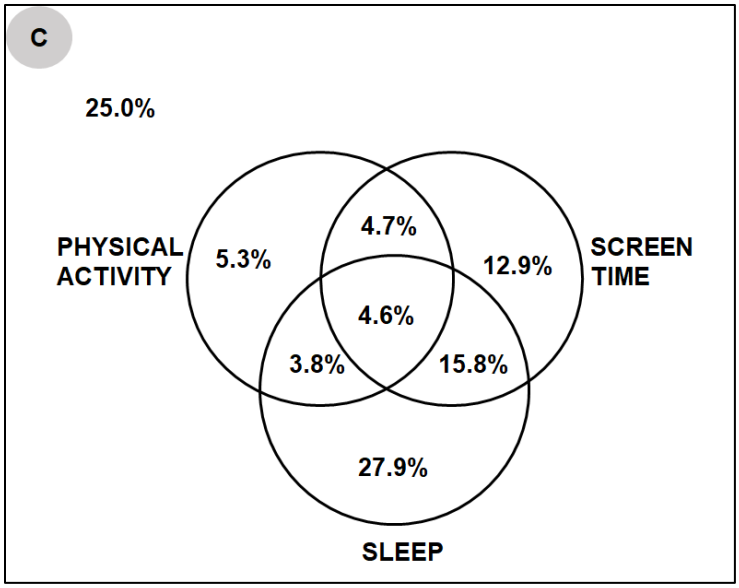
OR: odds ratio; CI: confidence interval.

Covariates in the adjusted models include age, ethnicity, subjective socioeconomic status, and body mass index z-score.

Figure 1. Venn diagrams showing the prevalence of students who meet the physical activity, screen time, and sleep duration recommendations, their combinations, and those who meet none of the 3 recommendations in the total study sample (Fig 1A; N = 10,183), 11- to 14-year-old boys (Fig 1B; N = 2,104), 11- to 14-year-old girls (Fig 1C; N= 2,615), 15- to 20-year-old boys (Fig 1D; N = 2,416), and 15- to 20-year-old girls (Fig 1E; N = 3,048).






C
25.0%
PHYSICAL ACTIVITY
5.3%
4.7%
12.9%
SCREEN TIME
4.6%
3.8%
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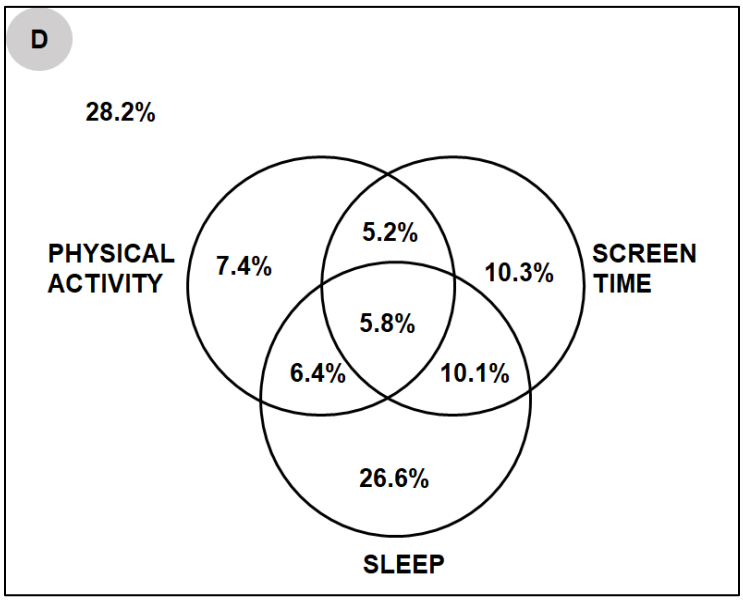
SLEEP


D
28.2%
PHYSICAL ACTIVITY
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SCREEN TIME
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SLEEP

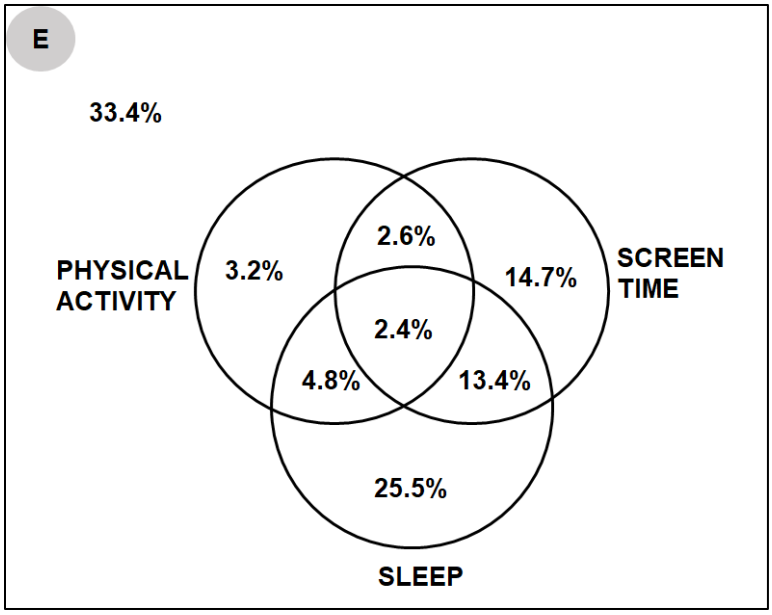
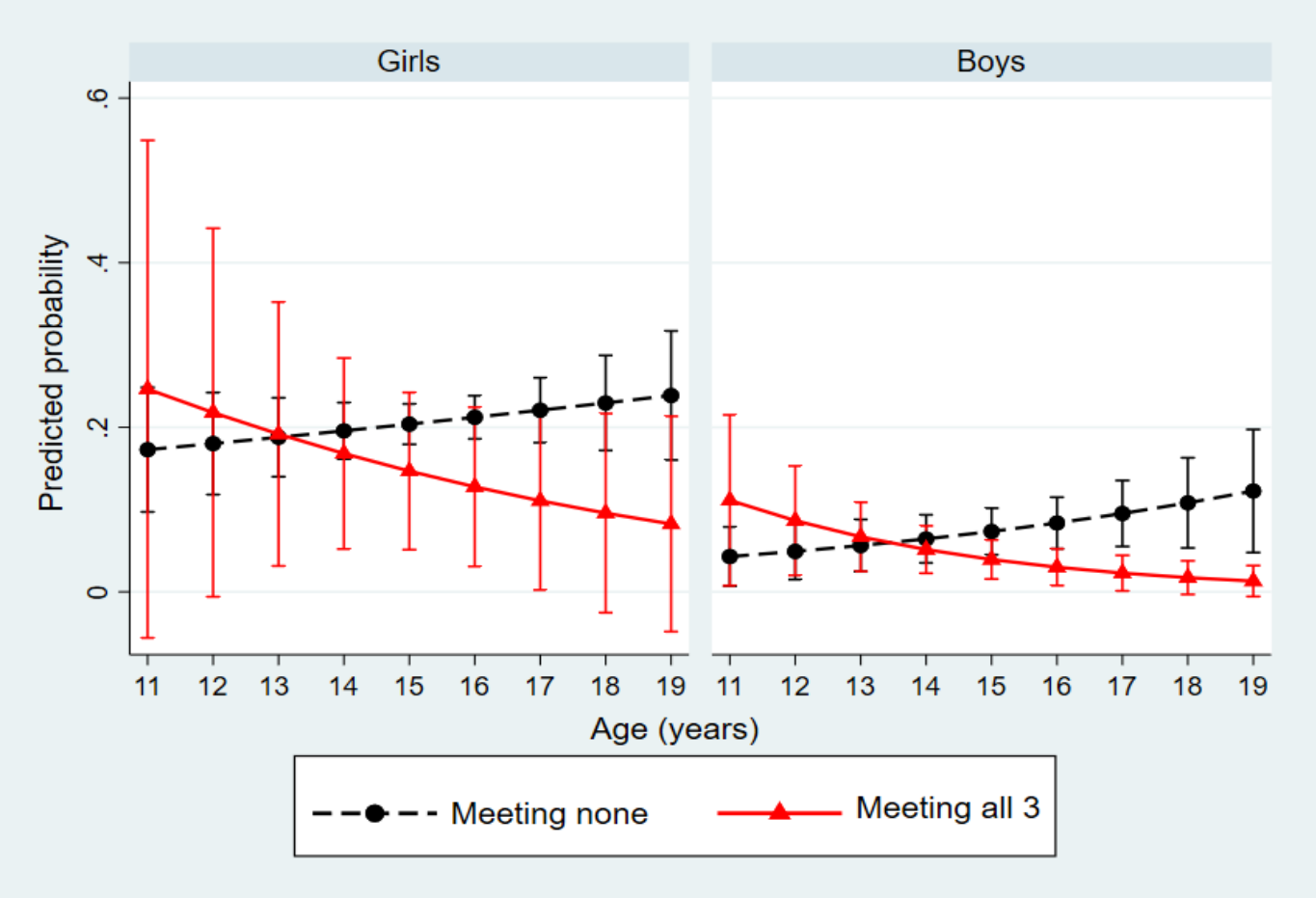
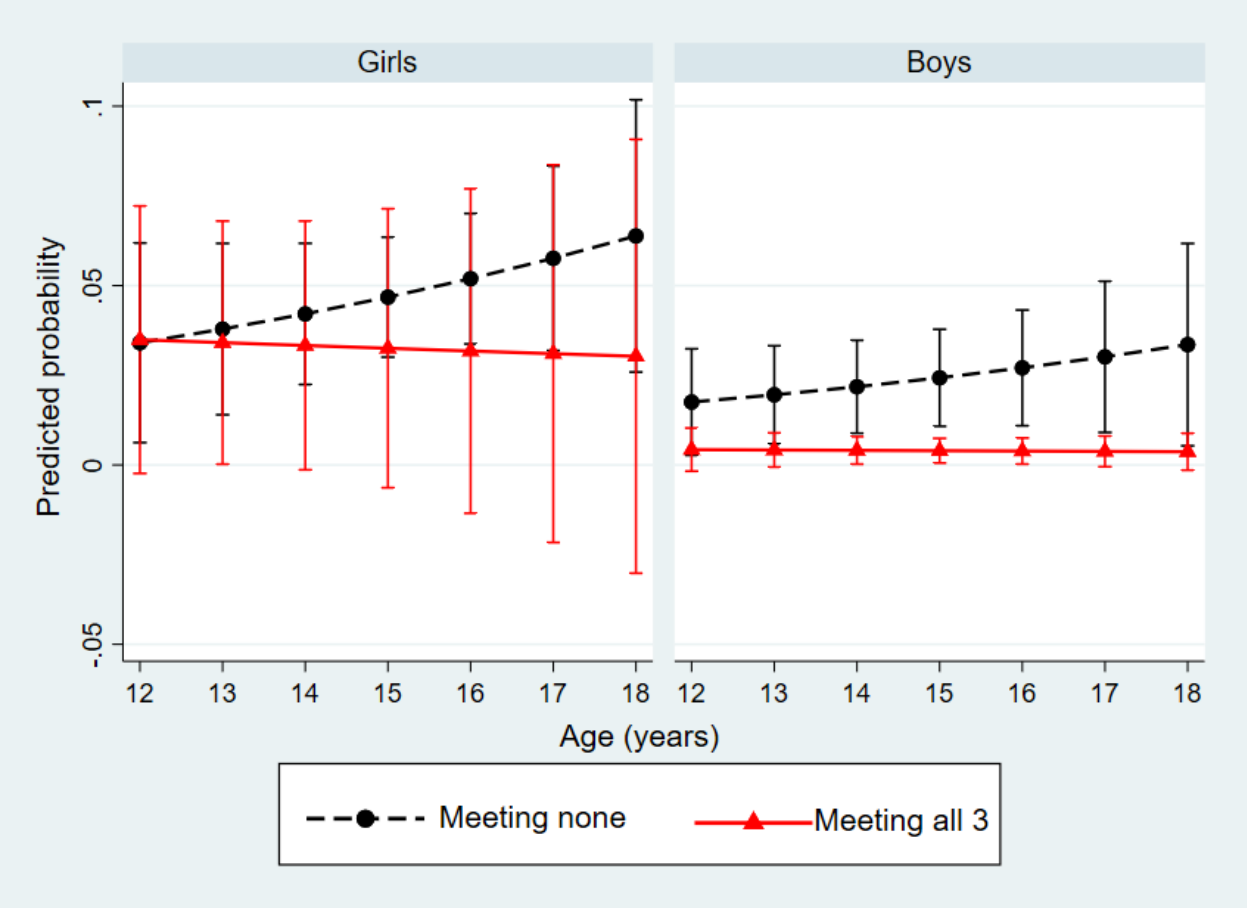

E
33.4%
PHYSICAL ACTIVITY
3.2%
2.6%
14.7%
SCREEN TIME
2.4%
4.8%
13.4%
25.5%
SLEEP

Figure 2A. Age variations in the association between the number of guideline recommendations met and suicidal ideation among adolescent boys (N = 4,520) and girls (N = 5,663).



Vertical bars represent 95% confidence intervals. Lines for meeting one or two recommendations are not displayed for clarity purpose. For boys, the interaction was statistically significant for age by meeting all 3 recommendations (OR=0.66, 95% CI: 0.48 – 0.89), but not for age by meeting one recommendation (OR=1.03, 95% CI: 0.80 – 1.33) or age by meeting two recommendations (OR=1.14, 95% CI: 0.89 – 1.46). For girls, the interaction was not statistically significant for age by meeting one recommendation (OR=1.04, 95% CI: 0.88 – 1.24), age by meeting two recommendations (OR=1.15, 95% CI: 0.93 – 1.41) nor age by meeting all three recommendations (OR=0.79, 95% CI: 0.54 – 1.18).

Figure 2B. Age variations in the association between the number of guideline recommendations met and suicide attempts among adolescent boys (N = 4,520) and girls (N = 5,663).



