

Does physical activity mediate the relationship between loneliness and mental health in
Canadian adolescents?

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Abstract

Objectives: Loneliness in adolescents has been consistently increasing over the previous two decades, a trend further exacerbated during to the COVID-19 pandemic. This is particularly concerning considering the links between loneliness and poor mental health. This thesis investigated prospective bidirectional relationships between loneliness and mental health outcomes (anxiety and psychological wellbeing), and additionally, aimed to assess the mediating role of physical activity (PA) within these relationships over a one-year period.

Methods: This study used linked student-level survey data of 20,532 Canadian adolescents from the 9th (2020-2021) and 10th (2021-2022) years of the COMPASS study. Cross-lagged panel mediation models were used to test bidirectional associations between loneliness, anxiety symptoms, psychological wellbeing, and PA. Bootstrapping was used to detect mediation effects of PA in the relationships. Models were stratified by gender, and controlled for student grade, family affluence, province, ethnicity, and school-level clustering.

Results: Gender-diverse/other adolescents reported higher loneliness frequency and anxiety scores, and lower psychological wellbeing, compared to cis-gender adolescents. Bidirectional relationships between loneliness and anxiety, and loneliness and psychological wellbeing were established in the full sample, with associations varying when stratified by gender. PA did not significantly mediate the relationships between loneliness and the mental health outcomes.

Conclusions: Loneliness, anxiety, and psychological wellbeing prospectively and bidirectionally predicted each other, which reinforces current literature that supports loneliness as a risk factor for poor mental health outcomes among adolescents. PA did not mediate these relationships, thus future research should explore novel mediators to help explain the underlying mechanisms in the relationship between loneliness and mental health.

Keywords: Loneliness, adolescence, gender differences, mental health, longitudinal analysis

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List of Abbreviations

COMPASS	Cannabis, Obesity, Mental health, Physical activity, Alcohol, Smoking, Sedentary behaviour
PA	Physical Activity
MVPA	Moderate-to-Vigorous Physical Activity
FS	Flourishing Scale
GAD-7	Generalized Anxiety Disorder 7 Item Scale
CES-D	Center of Epidemiological Studies Depression Scale
ICC	Intraclass Correlation Coefficient
SD	Standard Deviation
T1	Time 1 (2020-2021)
T2	Time 2 (2021-2022)
FIML	Full Information Maximum Likelihood
CFI	Comparative Fit Index
TLI	Tucker-Lewis Index
RMSEA	Root Mean Square Error of Approximation
SRMR	Standardized Root Mean Square Residual
BIPOC	Black, Indigenous, People of Colour

1. Introduction

Loneliness is defined as a negative emotional state whereby individuals perceive conflicts between their current and desired relationships¹. Individuals may appear to be socially connected and have a wealth of relationships, yet still perceive their relationships as insignificant or low-quality². Moderate to severe perceived loneliness has been shown to be highly prevalent during adolescence³. Loneliness presents a unique issue in adolescence, as a critical developmental period characterized by several co-occurring transitions, including biological changes such as those related to puberty, psychological changes as they engage in identity exploration, social changes as they establish social networks, increased interest in romantic relationships, and perceptions of peer acceptance that become increasingly important^{1,4}. Experiencing loneliness in the formative years of life may induce developmental delays for children and adolescents⁵.

The COVID-19 pandemic has drawn increased attention to the critical need to address youth mental health and wellbeing. A rapid review of youth mental health during the pandemic found support for increases in depression and anxiety symptoms, psychological distress, externalizing behaviours, self-harm and suicidal ideation, and decreases in psychological wellbeing⁶. When considering loneliness during the pandemic, research using cross-sectional data determined that adolescents reported concerns regarding schooling and peer relationships, and experienced high levels of COVID-19 stress due to feelings of loneliness and depressive symptoms⁷. However, much COVID-19 research has been conducted during the early lockdown phases, and is limited by cross-sectional and retrospective designs which are unable to examine within-individual changes⁶. Prospective research is needed to examine the ongoing impact of the pandemic response, and whether any mental health impacts are sustained in adolescents. Further, while research conducted in adult populations suggests that there are significant bidirectional

associations between loneliness and anxiety⁸, scant literature explores bidirectional associations between loneliness and psychological wellbeing. Altogether, it is unclear whether these bidirectional relationships exist in adolescents, particularly during the COVID-19 pandemic.

Adolescence is when many health behaviours and patterns become established, which oftentimes persist across the life course⁹. Therefore, early intervention and prevention of poor mental health in adolescence may offer a window of opportunity to set youth on positive life trajectories. Physical activity (PA) refers to bodily movements produced by skeletal muscles that requires energy expenditure, and can include activities such as daily chores, active travel, sport, or more structured exercise which specifically targets physical fitness¹⁰. Extant literature supports PA as a predictor of increased psychological wellbeing and reduced anxiety^{11,12}. However, limited research has explored these relationships in adolescence and existing prospective evidence is inconsistent. Studies among older adults do suggest that PA can contribute to decreases in loneliness¹³. Recent research investigating physical inactivity and mental health in adults throughout the COVID-19 pandemic found higher levels of loneliness and anxiety among adults who engaged in lower frequencies of PA¹⁴, and adults who engaged in some PA reported significantly lower anxiety and psychological distress than those who did not engage in any PA¹⁵. Additionally, both loneliness and decreased PA were identified as risk factors for worsening mental health¹⁶. Based on these findings, PA may offer a promising intervention; a previously administered community-based PA intervention targeting loneliness reduced social isolation and loneliness in older adults¹⁷, however similar interventions have not been tested in adolescents. Reductions in loneliness were not completely attributable to PA however, as social connectedness played a role in the intervention. Further, adolescents engaged in less PA during the early lockdown compared to pre-pandemic, and reductions in PA were

associated with declines in mental health^{18,19}. Literature also indicates gender differences; girls consistently engage in less PA than boys, which may result from a lack of support at the school-level and lower levels of favourable PA attributes (e.g., eye-hand coordination, body fat percentage, cardio-respiratory fitness, perceived competence in physical education)²⁰. Further, girls' engagement in PA continues to decline over adolescence at a higher rate than boys, which is concerning considering the formative years of adolescence²¹. Given the known and potential benefits of PA, there is a need for research that explores its mediating effect in the relationships between loneliness and mental health outcomes to help guide novel interventions tailored to adolescent populations.

Finally, current literature is inconsistent in examining gender differences in loneliness, mental health outcomes, and PA. Some research suggests that girls and women are disproportionately affected by loneliness²², however this is conflicted by findings from a meta-analysis which did not find significant gender differences in loneliness in childhood and adolescence²³. Further, a rapid review found that adolescent girls reported experiencing greater negative impacts of the pandemic on their psychological wellbeing and mental health, and higher levels of internalizing problems and pandemic-related stressors than boys⁶. Taken together, evidence shows that girls experience higher anxiety symptoms than boys and may differ in experiences of loneliness, which warrants a thorough exploration of this gender gap.

Extant literature consistently reports poorer mental health outcomes among gender-diverse compared to cis-gender adolescents²⁴. Gender-diverse adolescents, compared to their cis-gender peers, experience higher social rejection, victimization, and discrimination, which can lead to increased levels of psychological distress and mental illness symptomatology such as depression, anxiety, suicidality, and self-injury²⁵. Experiences of social dysphoria (others' non-

affirmation of their gender identity), and physical dysphoria (perceived conflicts between one's body and their gender identity) are stressors typically unique to gender-diverse adolescents which may explain their disproportionate levels of mental illness compared to cis-gender adolescents²⁵. Furthermore, repeatedly hearing discriminatory or stigmatized remarks regarding gender identity may elevate levels of internalized transphobia (self-stigmatization of one's own gender identity), which may play a key role in poor mental health outcomes in gender-diverse individuals^{26,27}. Altogether, research suggests differences in mental health by gender, with particularly concerning levels of adversity for cis-girls and gender-diverse adolescents. Further longitudinal research is important to examine these gender differences and to target interventions to higher-risk groups.

2. Literature Review

2.1 Trends in loneliness

The risk for loneliness is particularly high in adolescence compared to other age groups due to the various psychosocial and behavioural changes that are experienced²⁸. Prior to the pandemic, research showed consistent increases in loneliness over 18 years²⁹. Worldwide trends of loneliness in a sample of one million adolescents over 37 countries demonstrated a near two-fold increase in frequencies of loneliness from 2000 to 2018 for both boys and girls, with girls being affected more²⁹. As a result of COVID-19 pandemic containment measures, levels of loneliness and social isolation have been further exacerbated with some research showing retrospective reports of heightened levels of loneliness nine months into the pandemic³⁰. Lockdowns and social distancing have caused disconnect between communities, relationship stress, and reduced opportunities for adolescents to connect with and receive support from their usual sources such as school³¹. Other research has reported that adolescent perceptions of negative changes due to COVID-19 was a result of higher feelings of loneliness and depressive

symptoms³². Qualitative accounts of UK adolescents' experience with the initial stages of the COVID-19 pandemic reported strained personal relationships, loss of in-person interaction, perceptions of constrained freedom, challenging emotions, and disrupted coping methods, which all contributed to feelings of loneliness³³. Additionally, adolescents reported that digital interactions were not adequate in substituting for face-to-face interactions, despite significant increases in time spent on social media⁷. In line with these findings, a U.S. mixed-methods study reported on adolescent social challenges of the pandemic, including less in-person interaction, not getting out of the house, COVID-related anxiety, lethargy, lack of motivation, and even too much family time³⁴. Some adolescents reported that increased time spent with families led to irritation and conflict as a result of lack of privacy, which caused strains in familial relationships³⁴. As high-quality familial relationships are a protective factor of loneliness and mental health in adolescents, adolescents experiencing these pandemic-related strains to their relationships may contribute to higher levels of loneliness and poor mental health^{35,36}. A Canadian study with a sample of 1316 adolescents collected data 3 weeks after school closures and found high levels of pandemic stress, which was associated with loneliness and depressive symptoms⁷. Though extant literature strongly suggests significant increases in adolescents' loneliness in response to the early COVID-19 pandemic and containment measures, little research explores how feelings of loneliness have changed prospectively and in later stages of the pandemic. Scant literature reports within-individual differences of loneliness from pre-pandemic to during pandemic stages. Altogether, there is a need for prospective analyses to better understand the impact of loneliness on adolescent mental health.

