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Physical activity during adolescence protects against depression in adulthood: a systematic review and meta-analysis

Qin Deng, Jiaojiao Hou, Peijing Yan, Rong Xiang, Linna Sha, Jiangbo Zhu, Xunying Zhao, Changfeng Xiao, Chenjiarui Qin, Yang Qu, Tao Han, Xin Song, Bin Yang, Ting Yu, Jinyu Zhou, Sirui Zheng, Mengyu Fan, Xia Jiang

Submitted to: JMIR Mental Health
on: October 14, 2025

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Qin Deng[1]; Jiaojiao Hou[1]; Peijing Yan[1]; Rong Xiang[1]; Linna Sha[1]; Jiangbo Zhu[1]; Xunying Zhao[1]; Changfeng Xiao[1]; Chenjiarui Qin[1]; Yang Qu[1]; Tao Han[1]; Xin Song[1]; Bin Yang[1]; Ting Yu[1]; Jinyu Zhou[1]; Sirui Zheng[1]; Mengyu Fan[1]; Xia Jiang[1]

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Abstract

Background: Growing evidence indicates physical activity (PA) in early life appear to influence depression development in later life. However, questions remain regarding whether PA during adolescence, a critical early-life period, has a long-term impact on depression in adulthood.

Objective: This systematic review and meta-analysis aimed to examine the association between PA during adolescence and depression in adulthood.

Methods: We systematically searched Ovid Medline, Ovid Embase, Ovid Cochrane, and PsycINFO, to identify prospective observational studies that examined the association between PA during adolescence and the risk of depression in adulthood. The literature search was conducted from the inception of these databases to November 17, 2022, with an update to December 20, 2024. Two reviewers independently extracted data and assessed the quality of evidence through Newcastle - Ottawa Scale. We employed a random-effects model with inverse variance weighting to calculate odds ratios (ORs) and 95% confidence intervals (95%CIs). Subgroup analyses were conducted to explore potential sources of heterogeneity.

Results: Eleven original studies including 45,281 adolescents (49% boys) were reviewed. Compared to adolescents with lower levels of PA, adolescents with higher levels of PA had a 29% decreased risk of developing depression in adulthood (OR = 0.71, 95%CI = 0.59-0.86, P < 0.01; ?^2 = 0.07; I^2 = 86.0%). Notably, compared to those with a stable low level of PA, adolescents who increased their PA levels showed a 21% reduced risk of depression in adulthood (OR = 0.79, 95%CI = 0.68-0.92), while those who sustained high levels of PA experienced an even greater reduction (OR = 0.66, 95%CI = 0.54-0.81). Sensitivity analyses confirmed the robustness of findings. Subgroup analyses indicated that heterogeneity was primarily attributed to data source (Pinteraction = 0.04) and follow-up period (Pinteraction < 0.01).

Conclusions: Our systematic review and meta-analysis of prospective observational studies indicates that higher levels of PA during adolescence protect against depression in adulthood. These findings reinforce the importance of promoting PA during adolescence as a key focus of public policies to reduce mental health issues in later life.

(JMIR Preprints 14/10/2025:85851)
DOI: https://doi.org/10.2196/preprints.85851

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Physical activity during adolescence protects against depression in adulthood: a systematic review and meta-analysis of prospective observational studies

Qin Deng [1, ¶], Jiaojiao Hou [2, ¶], Peijing Yan [2], Rong Xiang [1], Linna Sha [1], Jiangbo Zhu [1], Xunying Zhao [2], Changfeng Xiao [2], Chenjiarui Qin [1], Yang Qu [2], Tao Han [1], Xin Song [2], Bin Yang [1], Ting Yu [2], Jinyu Zhou [1], Sirui Zheng [1], Mengyu Fan [2 *], Xia Jiang [1,2,3, *]

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Abstract word count: 341

Main text word count: 3,716

Number of Tables: 2

Number of Figures: 3

Running title: Physical activity during adolescence and depression in adulthood.

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Conclusions: Our systematic review and meta-analysis of prospective observational studies indicates that higher levels of PA during adolescence protect against depression in adulthood. These findings reinforce the importance of promoting PA in adolescence as a primary focus of public policies to reduce mental health issues in later life.

Keywords: physical activity; change in physical activity; adolescence; long term effect; depression; meta-analysis.

