Association of mentally-active and mentally-passive sedentary behaviour with depressive symptoms among adolescents

André O. Werneck1,2, Erin Hoare1,3, Brendon Stubbs4,5, Esther M. F. van Sluijs1, Kirsten Corder1

1MRC Epidemiology Unit and Centre for Diet and Activity Research (CEDAR), University of Cambridge, Cambridge, UK

2Department of Physical Education. Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Presidente Prudente, Brazil

3Food & Mood Centre, Centre for Innovation in Mental and Physical Health and Clinical Treatment, School of Medicine, Faculty of Health, Deakin University

4Department of Psychological Medicine, Institute of Psychiatry, Psychology and Neuroscience, King's College London, De Crespigny Park, London, Box SE5 8AF, United Kingdom and South London

5Maudsley NHS Foundation Trust, London, UK

Abstract

Background—The evidence on the association between sedentary behaviour and depression in adolescence is mixed. We aimed to investigate the association between mentally-active and mentally-passive sedentary behaviours at 11 years (11y) and depressive symptoms at 14y, and to examine potential mediators.

Methods—UK Millennium Cohort Study data were used (n=7,124; 49% boys). At 11y, participants self-reported frequency of mentally-passive (listening to music, internet use) and mentally-active sedentary behaviours (reading, playing electronic games). Additional parental-reported behaviours (mentally-passive: TV viewing; mentally-active: homework) were summed with self-reported behaviours to represent continuous indicators of mentally-active and mentally-passive sedentary behaviour. Depressive symptoms were assessed (at 11y and 14y) using the short-version of Mood and Feelings Questionnaire. Body mass index (BMI), mentally-passive sedentary behaviour and cognition at 14y were examined as potential mediators. Linear regression models
were adjusted for confounders and stratified by sex. Subsequent mediation analyses reporting e-values were used to assess unmeasured confounding.

**Results**—Among girls, mentally-passive sedentary behaviour at 11y was associated with later depressive symptoms (14y) \(\beta:0.089 (95\%CI:0.055-0.122), \) e-value:1.32. This association was mediated by BMI [5.6\% (95\%CI:4.1\%-8.6\%)] and mentally-passive sedentary behaviour [105.6\% (95\%CI:79.6\%-156.7\%)]. No associations were observed in boys or between mentally-active sedentary behaviour and later depressive symptoms.

**Limitations**—The parental report of behaviours and the assessment of mediators and outcome in the same wave are the main limitations.

**Conclusion**—Future interventions aiming to improve mental health among girls could aim to reduce mentally-passive sedentary behaviour in early teens and could target potential mediators including BMI.

**Keywords**  
psychological distress; physical activity; sitting; passive; depression

**Introduction**

Major depressive disorder is a leading cause of disability worldwide (Kyu et al., 2018). The onset of depression commonly occurs during middle-adolescence, especially after puberty, and is more common among girls (Kessler et al., 2007). Previous studies have found a considerable prevalence of depressive symptoms among adolescents, at approximately 30\% across different middle-income countries (Vancampfort et al., 2018). Specifically, previous findings from the UK Millennium Birth Cohort Study showed a prevalence of depressive symptoms at the 15 years wave of 9.2\% for boys and 24.0\% for girls (Patalay and Gage, 2019). Depressive symptoms are not only a precursor to subsequent clinical depression, but are a major factor for suicide ideation (Consoli et al., 2013) as well as early development of negative cardiovascular outcomes (Correll et al., 2017; Gross et al., 2018).

Both higher physical activity and lower sedentary behaviour are associated as protective factors with mental health indicators (Hoare et al., 2016; Rodriguez-Ayllon et al., 2019; Schuch et al., 2018; Vancampfort et al., 2018). However, a previous systematic review investigating adolescents, found that different types of sedentary behaviours can be differently associated with depressive symptoms (Hoare et al., 2016). The authors suggested that screen behaviours are the most consistently associated with depressive symptoms.

For studying associations with mental health outcomes, the division of different types of sedentary behaviours into mentally-active (behaviours that increase mental demands as reading and during work) and mentally-passive (behaviours that require minimal demands as TV-viewing and listening to music) has been proposed (Hallgren et al., 2018; Kikuchi et al., 2014). Recent evidence has suggested that mentally-passive, but not mentally-active sedentary behaviour is associated with a higher risk for depression among adults (Hallgren et al., 2019, 2018; Hamer et al., 2016). However, the association between type of sedentary behaviours and depressive symptoms among adolescents is unclear.
There are a number of potential mechanisms that may explain the association between different types of sedentary behaviour and depressive symptoms. The main theoretical difference between mentally-passive and mentally-active sedentary behaviour is the higher cognitive demands of mentally-active sedentary behaviour, making it plausible that cognition may mediate this association (Aggio et al., 2016; Dunning et al., 2018). Obesity is associated with depressive symptoms (Köhler et al., 2018; Mannan et al., 2016) and has been suggested to mediate the association between types of sedentary behaviour and depressive symptoms (de Jong et al., 2013). Lastly, sedentary behaviour has a moderate tracking during adolescence, thus, higher sedentary behaviour during early adolescence is associated with a higher sedentary behaviour during mid-adolescence (Biddle et al., 2010; Busschaert et al., 2015). This can be a pathway linking sedentary behaviour during early adolescence to later depressive symptoms. Therefore, current levels of behaviour are relevant to examine as potential mediators of the prospective association between sedentary behaviour and depressive symptoms. To the best of our knowledge, no population representative cohort study has investigated the relationship between the different types of sedentary behaviour and depressive symptoms during adolescence.