Vertical bars represent 95% confidence intervals. Lines for meeting one or two recommendations are not displayed for clarity purpose. For boys, the interaction was statistically significant for age by meeting all 3 recommendations (OR=0.52, 95% CI: 0.30 – 0.88) and age by meeting one recommendation (OR=0.57, 95% CI: 0.35 – 0.95), but not for or age by meeting two recommendations (OR=0.81, 95% CI: 0.47 – 1.41). For girls, the interaction was not statistically significant for age by meeting one recommendation (OR=1.01, 95% CI: 0.80 – 1.29), age by meeting two recommendations (OR=1.04, 95% CI: 0.76 – 1.43) nor age by meeting all three recommendations (OR=1.04, 95% CI: 0.62 – 1.72).

Chapter 6

Longitudinal association between movement behaviours and depressive symptoms among adolescents using compositional data analysis

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The article presented in this chapter was submitted to *Plos One* in January 2021 (see Appendix 2 for confirmation letter). All tables and figures were numbered using two digits, including chapter number followed by table or figure number to avoid confusion with those in other chapters.

Additional supporting documents, including participant flow-diagram and ethical approval are included in appendices at the end of this chapter.

Article preface: This study has three objectives. First, to describe change in adolescents' movement behaviour composition over time. Second, to explore the association between change in movement behaviour composition and change in depressive symptoms during adolescence. Third, to explore how reallocations of time between movement behaviours are associated with changes in depressive symptoms during adolescence.

Contribution statement: I am the first author on this article. I was responsible for generating the study objectives and design, with guidance from my supervisor and co-authors. I conducted the necessary statistical analyses, created all of the tables and figures, wrote the first draft of the manuscript, and submitted the final version for publication. I will also be responding to all comments arising from the peer review process.

ABSTRACT

Background: Research examining the associations between movement behaviours and mental health indicators within a compositional framework are sparse and limited by their cross-sectional study design. This study has three objectives. First, to describe the change in movement behaviour composition over time. Second, to explore the association between change in movement behaviour composition and change in depressive symptoms. Third, to explore how reallocations of time between movement behaviours are associated with changes in depressive symptoms.

Methods: Longitudinal data of 14,620 students in grades 9–12 (mean age: 14.9 years) attending secondary schools in Canada (Ontario, British Columbia, Alberta, Quebec) were obtained from two waves (2017/18, 2018/19) of the COMPASS study. Moderate-to-vigorous physical activity (MVPA), recreational screen time, and sleep duration were self-reported. Depressive symptoms were measured using the Center for Epidemiologic Studies Depression Scale (Revised)−10 (CESD-R-10). Compositional data analyses using pivot coordinates and compositional isotemporal substitution for longitudinal data were used to analyse the data. Analyses accounted for school clustering, were stratified by gender and age (< or ≥ 15 years), and were adjusted for race/ethnicity, body mass index z-score, baseline movement behaviour composition, and baseline depressive symptoms.

Results: There were significant differences in movement behaviour composition over time across all subgroups. For example, the relative contributions of MVPA and sleep duration to the movement behaviour composition decreased over time while screen time increased among younger boys and girls and older girls. Increasing sleep duration relative to the remaining behaviours (i.e., screen time and MVPA) was associated with lower depressive symptoms among

all subgroups. Increasing screen time relative to the remaining behaviours (i.e., MVPA and sleep duration) was associated with higher depressive symptoms among all subgroups. Increasing MVPA relative to the remaining behaviours (i.e., screen time and sleep duration) was associated with lower depressive symptoms in older girls only. Isotemporal substitution estimates indicated that decreasing screen time by 60 minutes/day and replacing that time with 60 minutes of additional sleep is associated with the largest change in depressive symptoms across all subgroups.

Conclusion: Findings from this prospective analysis suggest that increased sleep duration and reduced screen time are important determinants of lower depressive symptoms among adolescents.

Keywords: physical activity, sedentary behaviour, screen time, sleep duration, compositional data analysis, isotemporal substitution, youth, public health

INTRODUCTION

Adolescence is a sensitive period in the lifespan. It is the period of transition between childhood and adulthood, marked by important biological changes during puberty and the heightened influence of the social context in which young people are growing up [1, 2]. As adolescents become more independent, they become more responsible for making their own lifestyle choices [2, 3]. It is during this developmental period that more divergence in lifestyle behaviours and mental health outcomes emerge [4]. It is therefore important to examine how developmental changes in health behaviours impact health outcomes, in order to intervene before those behaviours become ingrained.

Research has shown that half of mental health problems have their onset during adolescence, particularly by age 14 [4]. It is estimated that 10 to 20% of adolescents globally experience mental health problems [5]. Depression is one of the most common forms of mental disorders that adolescents experience [5]. It is a leading cause of disability worldwide and a major contributor to the overall global burden of disease [5]. Adolescent depression is associated with long-term negative outcomes in adulthood [6, 7]. A recent study has indicated that 8% of Ontario (Canada) youth aged 12 to 17 years had symptoms that met criteria for major depression in 2014 [8]. A US study in adolescents reported that the prevalence of depression changed from 8.7% in 2005 to 11.3% in 2014 [9], indicating that the prevalence of depression has increased over the past years. Experience of depression increases with age, and more girls are affected by depression than boys [10-12]. Research is needed to identify modifiable risk factors of depression among adolescents as

the results from such research would provide insights into the design of interventions that could reduce depression incidence.

Sleep, sedentary time, and physical activity are associated with changes in depressive symptoms across adolescence [13, 14]; however, research that looks at these behaviours concurrently is sparse, even though it is evident that these movement behaviours are intrinsically linked. It is not possible to increase time spent in one behaviour without equivalent reduction in time spent across the remaining behaviours, because the day only has 24 hours. Compositional data analysis is an appropriate analytical approach to deal with data that is a proportion of a finite total, and can be used when all components or just some components of the finite total have been measured [15]. Compositional data analyses use the correct geometry (i.e., closed space versus open space) for bounded data and findings are interpreted as the effects of a behaviour as a proportion relative to the other behaviours instead of a behaviour being independent of another behaviour [15, 16]. To date, compositional data analyses have been mostly used to examine the health implications of sleep duration, sedentary time, and physical activity on obesity and cardio-metabolic health markers in both adults and children [15-17]. Very few studies have used such methodology in relation to mental health outcomes in children and adolescents specifically [18]. Furthermore, previous studies are limited either by their cross-sectional designs and/or small sample sizes [18]. Studies examining the prospective relationships between movement behaviours (sleep duration, sedentary time, and physical activity) and mental health indicators in adolescents using compositional analyses are thus warranted.

The isotemporal substitution model was developed as a modelling strategy that can be used to estimate the effects of substituting time from one movement behaviour with an equal amount of time from another movement behaviour [19]. For instance, a recent study investigating reallocating time between sleep, sedentary behaviour, and physical activity among adults generally found beneficial effects of replacing time spent sedentary or sleeping with physical activity for reducing mortality risk [20]. Studies that have examined the isotemporal substitution between physical activity, sedentary time and sleep duration on specific mental health outcomes such as depressive symptoms are sparse, particularly among children and adolescents. Indeed, a previous systematic review of studies that employed isotemporal substitution model in sleep, sedentary behaviour, and physical activity research has indicated that only three studies have been conducted in relation to mental health outcomes; two among adults and one in adolescents [21]. In a study of more than 20,000 children from the Canadian Health Behavior in School-aged Children study, Janssen [22] used isotemporal substitution models to estimate whether replacing time spent in sedentary video games and active outdoor play with active video games was associated with changes in youth's mental health. His results showed that replacing sedentary video games with active video games was associated with better mental health, whereas replacing active outdoor play with active video games was associated with more deleterious mental health indicators [22]. However, this study did not examine other types of movement behaviours such as sleep duration, total recreational screen time or physical activity, and also did not account for the compositional properties of time-use data [23, 24]. Furthermore, this study was limited by a cross-sectional design, thus supporting the need for prospective studies to confirm temporality.

Within a compositional framework, the present study has three objectives. First, to describe change in adolescents' movement behaviour composition over time. Second, to explore the association between change in movement behaviour composition and change in depressive symptoms during adolescence. Third, to explore how reallocations of time between movement behaviours are associated with changes in depressive symptoms during adolescence.

METHODS

Design

The COMPASS study is a prospective cohort study (2012-2021) collecting longitudinal hierarchical data at the student, school and community levels in Ontario, British Columbia, Alberta and Quebec (Canada) to understand how changes in school characteristics (policies, programs, built environment) are associated with changes in youth health behaviours [25]. A large convenience sample of schools that allow active-information passive-consent protocols were recruited and eligible students in those schools participate in the COMPASS survey during class time once annually. All students present during data collection were eligible to complete the questionnaire during class, enabling collection of whole-school samples. All student-level data were collected through a paper-based questionnaire comprising questions on many health, social, and academic outcomes. The questionnaire underwent and performed well in validity and reliability testing [26, 27]. This paper uses student-level data from Year 6 (2017/18) and Year 7 (2018/19) of the COMPASS host study (www.compass.uwaterloo.ca) [25]. COMPASS received ethics approval from the University of Waterloo Human Research Ethics Committee (ORE #: 30118) and all participating school boards.

Data from schools that participated in both Year 6 (2017/18) and Year 7 (2018/19) of COMPASS were used. In Year 6, 66,501 grade 9-12 students from 124 schools (8 in Alberta, 16 in British Columbia, 61 in Ontario, 37 in Quebec, and 2 in Nunavut) participated and in Year 7, 74,501 students from 136 secondary schools (8 in Alberta, 15 in British Columbia, 61 in Ontario, and 52 in Quebec) participated. Student participation rates for Year 6 and 7 of the COMPASS study was 81.9% and 84.2%, respectively. Each school was assigned a unique identifier, which was used to link the school samples across waves. Unique self-generated identification codes are used to link student-level data sets across different waves [28]. Reasons for non-linkage included students graduating or being newly admitted to school within the waves, students transferring schools, having a spare/free period or being otherwise absent during data collection, dropping out of school, or inaccurate data provided on the data linkage measures. Detailed information on the COMPASS design and methodology are available elsewhere [25].

Dependent variable

Depressive symptoms were assessed using the Center for Epidemiologic Studies Depression Scale (Revised)−10 (CESD-R-10) [29]. This 10-item scale was designed to assess self-reported symptoms of depression such as feelings of sadness, hopelessness, apathy and motivation, irritability, and difficulties sleeping, making decisions, and concentrating over a 1-week period. The CESD-R-10 has shown strong psychometric properties in a sample of adolescents, with good model fit of a 1-factor model [30]. All questions include four response categories (0–3). The total score was calculated by summing all 10 items, with higher scores indicating higher levels of depressive symptoms. Internal consistency of the CESD-R-10 scale was high (α=0.98).

Independent variables

Independent variables included moderate-to-vigorous intensity physical activity (MVPA), recreational screen time, and sleep duration. MVPA was measured using items that asked students how many minutes of moderate physical activity (defined in the survey as lower intensity activities such as walking, biking to school, and recreational swimming) and how many minutes of hard physical activity (i.e., vigorous – defined as physical activities that increase their heart rate and make them breathe hard and sweat) they had done in the past seven days. Students reported the number of hours and minutes spent in each intensity level of physical activity for each day in the previous week. Average daily duration of MVPA in minutes was calculated as: (5 * MVPA on weekdays) + (2 * MVPA on weekend days)/7. Recreational screen time was measured using an item that asked students how much time per day they usually spend doing the following activities: watching/streaming TV shows or movies, playing video/computer games, surfing the internet, and texting/messaging/emailing. Students reported their screen time in hours and minutes. Time duration from each of the 4 activities were summed to represent total average daily recreational screen time. Sleep duration was measured using an item that asked students how much time per day they usually spend sleeping. Students reported their sleep duration in hours and minutes.

Covariates: Age (years), gender (boy/girl), race/ethnicity (White/Black/Asian/Latin American/Hispanic/Other), body mass index (BMI) z-score, baseline movement behaviour, and baseline depressive symptoms were used as covariates. BMI was calculated using self-reported height and body mass. BMI z-scores were computed according to the WHO's reference data [31].

Data processing

Of the 21,604 students who were successfully linked for their participation in COMPASS in Year 6 (2016/17, considered herein as the baseline data) and Year 7 (2018/19, considered herein as the follow-up data)**,** 19,160 answered questions regarding depressive symptoms and movement behaviours at both time points (Figure 1). Of those, 14,620 students had complete data for all variables included in our analyses at both time points and constituted our analytical sample.

Gender at time 2 was replaced by gender at time 1 if participants changed gender (n=21). A total of 1,156 respondents reclassified race/ethnicity or had not reported race/ethnicity for one time point. Of those, 30 did not report race/ethnicity at time 1. Eight out of those 30 were excluded because they had no information on race/ethnicity at both time points. Race/ethnicity at time 1 was replaced by race/ethnicity at time 2 if participants did not report race/ethnicity at time 1 (n=22). Whereas, race/ethnicity at time 2 was replaced by race/ethnicity at time 1 if participants changed race/ethnicity (n=1,126). Time use across the three movement behaviours was adding up to greater than 24-hours per day. Therefore, movement behaviour variables were checked for outliers ($\geq \pm 2$ standard deviations) and truncation was performed for all daily duration values exceeding +2 standard deviations (SD) for MVPA and screen time and -2 SD for sleep duration to avoid implausible data.

Statistical analyses

All analyses were carried out in R using the Compositions [32], zCompositions [33], lme4 [34] and ggtern [35] packages.

Change in movement behaviour composition (1st objective)

Repeated-measures multivariate analysis of variance (MANOVA) models with isometric log-ratios (ilrs) as dependent variables and time-point as the independent variable were used to determine whether the movement behaviour composition changed between the two time-points [36]. Interactions between time-point and age and time-point and gender were tested. Given that these were significant ($p<0.001$), all subsequent analyses were stratified by gender and age (median split at 15 years). The repeated-measures MANOVA indicates whether within-participant composition changed between the time points but provides no information about which behaviours were driving the changes. To explore which behaviours were driving the changes, we calculated the mean within-person log-ratio change for each behaviour; for example, $ln(\text{Sleep}^{\text{Time2}} / \text{Sleep}^{\text{Time1}})$ for each participant, and then averaged across the strata. Bootstrapping with 1000 replicates generated 95% confidence intervals for each mean log-ratio difference.