Introduction

Depression has been recognized as one of the heaviest and fastest-growing burdens to global public health[1], and that growth is occurring most markedly among young adults aged 18-25 and among females[2,3]. Despite the tremendous advances in psychotherapy and antidepressants, a substantial proportion of individuals either

have limited access to conventional mental health care or are resistant to standard treatment[4,5]. Moreover, adverse actions and financial costs associated with prescribed antidepressants pose an additional layer of challenges[6,7]. A better understanding of modifiable risk factors is therefore needed, which would enable the implementation of early and effective preventive measures.

Physical activity (PA), a non-pharmacological and cost-effective strategy, may serve as a useful complement or alternative to drugs and psychotherapies. At the level of adults (≥ 18 years), a comprehensive systematic review and meta-analysis of 15 prospective studies revealed that relative to those not reporting any PA, adults who engaged in the recommended volume of 8.8 mMET-hours per week experienced a 25% reduced risk of depression (RR = 0.75, 95%CI = 0.68-0.82, $P < 0.01$)[8]. Among adolescents in particular (12-18 years), our research group recently conducted a systematic review and meta-analysis of prospective studies and confirmed a modest yet significant protective effect of PA on the risk of depression (OR = 0.97, 95%CI = 0.94-0.99, $P = 0.01$)[9].

While there is strong evidence linking PA with depression either within adults or within adolescents, it remains unclear whether the beneficial effect of PA in adolescence, a relatively early and unique stage of life, could be extended to reduce the subsequent risk of depression in young adulthood – a period of rapid social, emotional, and cognitive development, and key life transitions[10]. Limited epidemiological studies have attempted to answer this question, and findings remain inconsistent. Although some prospective observational studies reported being physically active during adolescence reduced the risk of incident depression throughout adulthood[11,12], other studies did not support such a correlation[13,14]. A recently published meta-analysis found that engaging in PA during adolescence could protect against subsequent depression measured at an age range of 13-35 years, unable to differentiate adolescence from adulthood (N_{study} = 14, N_{sample} = 15,926; r = −0.07, 95%CI = –0.10- –0.04)[15]. Moreover, a simple correlation coefficient without adequate control for confounding bias might fail to quantify the actual effect size of PA on depression. In addition to preexisting PA levels based on a single-time measurement, dynamic changes in PA also influence the risk of depression[16,17]. Such trends (increasing, decreasing, and stable levels of PA), to the best of our knowledge, has not been systemically examined by prior meta-analysis. Together being neglected are the effects of potential modifiers including data sources (school vs. community), regions, follow-up periods, and individual characteristics (boys vs. girls). For example, a longitudinal study reported that PA at 15-16 years of age was inversely associated with negative emotional symptoms at 18-19 years of age, but only among boys[18].

Adolescence, spanning ages 12 to 18, is a critical transitional phase connecting childhood and adulthood[19]. This period is characterized by high brain plasticity, during which the developing adolescent brain can adapt and learn to establish important behaviors for mental well-being[20]. On the other hand, adolescence is also a stage known for its susceptibility to the onset of mental disorders[21]. Exploring the long-term consequences of PA during this particular life period may establish a foundation for an effective prevention of mental health

issues and a sustained promotion of mental well-being. Therefore, the current systematic review and meta-analysis of prospective studies was done to examine the relationship between PA during adolescence and depression in adulthood. Specifically we aimed to: 1) clarify the strength of the association, 2) explore the impact of changes in PA on the association, and 3) establish whether potential factors modify the association.

Method

We registered this systematic review in the International Prospective Register of Systematic Reviews (PROSPERO) with an identification number CRD42023388297, and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for reporting.

Literature search

A detailed overall search strategy is shown in **Supplementary Table S1**. We conducted a comprehensive literature search without language restriction in four electronic databases (Ovid Medline, Ovid Embase, Ovid Cochrane, and PsycINFO), during which a combination of medical subject headings or synonyms related to the exposure, the outcome, and the population framework was adopted. Two reviewers conducted searches in all four databases from database inception to 17 November 2022, and updated the literature search on 14 January 2024. The search terms encompassed various relevant concepts including “physical activity”, “exercise”, “sports”, “physical fitness”, “physical education and training”, “depressive symptoms”, “depression”, “adolescents” and “young adults”. Additionally, complementary to the aforementioned procedure, a manual search was conducted in the reference lists of previous related articles included to identify other potentially eligible studies.

Eligibility and study selection

Studies were included if 1) participants were adolescents at baseline and were free of depression or depressive symptoms, 2) participants were followed up into adulthood, 3) the study was in a prospective cohort, a nested case-control or a case-cohort design with at least 1 year of follow-up, and 4) the study reported adjusted odds ratios (ORs), relative risks (RRs), hazard ratios (HRs) or β-coefficients, as well as 95% confidence intervals (95%CIs) of the effect size.