2.2 Adolescent mental health

Adolescence is a formative period characterized by the occurrence of changes in cognition, emotions, and psychosocial behaviour³⁷. It is also a period which is met with

heightened expectations from family and peers, which may invoke stress, helplessness, and emotional insecurity³⁸. Adequately supporting adolescents in their formative years can lead to positive life outcomes and trajectories. The onset of mental illness often occurs in adolescence³⁹ and psychosocial wellbeing declines over this period, on average^{40,41}. Further research is needed to inform effective strategies for the promotion of positive mental health and mental illness prevention and early intervention targeting adolescents.

Anxiety disorders are a highly prevalent mental illness among adolescents, characterized by symptoms such as persistent and excessive worrying that interferes with daily life, restlessness, insomnia, muscle tension, and difficulty concentrating⁴². Research from a nationally representative sample of 10,123 U.S. adolescents found that nearly one-third (31.9%) met the criteria for an anxiety disorder, with 8.3% of the sample meeting the criteria for severe anxiety disorders⁴³. Additionally, anxiety disorders occurred more frequently in females than males. A global meta-analysis including 29 studies and 80879 children and adolescents reported clinically elevated depression and anxiety symptoms over the first year of the COVID-19 pandemic⁴⁴.

Keyes' dual continuum model of mental health establishes that mental illness and mental health exist on separate continua⁴⁵. Complete mental health refers to the absence of mental illness and the presence of flourishing (also known as positive mental health or psychological wellbeing). Accordingly, individuals can experience positive mental health (i.e., flourishing) while having a mental illness, and on the other end of the spectrum, individuals can experience negative mental health (i.e., languishing) with or without having a mental illness. In this thesis, the term psychological wellbeing will primarily be used, which is used interchangeably with positive mental health and flourishing in the literature. Psychological wellbeing is a construct

consisting of life satisfaction, hedonic wellbeing (feelings of happiness or sadness), and eudemonic wellbeing (a sense of purpose and meaning in life)⁴⁶. During adolescence, higher levels of psychological wellbeing are crucial as they positively predict quality of life, physical health, employment, pro-social behaviour, and life expectancy^{47,48}. Khan and Colleagues (2015) describe psychological wellbeing in adolescence as “being content with life” and when combined with the absence of mental illness, psychological wellbeing is linked with strong academic function and social skills⁴⁷.

2.3 Adolescent mental health in the context of COVID-19

The arrival of the COVID-19 pandemic and its accompanying measures, such as lockdowns and social distancing, initiated a push to evaluate the impact on adolescent mental health. A systematic review including 61 studies with a total of 54,999 children and adolescents across 5 continents (Europe, Asia, Australia, North America, and South America) found that anxiety and depressive symptoms were significantly increased during lockdowns, with the highest impacted demographic being female adolescents⁴⁹. PA, parent-child discussions, and routines emerged as protective factors to experiencing poor mental health. However, the majority (73.8%) of studies included in the systematic review were cross-sectional, which limits the ability to establish temporality. Of the 16 included longitudinal studies, most suffered from smaller sample sizes, were unable to examine within-individual change as a result of repeated cross-sectional data collection or had short follow-up periods. In addition to heightened symptoms of mental illness during lockdowns, research from previous pandemics suggests that these effects are likely to last even after lockdown and other measures have ceased⁵⁰.

The current state of literature supports decreases in psychological wellbeing as a result of the pandemic, however findings are inconsistent and largely limited to the initial stages of the pandemic. Cross-sectional research in a sample of 523 Icelandic adolescents found that

compared to boys, girls reported larger decreases in their wellbeing and overall mental health in response to the COVID-19 pandemic⁵¹. Prospective research in a sample of 2097 German children and adolescents found pandemic-related increases in low health-related quality of life and both anxiety and depression symptoms in two successive waves of data (Spring 2020, Winter 2020/2021), and slight decreases in the third wave (Fall 2021) due to loosening of restrictions⁵². A higher proportion of girls reported lower health-related quality of life and anxiety symptoms compared to boys. However, this study was limited in its ability to establish within-individual changes as they used repeat cross-sectional data and did not follow participants over time. Research done in a sample of 7653 Canadian adolescents reported conflicting results and found lack of significant within-individual effects of the pandemic on psychological wellbeing from pre-pandemic to 2-3 months during the pandemic⁵³. Due to follow-up periods being in the initial months of the pandemic, it is unclear whether some relationships may take longer to appear as individuals continue to deal with COVID-19 related restrictions. Taken together, the literature suggests decreases in adolescent psychological wellbeing due to the COVID-19 pandemic. Prospective research that assesses within-individual changes over a longer follow-up period is warranted to explore adolescent psychological wellbeing and how it may have changed during this period.

Another emerging concern that is linked with mental health in the context of the COVID-19 pandemic is increases in sedentary behaviour. A systematic review that explored the impact of the pandemic on adolescent mental health included 16 studies with 40,076 adolescents across 8 countries (China, United States, Canada, Denmark, Germany, Japan, Philippines, United Kingdom), and found that adolescents compensated for their loss of in-person connections with overuse of the internet and social media as a new form of socializing, which ultimately led to

poor mental health outcomes⁵⁴. Adolescents particularly require social contact and peer relationships for positive development and psychological wellbeing⁵⁵, and transitions to online learning may impede in the process of establishing these important relationships. Other literature determines higher feelings of loneliness in adolescents as a predictor of social media use, with additional context that adolescents found social media to be an inadequate substitute for in-person social relations, contributing to lower feelings of happiness⁵⁶.

Pandemic-related loneliness in children and adolescents has been linked with depressive and anxiety symptoms, with the length of loneliness predicting future mental illness⁵⁰. These findings suggest that there are varying levels of loneliness at different stages of the pandemic, dependent on the frequency and length of lockdowns and social distancing measures.

Additionally, a UK study explored the interrelationships between loneliness and mental health during the COVID-19 pandemic in a sample of 894 adolescents and found that higher levels of loneliness were cross-sectionally associated with higher emotional distress⁵⁷. Overall, despite evidence of significant increases in mental illness and loneliness⁵⁸, limited literature explores prospective relationships between loneliness and mental health during the pandemic.

2.4 Loneliness links to mental health

Extant literature supports a link between loneliness and anxiety across age groups, yet research able to determine the temporality of relationships remains limited, particularly during adolescence. For instance, longitudinal analyses conducted in a sample of 892 Chinese adolescents established loneliness to be a risk factor of social anxiety⁵⁹. Bidirectional associations have been explored in adult populations; research conducted within a representative sample of Dutch adults aged 18-64 established bidirectional associations between loneliness and mental disorders (treated as a composite of mood disorders, anxiety disorders, substance-use disorders)⁶⁰. Further research conducted in a non-representative sample of 2361 university

students in the U.S. found bidirectional associations between loneliness and anxiety symptoms, where loneliness was a strong predictor of anxiety prospectively, and anxiety was associated with a small subsequent increase in loneliness⁸. These findings together highlight the importance of exploring similar bidirectional relationships in adolescence.

Literature is limited on the effects of loneliness on psychological wellbeing, or vice-versa, in adolescence. Cross-sectional data from a sample of 340 Turkish university students established significant links between loneliness and psychological wellbeing⁶¹. The results from this study are in line with the findings of a systematic overview including 40 systematic reviews, which together showed support for associations between both loneliness and fewer social relationships with overall poor health, psychological well-being, and all-cause mortality⁶². Additionally, links between loneliness and psychological wellbeing have been established in multiple studies conducted in older populations^{63,64}. Overall, research suggests links between loneliness and psychological wellbeing, however bidirectional associations in adolescents have not been examined.

2.5 Links between PA, mental health, and loneliness

Physical inactivity is among the leading predictors of chronic diseases and is associated with poor psychological health outcomes⁶⁵. The World Health Organization (WHO) reported that globally in 2010, 81% of adolescents did not meet the daily guidelines of 60 minutes of moderate-to-vigorous physical activity (MVPA)⁶⁶. In 2021, physical inactivity was identified as one of the top 10 threats to childhood in Canada, with less than one in five children and adolescents meeting guidelines for PA, sedentary behaviour, and sleep⁶⁷. Research conducted in a sample of 520,533 adolescents across 105 countries and regions determined that daily engagement in PA decreases over adolescence (28.2% at age 11-12 vs 21.2% at age 16-17), with

girls consistently reporting lower levels of PA compared to boys⁶⁸. Further, declining levels of PA carry into adulthood⁶⁹. Physical inactivity and sedentary behaviour have been a concern for adolescent health since before the COVID-19 onset; they further increased during the pandemic and are expected to remain at heightened levels long after⁷⁰. Extant literature has established decreases in daily adolescent PA as a result of the COVID-19 pandemic and its containment measures^{71,72,73}. Pandemic related restrictions have caused disruptions to familial, social, and communal sources of support that promote adolescent PA⁷¹. Displacement of PA in favour of sedentary behaviours, such as screen time, have further contributed to reductions in PA⁷¹.

Evidence on the relationship between PA and mental health among adolescents is inconsistent and largely limited to cross-sectional designs. Extant pre-pandemic literature supports associations between PA and mental health; research suggests PA and exercise-based interventions can protect against anxiety symptoms and disorders⁷². Research conducted in UK adolescents found protective associations between PA and emotional problems (defined as anxiety and depressive symptoms), however there was a lack of significant associations between PA and mental wellbeing⁷³. Other research conducted in a sample of 28567 Canadian adolescents found prospective associations between high levels PA and decreased symptoms of anxiety and depression in males, however among females, higher levels of PA predicted greater symptoms of anxiety⁷⁴. Pre-pandemic data from a sample of 29133 Canadian adolescents found that individuals who reported higher psychological wellbeing were more likely to meet PA guidelines⁷⁵. In the reverse direction, similar research in a large sample of adolescents found differences by sex; boys who met Canadian MVPA guidelines were more likely to have higher psychological wellbeing, while this association was not significant in girls⁷⁶. Further, findings from a systematic review that included 114 studies identified significant positive associations

between PA and psychological wellbeing in adolescents⁷⁷. Biddle et al. conducted a review of systematic reviews and meta-analyses that included 42 reviews and found support for links between PA and mental health outcomes in adolescents, including anxiety, depression, self-esteem, and cognitive functioning⁷⁸. However, anxiety literature (3 reviews) was reported as being small and fragmented, and effect sizes varied from very small to moderate, dependent on the intervention and sample, overall providing experimental and inconclusive evidence to infer causality⁷⁸. Self-esteem, which has strong associations with psychological wellbeing⁷⁹, only showed support for a partial strength of association which further diminished when considering observational studies compared to experimental⁷⁸. During the COVID-19 pandemic, the COVID-19 Advisory for Ontario determined benefits of PA on mental health and reductions in depression and anxiety symptomatology⁸⁰, and additionally found differences by socioeconomic status (SES) and race/ethnicity, in which lower proportions of individuals from lower SES backgrounds and ethnic minority groups met PA guidelines during the pandemic. Overall, some research suggests associations between PA and mental health outcomes with results varying by gender, while other studies have not found a relationship. Due to inconsistent and limited literature on adolescents and conflicting results by gender, there is a need for prospective research exploring the impacts of PA on outcomes on mental health and wellbeing throughout the COVID-19 pandemic.