Association between change in movement behaviour composition and change in depressive symptoms (2nd objective)

The movement behaviour composition was expressed as a specific type of *ilr* previously called pivot coordinates [37]. Briefly, pivot coordinates are a set of *ilrs* where the first coordinate enables one part of the composition (e.g., sleep) to be considered relative to the remaining parts of the composition (i.e., sedentary time and MVPA) [15, 38]. Sleep is in the numerator of the log-ratio while the remaining parts are in the denominator. We created three sets of pivot coordinates to enable each behaviour (sleep, sedentary behaviour, and MVPA) to be considered relative to the remaining behaviours. We used the change in pivot coordinates as the explanatory variable in mixed effects multiple linear regression models. The dependent variable was change in depressive symptoms. The models were run, one for each set of pivot coordinates. The models also included

covariates of time 1 composition (expressed as *ilrs*), time 1 depressive symptoms, time 1 BMI z-score and race/ethnicity. A random intercept for school was used to account for the school-based sampling frame. A Wilks' analysis of variance (ANOVA) test of the mixed effects multiple linear regression models was used to determine whether the change in movement behaviour composition was associated with change in depressive symptoms. The standardized beta coefficients for change in each pivot coordinate (one for each behaviour, relative to remaining behaviours) from each of the three models was presented in a table to describe how change in one behaviour (relative to the remaining behaviours) was associated with change in depressive symptoms.

We used the mixed effects multiple linear regression model to predict change in depressive symptoms for 10,000 random hypothetical time 2 compositions within the empirical ranges observed in the sample. The hypothetical time 2 compositions were considered relative to the centre of the time 1 composition. As in Olds *et al.* [39], the estimated change in depressive symptoms associated with no change in time-use composition was subtracted from the predictions to isolate change in depressive symptoms associated with change in time-use only. Estimated changes in depressive symptoms were expressed as effect sizes, using pooled standard deviations of time 1 and time 2 depression scores. Estimated change in depressive symptoms were colour-coded within ternary diagrams so that yellow indicates no change from time 1 depressive symptoms, increases in depressive symptoms are coloured orange-to-red, and decreases are coloured green-to-blue.

Compositional isotemporal substitution (3rd objective)

Using compositional isotemporal substitution [40] for longitudinal data [41], we estimated the change in depressive symptoms (presented as standardized effect sizes) associated with reallocating 60 minutes between movement behaviours around the centre time 1 composition. The centre time 1 movement behaviour composition was linearly adjusted so that the behaviours summed to the mean total time of 957 minutes. Hypothetical situations of all possible reallocations of 60 minutes to/from the time 1 centre composition were used as new data for prediction in the mixed effects multiple linear regression models. Again, estimated change in depressive symptoms for no change in composition was subtracted to isolate change in depressive symptoms associated with changes in composition only. We derived 95% confidence intervals (CI) for the estimated difference in depressive symptoms using the model-estimated standard error of the difference.

RESULTS

Characteristics of the study sample at time 1 and time 2 are presented in Table 1. At time 1, the mean age was 14.9 years and most participants identified themselves as White (73.3%). The average body mass status was within normal range in the total sample and across all age/gender groups. In the total sample and across all subgroups, sleep duration represented the greatest portion of the composition, followed by screen time, and far behind was MVPA.

Change in movement behaviour composition (1st objective)

Results from analyses examining whether the movement behaviour composition changed between the two time points are outlined in Table 2. Overall, there were significant intra-individual relative

differences in movement behaviour composition over time in the total sample and in all age/gender groups ($p<0.001$). Results further indicated that all the contribution of each component to the overall movement behaviour composition varied significantly from time 1 to time 2. For example, in the overall sample, the relative contribution of MVPA to the movement behaviour composition decreased by 13% (estimate: -0.133; 95% CI: -0.107;-0.159), the relative contribution of screen time increased by 5% (estimate: 0.048; 95% CI: 0.056;0.041), and the relative contribution of sleep duration decreased by 1% (estimate: -0.012; 95% CI: -0.007;-0.017) over time (Figure 2A). Patterns were similar among younger boys (Figure 2B), younger girls (Figure 2D), and older girls (Figure 2E). However, among older boys, MVPA decreased by 17% (estimate: -0.174; 95% CI: -0.130; -0.221) (Figure 2C), whereas sleep duration increased by 1% (estimate: 0.008;95% CI: 0.001; 0.016) and screen time increased by 2% (estimate: 0.021; 95% CI: 0.007; 0.034) over time.

Association between change in movement behaviour composition and change in depressive symptoms (2nd objective)

Table 3 summarizes results of analyses examining the longitudinal associations between changes in pivot log-ratio coefficients and follow-up depressive symptoms. Before and after adjusting for covariates, the beta estimates for the pivot coordinates indicated that increasing sleep duration relative to remaining behaviours (i.e. screen time and MVPA) was associated with lower depressive symptoms among all subgroups. Conversely, increasing screen time relative to the remaining behaviours (i.e., MVPA and sleep duration) was associated with higher depressive symptoms among all age/gender groups. There was no association between MVPA, relative to the remaining behaviours, and depressive symptoms among younger and older boys and younger girls.

However, among older girls, increasing MVPA relative to the remaining behaviours (i.e., screen time and sleep duration) was associated with lower depressive symptoms.

Color-coding the datapoints according to their model-predicted change in depressive symptoms (yellow=no change, red=increased depressive symptoms, blue=decreased depressive symptoms) shows that a change away from the centre (mean composition at time 1) towards physical activity is flat, indicating no variation in color for the total sample and all subgroups, except older girls (Figure 3). This suggests that a change towards MVPA did not change depressive symptoms for younger boys, older boys, and younger girls. However, among older girls, increasing MVPA while equally reducing screen time and sleep duration was associated with decreased depressive symptoms. A change away from the mean composition at time 1 towards screen time was associated with increased depressive symptoms across all subgroups. Finally, increasing sleep duration while equally reducing MVPA and screen time was associated with decreased depressive symptoms.

Compositional isotemporal substitution (3rd objective)

Estimated changes in follow-up depressive symptoms associated with 60-minute reallocations from the mean baseline movement behaviour composition are presented in Table 4. Replacing 60 minutes of screen time by 60 minutes of either sleep duration or MVPA was associated with decreased depressive symptoms in all age/gender groups. In contrast, replacing 60 minutes of sleep duration by 60 minutes of either MVPA or screen time was associated with increased depressive symptoms in all age/gender groups. Similarly, replacing 60 minutes of MVPA by 60 minutes of screen time was associated with increased depressive symptoms in all age/gender groups.

However, replacing 60 minutes of MVPA by 60 minutes of sleep duration was associated with lower depressive symptoms in all age/gender groups, except older girls, for whom such a time reallocation was associated with increased depressive symptoms. It is noteworthy that predicted changes in depressive symptoms were strongest and most beneficial when replacing 60 minutes of screen time by 60 minutes of sleep duration across all subgroups, as it had the lowest coefficient for depressive symptoms.

DISCUSSION

Using compositional data analysis on a large and prospective cohort of adolescents, our results showed that the relative contribution of MVPA to the overall movement behaviour composition decreased over time among all subgroups, whereas the relative contribution of sleep duration decreased, and that of screen time increased among younger boys, younger girls, and older girls. Before and after adjusting for covariates, increasing sleep duration relative to the remaining behaviours (i.e. screen time and MVPA) was associated with lower depressive symptoms among all subgroups. Conversely, increasing screen time relative to the remaining behaviours (i.e. MVPA and sleep duration) was associated with higher depressive symptoms among all subgroups. Increasing MVPA relative to the remaining behaviours (i.e. screen time and sleep duration) was associated with lower depressive symptoms in older girls only. Results further indicated that predicted changes in depressive symptoms were strongest and most beneficial when replacing 60 minutes of screen time by 60 minutes of sleep duration across all subgroups.

Change in movement behaviour composition

Our results showed that there was a decrease in the relative contributions of MVPA and sleep duration to the overall movement behaviour composition and an increase in the relative contribution of screen time at 1-year follow-up among all subgroups, except older boys. In the latter subgroup, the relative contribution of MVPA significantly decreased, whereas the relative contributions of both screen time and sleep duration to the overall movement behaviour composition has significantly increased over time. The overall pattern is consistent with current literature indicating that as adolescents get older, they become less active and well versed into modern sedentary activities [42, 43]. In a large nationally representative sample of the US population, Yang *et al.* [42] found an increase in the prevalence of computer use during leisure time and the total sitting time among adolescents. They also found that the prevalence of sitting watching television or videos for 2 hours or more per day remained high and stable from 2001 through 2016 in this age group [42]. In parallel, recent research has shown that heavy screen time is associated with short sleep duration among adolescents [44, 45]. It is possible that a simple time displacement of sleep duration by screen time, particularly around sleep time, at least in part explains this association. In addition, late night screen time use could shift the circadian rhythm towards a later midpoint of sleep and increase mental and physiological arousal before bedtime, which could delay sleep onset [46]. It is also possible that screen time results directly in short sleep duration via melatonin suppression by the blue light of screen devices, thus resulting in a desynchronization of the circadian rhythm [47]. However, among older boys, the relative contributions of MVPA and screen time follow the same pattern as in the other subgroups, except for a negligible 1% increase in the relative contribution of sleep duration. Regardless, there is an aging effect that should be acknowledged, according to which it could be normal for physical activity and sleep to decline as teenagers age. Future studies with a longer follow up are necessary

to examine change in movement behaviours over time across different subgroups. Nevertheless, our findings underscore the need for interventions to encourage active living and sufficient sleep duration among adolescents.

Association between change in movement behaviour composition and change in depressive symptoms

Our results showed that increasing sleep duration relative to remaining behaviours was associated with lower depressive symptoms whereas increasing screen time relative to the remaining behaviours was associated with higher depressive symptoms among all subgroups. Increasing MVPA relative to the remaining behaviours was associated with lower depressive symptoms in older girls only. The results of this study are consistent with recent studies indicating that sleep duration and recreational screen time are stronger predictors of mental health among adolescents than physical activity [48-51]. Using a representative sample of over 10,000 Canadian middle and high school students, we have previously found that meeting the screen time recommendation alone or the sleep duration recommendation alone were strongly associated with lower odds of suicidal ideation and suicide attempts, particularly among girls [49]. Similarly, Walsh *et al.* [50] and Guerrero *et al.* [48] found that meeting the screen time and sleep duration recommendations were strongly associated with better cognitive function and less impulsivity in a representative sample of US children, respectively, while meeting physical activity recommendations was not. However, these studies were limited by their cross-sectional design. Studies looking at the prospective association between changes in adherence to movement behaviours and mental health indicators have found that adherence to the sleep duration recommendation was the most consistent predictor of lower depression symptoms and flourishing among adolescents [13, 52]. The present

study extends previous evidence by using compositional data analysis, which provides estimates that are fully adjusted for all time use and permit an exploration of the combined associations of the different movement behaviours.

The finding that increasing MVPA relative to the remaining behaviours was associated with lower depressive symptoms in older girls only is interesting and deserves further investigation. The benefits of regular physical activity on adolescent mental health are well known [53]. Boys are known to be more active than girls, and the prevalence of adherence to MVPA decreases with age [54-56]. On the other hand, girls are well known to have more mental health problems than boys and experience of mental health problems increases with age [57]. Sampasa-Kanyinga *et al.* [49] have recently shown that older girls had the lowest prevalence of adherence to the physical activity recommendation and reported more suicidal ideation and suicide attempts than older boys, young girls, and younger boys. In parallel, research has shown that physical activity is prospectively associated with lower depressive symptoms among adolescents [58]. Moreover, physical activity has been identified as an effective first-line treatment for mild-to-moderate depression, improving depressive symptoms to a comparable extent as pharmacotherapy and psychotherapy [59, 60]. Our results suggest that increasing physical activity could be a good behavioural intervention to prevent depressive symptoms among older girls. It is difficult to speculate on what could explain such difference given the novel nature of our findings. It is possible that MVPA could be more beneficial to older girls given their greater drop in activity levels and vulnerability to depressive symptoms. Future research is needed to better understand why and how increasing MVPA relative to the remaining behaviours is associated with lower depressive symptoms among older girls only.

Compositional isotemporal substitution

Our isotemporal substitution estimates suggest that decreasing screen time by 60 minutes/day and replacing that time with 60 minutes of additional sleep is associated with the largest changes in depressive symptoms across all subgroups. These findings are interesting because research has shown that heavy screen time occurs in tandem with short sleep duration among adolescents [44, 45]. Our results suggest that getting sufficient sleep duration and decreasing recreational screen time could be good behavioural targets to prevent depressive symptoms among adolescents. However, this is challenging, because with rapid progress in information communication and technology, screen time, particularly time spent using electronic media and video games, have become omnipresent in the daily life of most adolescents [61, 62]. In parallel, heavy use of electronic media, such as use of social networking sites, particularly around bedtime has been shown to result in short sleep duration [63]. It is possible that heavy screen time displaces sleep duration, as it could shift circadian timing to a latter point. It is also possible that the blue light from electronic media explains short sleep duration among adolescents [63]. As such, it is possible that effective interventions that reduce screen time also improve sleep duration among adolescents. This is particularly important because short sleep duration is increasingly widespread among adolescents [64]. This supports the need for the development, implementation and evaluation of sleep promotion interventions (especially within schools where students could be provided equitable access), as school-based sleep programs have previously shown potential long-term benefits [65].

Strengths and limitations

This study has several strengths worth mentioning. First, it uses a large and linked sample of adolescents, thus supporting temporality between movement behaviours and depressive symptoms. Second, we used compositional data analysis, which has been identified as the most appropriate method to account for the co-dependent nature of movement behaviour data [15]. Third, our analyses are stratified by age groups and gender. Differences by subgroup help inform the development of tailored interventions intended to prevent depressive symptoms among adolescents (e.g., by finding ways to increase MVPA levels in older girls).

Our study also has several limitations that should be recognized. First, the analyses are based on self-reported measures, thus subject to desirability and recall biases. Second, our study did not include light-intensity physical activity, because it is not available in COMPASS, but is an important component of daily movement behaviour. Future studies including this component are needed to examine how the full 24-hour movement behaviours impact upon depressive symptoms. Third, it is important to note that we did not include non-screen sedentary behaviours (e.g., reading a book, driving a car) because there were not available. Finally, it is possible that the strength of the associations reported herein are biased because the survey excluded adolescents who dropped out of school, adolescents experiencing homelessness, or institutionalized adolescents. These excluded groups are well known to have greater risk of engaging in health compromising behaviours and experiencing mental health problems [66, 67].