Studies were excluded if 1) the study focused on adolescents who already had depression at baseline (i.e., focused on prognosis rather than onset), 2) the study did not follow the participants up into their adulthood, meaning both the exposure and the outcome were assessed solely during adolescence or even younger, 3) the study had incomplete data, 4) the study was written in languages other than English or Chinese, and 5) the study included non-human subjects. Furthermore, we did not consider conference abstracts due to concerns regarding the quality of reporting and accessibility of data. When two or more studies reported data from the same cohort, we selected the one with the highest statistical power, determined by factors such as the largest sample size or the longest follow-up period.

We used EndNote X9 software to remove the duplicates from search results. Thereafter, two authors (QD and

JH) independently evaluated the eligibility of each study based on the pre-determined inclusion and exclusion criteria as outlined above. First, the titles and abstracts were reviewed to conduct a preliminary screening of the articles, and those that failed to meet the criteria were deleted. Second, the full text of the remaining articles was downloaded and re-evaluated to further screen for eligible articles. If a disagreement occurred between the two authors, a third author (PY) would review the article and the three authors would discuss until consensus was reached.

The exposure PA was measured encompassing participation in exercise, sports, or any form of physical movement that involved energy expenditure (specific restrictions on the measurement were not imposed).

The outcome depression was assessed as: 1) incident depression based on a diagnosis using a standardized, structured diagnostic interview, such as Composite International Diagnostic Interview (CIDI)[22], or self-reported physician diagnosis of depression; 2) increased subclinical depressive symptoms assessed by a validated scale.

Data extraction

Data from the included articles were extracted and cross-checked by two authors (QD and JH). We extracted the following information: name of the first author, year of publication, study location and details of the population cohort, age and sex of participants, numbers of participants, follow-up period, assessment details for PA and for depression, covariates included in the statistical model, and the effect estimates and its 95%CIs. If specific information regarding the cohort was not available in a particular study, we conducted an extensive search in the original cohort profile or other published studies affiliated to the same cohort to collect the required information. In cases where multiple statistical models with different adjustment methods were employed, we selected the effect estimate from the most extensively adjusted model. The results were reviewed for consensus, and any disagreements were discussed until consensus was reached.

Risk of bias assessment

Two authors (QD and JH) independently evaluated the risk of bias for each eligible study. The methodological quality of studies was assessed using the Newcastle-Ottawa Scale (NOS)[23], containing eight items categorized into three dimensions: selection, comparability, and outcome (for cohort studies) or exposure (for case-control studies). A study can be awarded a maximum of 1 point for each item within the selection and outcome categories, and a maximum of 2 points for each item within the comparability category. The highest quality score on the NOS is 9, and we categorized studies into low (scores 0-3), moderate (scores 4-6), and high quality (scores 7-9)[24]. In case of disagreement, a consensus was reached through discussion.

Statistical analysis

In the primary analysis, an inverse variance random-effects meta-analysis was conducted to investigate the relationship between PA during adolescence and incident depression in adulthood, with the pooled ORs and 95%CIs selected as the effect estimates for reporting the results. For studies that provided β-coefficients and

its 95%CIs of the association between PA and depression, the ORs were recalculated using conversion method reported elsewhere[25]. When studies provided effect estimates stratified by sex, we utilized a fixed-effects model to calculate the combined effect. We used Q-test, I^2, and τ^2 statistics to determine the level of heterogeneity. The Q-test examines the null hypothesis that all studies share a common effect size, while the I^2 statistic quantifies the percentage of variation in the pooled estimates due to between-study heterogeneity. General guidelines for the interpretation of I^2 are as follows: 25%, 50%, and 75% indicate low, moderate, and high level of heterogeneity, respectively. In addition, the τ^2 statistic describes the degree of inconsistency among different effect estimates[26].

We performed subgroup analyses to evaluate potential sources of heterogeneity in associations by different study characteristics. Given the known sex differences in PA, subgroup analysis was conducted separately by sex[27]. Also, taking into account the varying effects of different trends in PA during adolescence on the occurrence of adult depression[28], we conducted a subgroup analysis by categorizing the changes of PA into three groups (increase vs. stable low, decrease vs. stable low, and stable high vs. stable low). Moreover, to account for factors that could potentially impact the relationship between PA and depression, further subgroup analyses were performed based on 1) data source (school vs. community), 2) geographical areas[29] (north America, Europe, and Oceania), 3) duration of follow-up period (<11 years vs. ≥ 11 years), 4) measurement of depression[30] (diagnostic interview vs. self-reported scale), and 5) NOS score (high vs. moderate)[31].