Therefore, our aims were two-fold. First, we analysed the association between mentally-active and mentally-passive sedentary behaviours at 11 years and depressive symptoms at 14 years, and second we analysed the roles of mentally-passive sedentary behaviour, body mass index (BMI) and cognition as potential mediators of the association.

**Methods**

**Cohort design and sample**

We used data from the UK Millennium Cohort Study (MCS), a nationally representative longitudinal study of children born in the UK between September 2000 and January 2002. Children were oversampled from disadvantaged wards across the UK, ethnic minority areas in England, and from Scotland, Wales and Northern Ireland (Connelly and Platt, 2014). The Millennium cohort has seven waves so far: 9 months (2001), 3 years (2004), 5 years (2006), 7 years (2008), 11 years (2012), 14 years (2015) and 17 years (2018). For the present study, we used data from the 11-year and 14-year follow-ups. The initial sample consisted of 18,827 children assessed in 2001. From this, adolescents (63% from the initial) completed the questionnaires at 14 years. A total of 7,124 participants (38% of the original sample) (3,494 boys – 49%) provided full data for the current analyses and were included in the final sample. Ethics approval for all procedures was obtained from the Northern and Yorkshire Multi-Centre Research Ethics Committee of the NHS. Informed consent was secured from all participating families.

**Sedentary behaviour type at 11 years**

We used two sources of information to characterise sedentary behaviour at 11 years. We used parentally reported data of how much time per day their child spent watching television and doing homework, in which parents reported the exact amount of time (open answers). Additionally, we used data from the adolescent self-reported questionnaire, which included questions regarding the frequency of listening to music, reading for enjoyment, playing
electronic games and internet use for leisure (not for school) (five response categories corresponding with 1=never, 2=less often than once a month, 3=at least once a month, 4=at least once a week and 5=most days). Parental report of adolescents’ sedentary behaviours was also transformed into five categories (1=less than 60min, 2=60-119min, 3=120-179min, 4=180-299min and 5=300min or more). Activities were divided into mentally-active (doing homework, reading for enjoyment and playing electronic games) and mentally-passive (TV-viewing, listen to music and internet use) according to previous studies (Hallgren et al., 2018) and summed (including both parental report and adolescent report), creating two continuous indicators with a potential range of 2 to 10 (mentally-active and mentally-passive sedentary behaviour).

**Depressive symptoms**

The short-version of the Mood and Feelings Questionnaire (MFQ) was used to completed by adolescents to assess depressive symptoms at 14 years (Angold et al., 1995). The short MFQ comprises 13 items and aims to assess how true a set of statements are, in relation to the completer’s recent experiences (considering previous two weeks). It asks about depressive and anxiety symptoms with a 3-point Likert response (not true, sometimes or true). The items were scored and added to give a final overall score ranging from 0 to 26, with higher scores reflecting higher presence of depressive symptoms. The short MFQ has been validated previously (Angold et al., 1995; Turner et al., 2014) and deemed reliable due to a good Cronbach’s alpha (0.928) (Tavakol and Dennick, 2011).

**Mediators**

We considered the following indicators at age 14 years as mediators: BMI, mentally-passive sedentary behaviour and cognition. All have been previously demonstrated to be associated with both types of sedentary behaviour and depressive symptoms (Aggio et al., 2016; de Jong et al., 2013; Dunning et al., 2018; Faragher et al., 2005; Mannan et al., 2016).

BMI at 14y was calculated using values of research assistant-measured stature (in metres) and body mass (in kilograms) and was used continuously in the analysis. For association analyses, BMI was used as z-score (Must and Anderson, 2006). Sedentary behaviour at 14y was adolescent-reported using questions regarding time spent in sedentary activities (playing electronic games, watching TV/films, using internet and doing homework) during a normal weekday. Categories were re-coded to the midpoint in each category to represent the amount of time in each activity (e.g. for category 1-2h, was computed 1.5h). Subsequently, sedentary behaviours were divided into mentally-active (playing electronic games and doing homework) and mentally-passive sedentary behaviour (watching TV/films and using internet) and summed to create continuous indicators of time spent in each type of sedentary behaviour. To estimate cognition at 14y, we used data from the Cambridge Gambling Task, which is taken from the Cambridge Neuropsychological Test Automated Battery (Robbins et al., 1994). It measures decision-making and as a final indicator, we adopted quality of decision making (the total number of rational choices made by the participants).
Confounding variables

Psychological distress at 11 years, parental education, parental psychological distress, sports practice and soft drinks consumption were included in the analyses as potential confounders considering their associations with the exposure and outcome (Hoare et al., 2016; Kandola et al., 2021).