CONCLUSION

To the best of our knowledge, the present study is the first to examine prospective associations between movement behaviours and depressive symptoms among adolescents within a compositional data analysis framework among different age/gender subgroups of adolescents.

Results suggest that increased sleep duration and reduced screen time are important determinants of lower depressive symptoms among adolescents. Increased awareness among different stakeholders, including parents, schools, health services providers, and adolescents themselves about the potential value of adequate sleep and engaging in less recreational screen time may help prevent mental health problems in this age group. School-based interventions promoting healthy active living and sufficient sleep are also needed as behavioural strategies to prevent mental health problems among adolescents. Future research is also needed to better understand some of the differences among subgroups.

DECLARATIONS

Ethics approval and consent to participate

The COMPASS study was approved by the University of Waterloo Office of Research Ethics (ORE #: 30118) and all participating school boards. All students attending participating schools were invited to participate using active-information passive-consent parental permission protocols. Students could withdraw from the study at any time.

Consent for publication

Not applicable.

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

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

HS, IC, GSG, IJ, JW, DD, and JPC participated in the conception of the study. HS and DD conducted statistical analyses. HS wrote the first version of the manuscript. IJ and DD substantially contributed to the methods and interpretation of results. STL lead the COMPASS host study, and KAP lead the COMPASS Mental Health pilot study. IC, GSG, IJ, JW, DD, KAP, STL, and JPC provided comments related to the presentation of the findings and critically reviewed the manuscript. All authors read and approved the final manuscript.

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Table 1. Descriptive characteristics of the study sample.

Characteristics	Total population	Younger boys	Younger girls	Older boys	Older girls
2017 sample	N=14,620	N=2,836	N=2,264	N=5,060	N=4,460
Age (mean (SD))	14.92 (1.15)	13.62 (0.64)	13.65 (0.62)	15.59 (0.66)	15.62 (0.69)
Race/ethnicity (%)					
White	10,722 (73.3)	2,168 (76.4)	1,774 (78.4)	3,621 (71.6)	3,159 (70.8)
Black	392 (2.7)	67 (2.4)	70 (3.1)	119 (2.4)	136 (3.0)
Asian	1,723 (11.8)	262 (9.2)	152 (6.7)	726 (14.3)	583 (13.1)
Latin American/Hispanic	395 (2.7)	69 (2.4)	55 (2.4)	135 (2.7)	136 (3.0)
Other	1,388 (9.5)	270 (9.6)	213 (9.4)	459 (9.1)	446 (10.0)
BMI (mean (SD))	21.43 (4.05)	20.45 (3.90)	20.67 (4.00)	21.66 (3.87)	22.17 (4.17)
BMI z-score (mean (SD))	0.25 (0.99)	0.26 (1.01)	0.22 (0.96)	0.21 (1.02)	0.31 (0.94)
Depressive symptoms score (mean (SD))	8.05 (5.76)	8.22 (5.87)	5.89 (4.48)	9.81 (6.26)	7.04 (5.02)
Depressive symptoms z-scores (mean (SD))	-0.04 (0.99)	-0.01 (1.01)	-0.41 (0.77)	0.26 (1.07)	-0.22 (0.86)
Average overall sum of times recorded for each person (%)					
MVPA	9.5	9.2	9.2	8.6	8.6
Screen time	40.1	36.8	36.8	41.8	41.8
Sleep duration	50.4	53.9	53.9	49.7	49.7
2018 sample	N=14,620	N=2,836	N=2,264	N=5,060	N=4,460
Age (mean (SD))	15.91 (1.15)	14.62 (0.68)	14.67 (0.66)	16.58 (0.67)	16.61 (0.70)
Race/ethnicity (%)					
White	10722 (73.3)	2168 (76.4)	1774 (78.4)	3621 (71.6)	3159 (70.8)
Black	392 (2.7)	67 (2.4)	70 (3.1)	119 (2.4)	136 (3.0)
Asian	1723 (11.8)	262 (9.2)	152 (6.7)	726 (14.3)	583 (13.1)
Indigenous	553 (3.8)	87 (3.1)	78 (3.4)	200 (4.0)	188 (4.2)
Latin American/Hispanic	395 (2.7)	69 (2.4)	55 (2.4)	135 (2.7)	136 (3.0)
Other	835 (5.7)	183 (6.5)	135 (6.0)	259 (5.1)	258 (5.8)
BMI (mean (SD))	21.99 (4.03)	21.08 (3.62)	21.47 (4.08)	22.05 (3.87)	22.76 (4.26)
BMI z-scores (mean (SD))	0.23 (0.99)	0.27 (0.96)	0.27 (0.95)	0.11 (1.06)	0.32 (0.95)
Depression (mean (SD))	8.83 (5.99)	9.72 (6.32)	6.78 (5.14)	10.30 (6.22)	7.63 (5.33)
Depression z-scores (mean (SD))	-0.00 (1.00)	0.15 (1.06)	-0.34 (0.86)	0.25 (1.04)	-0.20 (0.89)
Average sum of times recorded for each student (%)					
MVPA	8.3	8.2	8.2	7.2	7.2
Screen time	42.0	39.4	39.4	42.7	42.7
Sleep duration	49.7	52.4	52.4	50.2	50.2

BMI, body mass index; MVPA, moderate-to-vigorous physical activity; SD, standard deviation.

Table 2. Differences in movement behaviour composition over time.

Characteristics	**Total population** (N=14,620)	**Younger boys** (N=2,836)	**Older boys** (N=2,264)	**Younger girls** (N=5,060)	**Older girls** (N=4,460)
Overall difference in composition over time					
F	106.200	37.688	30.376	42.628	22.447
df	2, 146	2, 283	2, 506	2, 226	2, 446
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Mean log-ratio difference in behaviours over time*					
MVPA	-0.133 (-0.107; -0.062)	-0.112 (-0.062; -0.157)	-0.174 (-0.130; -0.221)	-0.107 (-0.054; -0.156)	-0.111 (-0.160; -0.06)
Screen time	0.048 (0.041; 0.056)	0.069 (0.052; 0.085)	0.021 (0.007; 0.034)	0.102 (0.079; 0.126)	0.040 (0.026; 0.057)
Sleep duration	-0.012 (-0.007; -0.017)	-0.028 (-0.018; -0.038)	0.008 (0.001; 0.016)	-0.039 (-0.051; -0.027)	-0.012 (-0.020; -0.004)

df: degrees of freedom; MVPA: moderate-to-vigorous physical activity. *These changes reflect changes in the relative contribution of the movement behaviours to the overall movement behaviour composition. A log-ratio difference of -0.133 indicates an average within-person reduction of 13.3% between the two time-points. That means it is taking up 13% less of the total time spent in MVPA + screen time + sleep duration.

Table 3. Longitudinal associations between changes in first pivot coordinate coefficient (standardized betas) and change in depressive symptoms.

Models[a]	**Younger boys** (N=2,836)		**Older boys** (N=2,264)		**Younger girls** (N=5,060)		**Older girls** (N=4,460)	
	Std_β (SE)	**p value**	**Std_β (SE)**	**p value**	**Std_β (SE)**	**p value**	**Std_β (SE)**	**p value**
Model 1								
Sleep vs. remaining	-0.196 (0.025)	<0.001	-0.209 (0.022)	<0.001	-0.215 (0.028)	<0.001	-0.154 (0.023)	<0.001
Screen time vs. remaining	0.218 (0.026)	<0.001	0.233 (0.023)	<0.001	0.241 (0.031)	<0.001	0.224 (0.024)	<0.001
MVPA vs. remaining	0.011 (0.020)	0.577	0.002 (0.014)	0.906	0.034 (0.023)	0.143	-0.081 (0.015)	<0.001
Model 2								
Sleep vs. remaining	-0.196 (0.025)	<0.001	-0.208 (0.022)	<0.001	-0.216 (0.028)	<0.001	-0.151 (0.023)	<0.001
Screen time vs. remaining	0.218 (0.026)	<0.001	0.230 (0.023)	<0.001	0.243 (0.031)	<0.001	0.221 (0.024)	<0.001
MVPA vs. remaining	0.011 (0.020)	0.578	0.004 (0.014)	0.792	0.033 (0.023)	0.153	-0.080 (0.015)	<0.001

Std_β: standardized beta; SE: standard error.

[a]All models are adjusted for 2017 movement behaviour composition and baseline depressive symptoms. Model 2 is further adjusted for race/ethnicity and time 1 BMI z-scores.

Table 4. Estimated changes in follow-up depressive symptoms associated with 60-minute reallocations from the mean baseline movement behaviour composition.*

	Younger boys (N=2,836)	**Older boys** (N=2,264)	**Younger girls** (N=5,060)	**Older girls** (N=4,460)
Reallocation	**Change (95% CI)**	**Change (95% CI)**	**Change (95% CI)**	**Change (95% CI)**
+ Sleep duration; − MVPA	-0.033 (-0.065; -0.001)	-0.026 (-0.046; -0.005)	-0.049 (-0.079; -0.019)	0.025 (0.006; 0.044)
+ Screen time; − MVPA	0.026 (-0.005; 0.057)	0.024 (0.005; 0.044)	0.019 (-0.009; 0.048)	0.072 (0.054; 0.090)
+ Sleep duration; − Screen time	-0.065 (-0.080; -0.050)	-0.054 (-0.065; -0.044)	-0.075 (-0.093; -0.057)	-0.052 (-0.064; -0.039)
+ MVPA; − Screen time	-0.037 (-0.054; -0.020)	-0.030 (-0.040; -0.020)	-0.035 (-0.054; -0.016)	-0.054 (-0.066; -0.043)
+ Screen time; − Sleep duration	0.062 (0.047; 0.076)	0.053 (0.043; 0.063)	0.072 (0.054; 0.089)	0.050 (0.038; 0.062)
+ MVPA; − Sleep duration	0.031 (0.015; 0.048)	0.027 (0.017; 0.038)	0.044 (0.025; 0.063)	0.000 (-0.012; 0.012)

MVPA, moderate-to-vigorous physical activity; CI, confidence interval.

All models are adjusted for race/ethnicity, BMI z-scores, baseline movement behaviour composition, and baseline depressive symptoms.

*These changes are expressed as proportions of the pooled SD. Reallocation of 60 minutes to one activity (+) from another activity (-) and resulting change in depressive symptoms, which could be either significant (decrease (-) or increase (+) while the 95% confidence intervals do not include value 1) or not significant (when the 95% confidence intervals include value 1).

Figure 1. Participant flow-diagram.