Extant literature has determined negative associations between PA and loneliness in general populations, however the direction of these associations are not well known due to a lack of prospective research⁸¹. Cross-sectional data have demonstrated a protective effect of PA against loneliness and depressive symptoms in adolescents⁷. Other research in a sample of 2517 Brazilian adolescents found that adolescents were more likely to feel lonely when physically

inactive and not participating in physical education class⁸². Further, data from 12133 adolescents at risk of overweight/obesity across 23 countries reported higher levels of loneliness being associated sedentary behaviours and insufficient PA⁸³. Pertinent to the COVID-19 pandemic, little literature establishes prospective associations between PA and loneliness in adolescents during the pandemic, though findings in university students suggest that feelings of loneliness due to the pandemic may be reduced through PA⁸⁴.

3. Study Objectives

The purpose of this thesis was to investigate the associations between loneliness and mental health, and to examine whether PA mediates these relationships, in a large prospective sample of Canadian adolescents. Based on the findings reviewed above, I hypothesized PA to be a novel mediation variable which may help explain the processes in which loneliness and mental health outcomes are linked. As such, results may inform potential point of intervention to improve mental health. Additionally, research suggests there are gender differences in how adolescents experience loneliness, mental health, and PA^{6,16,18,38,46,74}, including throughout the COVID-19 pandemic, which warrants the use of a large, prospective sample to further examine disparities. These disparities in mental health are particularly pronounced in gender diverse populations^{24,85}. This thesis aims to address the following objectives: 1) to prospectively investigate bidirectional relationships between loneliness and both anxiety symptoms and psychological wellbeing, 2) to assess whether PA mediates the relationships between loneliness and anxiety symptoms and psychological wellbeing over a one-year period, and 3) to inform on any potential gender disparities within these relationships. As this study was done during the COVID-19 pandemic, its impacts could not be directly examined in the analysis and whether it affected the hypothesized relationships.

3.1 Research Questions

RQ 1: Are there significant bidirectional associations between loneliness and mental health in adolescents?

RQ1.1) Is there a significant bidirectional association between loneliness and anxiety symptoms?

RQ1.1.1) Is there a significant bidirectional association between loneliness and anxiety symptoms when stratified by gender?

RQ1.2) Is there a significant bidirectional association between loneliness and psychological wellbeing?

RQ1.2.1) Is there a significant bidirectional association between loneliness and psychological wellbeing when stratified by gender?

RQ 2: Does PA mediate the bidirectional relationships between loneliness and mental health?

RQ2.1) Does PA mediate the bidirectional association between loneliness and anxiety symptoms?

RQ2.1.1) Does PA mediate the bidirectional association between loneliness and anxiety symptoms when stratified by gender?

RQ2.2) Does PA mediate the bidirectional association between loneliness and psychological wellbeing?

RQ2.2.1) Does PA mediate the bidirectional association between loneliness and psychological wellbeing when stratified by gender?

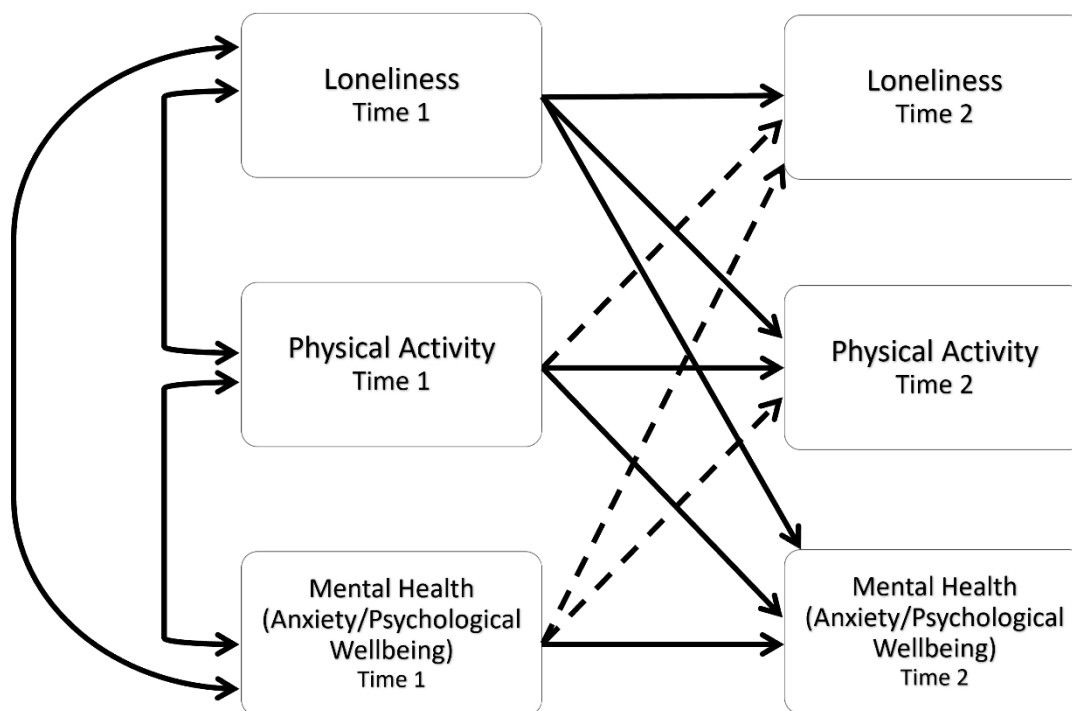


Figure 1. Conceptual model of cross-lagged panel mediation models over two waves of data modelling potential interrelationships between loneliness, PA, and anxiety and psychological wellbeing. Mediation pathways occur through indirect effects from time 1 predictors to time 2 outcomes. Time 1 refers to year 9 (2020-2021) and time 2 refers to year 10 (2021-2022) of the COMPASS study.

4. Methods

4.1 Study Design and Sample

The *Cannabis, Obesity, Mental health, Physical activity, Alcohol, Smoking, and Sedentary behaviour* (COMPASS) study is an ongoing prospective study (started in the 2012/2013 school year) that collects observational survey data once annually from a rolling cohort of high school students and the schools they attend in Canada (grade 9 to 12; Secondary I-V in Quebec)⁸⁶. The cohort replenishes as graduating students exit, and new students enter in grade 9/Secondary I. The COMPASS student questionnaire includes a series of questions used to create a self-generated code that is unique to each student. This allows for individual student data to be linked over time, while preserving anonymity by not requiring student names. COMPASS uses a convenience sample of schools and school boards selected based on permitted use of active-information passive-consent parental permission protocols⁸⁷. Using these protocols,

parents/guardians are informed about the survey prior to its administration to decide if they desire to withdraw their child. Less than 0.01% of students within the annual sample were withdrawn by parents. All students within the included schools and not withdrawn by their parent(s)/guardian(s) are eligible to participate. Whole school samples complete the COMPASS student questionnaire, which collects individual student-level data on demographic characteristics, mental health and ill-health, relationships, PA, and other health and risk behaviours. The student questionnaire was designed to be brief to preserve data quality and reduce school burden, as it is administered to students during one classroom period. Due to the COVID-19 pandemic restrictions, survey administration has moved to the online-based Qualtrics software since March 2020. Students were emailed a link to the survey by the school with an additional reminder email, and students were given time during class to complete the survey. The COMPASS study has ethics clearance through the Office of Research Ethics at the University of Waterloo (ORE#30118), the Brock University Human Research Ethics Committee (REB#18-099), and each participating school and school board. This research is covered by these existing ethics approvals. Further details on the COMPASS study protocols are available in print⁸⁶ and online (www.compass.uwaterloo.ca).

This current study used linked student-level data from year 9 (2020-2021) and year 10 (2021-2022) of the COMPASS study, where year 9 will be referred to as Time 1 (T1) and year 10 will be referred to as Time 2 (T2). Only these two years of data were chosen as the 8th year (2019-2020) of the COMPASS study was disrupted by the COVID-19 pandemic onset; in response to the school closures and related lockdown measures, methods shifted from paper-and-pencil surveys to online surveys halfway through year 8 data collection. Also, as online schooling was limited for most students during this first lockdown period (spring 2020), most

schools were not scheduling class time for survey completion; thus, response rates were lower for the online survey during this phase, introducing greater potential for self-selection bias. In the following school years, there was a return to more structured schooling, whether online, in person, or blended modes (half online, half in-person), and schools were encouraged to schedule class time for the survey completion. Only students that were successfully linked across both years were included. The annual COMPASS sample includes approximately 65,000 students within ~150 secondary schools across Alberta, British Columbia, Ontario, and Quebec. Due to student data linkage and the rolling cohort design, the final sample included 20,614 students. Missing responses within COMPASS largely result from student absenteeism and spare study periods during the administration of the survey questionnaires.

4.2 Measures

Loneliness

Loneliness is a subjective measure evaluated through a single-item question that was originally included on the COMPASS questionnaire through the 10-item *Centre of Epidemiological Studies-Depression (CES-D) Scale*, which has been validated for use in adolescent populations and demonstrated strict measurement invariance by both sex and grade⁸⁸. Additionally, direct single-item measures (i.e., which include the word that it measures) of loneliness have been validated for use in self-report surveys⁸⁹. The item asked students: “On how many of the last 7 days did you feel the following ways? I felt lonely”. Student response options included: “None or less than 1 day”, “1-2 days”, “3-4 days”, and “5-7 days”. Loneliness was treated as a continuous score, with possible values ranging from 0-3, and higher scores indicated more frequent feelings of loneliness.

Anxiety

Anxiety was assessed through the 7-item Generalized Anxiety Disorder Scale (GAD-7), which is a widely used scale that has shown good reliability, and criterion, construct, factorial, and procedural validity as a self-report measure for anxiety symptoms⁹⁰. Additionally, the GAD-7 has demonstrated strict measurement invariance in the COMPASS data by both sex and grade, which further supports the validity of the scale for use in adolescent populations⁸⁸. Cronbach alpha values demonstrated high internal consistency in the current sample; 0.90 at T1, and 0.91 at T2. Items on the GAD-7 asked participants to indicate their experience with different symptoms of anxiety (e.g., feeling nervous, anxious, or afraid, being easily irritated, not being able to control worrying or worrying too much, and trouble relaxing or restlessness) over a 2-week period on a 4-point Likert scale from “not at all” (0) to “nearly every day” (3). This study treated the scores continuously, with a total possible sum score ranging from 0 to 21. Higher scores indicated greater levels of anxiety symptomatology.