Child mental health at 11y was assessed the parent-reported Strengths and Difficulties Questionnaire, which is commonly used among children and adolescents (Goodman et al., 2000) and asks about difficulties in four domains (emotional symptoms, conduct problems, hyperactivity and peer problems), with five 3-point Likert scale items each. Individual item scores were summed to produce a component score for each domain. The sum of these components produces a total difficulties score.

Parental psychological distress (at the child’s 11y wave) was assessed using the Kessler 6-scale, which includes six questions about depressive and anxiety symptoms (5-point Likert answers categories plus “don’t know/don’t wish to answer”) (Kessler et al., 1998).

Parental education was assessed by asking the highest academic qualification achieved by the head of the family.

Child sports practice at 11y was assessed through the question “How often do you play sports or active games inside or outside?”, with the possible answers: “1= Never, 2=less often than once a month, 3=At least once a month, 4=At least once a week, 5=Most days.”

Child soft drinks consumption at 11y, which is a diet component associated with mental health (Kang et al., 2018; Zhang et al., 2019), was adopted as a healthy-diet proxy and assessed using the self-reported question: “How often does the cohort member drink sweetened drinks?”, with possible answers: “1=Hardly ever or never, 2=less than once a month, 3=less often but at least once a month, 4=1-2 days a week, 5=3-6 days a week, 7=once a day and 8=more than once a day”.

Statistical analysis

Characteristics of the sample were presented using values of mean or frequency and 95% confidence intervals. Non-crossed confidence intervals were used to detect differences between groups. Associations of mentally-passive and mentally-active sedentary behaviour (at 11y) with depressive symptoms (at 14y) as well as potential mediators (at 14y) were analysed using linear regression models (with square root transformation for the outcome given the non-normality). All models were adjusted for psychological distress at 11y, parental education, parental psychological distress, sports practice and soft drinks consumption. A sensitivity analysis was also conducted exploring the association between different types of sedentary behaviour and depressive symptoms using linear regression models. Preliminary analyses identified a statistically significant interaction between sex and mentally-passive sedentary behaviour in predicting depressive symptoms, but not for mentally-active sedentary behaviour (Mentally-active SB: $\beta$: 0.013; 95%CI: -0.017 to 0.043. Mentally-passive SB: $\beta$: 0.027; 95%CI: 0.001 to 0.055). For consistency we stratified all analyses by sex.
After the first set of analyses, we created mediation model, using age 14y data on BMI z-score, physical activity, mentally-passive sedentary behaviour and cognition as mediators, in the association of mentally-passive sedentary behaviour and depressive symptoms among girls (Figure 1). The mediation models were created using the concepts of Valeri and Vanderweele (2013), including interactions between exposure and mediator when appropriate, with linear regression models, using the command “medeff” (Imai et al., 2010). After this, the level of potential unmeasured confounders was estimated using E-values, which are defined as the minimum strength of association (risk ratio scale) that an unmeasured confounder would need to have with both exposure and the outcome to fully explain the specific exposure-outcome association, conditional on the measured covariates (VanderWeele and Ding, 2017). As a sensitivity analysis, we re-ran the mediation models excluding leisure-time computer use as a mentally-passive sedentary behaviour, as some of the activities during the leisure-time use of the computer may be considered mentally-active. All analyses accounted for non-response sampling weights and were conducted in the software Stata 15.1.

Results

Table 1 presents the characteristics of analysis sample. Girls reported more time in mentally-passive sedentary behaviour at both time-points and also less time in mentally-active sedentary behaviour at 14y. Also, girls reported lower levels of physical activity and a higher number of depressive symptoms at 14y.

Neither mentally-active nor mentally-passive sedentary behaviours were associated with depressive symptoms among boys (Table 2). However, higher mentally-passive sedentary behaviour was associated with subsequent higher levels of depressive symptoms among girls, with an e-value of 1.32. Mediation analyses were pursued for this association. Considering the different types of sedentary behaviour individually (Supplementary Table A), there were no associations among boys, while reading for enjoyment, TV-viewing and listen to music were associated with higher depressive symptoms among girls.

The association between different types of sedentary behaviour and potential mediators of the association between the sedentary behaviour and depressive symptoms are presented in Table 3. Mentally-passive sedentary behaviour at 11y was consistently associated with higher mentally-passive sedentary behaviour among boys and girls at 14y as well as with lower cognition scores and higher BMI among girls.