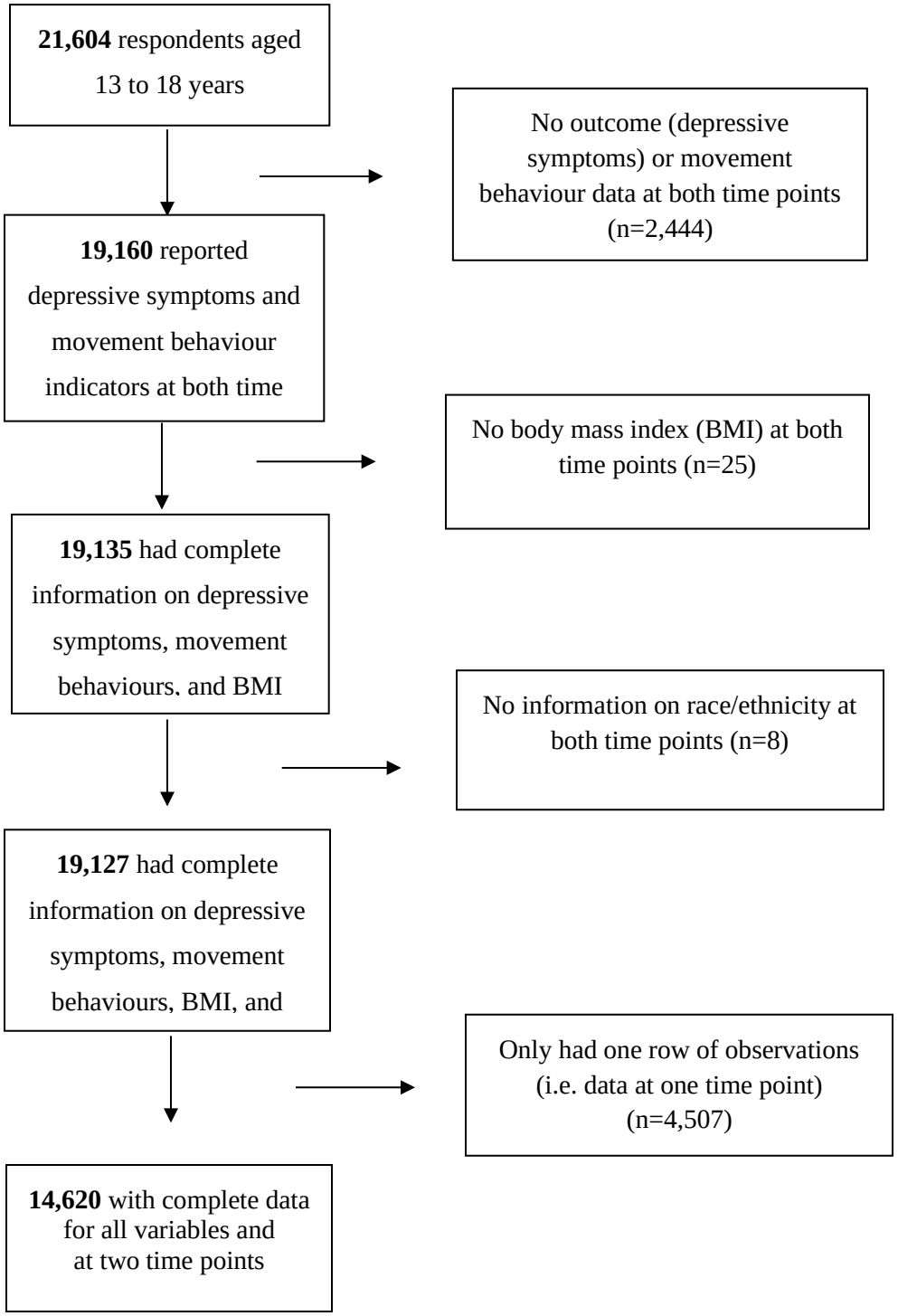
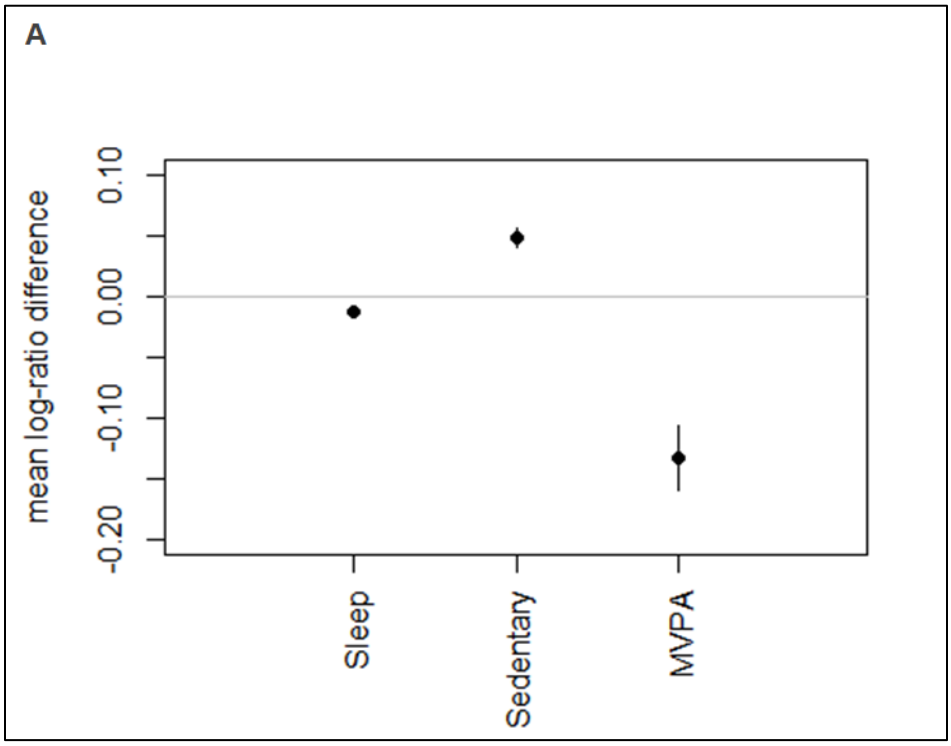
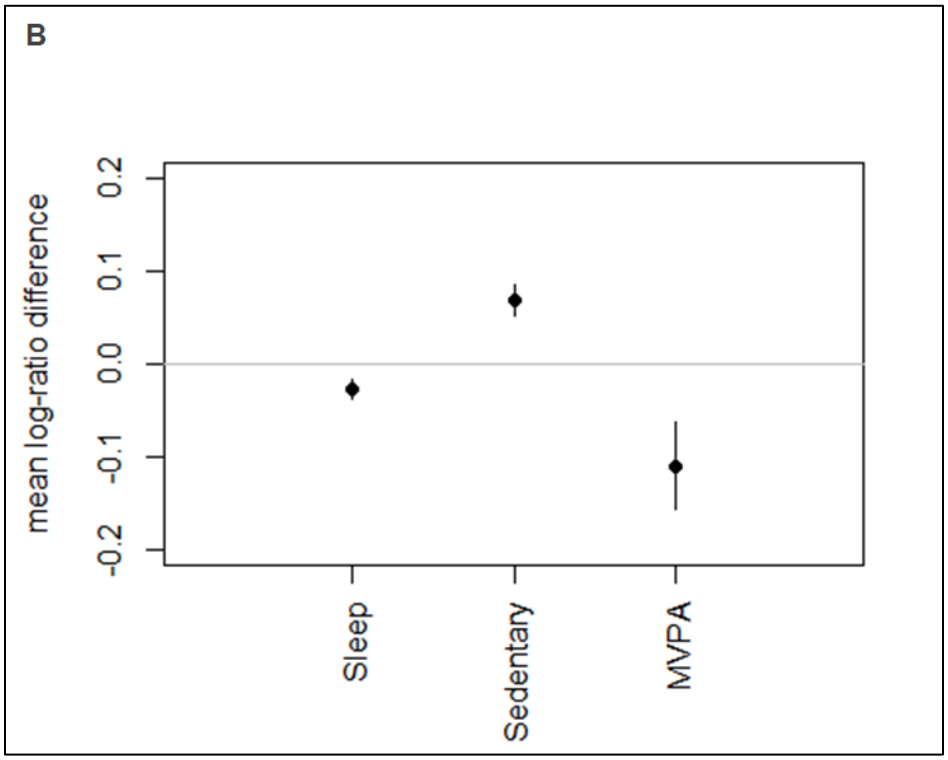


Figure 2. Change in movement behaviours over time.

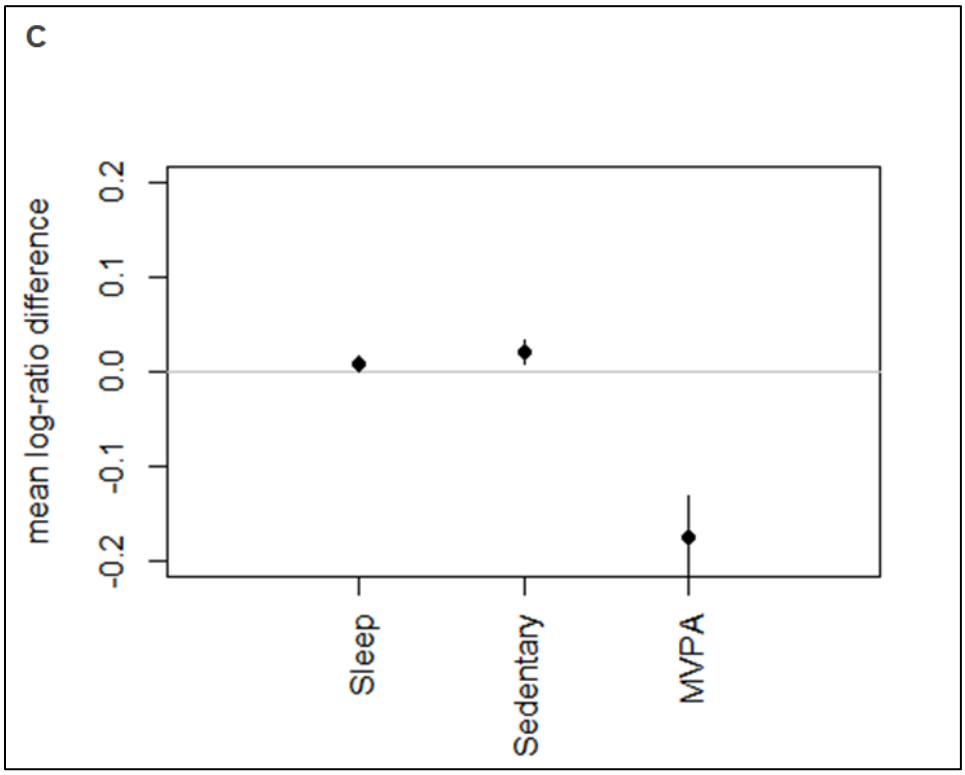
Panel A. Total sample (n=14,620)



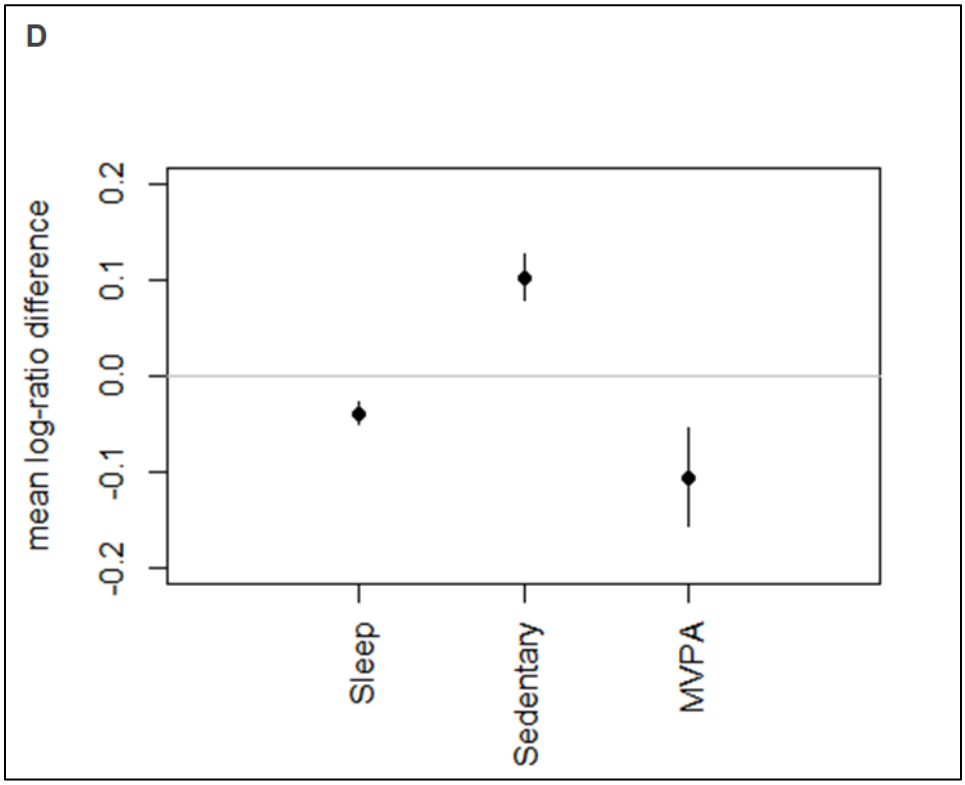
Panel B. Younger boys (n=2,836)



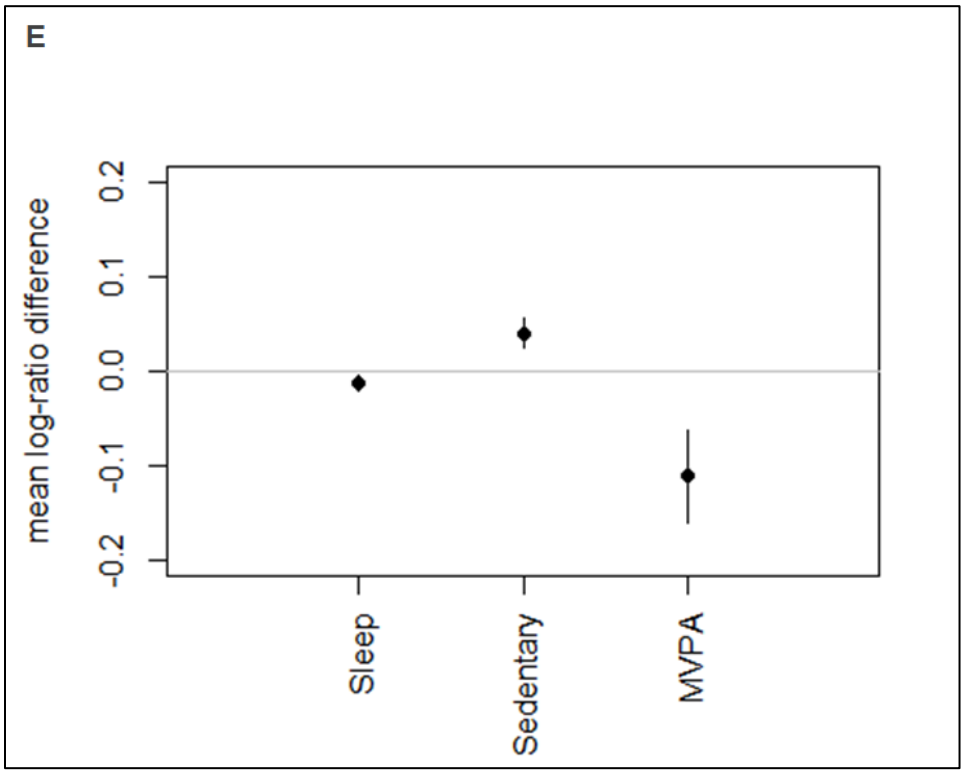
Panel C. Older boys (n=2,264)



Panel D. Younger girls (n=5,060)



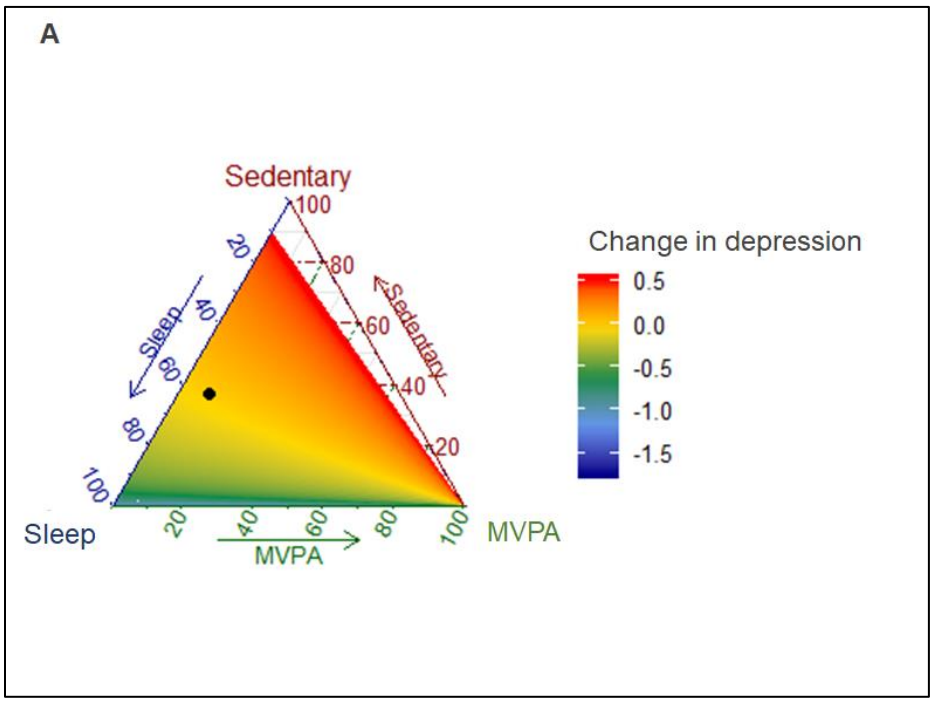
Panel E. Older girls (n=4,460)