We assessed the robustness of the overall results through three sensitivity analyses. First, to examine the effects of each study on the overall effect estimates, we conducted a leave-one-out sensitivity analysis. Second, to verify whether the values transformed from β-coefficients into ORs would alter the overall association, we excluded studies that reported β-coefficients as the effect estimates. Third, to further ensure the stability of findings, we performed another sensitivity analysis by converting the ORs back into β-coefficients. Finally, the potential for publication bias was assessed using the Egger's regression test[32], and by inspection of funnel plots. Statistical analyses and forest plots were conducted with R software version 4.2.3. P <0.05 was considered significant.

Results

Study selection

The PRISMA flowchart for the included studies is illustrated in **Figure 1**. Our initial search yielded a total of 16,980 articles, of which 5,566 were removed for duplicates. After excluding 11,166 unrelated records based on titles and abstracts screening, 248 full-text articles were retrieved, and 11 eligible studies were finally included in the current systematic review and meta-analysis[11-14,16,28,33-37]. A list of full-text articles that were excluded as well as detailed justifications for exclusion is available in online **Supplementary Table S2**.

Study characteristics

The characteristics of 11 selected studies are presented in **Table 1**. A total of 45,281 adolescents were evaluated, with balanced sex distribution (49% boys). The studies were followed up for a median of 11.0 years. A slightly more studies were conducted in the school (55%, N = 6) rather than in the community (45%, N = 5) setting. All included studies were originated in developed regions, north America (36%, N = 4), Europe (36%, N = 4), Oceania (18%, N = 2), except for one from developing south American (Brazil).

Exposure (here, PA) was measured by subjective questionnaires in all the analyzed studies (100%, N = 11). Outcome (here, depression or depressive symptoms) was largely evaluated by well-validated scales such as the Center for Epidemiological Studies Depression (73%, N = 8); and three studies used self-administrated structured or semi-structured diagnostic interviews.

Risk of bias assessment

The risk of bias assessment scores for each included study are provided in **Table 1**. Quality scores ranged from 4 to 9, with a mean score of 6.9 out of a maximum possible 9. According to our pre-defined cut-points, all studies were judged as of moderate-to-high methodological quality and 7 studies were considered as of high quality (64%).

Physical activity and incident depression

Higher versus lower levels of PA

The results of meta-analysis of PA levels and depression risk are shown in **Figure 2**. Compared with lower levels of PA, adolescents with higher levels of PA had a 29% decreased risk of incident depression during adulthood, as shown in **Figure 2A** (OR = 0.71, 95%CI = 0.59-0.86, $P < 0.01$; $\tau^2 = 0.07$; $I^2 = 86.0\%$; $P_{Q\text{-}test} < 0.01$). In sensitivity analysis, we evaluated alternative approaches: removing the studies that reported β-coefficients as effect estimates (**Figure 2B**, N = 7; OR = 0.79, 95%CI = 0.66-0.92, $P = 0.04$; $\tau^2 = 0.04$; $I^2 = 85.0\%$; $P_{Q\text{-}test} < 0.01$); conducting analyses after converting the ORs into β-coefficients (**Supplementary Figure S1,** $\beta = -0.34$, 95%CI = −0.52- −0.15, $P < 0.01$; $\tau^2 = 0.07$; $I^2 = 86.0\%$; $P_{Q\text{-}test} < 0.01$). These alternative approaches did not alter the pooled risk estimates from our main analysis remarkably. Leave-one-out analysis suggested that the overall effect estimate of PA was not driven by any of the individual study and omission of any study did not change the effect estimate substantially (**Supplementary Figure S2**). The likelihood of presence of publication bias was evaluated by examining funnel plots and conducting Egger's regression test. Both graphical (**Supplementary Figure S3**) and statistical evidence (Egger's test, $P < 0.01$) indicated the existence of publication bias.