Mediation models revealed that the most consistent mediator of the association between mentally-passive sedentary behaviour and depressive symptoms among girls was mentally-passive sedentary behaviour at 14y [%mediation: 105.6% (95%CI: 79.6% to 156.7%)]. In addition, BMI [%mediation: 5.6% (95%CI: 4.1% to 8.6%)] presented small mediation effects, while cognition did not demonstrate a consistent mediation effect (Table 4). The sensitivity analysis excluding leisure-time computer use of the indicator of mentally-passive sedentary behaviour revealed similar findings (Supplementary table B).
Discussion

In a large representative cohort of UK adolescents, Mentally-active sedentary behaviour at 11y was not associated with depressive symptoms at 14y in either boys or girls. In contrast, mentally-passive sedentary behaviour at 11y was associated with increased depressive symptoms among girls at 14y. This association was mediated by mentally-passive sedentary behaviour, and BMI at 14y.

Previous studies have shown that more time spent sedentary was associated with higher depressive symptoms among adolescents (Hoare et al., 2016; Rodriguez-Ayllon et al., 2019; Vancampfort et al., 2018), but this evidence is large based on screen-based behaviours. We examined mentally-active and mentally-passive sedentary behaviours separately as recommended previously (Hallgren et al., 2018; Kikuchi et al., 2014) and our results align with evidence suggesting a potentially association between mentally-passive sedentary behaviour and depressive symptoms among adults (Hallgren et al., 2019, 2018). To our knowledge, this is the first study to investigate this association among adolescents, and to examine the role of potential mediators. We showed that the association between mentally-passive sedentary behaviour and depressive symptoms was statistically significant only among girls but not boys. These sex differences highlight that risk factors for depressive symptoms may be sex-specific and that other (non-sedentary) behaviours are likely to be more important for boys (Hoare et al., 2016; Kandola et al., 2021). This observation may have important public health implications, as adolescent females experience higher rates of mental health problems than males, but also engage in greater mentally-passive sedentary behaviour. On the other hand, it is encouraging to note that mentally-active sedentary behaviour was not associated with depressive symptoms. Theoretically, mentally-active behaviours should even be associated with lower depressive symptoms due its characteristics and brain activation (Horowitz-Kraus and Hutton, 2018). The global response to the COVID-19 pandemic has given rise to concerns about increased screen use amongst young people and this evidence suggests that greater screen use for mentally-active sedentary behaviours (such as home schooling) may not carry the mental health risks feared. However, excessive engagement in mentally-passive sedentary behaviours should be discouraged.

In order to investigate potential mechanisms underlying the proposed association between mentally-passive sedentary behaviour and depressive symptoms, we also analysed the role of potential mediators. This showed that later mentally-passive sedentary behaviour mediated the association in girls. As mentally-active sedentary behaviour at 11y was associated with mentally-passive sedentary behaviour at 14y, this suggests a potential maintenance pathway, as supported by previous studies (Smith et al., 2015; Telama, 2009).

BMI demonstrated only a small mediation effect in the association between mentally-passive sedentary behaviour and depressive symptoms. It is plausible to infer that there are also other potential psychological mechanisms linking obesity and depression such as body image perception (Mond et al., 2011) and lower self-esteem (Russell-Mayhew et al., 2012). There may also be other biological mechanisms, such as through changes in inflammatory and immunological profiles (Köhler et al., 2017; Luppino et al., 2010; Schachter et al., 2018), which were not available in the current study but warrant further investigation.
We hypothesized that higher mentally-passive sedentary behaviour could be associated with reduced brain activity (Horowitz-Kraus and Hutton, 2018), particularly in the hippocampus (Firth et al., 2018) and consequently with lower cognitive performance, given that mentally-passive sedentary behaviour requires minimal cognitive efforts (Aggio et al., 2016; Bakrania et al., 2018). However, we found that even though mentally-passive sedentary behaviour was associated with lower cognitive performance, cognition did not mediate the association between mentally-passive sedentary behaviour and depressive symptoms, raising questions about this mechanisms.

Our results consistently show that different types of sedentary behaviour have different associations with depressive symptoms. Our data has identified a range of potentially modifiable factors from which to inform mental health promotion among adolescent girls. Interventions could aim to target mentally-passive sedentary behaviours during early adolescence, which may be especially important considering the potential tracking of sedentary behaviour through mid-adolescence. Mental health promotion could also focus on the reduction of passive screen behaviours such as TV-viewing and computer use for leisure (Wu et al., 2016).