Psychological Wellbeing

Psychological wellbeing was assessed through the 8-item Flourishing Scale (FS)⁹¹, which asked participants their level of agreement with statements of positive mental and social health, life purpose, life satisfaction, and perceived relationships. The FS has shown good validity and reliability, as well as congruent validity with relevant validated wellbeing scales such as the Satisfaction with Life scale⁹². Previous research with the COMPASS study data has supported the validity of FS for use in Canadian adolescent populations, specifically demonstrating strict measurement invariance across gender, grade, and ethno-racial identity⁹³. Cronbach alpha values demonstrated high internal consistency in the current sample; 0.92 at T1, and 0.90 at T2. A 7-point Likert scale was used with options ranging from strongly disagree (1) to strongly agree (7),

and a total sum score was calculated with scores ranging from 8 to 56. The sum score was treated continuously, with higher scores indicating greater perceptions of psychological wellbeing.

Physical Activity

PA was assessed through a cumulative measure of total average MVPA that combined both moderate and hard PA efforts in minutes over a period of 7 days. PA questions on the COMPASS questionnaire have demonstrated reliability and validity as measures of self-reported PA for large scale school-based research⁹⁴. Students were asked to mark how many minutes (0, 15, 30, 45) and hours (0-4) of moderate and hard PA they engaged in on each individual day of the week, including PA during physical education class, lunch, after school, evenings, and spare time. Average PA per day was treated as continuous, with possible values ranging from 0 to 570 minutes.

Covariates

Demographic characteristics, specifically participant grade (9, 10, 11, 12, and other [secondary I-II in Quebec]), race/ethnicity (White, Black, Asian, Latin American/Hispanic, and mixed/other), and school-level province (Ontario, Alberta, Quebec, British Columbia) were included in the models as covariates. Additionally, perceived relative family affluence was included through an item that asked participants: “Would you say that you and your family are more or less financially comfortable than the average student in your class?”, with response options including: “More comfortable”, “As comfortable”, and “Less comfortable”. To inform on conflicting literature on gender differences in loneliness and mental health, the models were stratified by a composite measure combining sex and gender identity to determine whether adolescents identified as cisgender or gender-diverse/other. Participants were asked: What sex were you assigned at birth?” and provided the response options: “Female”, “Male”, and “I prefer

not to say”. For gender, participants were asked: “Which gender do you most identify with?” and provided the response options: “Girl/Woman”, “Non-binary person”, “Two-Spirit”, “Boy/Man”, “I describe my gender differently”, and “I prefer not to say”. Students reporting male sex and boy/man gender were classified as cisgender male, and students reporting female and girl/woman were classified as cisgender female. All other students were classified as gender-diverse/other, given the small frequencies of these other response combinations.

4.3 Statistical Analysis

The first stage of analysis was completed in SPSS statistics software version 28.

Descriptive analyses were conducted to explore variable distributions and frequencies, in the full sample and by gender. Bivariate correlations were tested among all predictor and outcome variables over both time waves, and continuous variables were tested for normality to satisfy model assumptions. Cases with some missing values were retained through full information maximum likelihood (FIML) estimations, which utilizes all available information from existing observations to estimate parameters⁹⁵. FIML is a strong approach to address missing data in cross-lagged panel models⁹⁶. The Intraclass Correlation Coefficient (ICC) was calculated for the predictors, mediator, and outcome measures (given the cross-lagged modeling) to determine how much variance can be explained by school level differences.

The main statistical analyses were conducted in Mplus version 8.8. Cross-lagged panel models were fit to test bidirectional associations between loneliness, anxiety symptoms, psychological wellbeing, and PA. The models included autoregressive effects which predicted associations between the same variable from T1 to T2, and cross-lagged estimates which predicted associations between the predictor and outcome variables from T1 to T2. Mediation models were tested through indirect effects, from loneliness at T1 through PA at T2, to anxiety

and psychosocial wellbeing at T2, and vice versa to test mediation in the opposite direction. Bootstrapping was used in mediation models to detect indirect effects, examine the significance of mediation, and build confidence intervals; 1000 bootstrap samples were computed, which is the preferred number of iterations⁹⁷. All models were stratified by gender, and controlled for student grade, perceived family affluence, province, ethnicity, and school-level clustering. Model fit was estimated through the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). Good fit of the models was indicated by fit indices of >0.95 for CFI and TLI, <0.06 for RMSEA, and <0.08 for SRMR⁹⁸. Chi-square results were reported, but not used to determine model fit given the sensitivity to large sample sizes.

5. Results

5.1 Descriptive Statistics

Descriptive statistics of the sociodemographic measures are presented in Table 1 for the second year of linkage (2021-2022 school year). The final analytic sample included 20,532 secondary school students linked over the 9th (2020-2021) and 10th (2021-2022) years of the COMPASS study. Baseline missing values for covariates were: Grade ($n = 10$), ethnicity ($n = 34$), and perceived relative family affluence ($n = 110$). The largest proportion of the sample identified as cis-girl (52.5%), followed by cis-boy (42.5%), and finally gender diverse/other (4.9%). Most of the sample reported their ethnicity as White (75.1%), attended schools in Quebec (67.7%) or Ontario (22.5%), and perceived their family to be as comfortable as those of other students in their class (65.9%).

Distributions of loneliness are presented in the appendix, in supplementary Figure 1. At T1, a higher proportion of cis-boys (58.5%) reported feeling lonely less than one day in the past week compared to cis-girls (33.2%) and gender diverse/other (29.3%), whereas more gender-

diverse/other students (28.1%) reported feeling lonely 5-7 days in the past week compared to cis-girls (19.3%) and cis-boys (8.8%). The same patterns were observed across gender at T2.

Descriptive statistics for continuous predictor and outcome variables are presented in Table 2. Person mean-imputation was done on missing values from the GAD-7 and FS where an individual had no more than 2 items missing. This replaced the missing values on the scale with the mean from the filled items for that specific participant. As a result, 866 and 577 individuals were retained on the GAD-7 and FS respectively. After mean-imputation, missing values for continuous predictors/mediators at T1 were: Loneliness ($n = 1470$, 7.2%), GAD-7 ($n = 1229$, 6.0%), FS ($n = 1080$, 5.3%), and MVPA ($n = 1347$, 6.6%), and at T2: Loneliness ($n = 1197$, 5.8%), GAD-7 ($n = 959$, 4.7%), FS ($n = 851$, 4.1%), and MVPA ($n = 1250$, 6.1%). Cases that included missing observations on all predictors and outcomes ($n = 79$), and on gender ($n = 7$), were removed. The ICC indicated that following variances were attributable to school level differences at T1: 1.7% in Loneliness, 4.1% in GAD-7, 4.0% in FS, 5.0% in PA, and at T2: 2.2% in Loneliness, 5.0% in GAD-7, 2.9% in FS, and 5.5% in PA. Based on these variances school-level clustering was controlled for, to isolate for within-individual changes in the modelling. At T1, gender-diverse/other students reported higher GAD-7 scores ($M = 9.76$, $SD = 6.60$), while cis-boys had the lowest scores ($M = 4.30$, $SD = 4.42$). Conversely, cis-boys reported the highest average psychological wellbeing scores ($M = 33.20$, $SD = 5.33$) and gender-diverse/other students had the lowest average scores ($M = 28.16$, $SD = 6.75$). Daily average MVPA was highest in cis-boys ($M = 107.78$ min/day, $SD = 83.39$) and lowest in gender-diverse/other students ($M = 75.18$ min/day, $SD = 71.21$). Finally, gender-diverse/other students reported more frequent feelings of loneliness ($M = 2.51$, $SD = 1.18$) compared to cis-girls ($M = 2.26$, $SD = 1.11$) and cis-boys ($M = 1.69$, $SD = 0.97$). The same patterns were observed across gender at T2.

Regarding changes from T1 to T2; cis-girls experienced the largest average increases in anxiety symptomatology ($M = 1.11$; a 13% increase), while gender-diverse adolescents had the largest decreases in psychological wellbeing ($M = -1.26$; a 4.5% decrease). Gender-diverse adolescents faced larger increases in loneliness ($M = 0.07$; a 2.8% increase), while cis-girls had decreased loneliness scores ($M = -0.09$; a 4% decrease). Finally, cis-girls showed the largest improvements in PA ($M = 6.41$; an 8% increase) compared to cis-boys ($M = 0.72$; a 0.7% increase) and gender-diverse adolescents ($M = 3.80$; a 5.1% increase).

Model assumptions were tested through bivariate correlations and tests of normality, presented in supplementary Tables 1 and 2 respectively. A Pearson correlation matrix shows all predictors and outcomes at both time points were significantly correlated with each other; the strength of correlations between loneliness, anxiety, and psychological wellbeing were moderate, while correlations of all variables with PA were very weak. The Kolmogorov-Smirnov tests of normality confirmed that all predictors and outcomes at both time points were normally distributed.

Table 1. Descriptive statistics in the full sample and by gender in a two-year linked sample of secondary students in the COMPASS study (2020-21, 2021-22)

		Full sample (n = 20,532) n (%)	Cis-girl (n = 10,789) n (%)	Cis-boy (n = 8,734) n (%)	Gender- diverse/Other (n = 1,009) n (%)
Grade	Secondary I-II	4228 (20.6)	2095 (19.4)	1953 (22.4)	180 (17.8)
	9	3442 (16.8)	1751 (16.2)	1551 (17.8)	140 (13.9)
	10	5566 (27.1)	2944 (27.3)	2322 (26.6)	300 (29.8)
	11	5360 (26.1)	2935 (27.2)	2167 (24.8)	258 (25.6)
	12	1784 (8.7)	1004 (9.3)	663 (7.6)	117 (11.6)
	Other	142 (0.7)	56 (0.5)	73 (0.8)	13 (1.3)
Ethnicity	White	15390 (75.1)	8169 (75.8)	6600 (75.7)	621 (61.7)
	BIPOC	5108 (24.9)	2603 (24.2)	2120 (24.3)	385 (38.3)
Province	AB	746 (3.6)	392 (3.6)	295 (3.4)	57 (5.6)
	BC	1272 (6.2)	671 (6.2)	492 (5.6)	98 (9.7)

	ON	4632 (22.5)	2468 (22.9)	1828 (20.9)	282 (27.9)
	QC	13964 (67.7)	7258 (67.3)	6119 (70.1)	572 (56.7)
Perceived Relative Family Affluence	More comfortable	5573 (27.3)	2655 (24.7)	2702 (31.1)	216 (21.6)
	As comfortable	13454 (65.9)	7314 (68.2)	5499 (63.3)	641 (64.2)
	Less comfortable	1395 (6.8)	761 (7.1)	492 (5.7)	142 (14.2)

Descriptive statistics from T2 (2021-22).