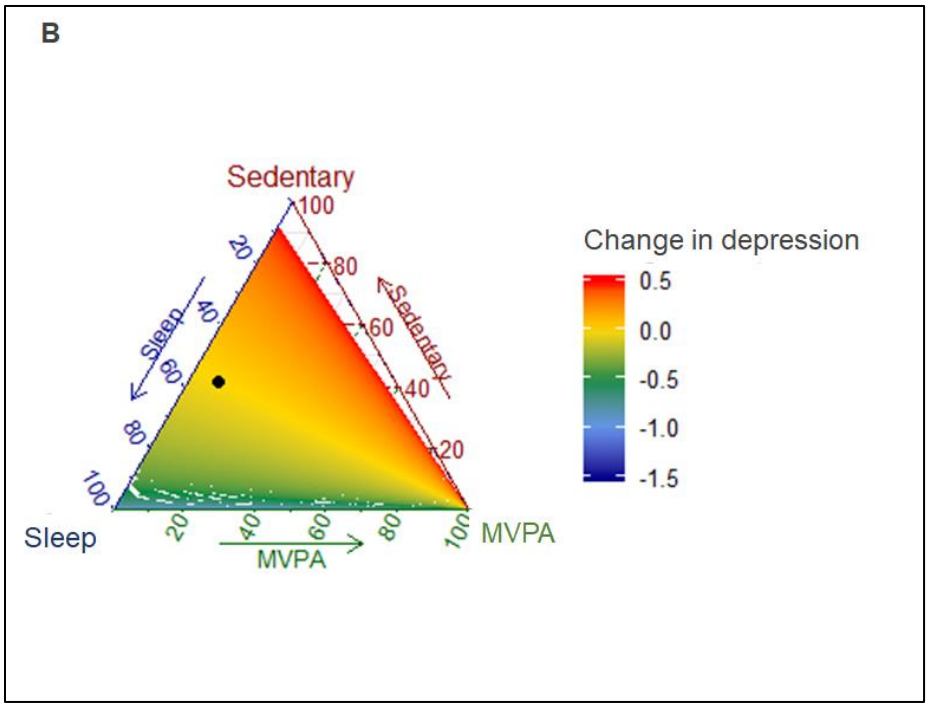
Note: Graphs display the mean log-ratio difference plots and their 95% confidence intervals for change over time of movement behaviours in the total sample (Panel A), younger boys (Panel B), older boys (Panel C), younger girls (Panel D), and older girls (Panel E). MVPA, moderate-to-vigorous physical activity. These changes reflect changes in the relative contribution to the movement behaviours to the overall movement behaviour contribution.

Figure 3. Data frame showing the predictive changes in composition and the predicted change in depressive symptoms.

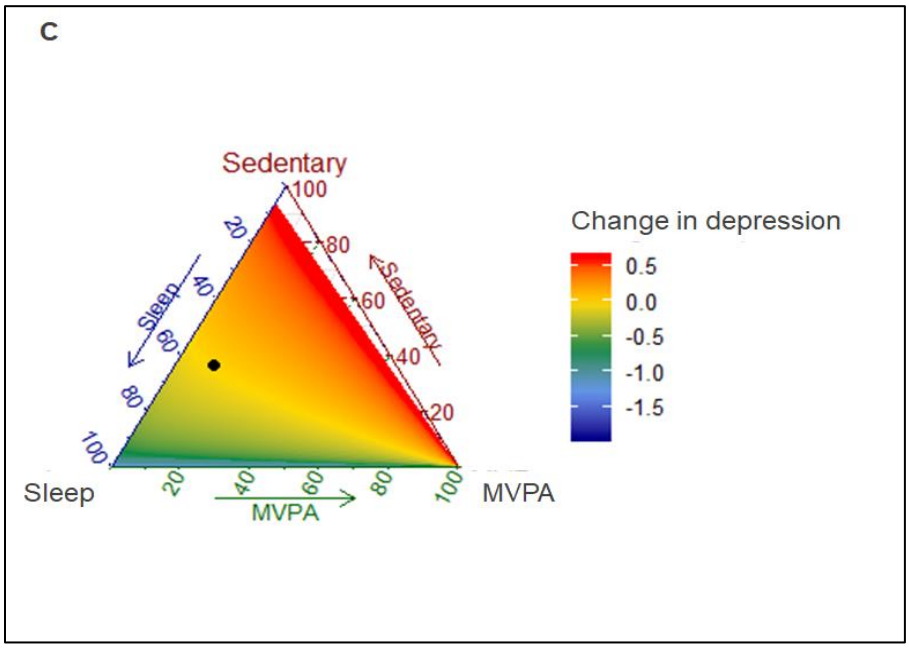
Panel A. Younger boys (n=2,836)



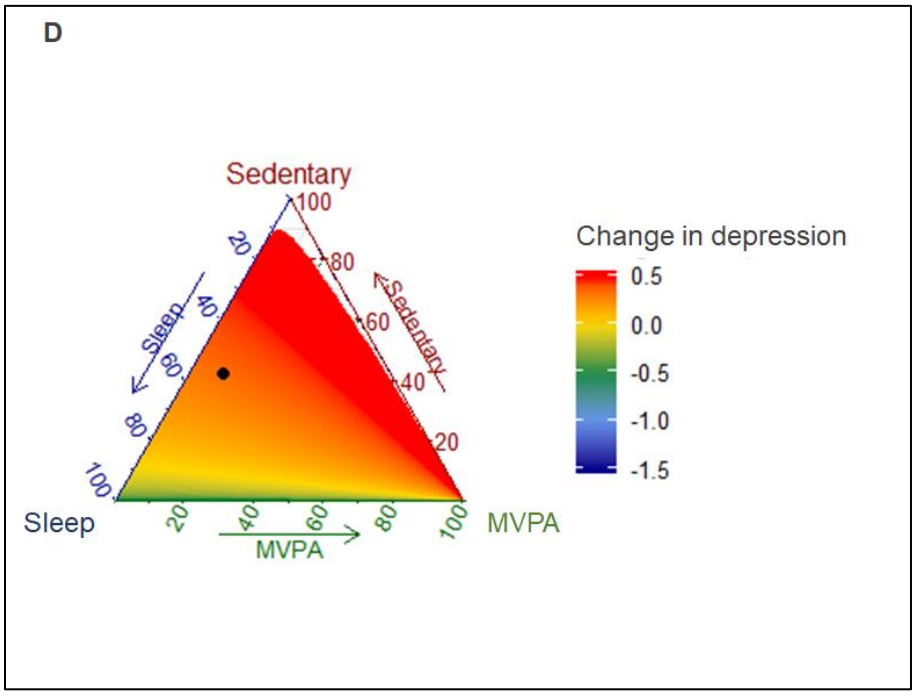
Panel B. Older boys (n=2,264)



Panel C. Younger girls (n=5,060)



Panel D. Older girls (n=4,460)



Black dot represents mean composition at time 1.

The datapoints are color-coded according to their model-predicted change in depressive symptoms such that yellow=no change, red=increased depressive symptoms, blue=decreased depressive

symptoms. Change away from the centre (mean composition at time 1) towards each activity informs the presence or absence of variation in color, which suggest no change, increased or decreased depressive symptoms.

Chapter 7

GENERAL DISCUSSION

7.1 Summary of key findings

This dissertation includes 5 research studies (one systematic review, 4 cross-sectional studies, and one longitudinal study) that used data from 3 large and diverse samples of children and adolescents to examine the associations between combinations of physical activity, screen time, and sleep duration with depressive symptoms and other mental health symptoms. A summary of key findings from those studies (presented in Chapters 2 through 6 of this dissertation) is outlined in Table 7.1.

Table 7.1: Summary of research findings from Chapters 2 to 6.

Study	**Key findings**
Chapter 2 (study 1)	• Only 13 studies have examined mental health indicators in the context of the 24-hour movement guidelines among children and adolescents. • The majority (80%) of papers used traditional regression models to examine the associations between 24-hour movement behaviours and mental health indicators in children and adolescents. • There were favourable associations between meeting all 3 recommendations and better mental health indicators among children and adolescents when compared with meeting none of the recommendations. • Meeting the screen time and sleep duration recommendations seemed to be more strongly associated with mental health than meeting the physical activity recommendation. • Only two studies have examined and documented a dose-response gradient between the number of recommendations met and mental health outcomes.

Study	Key findings
Chapter 3 (study 2)	• Compared to meeting no recommendations, meeting all three recommendations was associated with a lower risk of total, internalizing, and externalizing problems. • The associations were mainly explained by meeting the screen time and sleep duration recommendations. • There was a dose-response gradient from meeting none of the recommendations up to meeting two recommendations, but not from two to three recommendations. • Meeting the physical activity recommendation was associated with higher externalizing behaviour.
Chapter 4 (study 3)	• Compared to meeting none of the recommendations, meeting all 3 movement behaviour recommendations was associated with lower anxiety and depressive symptoms. • Meeting the screen time + sleep duration recommendations had the strongest association with anxiety and depressive symptoms, followed by meeting the sleep duration recommendation only for both anxiety and depressive symptoms. • Meeting the sleep duration recommendation alone was as beneficial for the outcomes as meeting all 3 recommendations (i.e. getting sufficient sleep + sufficient physical activity + low screen time).
Chapter 5 (study 4)	• Meeting individual recommendations or combinations of recommendations were differentially associated with suicidal ideation and suicide attempts between adolescent boys and girls and younger and older children (three-way interactions statistically significant for both outcomes). • Meeting all 3 recommendations was associated with lower odds of suicidal ideation and suicide attempts among boys aged 15 to 20 years, but not those aged 11 to 14 years nor girls in both age groups. • 11 to 14-year-olds were more likely than 15 to 20-year-olds to meet all three recommendations. • The probability of suicidal ideation and suicide attempts among students who met all 3 movement guidelines significantly decreased with age.

Study	Key findings
Chapter 6 (study 5)	• The association between change in movement behaviour composition and change in depressive symptoms significantly varied by age and by sex. • Increasing sleep duration relative to the remaining behaviours (i.e. screen time and MVPA) was associated with lower depressive symptoms among all age subgroups. • Increasing screen time relative to the remaining behaviours (i.e. MVPA and sleep duration) was associated with higher depressive symptoms among all age subgroups. • Increasing MVPA relative to the remaining behaviours (i.e. screen time and sleep duration) was associated with lower depressive symptoms in older girls only. • Isotemporal substitution estimates indicated that decreasing screen time by 60 minutes/day and replacing that time with 60 minutes of additional sleep is associated with the largest change in depressive symptoms across all age subgroups.

Collectively, the results from cross-sectional studies (Chapter 3 through 5) showed that meeting all three recommendations was associated with lower odds of depressive symptoms and other mental health outcomes. However, this association appeared to be mainly driven by meeting the sleep duration recommendation, and to a lesser extent the screen time + sleep duration recommendations. There was a dose-response gradient from meeting none of the recommendations up to meeting two recommendations. Results from the longitudinal study (Chapter 6) using compositional data analysis provided further evidence suggesting that increasing sleep duration relative to the remaining behaviours (i.e. screen time and MVPA) was associated with lower depressive symptoms among all age/sex subgroups. Results further indicated that predicted changes in depressive symptoms were strongest and most beneficial when removing screen time while adding sleep duration. Finally, results from both cross-sectional and longitudinal analyses suggest that age and sex moderate some of the associations between movement behaviour

recommendations (individual or combined) and mental health indicators, depending on the type of movement behaviour and the type of mental health indicators.

7.2 Comparison with other relevant literature

The findings in this thesis are consistent with previous studies that showed that meeting all 3 movement behaviour recommendations is associated with a lower risk of depressive symptoms and other mental health problems in children and adolescents [1-6]. These findings are in line with compelling evidence that accumulating sufficient physical activity [7, 8], limiting recreational screen time [9-11], and getting enough sleep [12] are associated with a variety of physical, mental, and social health indicators among children and adolescents, and provide further support to the 24-hour movement guidelines. However, the results further indicated that increasing sleep duration relative to the remaining behaviours (i.e. physical activity and screen time) was associated with lower depressive symptoms. Whereas, increasing screen time relative to the remaining behaviours (i.e. physical activity and sleep duration) was associated with higher depressive symptoms. Increasing MVPA relative to the remaining behaviours (i.e. screen time and sleep duration) was associated with lower depressive symptoms in older girls only. These results are consistent with recent studies indicating that sleep duration and recreational screen time are stronger predictors of mental health problems among adolescents than physical activity [4, 5, 13-15].

Contrary to the literature pointing towards MVPA as being the most important part of the movement behaviour composition for physical health outcomes, our results suggest that it is sleep duration and to some extent sleep and screen time that are the most important behaviours in regards to mental health outcomes. These findings provide further support for the 24-hour movement

behaviour guidelines, representing a paradigm shift emphasizing the integration of all movement behaviours occurring over a whole day, thus shifting the focus from the individual components to emphasize the whole [34]. These findings not only support the need for awareness and behaviour change in children and adolescents, but also offer an opportunity for interdisciplinary collaboration, policy change, and refocused service provision. Our findings also support the need to think of health quite broadly (encompassing physical, social, and emotional well-being) and not to pay attention to one or two specific health outcomes. While the generalizability of our findings may be limited to Canadian and US children and adolescents, replication studies from other settings are needed to confirm results.

The findings that the association between meeting all three movement behaviour recommendations and lower odds of depressive symptoms and other mental health outcomes seem to be mainly driven by meeting the sleep duration recommendation warrants further investigation. Although it is well known that sleep is strongly associated with mental health indicators in children and adolescents, little is known about the mechanisms that could explain this association. Bake *et al.* [16] have nicely summarized the mechanisms underlying the association between sleep and mental health in adolescence. Briefly, they indicated that the mechanisms linking sleep to mental health are biological, psychological, and social [16]. Biological mechanisms include genetic vulnerability and neurotransmitter polymorphisms (particularly polymorphisms and dysregulation in serotonin, dopamine, and circadian clock genes), dysregulation of corticolimbic and mesolimbic brain circuits, cortisol reactivity to stress, higher levels of inflammatory cytokines (e.g. interleukin IL-6 and C-reactive protein) [17], biased memory consolidation [18], and changes in sleep architecture [19]. Psychological mechanisms include cognitive inflexibility, interpretational biases, judgment

biases, negative attribution styles, worry, rumination, biased attention to threat, dysfunctional beliefs and attitudes about sleep, and misperception of sleep deficit [16]. Social mechanisms include reduced/impaired social interactions, unhelpful parenting behaviours, and family stress [16].