Despite the nationally representative prospective design used in the present study, our results should be interpreted in light of potential limitations. We combined parentally- and adolescent-reported measures of sedentary behaviour which involved translating response categories for the parental items from reported time into frequency. However, despite limited accuracy in estimating time, self-reported data on behaviour is likely to be able to rank time spent in behaviour (Corder et al., 2009), and is still the predominant method for assessing type of sedentary behaviour. This analysis therefore presents a pragmatic use of the data available, which also allows incorporation of a wider range of sedentary behaviours. Moreover, we also created continuous indicators based on Likert scales, which may be susceptible to potential bias, especially considering the merge of different scales of parental and adolescent report. We were also unable to adjust for depressive symptoms at 11 years due to unavailability of data. However, we adjusted the analyses for the parent-reported psychological distress. We were also unable to adjust the analyses for a broader indicator of physical activity as only data on sports practice was available in the dataset. Although sports participation is a frequent physical activity practice among adolescents there are other frequent activities (e.g. active transport, active play) that are not captured by this indicator (Payne et al., 2013). Further work should consider the mediating role of other physical activity behaviours. Unmeasured confounding, such as anxiety, which can be associated with exposures, mediators and outcome may have also affected the analyses. In addition, we did not have intermediary time-points and consequently, mediators and outcomes were measured in the same wave, limiting our ability to infer causality. Even though we hypothesised a consistent framework as a potential causal model for structuring this analysis, we acknowledge the possibility of potential reverse causality in the associations. For example, it is plausible that depressive symptoms could be associated with increased mentally-passive sedentary behaviours due to depressive symptoms causing a lack of energy and motivation (Firth et al., 2016; Vancampfort et al., 2017).
In conclusion, mentally-passive sedentary behaviour at 11y was associated with depressive symptoms at 14y among girls only, and this association was mediated by BMI, and mentally-passive sedentary behaviour at 14 years. In contrast, mentally-active sedentary behaviour was not associated with depressive symptoms in either boys or girls. Future interventions aiming to improve mental health among girls could consider targeting reductions in mentally-passive sedentary behaviours rather than focussing on overall time spent sedentary.

**Supplementary Material**

Refer to Web version on PubMed Central for supplementary material.

**Acknowledgments**

We thank the Centre for Longitudinal Studies (CLS), UCL Institute of Education, for the use of these data and the UK Data Service for making them available. We also would like to thank the Millennium Cohort Study families for their time and cooperation, as well as the Millennium Cohort Study team at the Institute of Education. The Millennium Cohort Study is funded by grants from Economic and Social Research Council. Neither CLS nor the UK Data Service bear any responsibility for the analysis or interpretation of these data.

**Funding**

André O. Werneck is supported by São Paulo Research Foundation (FAPESP) (FAPESP process: 2018/19183-1). Funding for this study and the work of all authors was supported, wholly or in part, by the Centre for Diet and Activity Research (CEDAR), a UKCRC Public Health Research Centre of Excellence (RES-590-28-0002). Funding from the British Heart Foundation, Department of Health, Economic and Social Research Council, Medical Research Council, and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged. The work of Kirsten Corder, Esther M F van Sluijs was supported by the Medical Research Council (MC_UU_12015/7). Brendon Stubbs is supported by a Clinical Lectureship (ICA-CL-2017-03-001) jointly funded by Health Education England (HEE) and the National Institute for Health Research (NIHR). Brendon Stubbs is part funded by the NIHR Biomedical Research Centre at South London and Maudsley NHS Foundation Trust. Brendon Stubbs is also supported by the Maudsley Charity, King’s College London and the NIHR South London Collaboration for Leadership in Applied Health Research and Care (CLAHRC) funding. EH is funded by an Australian National Health and Medical Research Council Early Career Fellowship (1156909). This paper presents independent research. The views expressed in this publication are those of the authors and not necessarily those of the acknowledged institutions.

**Availability of data**

Cohort data comply with ESRC data sharing policies, readers can access data via the UK Data Archive (www.data-archive.ac.uk).

**References**

Aggio D, Smith L, Fisher A, Hamer M. Context-Specific Associations of Physical Activity and Sedentary Behavior With Cognition in Children. Am J Epidemiol. 2016; 183: 1075–1082. DOI: 10.1093/aje/kww031 [PubMed: 27226249]

Angold A, Costello EJ, Messer SC, Pickles A. Development of a short questionnaire for use in epidemiological studies of depression in children and adolescents. International Journal of Methods in Psychiatric Research. 1995; 5: 237–249.

Bakrania K, Edwardson CL, Khunti K, Bandelow S, Davies MJ, Yates T. Associations Between Sedentary Behaviors and Cognitive Function: Cross-Sectional and Prospective Findings From the UK Biobank. American Journal of Epidemiology. 2018; 187: 441–454. DOI: 10.1093/aje/kwx273 [PubMed: 28992036]
Hoare E, Milton K, Foster C, Allender S. The associations between sedentary behaviour and mental health among adolescents: a systematic review. International Journal of Behavioral Nutrition and Physical Activity. 2016; 13 doi: 10.1186/s12966-016-0432-4

Horowitz-Kraus T, Hutton JS. Brain connectivity in children is increased by the time they spend reading books and decreased by the length of exposure to screen-based media. Acta Paediatrica. 2018; 107: 685–693. DOI: 10.1111/apa.14176 [PubMed: 29215151]

Imai K, Keele L, Tingley D. A general approach to causal mediation analysis. Psychol Methods. 2010; 15: 309–34. [PubMed: 20954780]