Table 2. Mean values of anxiety, psychological wellbeing, and moderate-to-vigorous physical activity, stratified by gender, across a two-year linked sample of secondary students in the COMPASS study

Measure	Time 1 (2020-21)				Time 2 (2021-22)				Change from T1 to T2		
	Cis-girl M (SD)	Cis-boy M (SD)	Gender- diverse/Other M (SD)	χ^2 (p-value)	Cis-girl M (SD)	Cis-boy M (SD)	Gender- diverse/Other M (SD)	χ^2 (p-value)	Cis-girl M (%)	Cis-boy M (%)	Gender- diverse/Other M (%)
Anxiety	8.27 (5.79)	4.30 (4.42)	9.76 (6.60)	2964.0 (<0.001)	9.38 (5.89)	5.02 (4.90)	11.05 (6.63)	3361.3 (<0.001)	1.11 (13.4)	0.72 (16.7)	1.29 (13.2)
Psychological Wellbeing	31.64 (5.86)	33.20 (5.33)	28.16 (6.75)	1174.7 (<0.001)	30.98 (5.78)	32.71 (5.62)	26.90 (6.88)	1410.6 (<0.001)	-0.66 (-2.1)	-0.49 (-1.5)	-1.26 (-4.5)
Physical Activity	79.78 (64.08)	107.78 (83.39)	75.18 (71.21)	1302.7 (<0.001)	86.19 (65.97)	108.50 (77.58)	78.98 (73.45)	1087.2 (<0.001)	6.41 (8.0)	0.72 (0.7)	3.80 (5.1)
Loneliness	2.26 (1.11)	1.69 (0.97)	2.51 (1.18)	1520.6 (<0.001)	2.17 (1.08)	1.70 (0.97)	2.58 (1.17)	1329.6 (<0.001)	-0.09 (-4.0)	0.01 (0.6)	0.07 (2.8)

Anxiety was measured using the GAD-7; scores ranged from 0-21, with higher scores indicating greater anxiety. Psychological wellbeing was measured by the Flourishing Scale; scores ranged from 8-40, with higher scores indicating greater wellbeing. Physical Activity was measured as the daily average moderate-to-vigorous physical activity in minutes, with a possible range from 0-570 minutes. Loneliness scores ranged from 0-4, with 4 representing more frequent loneliness.

5.2 Cross-lagged Panel Mediation Models

Model fit indices, presented in Table 3, indicated good fit of the models in both the full sample and by gender. Results from the cross-lagged panel models in the full sample are presented in Table 4 and Figure 2. In the full sample, autoregressive effects in loneliness ($\beta = 0.26, [0.24, 0.27]$), anxiety ($\beta = 0.57, [0.56, 0.58]$), psychological wellbeing ($\beta = 0.52, [0.50, 0.54]$), and PA ($\beta = 0.44, [0.42, 0.46]$) were all statistically significant. Positive bidirectional associations were established between loneliness and anxiety, where more frequent loneliness predicted higher anxiety scores ($\beta = 0.08, [0.06, 0.09]$), and reciprocally, higher anxiety scores predicted more frequent loneliness ($\beta = 0.18, [0.16, 0.19]$). Negative bidirectional associations were established between loneliness and psychological wellbeing, where more frequent loneliness predicted lower psychological wellbeing ($\beta = -0.04, [-0.05, -0.03]$), and reciprocally, higher psychological wellbeing predicted less frequent loneliness ($\beta = -0.13, [-0.14, -0.12]$). Additionally, negative bidirectional associations were observed between psychological wellbeing and anxiety, where higher psychological wellbeing predicted lower anxiety scores ($\beta = -0.03, [-0.04, -0.01]$), and reciprocally, higher anxiety scores predicted lower psychological wellbeing ($\beta = -0.10, [-0.11, -0.08]$). PA was not a significant predictor of loneliness, anxiety, or psychological wellbeing, and conversely, these measures were not significant predictors of PA. Indirect effects were tested between loneliness at T1 and anxiety and psychological wellbeing at T2, through PA at T2. No significant indirect effects were observed in the full sample, indicating that no mediation was present.

Results from the cross-lagged panel models by gender are presented in Table 5. Positive bidirectional associations were established between loneliness and anxiety; more frequent loneliness predicted higher anxiety scores in cis-girls ($\beta = 0.05, [0.03, 0.06]$), cis-boys ($\beta = 0.08,$

[0.06, 0.10]), and gender-diverse/other students ($\beta = 0.13$, [0.06, 0.20]), and higher anxiety scores predicted more frequent loneliness in cis-girls ($\beta = 0.16$, [0.14, 0.18]), cis-boys ($\beta = 0.12$, [0.10, 0.14]), and gender-diverse/other students ($\beta = 0.17$, [0.10, 0.23]). Negative bidirectional associations were observed between loneliness and psychological wellbeing; more frequent loneliness predicted lower psychological wellbeing in cis-girls ($\beta = -0.04$, [-0.06, -0.03]) and cis-boys ($\beta = -0.03$, [-0.05, -0.01]), and higher psychological wellbeing predicted less frequent loneliness in cis-girls ($\beta = -0.14$, [-0.16, -0.12]) and cis-boys ($\beta = -0.12$, [-0.14, -0.10]). Positive bidirectional associations were observed between anxiety and PA in cis-girls only; higher anxiety scores predicted higher levels of PA ($\beta = 0.04$, [0.02, 0.07]), and higher PA levels predicted higher anxiety scores ($\beta = 0.04$, [0.02, 0.05]). Psychological wellbeing positively predicted PA in cis-girls ($\beta = 0.08$, [0.06, 0.10]) and cis-boys ($\beta = 0.08$, [0.06, 0.10]), however, PA was not a significant predictor of loneliness or psychological wellbeing in any gender group. Longitudinal associations were observed in the gender-diverse/other group between psychological wellbeing and loneliness ($\beta = -0.13$, [-0.19, -0.07]), anxiety and psychological wellbeing ($\beta = -0.09$, [-0.16, -0.03]), and anxiety and loneliness ($\beta = 0.17$, [0.10, 0.23]). As in the full sample, loneliness was not a significant predictor of PA in any gender group. Indirect effects were tested between loneliness at T1 and anxiety and psychological wellbeing at T2, through PA at T2. No significant indirect effects were observed in any gender group, indicating that no mediation was present.

Table 3. Model fit statistics for autoregressive, cross-lagged, and indirect associations between loneliness, anxiety, psychological wellbeing, and physical activity across a two-year linked sample of secondary students in the COMPASS study

Index	Full Sample (n = 20,532)	Cis-girl (n = 10,789)	Cis-boy (n = 8,734)	Gender- diverse/ Other (n = 1,009)
CFI	0.997	0.996	0.996	0.996
TLI	0.968	0.959	0.958	0.959
RMSEA (90% CI)	0.039 (0.033, 0.045)	0.042 (0.034, 0.050)	0.040 (0.031, 0.049)	0.043 (0.015, 0.073)
Chi-Square (<i>p</i>)	36688.860 (<0.0001)	17675.899 (<0.0001)	12670.672 (<0.0001)	1789.885 (<0.0001)
SRMR	0.008	0.009	0.008	0.011

Good fit was indicated by values of >0.95 for CFI and TLI, <0.06 for RMSEA, and <0.08 for SRMR.

Table 4. Standardized model parameter estimates of autoregressive, cross-lagged, and indirect associations between loneliness, anxiety, psychological wellbeing, and physical activity across a two-year linked sample of secondary students in the COMPASS study

Parameter	β	95% CI	<i>p</i>
Autoregressive			
T1 L \rightarrow T2 L	0.26	0.24, 0.27	<0.001
T1 A \rightarrow T2 A	0.57	0.56, 0.58	<0.001
T1 PW \rightarrow T2 PW	0.52	0.50, 0.54	<0.001
T1 PA \rightarrow T2 PA	0.44	0.42, 0.46	<0.001
Cross-lagged			
T1 L \rightarrow T2 A	0.08	0.06, 0.09	<0.001
T1 L \rightarrow T2 PW	-0.04	-0.05, -0.03	<0.001
T1 L \rightarrow T2 PA	-0.00	-0.02, 0.01	0.802
T1 A \rightarrow T2 L	0.18	0.16, 0.19	<0.001
T1 A \rightarrow T2 PW	-0.10	-0.11, -0.08	<0.001
T1 A \rightarrow T2 PA	0.01	-0.01, 0.03	0.368
T1 PW \rightarrow T2 L	-0.13	-0.14, -0.12	<0.001
T1 PW \rightarrow T2 A	-0.03	-0.04, -0.01	<0.001
T1 PW \rightarrow T2 PA	0.07	0.06, 0.09	<0.001
T1 PA \rightarrow T2 L	-0.01	-0.02, 0.00	0.166
T1 PA \rightarrow T2 A	-0.02	-0.03, -0.00	0.059
T1 PA \rightarrow T2 PW	0.01	0.00, 0.03	0.103
Indirect Effects			
L \rightarrow PA \rightarrow A	0.00	0.00, 0.00	0.837
L \rightarrow PA \rightarrow PW	0.00	-0.00, 0.00	0.800
A \rightarrow PA \rightarrow L	0.00	-0.00, 0.00	0.451
PW \rightarrow PA \rightarrow L	-0.00	-0.00, 0.00	0.081