The lack of significant associations between physical activity and mental health indicators across several chapters of this thesis is intriguing. It is possible that the poor measure quality (self-reported) of physical activity explains, at least in part, the lack of association between meeting the physical activity recommendation and mental health indicators. Previous studies have shown that different measurement tools (e.g., device-based vs. subjective measures) lead to different findings [20-23]. For example, in a representative sample of Canadian adolescents, Colley *et al.* [21] found that self-reported and accelerometer-measured estimates of physical activity are poorly correlated, and that adolescents self-report considerably more physical activity than what they accumulate on the accelerometer. However, all the movement behaviours were self-reported in this thesis, and it is difficult to confirm if the error is greater with physical activity than with sleep duration and screen time. It is also possible that other physical activity intensities, such as light physical activity, are favourably associated with mental health outcomes. For example, a prospective study using repeated device-based measures of physical activity found that light physical activity was more consistently associated with lower depressive symptoms in adolescence than total physical activity and MVPA [24]. Nevertheless, physical activity should not be neglected in the package for good health, because its associations with a wide range of health benefits in children and adolescents are well known [7, 8]. Physical activity helps develop healthy musculoskeletal tissues, cardiovascular system, cognitive functioning, and helps maintain a healthy body mass [25]. It also

helps with the social development of children and adolescents by providing opportunities for self-expression, building self-confidence, social interaction and integration [25, 26]. Furthermore, research has shown that physical activity could prevent and/or alleviate depressive symptoms in children and adolescents [27-29]. More specifically, physical activity has been identified as an effective first-line treatment for mild-to-moderate depression, improving depressive symptoms to a comparable extent to pharmacotherapy and psychotherapy [30, 31]. Future research, particularly longitudinal studies with device-based measures of physical activity, is needed to disentangle these findings.

Results from Study 4 showed that meeting all 3 guideline recommendations was associated with lower odds of suicidal ideation and suicide attempts among boys aged 15 to 20 years, but not those aged 11 to 14 years nor girls in both age groups. Results further indicated that at younger ages, there was no difference in boys' odds of suicidal ideation and suicide attempts between meeting all 3 guideline recommendations and meeting none of the recommendations. However, at older ages, boys who meet all 3 guideline recommendations had lower odds of suicidal ideation and suicide attempts compared to those who meet none of the recommendations. Moreover, findings from Study 5 indicate that increasing MVPA relative to the remaining behaviours (i.e. screen time and sleep duration) is associated with lower depressive symptoms in older girls only. The observed age and sex differences across studies is interesting and deserves further investigations. The novelty of the findings makes it difficult to explain these differences. However, it is possible that age and sex differences in adherence to the movement behaviour recommendations and experiences of mental health problems, explains these differences. Indeed, research has shown that younger children are more likely than their older counterparts to meet the 24-hour movement

guidelines [32]. Among younger children, boys are more likely than girls to meet all 3 recommendations; whereas, among adolescents, there are no gender differences in meeting all 3 recommendations [32]. Moreover, boys are more active than girls in general, and the prevalence of adherence to MVPA decreases with age [32-34]. In parallel, girls are well known to have more mental health problems than boys and experience of mental health problems increases with age [35]. Future research is needed to disentangle the observed age and sex differences.

7.3 Contributions to the literature

The findings from this thesis represent original contributions to the psychiatric epidemiology and healthy active living literature for children and adolescents and have filled the majority of research gaps identified by the systematic reviews conducted by Saunders *et al.* [36] and by Study 1 of this dissertation. Saunders *et al.* [36] have previously identified three important gaps. First, they found that the existing evidence was mainly based on physical health indicators such as obesity, urging the need for mental and social health indicators to be considered in future studies [36]. With only 13 studies examining the associations between meeting the movement guidelines and mental health indicators, the present thesis has documented this research gap via the systematic review and has satisfactorily addressed it by examining both the cross-sectional and longitudinal associations between meeting the movement behaviour recommendations and mental health indicators in 3 different large samples of children and adolescents from the United States and Canada. Second, they found that it was unclear whether meeting a given specific guideline recommendation was associated with more health benefits than meeting the others [36]. Although meeting all 3 recommendations was associated with lower mental health problems among children and adolescents, the present thesis identified meeting the sleep duration and screen time

recommendations as being the most important determinants of mental health indicators among children and adolescents (at least in my studies). Third, researchers have mainly compared meeting all 3 recommendations versus meeting none, ignoring the potential influence of intermediate combinations [36]. This research gap has also been documented in Chapter 2 of this dissertation, where only two studies have examined all different intermediate combinations between physical activity, screen time, and sleep duration. Findings from Chapter 3 to Chapter 6 have examined all the intermediate combinations and have found that meeting the sleep duration only or meeting both sleep duration + screen time were strongly associated with positive mental health outcomes.

As already stated, the majority of research gaps identified in Chapter 1 have also been filled by subsequent studies (i.e. Chapter 3 to 6) of this dissertation. First, the studies included in the systematic review were all cross-sectional in nature, thus limiting confirmation on the temporality between movement behaviours and mental health indicators. The prospective study presented in Chapter 6 used a large and linked data set of Canadian high school students, thus supporting the temporality between movement behaviours and depressive symptoms. Second, the majority (80%) of papers used traditional regression models to examine the associations between 24-hour movement behaviours (sleep duration, sedentary time, and physical activity) and mental health indicators in children and adolescents. Chapter 6 used compositional data analysis, which has been identified as the most appropriate method to account for the co-dependent nature of movement behaviour data. Third, only two studies have examined and documented a dose-response gradient between the number of recommendations met and mental health outcomes [6, 37], suggesting that the greater number of recommendations met was associated with a lower risk of mental health problems. In the study presented in Chapter 3, results suggest a dose-response gradient from

meeting none of the recommendations up to meeting two recommendations, but not from two to three recommendations. Finally, evidence in relation to each specific mental health indicator was limited. The studies presented in Chapters 3 through 6 have provided evidence of the association between movement behaviours and a wide range of mental health outcomes, including more global measures such as internalizing and externalizing behaviours (Chapter 3) and more specific outcomes such as psychological distress (Chapter 4), suicidality (Chapter 5), and depressive symptoms (Chaper 6).

7.4 Strengths and Limitations

The present dissertation has several strengths. First, it included a systematic review that identified gaps in the literature that subsequent studies were designed to fill. Second, it included both cross-sectional and longitudinal studies, offering some diversity, replication, and consistency across findings. The longitudinal design provided more confidence about the temporality between movement behaviours and mental health indicators. Third, three different large data sources were used, encompassing children and adolescents from the US and Canada. This expands the external validity of the research findings of this dissertation. Fourth, most of the mental health outcomes were measured using validated tools, thus reducing the possibility of information bias associated with the outcome measures. Fifth, this research was able to examine age and sex differences in the association between movement behaviours and mental health outcomes, whereas previous studies have focused on pooled analyses [38]. Finally, this research is among the first to use longitudinal compositional data analysis in the context of 24-hour movement guidelines and mental health indicators among adolescents. Indeed, compositional data analysis has been identified as the most appropriate analytical approach to examine the association between movement behaviours and

health indicators because time is finite over a period of 24 hours, and it solves the issue of co-dependency among movement behaviours [39-41].

There are also several limitations that warrant consideration. First, movement behaviours were self-reported in the studies, thus have the potential for recall and social desirability bias. It is likely that these biases are non-differential and underestimate the strength of the associations. Evidence has shown that children and adolescents tend to report more physical activity than they accumulate on the accelerometer [21, 42]. Similarly, they also tend to report more sleep duration compared with actigraphy monitoring [43, 44]. Future studies using device-based assessment of the 24-hour movement behaviours, particularly physical activity and sleep duration are needed to replicate the findings of this dissertation. Second, although one study used a longitudinal design, causality cannot be confirmed, and the possibility of reverse causation cannot be ruled out. Thus, it is possible that mental health problems explain short sleep duration and excessive screen time among children and adolescents. Research has provided evidence of a bidirectional relationship between both sedentary behaviour [45, 46] and sleep [47, 48] with mental health outcomes among children, adolescent, and adult populations. Third, research has shown that movement behaviours differentially impact upon mental health following physical activity intensities (e.g. light physical activity and vigorous physical activity) [49-51], types of sedentary behaviour (e.g. watching TV, using social media, playing video games, etc.) [52-55], and sleep measures (e.g. sleep quality and consistency) [56, 57]. However, the present research did not include light physical activity, did not look at types of screens, total sedentary time or non-screen based forms of sedentary behaviour, and did not account for other sleep indicators. Future studies should consider looking into these other aspects to provide a better understanding of the link between 24-hour movement behaviours

and mental health. Another limitation is related to the fact that one symptom of depression is interrupted sleep [58-60]. This is problematic particularly for cross-sectional studies. However, the finding that sleep is also prospectively associated with depressive symptoms in the longitudinal study of this thesis partly addresses this limitation. Also interrupted sleep was only one item out of many in the measurement of depression [58-60], so the bias is likely small. Finally, although analyses are adjusted for important covariates, there is always a possibility of residual confounding by unmeasured variables, such as parenting style and role modelling.

7.5 Implications and recommendations for practice

The findings from this thesis will inform future interventions intended to prevent mental health problems among children and adolescents. The findings have shed new light on the association between movement behaviours and mental health indicators in children and adolescents by demonstrating that meeting all three movement behaviour recommendations is associated with better mental health, and that sleep duration and screen time were more strongly associated with mental health compared with MVPA in our studies. These novel findings support the need to promote adherence to the 24-hour movement guidelines in children and adolescents as a possible means to protect their mental health. Given that excessive screen time, particularly around bedtime, has been identified as an important contributor to short sleep duration among adolescents [61, 62], it is important to address both screen time and sleep duration concurrently for mental health benefits. All stakeholders, including healthcare workers, schools, parents, and students themselves should be informed about the value of sufficient sleep duration and limited recreational screen time on children and adolescent mental health. Increased awareness and readiness for behaviour modification will help prevent mental health problems in this vulnerable population.

Healthcare workers dealing with children and adolescents should also ask children and adolescents who endure mental health problems about their sleep and sedentary behaviours.

There is a vast literature on effective interventions to improve adherence to individual movement behaviour guidelines. Reviews of reviews investigating different interventions for physical activity promotion have indicated that school-based multi-component interventions including family components have the highest level of evidence for increasing overall physical activity in children and adolescents [63, 64]. The family component is important because evidence has shown that parents play a key role in promoting physical activity in children [63]. Reviews of reviews on interventions aimed at decreasing sedentary behaviours among children and adolescents have shown that interventions to reduce screen time are effective, but the effect size is small [65, 66]. Many of the interventions were behavioural in nature consisting of increasing children and adolescent control over their screen-time activity, by setting screen-time goals, developing a screen time plan, letting the child identify alternative activities or providing them with tangible ideas and giving them the opportunity to choose how to allocate and organize their leisure time and screen time [65]. A systematic review and meta-analysis of six randomized controlled trials suggested that cognitive and behavioural sleep interventions could be indicated to improve sleep in school-age children and adolescents [67]. Although most of the interventions are multi-component, combining particularly physical activity and screen time [63, 64], to date, there have been no reports of large scale public health interventions that systematically integrate all 3 movement behaviours to encourage a healthy composition of daily movement behaviours and thereby increase the prevalence of children and adolescents meeting the 24-hour movement guidelines. This is probably due to the recent nature of the 24-hour movement guidelines. Future multi-

component interventions integrating all 3 movement behaviours are necessary to fill this research gap.

7.6 Implications and future directions for research

The findings from this dissertation will inform the methodological designs of future research in this area. For example, additional research using device-based measures of physical activity, sedentary behaviour, and sleep duration in longitudinal designs is needed to replicate these findings. Research studies are also needed to closely examine the role of age, sex/gender, and other demographis characteristics such as race and indigeneity and geography on the relationships between movement behaviours and mental health outcomes. Future research could test if these relationships hold true in different populations studied in different parts of the world. The majority of the existing research is based out of primarily white samples from high income countries.

Future research should also expand on the findings from this dissertation in several ways. First, research could expand by using longitudinal and intervention designs to confirm both temporality and causality between movement behaviours and mental health indicators. Such work could benefit from more robust analytical approaches such as compositional data analysis to account for the codependence among movement behaviours in a 24-hour period. Another analytical approach that could help answer different research questions is latent class analysis, as it can identify unmeasured class membership among children and adolescents in regard to physical activity, screen time, and sleep duration. Second, research could expand by testing the mediating role of different factors, such as eating behaviours within a longitudinal compositional framework in order to identify those factors that could explain the association between movement behaviours and mental health indicators, and possibly the observed age and sex/gender differences on these associations. Third, it could expand by studying the moderating role of age and sex/gender on the

association between movement behaviour recommendations (individual or combined) and mental health indicators. Finally, research could expand by conducting intervention studies aimed at improving movement behaviours and mental health outcomes.

7.7 Conclusion

The findings from this dissertation have demonstrated that meeting all three 24-hour guideline recommendations was associated with lower odds of depressive symptoms and other mental health outcomes in children and adolescents. However, meeting the sleep duration and screen time recommendations was more strongly associated with mental health outcomes than meeting the physical activity recommendation. Results further indicated that increasing sleep duration relative to the remaining behaviours (i.e. screen time and MVPA) was associated with lower depressive symptoms. Moreover, the predicted changes in depressive symptoms were strongest and most beneficial when reducing screen time by increasing sleep duration. Finally, findings from this dissertation have demonstrated that, despite the slow growth of new research on the 24-hour movement guidelines as they relate to mental health indicators in children and adolescents, important gaps still exist and need to be filled in future research. Collectively, evidence from this thesis suggests that population-based intervention efforts that target the promotion of the 24-hour movement guidelines may be an effective public health approach to promoting better mental health and preventing mental distress in children and adolescents. These findings also provide further support for the international adoption of a 24-hour approach, particularly the 24-hour movement guidelines to foster a global reach.