Kandola A, Owen N, Dunstan DW, Hallgren M. Prospective relationships of adolescents’ screen-based sedentary behaviour with depressive symptoms: the Millennium Cohort Study. Psychol Med. 2021; 1–9. DOI: 10.1017/S0033291721000258

Kang D, Kim Y, Je Y. Non-alcoholic beverage consumption and risk of depression: epidemiological evidence from observational studies. Eur J Clin Nutr. 2018; 72: 1506–1516. DOI: 10.1038/s41430-018-0121-2 [PubMed: 29500461]

Kessler RC, Amminger GP, Aguilar-Gaxiola S, Alonso J, Lee S, Üstün TB. Age of onset of mental disorders: a review of recent literature. Current Opinion in Psychiatry. 2007; 20: 359–364. DOI: 10.1097/YCO.0b013e32816eb8c [PubMed: 17551351]

Kessler RC, Andrews G, Mroczek D, Ustun B, Wittchen H-U. The World Health Organization Composite International Diagnostic Interview short-form (CIDI-SF). International Journal of Methods in Psychiatric Research. 1998; 7: 171–185. DOI: 10.1002/mpr.47

Kikuchi H, Inoue S, Sugiyama T, Owen N, Oka K, Nakaya T, Shimomitsu T. Distinct associations of different sedentary behaviors with health-related attributes among older adults. Preventive Medicine. 2014; 67: 335–339. Preventive Medicine. [PubMed: 25117527]

Köhler CA, Evangelou E, Stubbs B, Solmi M, Veronese N, Belbasi L, Bortolato B, Melo MCA, Coelho CA, Fernandes BS, Olfson M, et al. Mapping risk factors for depression across the lifespan: An umbrella review of evidence from meta-analyses and Mendelian randomization studies. Journal of Psychiatric Research. 2018; 103: 189–207. DOI: 10.1016/j.jpsychires.2018.05.020 [PubMed: 29886003]

Köhler CA, Freitas TH, Maes M, de Andrade NQ, Liu CS, Fernandes BS, Stubbs B, Solmi M, Veronese N, Herrmann N, Raison CL, et al. Peripheral cytokine and chemokine alterations in depression: a meta-analysis of 82 studies. Acta Psychiatrica Scandinavica. 2017; 135: 373–387. DOI: 10.1111/acps.12698 [PubMed: 28122130]

Kyu HH, Abate D, Abate KH, Ayab SM, Abbafati C, Abbasi N, Abbastabar H, Abd-Allah F, Abdel J, Abdalim A, Abdollahpour I, et al. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2018; 392: 1859–1922. DOI: 10.1016/S0140-6736(18)32335-3

Luppino FS, de Wit LM, Bouvy PF, Stijnen T, Cuijpers P, Penninx BWJH, Zitman FG. Overweight, Obesity, and Depression: A Systematic Review and Meta-analysis of Longitudinal Studies. Arch Gen Psychiatry. 2010; 67: 220. doi: 10.1001/archgenpsychiatry.2010.2 [PubMed: 20194822]

Mannan M, Mamun A, Doi S, Clavarino A. Prospective Associations between Depression and Obesity for Adolescent Males and Females-A Systematic Review and Meta-Analysis of Longitudinal Studies. PLoS ONE. 2016; 11 e0157240 doi: 10.1371/journal.pone.0157240 [PubMed: 27285386]

Mond J, van den Berg P, Boutelle K, Hannan P, Neumark-Sztainer D. Obesity, Body Dissatisfaction, and Emotional Well-Being in Early and Late Adolescence: Findings From the Project EAT Study. Journal of Adolescent Health. 2011; 48: 373–378. DOI: 10.1016/j.jadohealth.2010.07.022

Must A, Anderson SE. Body mass index in children and adolescents: considerations for population-based applications. Int J Obes. 2006; 30: 590–594. DOI: 10.1038/sj.ijo.0803300

Patalay P, Gage SH. Changes in millennial adolescent mental health and health-related behaviours over 10 years: a population cohort comparison study. International Journal of Epidemiology. 2019; 48: 1650–1664. DOI: 10.1093/ije/dyz006 [PubMed: 30815691]

Payne S, Townsend N, Foster C. The physical activity profile of active children in England. Int J Behav Nutr Phys Act. 2013; 10: 136. doi: 10.1186/1479-5868-10-136 [PubMed: 24341402]

J Affect Disord. Author manuscript; available in PMC 2022 April 26.
Robbins TW, James M, Owen AM, Sahakian BJ, McInnes L, Rabbitt P. Cambridge Neuropsychological Test Automated Battery (CANTAB): A Factor Analytic Study of a Large Sample of Normal Elderly Volunteers. Dement Geriatr Cogn Disord. 1994; 5: 266–281. DOI: 10.1159/000106735

Rodriguez-Ayllon M, Cadenas-Sánchez C, Estévez-López F, Muñoz NE, Mora-Gonzalez J, Migueles JH, Molina-García P, Henriksson H, Mena-Molina A, Martínez-Vizcaíno V, Catena A, et al. Role of Physical Activity and Sedentary Behavior in the Mental Health of Preschoolers, Children and Adolescents: A Systematic Review and Meta-Analysis. Sports Med. 2019; 49: 1383–1410. DOI: 10.1007/s40279-019-01099-5 [PubMed: 30993594]