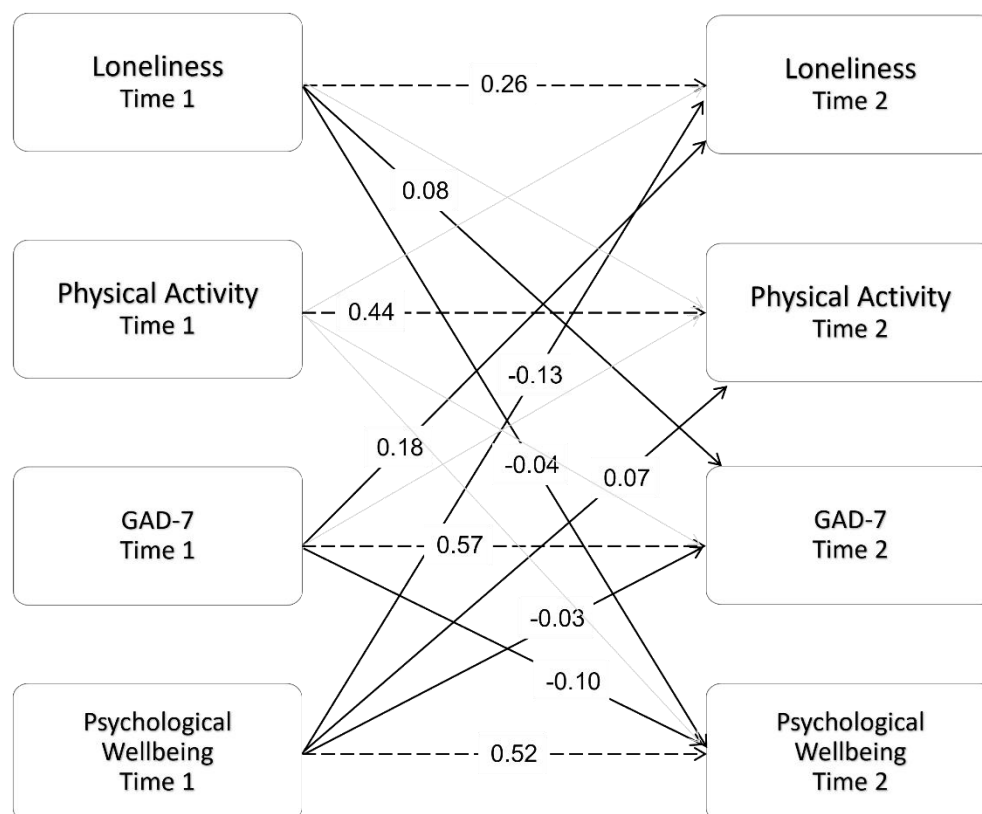
T1, Time 1 (2020-21); T2, Time 2 (2021-22); L, Loneliness; A, Anxiety; PW, Psychological Wellbeing; PA, Physical Activity. Model controlled for student grade, perceived family affluence, province, ethnicity, and school-level clustering.

Table 5. Standardized parameter estimates of autoregressive, cross-lagged, and indirect associations, stratified by gender, between loneliness, anxiety, psychological wellbeing, and physical activity across a two-year linked sample of secondary students in the COMPASS study

Parameter	Cis-girl			Cis-boy			Gender-diverse/other		
	β	95% CI	<i>p</i>	β	95% CI	<i>p</i>	β	95% CI	<i>p</i>
Autoregressive									
T1 L → T2 L	0.24	0.22, 0.26	<0.001	0.24	0.22, 0.27	<0.001	0.30	0.24, 0.35	<0.001
T1 A → T2 A	0.54	0.53, 0.56	<0.001	0.45	0.43, 0.47	<0.001	0.53	0.47, 0.59	<0.001
T1 PW → T2 PW	0.53	0.51, 0.54	<0.001	0.50	0.48, 0.52	<0.001	0.53	0.47, 0.58	<0.001
T1 PA → T2 PA	0.41	0.39, 0.44	<0.001	0.43	0.41, 0.45	<0.001	0.40	0.33, 0.47	<0.001
Cross-lagged									
T1 L → T2 A	0.05	0.03, 0.06	<0.001	0.08	0.06, 0.10	<0.001	0.13	0.06, 0.20	0.003
T1 L → T2 PW	-0.04	-0.06, -0.03	<0.001	-0.03	-0.05, -0.01	0.009	-0.03	-0.10, 0.04	0.495
T1 L → T2 PA	0.01	-0.01, 0.03	0.373	0.01	-0.01, 0.03	0.435	-0.08	-0.15, -0.00	0.087
T1 A → T2 L	0.16	0.14, 0.18	<0.001	0.12	0.10, 0.14	<0.001	0.17	0.10, 0.23	<0.001
T1 A → T2 PW	-0.09	-0.10, -0.07	<0.001	-0.08	-0.10, -0.06	<0.001	-0.09	-0.16, -0.03	0.014
T1 A → T2 PA	0.04	0.02, 0.07	0.005	0.02	-0.01, 0.04	0.218	0.05	-0.03, 0.13	0.249
T1 PW → T2 L	-0.14	-0.16, -0.12	<0.001	-0.12	-0.14, -0.10	<0.001	-0.13	-0.19, -0.07	0.001
T1 PW → T2 A	-0.04	-0.06, -0.02	<0.001	-0.05	-0.07, -0.03	<0.001	-0.00	-0.06, 0.06	0.965
T1 PW → T2 PA	0.08	0.06, 0.10	<0.001	0.08	0.06, 0.10	<0.001	0.07	0.00, 0.14	0.095
T1 PA → T2 L	0.02	0.00, 0.04	0.100	-0.02	-0.04, 0.01	0.255	-0.02	-0.08, 0.03	0.506
T1 PA → T2 A	0.04	0.02, 0.05	<0.001	-0.02	-0.04, 0.00	0.197	-0.03	-0.09, 0.02	0.325
T1 PA → T2 PW	-0.00	-0.02, 0.01	0.672	0.02	-0.00, 0.04	0.108	0.01	-0.05, 0.08	0.746
Indirect Effects									
L → PA → A	0.00	0.00, 0.00	0.482	0.00	0.00, 0.00	0.450	0.00	-0.00, 0.01	0.826
L → PA → PW	0.00	0.00, 0.00	0.380	0.00	-0.00, 0.00	0.453	-0.01	-0.01, 0.00	0.203
A → PA → L	0.00	-0.00, 0.00	0.388	0.00	-0.00, 0.00	0.848	0.00	-0.00, 0.00	0.912
PW → PA → L	-0.00	-0.00, 0.00	0.371	0.00	-0.00, 0.00	0.804	0.00	-0.01, 0.00	0.902

T1, Time 1 (2020-21); T2, Time 2 (2021-22); L, Loneliness; A, Anxiety; PW, Psychological Wellbeing; PA, Physical Activity. All models are stratified by gender, and are controlled for student grade, perceived family affluence, province, ethnicity, and school-level clustering.

Figure 2. Standardized model parameter estimates of autoregressive and cross-lagged associations between loneliness, anxiety, psychological wellbeing, and physical activity across a two-year linked sample of secondary students in the COMPASS study



All estimates are significant at $p < 0.001$; dotted lines represent autoregressive effects; solid lines represent cross-lagged effects; grey lines represent non-significant paths.

6. Discussion

This study aimed to investigate bidirectional relationships between loneliness, and anxiety and psychological wellbeing, and to examine the mediating effect of PA within these relationships in a large sample of Canadian adolescents. Overall, loneliness, anxiety, and psychological wellbeing reciprocally predicted each other across one year in the full sample, with associations varying when stratified by gender. Significant autoregressive effects indicated that loneliness, anxiety, psychological wellbeing, and PA were stable across one year within adolescents. Psychological wellbeing and anxiety were the most stable, while loneliness had the

smallest autoregressive effect compared to the mental health outcomes and PA, suggesting that within-individual loneliness was more varied over a one-year period. PA did not predict loneliness, anxiety, or psychological wellbeing one year later, and was not predicted by these measures over time, in the full sample; however, some associations were observed when models were stratified by gender. Results did not support the hypothesized mediation; PA was not a significant mediator of the bi-directional relationships between loneliness and anxiety or loneliness and psychological wellbeing in the full sample or in the gender groups examined.

6.1 Bidirectional associations between loneliness and mental health outcomes

The reciprocal positive associations between loneliness and anxiety suggest that experiences of loneliness and anxiety are cyclical and amplify each other over time in adolescents. These results align with and add prospective evidence to extant literature, which has primarily used cross-sectional designs or tested unidirectional relationships. For instance, a rapid systematic review by Hards et al. found support for both cross-sectional and longitudinal associations between loneliness and anxiety symptom severity in adolescents⁹⁹. Similarly, research with cross-sectional data collected from Nordic adolescents showed that loneliness was a significant risk factor of poor psychological wellbeing and anxiety¹⁰⁰. In the context of the COVID-19 pandemic, adolescents were isolated and experienced higher levels of loneliness which may have contributed to the emergence of symptoms of mental illness in some, while exacerbating pre-existing mental illness in others. My finding that anxiety symptoms predicted loneliness over a one-year period might be explained by adolescents socially isolating themselves as a maladaptive response to deal with their anxiety¹⁰¹, which may induce feelings of loneliness. Further, specific types of anxiety (e.g., social anxiety) may cause adolescents to socially withdraw and isolate themselves to manage their anxiety¹⁰². Loneliness, in turn, can increase perceived sensitivity to social threats and cause social withdrawal, which together can

lead to anxiety¹⁰³. While our study focused on generalised anxiety, future research should distinguish between which particular types of anxiety predominantly predict and are predicted by loneliness. Altogether our findings are in line with the literature and support the impacts of loneliness on anxiety symptoms while expanding on existing literature by establishing anxiety as a predictor of loneliness over time in adolescents, which had previously only been established in adult populations^{8,60}.

The reciprocal negative associations between loneliness and psychological wellbeing results are noteworthy and build on evidence of a unidirectional relationship, as they indicate loneliness may impede in positive mental health in adolescents and poor mental health may hinder social health and development. Consistent with our findings, a systematic review by Farrell et al. synthesized research on loneliness and wellbeing in adolescents during the pandemic and found significant relationships between loneliness and poorer psychological wellbeing¹⁰⁴. Furthermore, in university students, adults, and older populations, unidirectional relationships have been established indicating loneliness as a predictor of poor psychological wellbeing^{61,62,63,64}. A possible explanation for this relationship is that adolescents with feelings of loneliness may perceive and experience lower availability and quality of social support^{1,105}, which may pose a threat to psychological wellbeing.

To my knowledge, no previous research has prospectively explored psychological wellbeing as a predictor of loneliness in adolescents. Literature has established that perceptions of quality of friendships were predictive of psychological wellbeing in adolescents during the pandemic⁵⁸, and these friendships may provide the social support necessary to lower feelings of loneliness. Further, psychological wellbeing encompasses positive affect, self-esteem, and perceptions of rewarding and supportive social relationships, which may aid in protecting against

loneliness^{47,106}. Our findings confirm previously found relationships between loneliness and psychological wellbeing and add to the literature by establishing psychological wellbeing as a negative predictor of loneliness over time.