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APPENDIX 1. Search strategies for the systematic review (Chapter 2)

MEDLINE, Embase, PsycINFO

Note: Searches were conducted using an Ovid multi-database search and duplicate records were removed online giving preference to MEDLINE, then Embase, with no field preference. Lines 1-30 are optimized for MEDLINE. Lines 31-53 are optimized for Embase and lines 54-82 are optimized for PsycINFO. The next lines isolate the records to the database the search was designed for, combine those sets and then remove duplicate records and finally isolate the records from each database again so each can be downloaded and imported into the citation manager using a database-specific import filter. During duplicate removal, Medline records are kept in preference to Embase records which are kept in preference to PsycINFO records.

1. Physical Activity.mp.
2. exp Exercise/
3. exp Exercise Movement Techniques/
4. exp Exercise Therapy/
5. Physical Exertion/
6. exp "Physical Education and Training"/
7. exp Sports/
8. (sport$ or bicycl$ or swim$ or walk$ or run$ or jog$).tw,kf.
9. (physical$ adj2 activ$).tw,kf.
10. (aerobic adj2 (train$ or active$)).tw,kf.
11. "Play and Playthings"/ and (activ* or outdoor*).tw,kf.
12. ((activ* or outdoor*) adj3 play*).tw,kf.

13. playground*.tw,kf.

14. active.ti. and (space* or behavio?r* or transport* or commut* or neighbo?rhood* or park* or game* or gaming or lifestyle).mp.

15. (active adj3 (space* or behavio?r* or transport* or commut* or neighbo?rhood* or park* or game* or gaming or lifestyle)).tw,kf.

16. or/1-15

17. Sleep.mp.

18. exp *Sleep Apnea Syndromes/ and (apnea or apnoea).ti.

19. 17 not 18

20. Sedentary Lifestyle/

21. bed rest.mp. or (sedentary or inactiv* or sitting or (lack adj2 activity) or (low adj3 energy expend*)).ti,ab,kf.

22. ((chair or stroller or car or automobile* or auto or bus or motor vehicle* or indoor* or in-door* or screen or computer) adj time).ti,ab,kf.

23. Television/ or Computers/ or Video games/ or Software/ or Videodisc Recording/ or Cartoons as Topic/ or Motion Pictures as Topic/ or exp Internet/ or exp Computers, handheld/ or Communications Media/ or Mass Media/

24. (television or tv or screentime or ((watch* or view*) adj2 (dvd* or video*)) or screen media or social media or video gam* or videogam* or computer gam* or electronic gam*).ti,ab,kf.

25. (screen based entertainment or screen-based entertainment or smartphone* or ipad or apps or app or mobile applications).ti,ab,kf.

26. or/20-25

27. 16 and 19 and 26

28. 27 and (child* or adolesc*).mp.

29. limit 28 to (yr="2009 - 2020" and (english or french) and (journal article or published erratum or "retraction of publication"))

30. exp physical activity/ or exp exercise/ or exp kinesiotherapy/ or physical education/ or exp sport/

31. (sport* or bicycl* or swim* or walk* or run* or jog*).tw,kw.

32. (aerobic adj2 (train$ or active$)).tw,kw.

33. Play/ and (activ* or outdoor*).tw,kw.

34. (((activ* or outdoor*) adj3 play*) or playground*).tw,kw.

35. active.ti. and (space* or behavio?r* or transport* or commut* or neighbo?rhood* or park* or game* or gaming or lifestyle).mp.

36. (active adj3 (space* or behavio?r* or transport* or commut* or neighbo?rhood* or park* or game* or gaming or lifestyle)).tw,kw.

37. or/30-36

38. Sleep/

39. Sleep Time/

40. (sleep adj3 duration).tw.

41. exp Sleep Disordered Breathing/ and (apnea or apnoea).ti.

42. (or/38-40) not 41

43. sedentary lifestyle/

44. bed rest.mp. or (sedentary or inactiv* or sitting or (lack adj2 activity) or (low adj3 energy expend*)).ti,ab,kw.

45. ((chair or stroller or car or automobile* or auto or bus or motor vehicle* or indoor* or in-door* or screen or computer) adj time).ti,ab,kw.

46. video game/ or software/ or videorecording/ or movie/ or exp mass communication/ or television viewing/ or television/ or exp computer/ or internet addiction/ or mobile application/ or exp mobile phone/

47. (television or tv or screentime or ((watch* or view*) adj2 (dvd* or video*)) or screen media or social media or video gam* or videogam* or computer gam* or electronic gam*).ti,ab,kw.

48. (screen based entertainment or screen-based entertainment or smartphone* or ipad or apps or app or mobile applications).ti,ab,kw.

49. or/43-48

50. 37 and 42 and 49

51. 50 and (child* or pediatr* or paediatr* or teen* or adolescen*).mp.

52. limit 51 to (embase and (english or french) and yr="2009 -Current")

53. physical activity/ or exp exercise/ or activity level/ or movement therapy/ or dance therapy/ or mind body therapy/ or energy expenditure/ or physical education/ or exp sports/

54. (sport* or bicycl* or swim* or walk* or run* or jog*).tw,id.

55. (physical* adj2 activ*).tw,id.

56. (aerobic adj2 (train* or active*)).tw,id.

57. (childhood play behavior/ or childhood play development/ or games/ or recreation/) and (activ* or outdoor*).tw,id.

58. ((activ* or outdoor*) adj3 play*).tw,id.

59. playgrounds/ or playground*.tw,id.

60. active.ti. and (space* or behavio?r* or transport* or commut* or neighbo?rhood* or park* or game* or gaming or lifestyle).tw,id.

61. (active adj3 (space* or behavio?r* or transport* or commut* or neighbo?rhood* or park* or game* or gaming or lifestyle)).tw,id.

62. or/53-61

63. Sleep/ or Sleep Deprivation/

64. (sleep adj3 duration).tw.

65. *Sleep Apnea/ and (apnea or apnoea).ti.

66. (63 or 64) not 65

67. Sedentary Behavior/

68. bed rest.mp. or (sedentary or inactiv* or sitting or (lack adj2 activity) or (low adj3 energy expend*)).tw.

69. ((chair or stroller or car or automobile* or auto or bus or motor vehicle* or indoor* or in-door* or screen or computer) adj time).tw.

70. Screen Time/ or Television Viewing/ or exp Computers/ or exp Computer usage/ or Computer Games/ or Digital Gaming/ or Internet/ or exp Communications Media/ or Internet Addiction/ or exp Internet Usage/ or exp Mobile Devices/ or Smartphone/ or Mobile Applications/

71. (television or tv or screentime or ((watch* or view*) adj2 (dvd* or video*)) or screen media or social media or video gam* or videogam* or computer gam* or electronic gam*).tw.

72. (screen based entertainment or screen-based entertainment or smartphone* or ipad or apps or app or mobile applications).tw.

73. or/67-72

74. 62 and 66 and 73

75. 74 and (pre-school* or preschool* or early childhood).mp.

76. limit 74 to (140 infancy <2 to 23 mo> or 160 preschool age)

77. 75 or 76

78. limit 77 to (english or french)

79. limit 78 to ("erratum/correction" or journal article)

80. 79 or (78 and retraction.ti.)

81. limit 80 to yr="2009 -Current"

82. 29 use medall

83. 52 use emczd

84. 81 use psyh

85. or/82-84

SportDiscus Search

#	Query	Results
S6	S5 AND (child* OR adolescen*) Limiters - Published Date: 20090101-20191231; Language: English, French; Publication Type: Academic Journal; Document Type: Article	73
S5	S4 AND (child* OR adolescen*)	104
S4	S1 and S2 and S3	300
S3	DE "MASS media" or DE "INTERNET" OR DE "ELECTRONIC games" OR DE "INTERNET games" OR	40041

	DE "MULTIPLAYER games" OR DE "VIDEO games") or DE "SEDENTARY behavior" or DE "SEDENTARY behavior in children" or (Smartphone* or ipad or apps or app or mobile applications) or screen based entertainment or (television N3 time or screentime or screen N3 time or computer N3 time or (watch* N2 dvd or watch N2 video* or view* N2 dvd* or view N2 video*)) or screen media or social media or video gam* or videogam* or computer gam* or electronic gam* OR chair N3 time or stroller N3 time or car N3 time or automobile* N3 time or auto N3 time or motor vehicle* N3 time or bus N3 time or indoor* N3 time or in-door N3 time or computer N3 time OR sitting or ((sedentary or inactiv* or (lack N2 activity))) or ((low N3 energy expend*) or physical* inactiv*)	
S2	sleep	11712
S1	TI (exercise or (physical* n2 activ*) OR aerobic N2 train* or aerobic N2 active* OR sport* or outdoor* OR playground or play or playing OR "rough and tumble" or "active recreation*" OR run* OR walk* OR jog* OR bicycl* or biking or cycling or tricylc* or "tummy time" or "floor time" or prone position or crawl* OR swim* or soccer or gymnastic*) OR SU (exercise or (physical* n2 activ*) OR aerobic N2 train* or aerobic N2 active* OR	883908

sport* or outdoor* OR playground or play or playing OR

"rough and tumble" or "active recreation*" OR run* OR

walk* OR jog* OR bicycl* or biking or cycling or tricylc*

OR swim* or soccer or gymnastic*)

APPENDIX 2. Research Ethics Boards Approval from the University of Ottawa

14/10/2020

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE | CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number	H-10-19-5121
Titre du projet / Project Title	Sleep duration, sedentary behaviour, physical activity, depression, and other mental health outcomes among children and adolescents
Type de projet / Project Type	Thèse de doctorat / Doctoral thesis
Statut du projet / Project Status	Renouvelé / Renewed
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	05/11/2019
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	04/11/2021

Équipe de recherche / Research Team

Chercheur / Researcher	Affiliation	Role
Hugues SAMPASA-KANYINGA	Département d'épidémiologie et santé publique / Department of Epidemiology and Public Health	Chercheur Principal / Principal Investigator
Ian COLMAN	Département d'épidémiologie et santé publique / Department of Epidemiology and Public Health	Superviseur / Supervisor
Jean-Philippe CHAPUT	Département de pédiatrie / Department of Pediatrics	Co-superviseur / Co-supervisor

Conditions spéciales ou commentaires / Special conditions or comments

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Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Le Comité d'éthique de la recherche (CÉR) de l'Université d'Ottawa, opérant conformément à l'***Énoncé de politique des Trois conseils*** (2014) et toutes autres lois et tous règlements applicables, a examiné et approuvé la demande d'éthique du projet de recherche ci-nommé.

L'approbation est valide pour la durée indiquée plus haut et est sujette aux conditions énumérées dans la section intitulée "Conditions Spéciales ou Commentaires". Le formulaire « Renouvellement ou Fermeture de Projet » doit être complété quatre semaines avant la date d'échéance indiquée ci-haut afin de demander un renouvellement de cette approbation éthique ou afin de fermer le dossier.

Toutes modifications apportées au projet doivent être approuvées par le CÉR avant leur mise en place, sauf si le participant doit être retiré en raison d'un danger immédiat ou s'il s'agit d'un changement ayant trait à des éléments administratifs ou logistiques du projet. Les chercheurs doivent aviser le CÉR dans les plus brefs délais de tout changement pouvant augmenter le niveau de risque aux participants ou pouvant affecter considérablement le déroulement du projet, rapporter tout événement imprévu ou indésirable et soumettre toute nouvelle information pouvant nuire à la conduite du projet ou à la sécurité des participants.

The University of Ottawa Research Ethics Board, which operates in accordance with the ***Tri-Council Policy Statement*** (2014) and other applicable laws and regulations, has examined and approved the ethics application for the above-named research project.

Ethics approval is valid for the period indicated above and is subject to the conditions listed in the section entitled "Special Conditions or Comments". The "Renewal/Project Closure" form must be completedfour weeks before the above-referenced expiry date to request a renewal of this ethics approval or closure of the file.

Any changes made to the project must be approved by the REB before being implemented, except when necessary to remove participants from immediate endangerment or when the modification(s) only pertain to administrative or logistical components of the project. Investigators must also promptly alert the REB of any changes that increase the risk to participant(s), any changes that considerably affect the conduct of the project, all unanticipated and harmful events that occur, and new information that may negatively affect the conduct of the project or the safety of the participant(s).

Marc Alain BONENFANT
Coordonnateur de l'éthique / Ethics Coordinator
Pour/For **Daniel LAGARDE** Président(e) du/ Chair of the **Comité d'éthique de la recherche en sciences de la santé et sciences / Health Sciences and Sciences Research Ethics Board**

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APPENDIX 3. Screenshot of manuscript submission letter from *Plos One*

Submission Confirmation for PONE-D-21-01901 - [EMID:8d7e4605b56d848e]

Attention : courriel externe | external email

PONE-D-21-01901
Longitudinal association between movement behaviours and depressive symptoms among adolescents using compositional data analysis
PLOS ONE

Dear Dr. Sampasa-Kanyinga,

Thank you for submitting your manuscript entitled 'Longitudinal association between movement behaviours and depressive symptoms among adolescents using compositional data analysis' to PLOS ONE. Your assigned manuscript number is PONE-D-21-01901.

We will now begin processing your manuscript and may contact you if we require any further information. You will receive an update once your manuscript passes our in-house technical check; you can also check the status of your manuscript by logging into your account at https://www.editorialmanager.com/pone/.

If during submission you selected the option for your manuscript to be posted on the bioRxiv preprint server (http://biorxiv.org), we will be assessing the manuscript for suitability shortly. If suitable, your preprint will be made publicly available on bioRxiv and you will receive an email confirmation from them when it has posted. Please check your response to this question and email us as soon as possible at plosone@plos.org if it has been answered incorrectly. Further information about our partnership with bioRxiv to facilitate the rapid availability of life sciences research is available at http://journals.plos.org/plosone/s/preprints.

If you have any inquiries or other comments regarding this manuscript please contact plosone@plos.org.

Thank you for your support of PLOS ONE.

Kind regards,
PLOS ONE