Russell-Mayhew S, MeVey G, Bardick A, Ireland A. Mental Health, Wellness, and Childhood Overweight/Obesity. Journal of Obesity. 2012; 2012 281801 [PubMed: 2278915]

Schachter J, Martel J, Lin C-S, Chang C-J, Wu T-R, Lu C-C, Ko Y-F, Lai H-C, Ojcius DM, Young JD. Effects of obesity on depression: A role for inflammation and the gut microbiota. Brain, Behavior, and Immunity. 2018; 69: 1–8. DOI: 10.1016/j.bbi.2017.08.026

Schuch FB, Vancampfort D, Firth J, Rosenbaum S, Ward PB, Silva ES, Hallgren M, Ponce De Leon A, Dunn AL, Deslandes AC, Fleck MP, et al. Physical Activity and Incident Depression: A Meta-Analysis of Prospective Cohort Studies. American Journal of Psychiatry. 2018; 175: 631–648. DOI: 10.1176/appi.ajp.2018.17111194

Smith L, Gardner B, Hamer M. Childhood correlates of adult TV viewing time: a 32-year follow-up of the 1970 British Cohort Study. Journal of Epidemiology and Community Health. 2015; 69: 309–313. DOI: 10.1136/jech-2014-204365 [PubMed: 25147213]

Tavakol M, Dennick R. Making sense of Cronbach’s alpha. International Journal of Medical Education. 2011; 2: 53–55. DOI: 10.5116/ijme.4dfb.8dfd [PubMed: 28029643]

Telama R. Tracking of Physical Activity from Childhood to Adulthood: A Review. Obesity Facts. 2009; 2: 187–195. DOI: 10.1159/000222244 [PubMed: 20054224]

Turner N, Joinson C, Peters TJ, Wiles N, Lewis G. Validity of the Short Mood and Feelings Questionnaire in late adolescence. Psychological Assessment. 2014; 26: 752–762. DOI: 10.1037/a0036572 [PubMed: 24749755]

Valeri L, VanderWeele TJ. Mediation analysis allowing for exposure–mediator interactions and causal interpretation: Theoretical assumptions and implementation with SAS and SPSS macros. Psychological Methods. 2013; 18: 137–150. DOI: 10.1037/a0031034 [PubMed: 23379553]

Vancampfort D, Firth J, Schuch FB, Rosenbaum S, Mugisha J, Hallgren M, Probst M, Ward PB, Gaughran F, De Hert M, Carvalho AF, et al. Sedentary behavior and physical activity levels in people with schizophrenia, bipolar disorder and major depressive disorder: a global systematic review and meta-analysis. World Psychiatry. 2017; 16: 308–315. DOI: 10.1002/wps.20458 [PubMed: 28941119]

Vancampfort D, Stubbs B, Firth J, Van Damme T, Koyanagi A. Sedentary behavior and depressive symptoms among 67,077 adolescents aged 12–15 years from 30 low- and middle-income countries. International Journal of Behavioral Nutrition and Physical Activity. 2018; 15 doi: 10.1186/s12966-018-0708-y

VanderWeele TJ, Ding P. Sensitivity Analysis in Observational Research: Introducing the E-Value. Ann Intern Med. 2017; 167: 268–274. [PubMed: 28693043]

Wu L, Sun S, He Y, Jiang B. The effect of interventions targeting screen time reduction: A systematic review and meta-analysis. Medicine. 2016; 95 e4029 [PubMed: 2739085]

Zhang X, Huang X, Xiao Y, Jing D, Huang Y, Chen L, Luo D, Chen X, Shen M. Daily intake of soft drinks is associated with symptoms of anxiety and depression in Chinese adolescents. Public Health Nutr. 2019; 1–8. DOI: 10.1017/S1368980019001009
Figure 1. Theoretical model.
Note. SB, sedentary behaviour.
### Table 1