The observed relationships between loneliness and psychological wellbeing remained significant when stratifying by gender, except that loneliness did not predict psychological wellbeing in gender-diverse/other adolescents. One explanation could be that gender-diverse adolescents' psychological wellbeing may largely be, as mentioned, influenced by gender identity¹⁰⁷. Gender-diverse adolescents deal with similar challenges and barriers to mental health outcomes as cis-gender adolescents, however with the addition of gender identity concerns and adverse contexts (e.g., nonacceptance of their gender identity by family and peers, gender-based discrimination, limited access to gender-affirming care or appropriate mental health services^{25,108, 109,110}) which may have disparate impacts on their mental health compared to their cis-gender counterparts. As above, another likely explanation is that compared to cisgender adolescents, there was a much smaller sample of gender diverse adolescents, which may have masked potential associations.

6.2 PA as a mediator between loneliness and mental health outcomes

The results from the cross-lagged mediation models in the full sample indicated that PA did not explain the relationships between loneliness and the mental health outcomes, which was not surprising as there was also a lack of direct prospective associations between PA and loneliness, and PA and the mental health outcomes. With respect to mental health outcomes, previous prospective research found that adherence to 24-hour MVPA guidelines did not significantly predict depressive symptoms in adolescents over a one-year period¹¹¹. My findings contrast with some literature; a systematic review and meta-analysis that analysed school-based

interventions found PA to be beneficial in reducing anxiety and increasing psychological wellbeing¹¹². School-based PA typically includes a social aspect for adolescents as they may engage in these activities together with peers, which provides an opportunity to improve social interaction^{113,114}. Similarly, other research has shown that participation in team sports may increase perceptions of social support from peers and adults¹¹⁵. These studies contrast our findings by demonstrating benefits of PA on adolescent mental health and suggest the potential links between PA and loneliness may depend on the type or context of PA, and operate through improved social interactions and support.

The measure of PA used in the current study may account for the inconsistent results. That is, this study examined student reported daily average minutes of MVPA without differentiating the different types and contexts of PA, including whether they were active individually or with others (e.g., team sports, physical education class, or jogging by themselves). Furthermore, the PA measures in the literature largely assess engagement in specific or targeted school-based interventions. The type and setting are important dimensions of PA which may better reflect the effect of PA in the pathways between loneliness and mental health outcomes¹¹⁶ as they can relate to the level of social interaction and factors such as whether PA takes place in safe environments, indoors or outdoors, in a public park or gym, or at school or at home. Individually and together, these dimensions of PA have been shown to contribute to mental health outcomes^{117,118}, particularly during the COVID-19 pandemic where social interactions and accessibility of specific environments were limited. It is plausible that students in this study were engaging in more PA alone and at home than typical for adolescents, given the ongoing COVID-19 pandemic measures, particularly the cancellation of school sport activities and closures of recreational facilities. Partial school closures continued into the 2020-21

academic year in areas and at times with high case rates, and thus, many students were attending school fully or partially online.

Future research should examine the role of specific forms and contexts of PA in the relationships with loneliness and mental health outcomes. Also, while average daily PA time did not play a significant role in the relationships between loneliness and mental health, potential increases in screen time may be a key mediator. During the pandemic, adolescents who connected with friends and family virtually due to the loss of in-person connections may have felt less lonely, however these increases in screen time could potentially exacerbate mental illness¹¹⁹. Research has indicated adverse cross-sectional associations between internet use and loneliness¹²⁰, and positive bidirectional relationships between screen time and loneliness in adolescents over a five-month period¹²¹. Further prospective research assessing the mediating effect of sedentary behaviour within the relationships between loneliness and mental health may prove worthwhile to identify potential mechanisms and inform interventions.

6.2.1 Gender differences in PA and mental health outcome pathways

Consistent with the full sample, PA was not a significant mediator between loneliness and mental health outcomes in either direction when stratified by gender. However, positive bidirectional associations were detected between PA and anxiety in cis-girls, indicating that higher PA levels predicted higher anxiety over time and vice-versa. This result conflicts with existing research that supports negative associations between PA and anxiety symptoms in general across all age groups^{72,73,80,122}, but not specifically adolescent girls. Our study aligns with other research conducted in a large sample of Canadian adolescents that bidirectionally tested these relationships and found a unidirectional positive relationship between PA and anxiety in females only⁷⁴. The positive prospective associations between anxiety and PA may be explained

by adolescents using PA to cope with their feelings of anxiety. Previous cross-sectional research in adults found support for physical activity as a coping mechanism, particularly during the pandemic, where individuals were likely to engage in physical activity to manage their mental health¹²³. Prospective links indicating PA as a predictor of anxiety may be explained through engagement in sport, as the literature shows that adolescent girls demonstrate disproportionate levels of performance anxiety when compared to males¹²⁴. Anxiety symptomatology may also be linked to PA through body image or intention to manage weight; a lack of PA may exacerbate body weight dissatisfaction¹²⁵, and conversely, body image is common motivation to engage in PA among adolescent girls¹²⁶. Longitudinal research done in a sample of Canadian children found that girls and children with higher anxiety symptoms were particularly susceptible to greater body image dissatisfaction¹²⁷. Concerns about body image are significantly associated with anxiety disorders and symptoms in adolescent girls^{128,129}, which may lead to increased PA, and vice versa. Another potential explanation for the relationships between PA and anxiety in girls may be through eating disorders, which are highly comorbid with anxiety and are more common among females than males¹³⁰. Excessive PA may be used to control weight in females with eating disorder symptoms¹³¹, and excessive PA may further exacerbate eating disorders and anxiety.

The lack of prospective associations between PA and anxiety in boys might reflect the difference in experiences of PA when compared to girls. Cross-sectional research conducted by McMahon et al. found that PA was associated with improved mental health in adolescents¹³², however, in post-hoc analyses, there were no significant differences in anxiety or psychological wellbeing scores among boys based on whether they participated in team sports compared to individual sports, while among girls, higher involvement in team sport was associated with

higher psychological wellbeing and lower anxiety symptoms¹³². Some research shows that boys are more interested in PA for fun and enjoyment, while girls might be more motivated by the popularity gained with their peers as a result of PA¹³³. It is possible that boys' mental health may be less influenced by the social components of PA as compared to girls. Additionally, research establishes that boys receive more opportunities to participate and are more confident in their sporting ability¹³⁴, and larger investments are put into facilities and accessibility to PA for boys compared to girls¹³⁴. Altogether, boys and girls' experiences with PA differ, and this research suggests these gender differences may affect links between PA and anxiety symptomatology.

Consistent with cis-boys, there was a lack of bidirectional associations between PA and anxiety in gender diverse adolescents. Research has established that compared to their cisgender counterparts, gender diverse adolescents engage in less PA due to feeling unsafe and uncomfortable in school when activities are segregated by gender¹³⁵. They may also face discrimination and bullying from other students in settings where PA takes place¹³⁵. The experience of mental health outcomes in gender diverse adolescents may largely be influenced by gender identity¹⁰⁷, and therefore, these adolescents may be less able to experience the potential benefits of PA. The smaller sample size of gender diverse/other adolescents may have also contributed to null results.

Higher perceptions of psychological wellbeing predicted engaging in more PA for cis-girls and cis-boys one year later, however these relationships were not bidirectional in any gender group examined. These results are surprising, as current literature supports PA to be a predictor of psychological wellbeing^{77,136}, and prospective research in a large sample of Canadian adolescents has previously established a positive association between adherence to Canadian MVPA guidelines and psychological wellbeing, however in boys only⁷⁶. In line with

my findings, prospective research in Canadian adolescents has found that adolescents who reported higher psychological wellbeing were more likely to meet PA guidelines⁷⁵. Furthermore, results from studies in adult populations have similarly shown that greater perceptions of psychological wellbeing prospectively predict higher engagement in PA^{137,138}. Psychological wellbeing encompasses a sense of purpose, self-esteem, and optimism¹⁰⁶, which may help protect against key barriers to PA such as a lack of both motivation and confidence in one's physical abilities¹³⁹. Our findings established psychological wellbeing as a predictor of PA, which may serve as a point of intervention to combat the decline of PA over adolescence.

6.3 Gender differences in loneliness

Results from the descriptive analysis indicated that gender-diverse/other students reported higher unadjusted loneliness compared to their cis-gender counterparts, which is in line with previous research that found support for higher loneliness in sexual and gender diverse populations¹⁴⁰. Higher levels of loneliness among gender-diverse adolescents were expected as they were cut off from their social networks, which tend to be particularly important for individuals from gender-diverse communities, who may be surrounded by fewer individuals with positive attitudes toward them¹⁴¹. Among cis-gender adolescents, girls reported higher unadjusted loneliness than cis-boys. These results contrast findings from a meta-analysis which did not find significant gender differences in loneliness in childhood and adolescence²³. My results may be explained through males being more reluctant to admitting that they feel lonely; previous research has established that this reluctance is reduced when the word "lonely" is excluded from the measure^{142,143}. Given the literature, it is possible that actual levels of loneliness between boys and girls in the current study are similar but are not detected due to boys underreporting their feelings of loneliness. However, an alternative explanation is that girls felt particularly lonely during the pandemic as they value friendships differently than boys. Research

establishes that girls value more intimacy in their friendships, and therefore are more likely to seek out emotional support within these friendships when compared to boys¹⁴⁴. Boys, in comparison, are more likely to seek out recreation in their friendships, such as bonding over common interests and enjoying time together¹⁴⁴. Therefore, it is possible that boys are not as reliant as girls in their friendships to receive forms of social support that would alleviate loneliness. Furthermore, COVID-19 related lockdowns and social distancing limited or restricted girls' social interactions with their peers, which may have had adverse effects on both feelings of loneliness and mental health, due to a lack of social support. Overall, these results suggest cis-girls and gender-diverse adolescents may be particularly vulnerable to loneliness.

6.4 Strengths and Limitations

This study is among the first to examine PA as a mediator in the bidirectional relationships between loneliness and mental health in a large sample of adolescents. This research addresses the lack of prospective data that explores loneliness and mental health in adolescents during the COVID-19 pandemic. While the findings in this study may have been affected by the pandemic, I was unable to directly examine its impacts on the relationships between loneliness and mental health outcomes as data were collected during the pandemic. However, the findings in the current study were largely consistent with pre-COVID literature. Additionally, this research addresses the scarcity of literature that explores relationships between loneliness and mental health outcomes in gender diverse adolescents.