**Characteristics of sample**

|                         | Boys (n = 3,494) | Girls (n = 3,630) |
|-------------------------|------------------|-------------------|
| **11 years**            |                  |                   |
| **Mentally-passive SB** |                  |                   |
| Listen music (most days), % | 57.3 (55.3 to 59.2) | 64.3 (62.5 to 66.2) |
| Internet use (most days), % | 55.1 (53.1 to 57.1) | 53.1 (51.0 to 55.1) |
| TV-viewing (2h/day), %   | 39.4 (36.9 to 41.9) | 43.0 (40.6 to 45.4) |
| **Mentally-active SB**  |                  |                   |
| Playing games (most days), % | 67.9 (65.7 to 70.0) | 40.3 (38.4 to 42.3) |
| Reading for leisure (most days), % | 38.7 (36.4 to 41.0) | 53.2 (51.0 to 55.3) |
| Doing homework (2h/day), % | 47.8 (45.4 to 50.2) | 56.6 (54.4 to 58.8) |
| Mentally-passive SB (score) | 11.7 (11.6 to 11.8) | 12.1 (12.0 to 12.1) |
| Mentally-active SB (score) | 11.0 (10.9 to 11.1) | 11.1 (11.0 to 11.2) |
| Total difficulties, score  | 7.75 (7.45 to 8.04) | 6.75 (6.49 to 7.01) |
| Sports practice (most days), % | 66.2 (64.2 to 68.2) | 50.6 (48.5 to 52.7) |
| **14 years**            |                  |                   |
| Depressive symptoms, score | 4.16 (3.98 to 4.34) | 7.15 (6.86 to 7.44) |
| Mentally-passive SB (h/day) | 6.8 (6.7 to 7.0) | 7.4 (7.2 to 7.5) |
| Mentally-active SB (h/day) | 5.9 (5.8 to 6.0) | 4.3 (4.2 to 4.4) |
| Soft drinks ingestion (everyday), % | 26.3 (24.5 to 28.2) | 20.7 (19.0 to 22.5) |
| Happy with school, %     | 11.5 (10.2 to 13.1) | 16.3 (15.0 to 17.8) |
| MVPA (7 days during previous week), % | 23.9 (22.1 to 25.9) | 12.5 (11.0 to 14.1) |
| BMI kg/cm²               | 20.9 (20.7 to 21.0) | 21.9 (21.8 to 22.1) |
| Cognition, score         | 0.81 (0.80 to 0.82) | 0.82 (0.81 to 0.82) |
| Parental psychological distress, score | 4.25 (4.04 to 4.45) | 4.51 (4.30 to 4.72) |
| Parental academic status (college), % | 43.3 (40.7 to 46.0) | 43.4 (40.9 to 46.0) |

Note. Values are presented using values of frequency (percentages of sample) / mean and 95% confidence interval). SB, sedentary behaviour.
Table 2
Association of mentally-active and mentally-passive SB at 11 years with depressive symptoms at 14 years.

|                      | Boys         | Girls        | E-Value |
|----------------------|--------------|--------------|---------|
| Mentally-active SB   | 0.015 (-0.011 to 0.040) | 0.025 (-0.006 to 0.056) | 1.15    |
| Mentally-passive SB  | 0.018 (-0.007 to 0.043) | 0.089 (0.055 to 0.122) | 1.32    |

Note. Values of Mood and Feelings Questionnaire were transformed using the square root function. Adjusted for psychological distress, parental education, parental psychological distress, sports practice and soft drinks ingestion. Sex-interactions: Mentally-active SB: β: 0.013 (95% CI: -0.017 to 0.043); Mentally-passive SB: β: 0.027 (95% CI: 0.001 to 0.055).
Table 3
Association between mentally-active and mentally-passive SB and potential mediators.

| Sedentary behaviour at 11y | Mentally-passive 14y β (95% CI) | Cognition 14 years β (95% CI) | BMI (z-score) β (95% CI) |
|---------------------------|---------------------------------|-------------------------------|--------------------------|
| **Boys**                  |                                 |                               |                          |
| Mentally-active           | -0.003 (-0.019 to 0.012)        | 0.000 (-0.001 to 0.001)       | 0.005 (-0.015 to 0.026)  |
| Mentally-passive          | 0.182 (0.168 to 0.195)          | -0.001 (-0.002 to 0.001)      | 0.023 (0.001 to 0.045)   |
| **Girls**                 |                                 |                               |                          |
| Mentally-active           | -0.005 (-0.020 to 0.010)        | -0.000 (-0.002 to 0.001)      | 0.007 (-0.016 to 0.031)  |
| Mentally-passive          | 0.217 (0.204 to 0.230)          | -0.002 (-0.003 to -0.001)     | 0.060 (0.036 to 0.084)   |

Note. Adjusted for psychological distress at 11y, parental education, parental psychological distress, sports practice and soft drinks ingestion.
|                          | Total effect | Direct effect | Mediation effect | E-value | % of mediation |
|--------------------------|--------------|---------------|------------------|---------|----------------|
| Body mass index (z-score)| 0.089 (0.055 to 0.122) | 0.084 (0.051 to 0.116) | 0.005 (0.002 to 0.009) | 1.05 | 5.6% (4.1% to 8.6%) |
| Mentally-passive SB      | 0.089 (0.055 to 0.122) | -0.005 (-0.047 to 0.036) | 0.094 (0.070 to 0.118) | 1.34 | 105.6% (79.6% to 156.7%) |
| Cognition                | 0.089 (0.055 to 0.122) | 0.090 (0.059 to 0.122) | -0.001 (-0.003 to 0.001) | 1.03 | N/A |

Note. Adjusted for psychological distress at 11y, parental education, parental psychological distress, sports practice and soft drinks ingestion. % of mediation was only presented for significant indirect effects.