A strength of this study is the use of a large cohort of Canadian youth which ensures high statistical power and precise parameter estimates. Additionally, longitudinal data enable us to make stronger inferences about temporality within the observed relationships. Linked data allowed for robust analyses of within-individual changes over time, and these analyses on

adolescent mental health are limited in extant literature, particularly during the COVID-19 pandemic. The passive consent protocols within the COMPASS study are also strength due to reduced self-selection bias and improved generalizability through higher response rates and retainment of higher risk adolescents, particularly when asking participants about sensitive areas such as mental health^{87,145}. The large sample size was comprised of full school samples that are distributed across the four largest Canadian provinces (Ontario, Alberta, Quebec, British Columbia), in rural to large urban areas with varied median household incomes, which further improve generalizability to other adolescent populations. Finally, the questionnaire included well validated measures of anxiety and psychosocial wellbeing.

Some limitations of the study include potential response bias and recall error due to the self-report questionnaire method for data collection; although, to help promote honest reporting, COMPASS does not use student names. The large sample of adolescents was not designed to be representative as COMPASS selects a convenient sample of schools; however, as mentioned, favorable response rates, passive consent protocols, and full school samples support generalizability.

Another potential limitation is the use of a single-item measure for loneliness, as literature typically uses the “gold standard” UCLA 3-item loneliness scale¹⁴⁶, which limits the ability to compare results from this study to similar research. However, single item loneliness measures are frequently used in the literature as they reliably measure loneliness^{147,148,149}, and have been validated for use in self-report surveys⁹⁰. Further, previous research has found strong correlations between the single-item loneliness measure from the CES-D and the UCLA 3-item loneliness scale, and the single-item loneliness item was more strongly correlated to those loneliness items than other items from the CES-D scale^{96,150}. The measure was chosen for

pragmatism in the COMPASS survey as it has a broad scope, and was designed to be brief and completable within one classroom period to reduce burden and support data quality. However, the use of the single-item measure limited my ability to separate between types of loneliness (ie. emotional and social loneliness), which may provide valuable insights in how different gender groups experience loneliness. Therefore, future research should include testing measurement invariance of the single-item loneliness measure across age and gender groups to determine its validity for use among these populations. Further, subjective assessments of PA were used; however, actigraphy measures present feasibility concerns in a youth prospective and school-based study of this size, particularly during the ongoing pandemic. The currently used COMPASS self-report measures of PA have been shown to be significantly correlated with actigraphy measures using accelerometers, and are reliable and valid in measuring PA in large scale school-based research⁹⁵.

Our sample was fairly homogenous, as a large majority identified as white and cis-gender, however these demographics are expected in studies conducted in North America, and the sample size for gender-diverse adolescents was substantial compared to current literature. Another potential limitation was the classification of the gender-diverse group, as multiple different groups such as two-spirit, non-binary, those who describe their gender differently, or preferred not to say, were collapsed into one category due to small cell counts. These groups may individually experience mental health outcomes and loneliness differently and collapsing them into one category limits the ability to examine important within group differences.

6.5 Implications

The results of the current study expand on the growing field of literature regarding the effects of loneliness on mental health and further solidifies the need to combat the high levels of

loneliness in adolescent populations to improve mental health outcomes²⁹. Overall, the mechanisms in which loneliness and mental health are linked are currently not well known as literature lacks exploration of potential mediators in these pathways. Future research should prioritize examinations of loneliness in gender diverse adolescents, as current literature is largely limited and results from this study demonstrate the vulnerability of these adolescents to anxiety symptomatology as a result of loneliness. Differences by gender also highlight the necessity of tailored interventions and resources to better address mental health concerns and the specific needs of each group. Further, while our findings suggest that PA frequency may not be a significant factor in reducing loneliness and improving mental health, literature suggests that social components of PA are beneficial in these relationships. Therefore, it is imperative that future research incorporate the type and setting of PA within these relationships to determine whether PA with social components (e.g., team sports, group or partnered PA) lead to reductions in loneliness and mental illness. The observed bidirectional associations between loneliness and both anxiety and psychological wellbeing, and lack of mediation of PA within these pathways, highlight the importance of exploring novel programs or interventions to target loneliness and improve mental health outcomes. School administration, teachers, and other school staff should be aware, especially when developing or adapting school and programs to online formats, that adolescents should have more opportunities to build social networks and interact within them to alleviate loneliness and promote mental health at the school level. Increased attention should be placed on supporting the needs of particularly vulnerable adolescents (e.g., cis-girls and gender-diverse adolescents).

6.6 Conclusion

In conclusion, bidirectional associations were established between loneliness and both anxiety and psychological wellbeing across a one-year time period in the full sample and in cisgender and gender diverse adolescents. Bidirectional associations between loneliness and psychological wellbeing were also observed in the full sample and in cisgender boys and girls. PA was not found to be a significant mediator within the relationships between loneliness and mental health outcomes. Psychological wellbeing positively predicted PA in cisgender girls and boys, while anxiety was negative associated with PA in girls. Gender-diverse adolescents experienced worse mental health, psychological wellbeing, loneliness, and engagement in PA compared to their cis-gender peers. Overall, our results support the adverse effects of loneliness on adolescent mental health, and additionally, add to the mounting literature of gender differences in these relationships. Future research may examine how different formats of PA, particularly those with a social component such as team sports, interact with these relationships. Furthermore, it is warranted to further investigate mediators that may explain the relationships established in this study, as the underlying mechanisms remain largely unknown.

7. References

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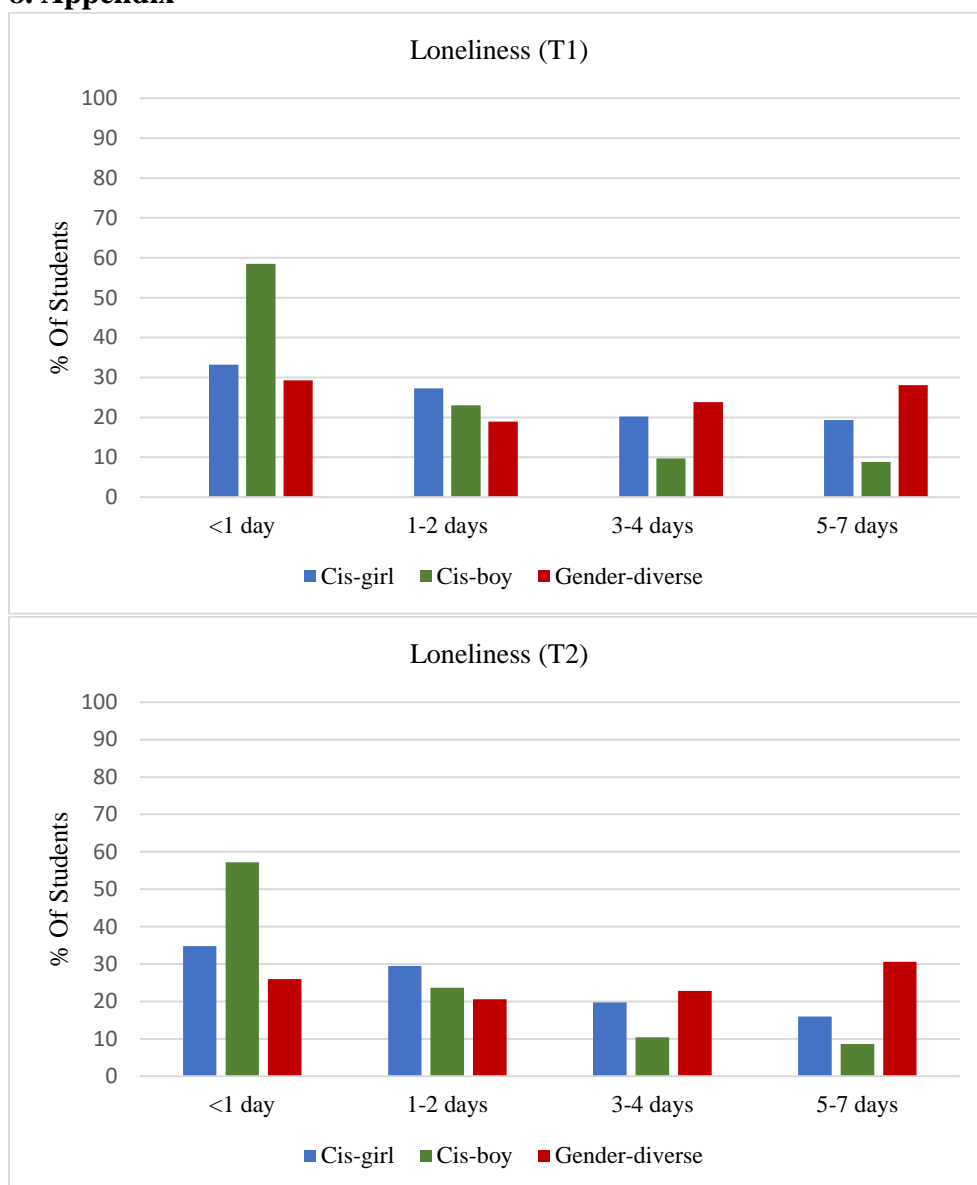
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8. Appendix



Supplementary Figure 1. Distribution of Loneliness by gender, across a two-year linked sample of secondary students in the COMPASS study

Supplementary Table 1. Pearson correlation matrix for all predictor and outcome variables across a two-year linked sample of secondary students in the COMPASS study

		Loneliness		GAD-7		Psychological Wellbeing		Physical Activity	
		T1	T2	T1	T2	T1	T2	T1	T2
Loneliness	T1	-							
	T2	0.43**	-						
GAD-7	T1	0.56**	0.40**	-					
	T2	0.42**	0.55**	0.64**	-				
Psychological Wellbeing	T1	-0.47**	-0.36**	-0.48**	-0.35**	-			
	T2	-0.35**	-0.50**	-0.39**	-0.48**	0.62**	-		
Physical Activity	T1	-0.09**	-0.08**	-0.06**	-0.06**	0.19**	0.16**	-	
	T2	-0.07**	-0.07**	-0.05**	-0.03**	0.15**	0.17**	0.45**	-

**Significant at the 0.01 level. T1, Time 1 (2020-21); T2, Time 2 (2021-22).

Supplementary Table 2. Kolmogorov-Smirnov tests of normality for all predictor and outcome variables across a two-year linked sample of secondary students in the COMPASS study

		Statistic <i>p</i>	
		Statistic	<i>p</i>
Loneliness	T1	0.26	<0.001
	T2	0.26	<0.001
GAD-7	T1	0.14	<0.001
	T2	0.12	<0.001
Psychological Wellbeing	T1	0.09	<0.001
	T2	0.08	<0.001
Physical Activity	T1	0.11	<0.001
	T2	0.10	<0.001

T1, Time 1 (2020-21); T2, Time 2 (2021-22).