Changes in PA

The results of meta-analysis of changes in PA and depression risk are described in **Figure 3.** Seven studies investigated the patterns of PA during adolescence, classifying changes as increased, decreased, or stable (including stable low and stable high) trends. Compared to those with a stable low level of PA, adolescents

who experienced an increased level of PA showed a 21% decreased risk of depression in adulthood (OR = 0.79, 95%CI = 0.69-0.92). Similarly, adolescents who maintained a stable high level of PA had an even more pronounced decreased risk of depression in adulthood (OR = 0.66, 95%CI = 0.54-0.81). Conversely, those who decreased their levels of PA, while displaying an elevated risk of depression, did not reach statistical significance (OR = 1.09, 95%CI = 0.83-1.44).

Subgroup analyses

Subgroup analyses by sex, data source, region, follow-up period, depression measurement, and the NOS score were performed to explore potential between-study heterogeneity and effect modifications (**Table 2** and **Supplementary Figure S4-S9)**. When stratified by data source, the protective effect of PA against depression was stronger in community-based studies (OR = 0.61, 95%CI = 0.47-0.80) compared to school-based studies (OR = 0.85, 95%CI = 0.73-0.99; $P_{interaction}$ = 0.04). When stratified by follow-up period, the beneficial effect was more pronounced among studies with a longer follow-up period (≥ 11 years: OR = 0.62, 95%CI = 0.48-0.81) than those with a shorter follow-up period (< 11 years: OR = 0.85, 95%CI = 0.71-1.02; $P_{interaction}$ < 0.01).

Subgroup effects were observed for other factors even though they did not contribute to heterogeneity ($P_{interaction}$ > 0.05). Specifically, regarding sex, significant and consistent protective associations of PA on incident depression were observed for overall population (OR = 0.68, 95%CI = 0.53-0.86) and for boys (OR = 0.68, 95%CI = 0.48-0.96), but not girls (OR = 0.81, 95%CI = 0.61-1.08). Region-wise, significant associations were found for studies conducted in Europe (OR = 0.62, 95%CI = 0.42-0.90) but not in north America (OR = 0.86, 95%CI = 0.72-1.03) or Oceania (OR = 0.68, 95%CI = 0.44-1.04). Additionally, studies that evaluated depression using diagnostic scales showed a significant association (OR = 0.72, 95%CI = 0.58-0.88), while those utilizing interviews did not (OR = 0.71, 95%CI = 0.47-1.09).

Discussion

To the best of our knowledge, this is the first systematic review and meta-analysis that explores the relationship of PA during adolescence with the risk of depression in adulthood. We included 11 prospective cohort studies totaling 45,281 adolescents at baseline. Our findings demonstrate that elevated levels of PA during adolescence decrease the risk of subsequent depression in adulthood. These results remain robust after an array of sensitivity analyses. Heterogeneity across studies is mainly attributed to variations in data source or follow-up period.

Comparison with previously published studies is limited by a lack of consistency in the ages at which exposure and outcome were assessed. We have not identified any systematic review or meta-analysis of similar kind, which designed to study the health effect of PA across key life stages (PA at adolescence → depression in adulthood). While earlier narrative reviews suggested PA be inversely associated with depression, it is important to note that these findings predominantly focused on outcomes occurred in children and adolescents, rather than in adults[38,39]. Although an existing meta-analysis indicated a protective effect of

PA on depression in youth (OR = 0.90, 95%CI = 0.83-0.98), this conclusion was based on merely three studies and the assessment of depression unfortunately encompassed both adolescence and adulthood[30]. Our study advances the field by conducting the first pooled meta-analysis with accurately defined timing for exposure and outcome. This allows a clearer understanding of the long-term impact of PA on mental health (here, depression) – PA during adolescence not only exerts protective effect within this period but also extended beyond.

Importantly, no prior systematic review and meta-analysis has investigated the association between trajectories of PA during adolescence and the onset of depression in early adulthood. Our current study identified three patterns of changes in PA during adolescence (increased, decreased and stable). Both increased and stable high levels of PA reduce the risk of subsequent depression. Similarly, previous studies on trajectories of PA found that adolescents who increased or met PA guidelines during adolescence had lower risk of depression at adulthood than those who were stably inactive or never met the guidelines[16,34]. Overall, our findings suggest that in order to further help prevent depression, individuals should sustain their activity levels over time and that despite an individual's history of inactivity, the initiation of PA may never be too late to aid the prevention of depression[40].

Our finding suggested a significant and consistent protective effect of PA for depression in overall population and boys, but not girls. This aligns with a previous sex-stratified analysis, indicating boys may derive more benefits from PA[41]. A systematic review reported that sex differences in PA may be explained by biological variations between males and females[42]. Males typically develop stronger and larger muscles with greater muscle fibers compared to females as they mature, the advantages of PA tend to be more pronounced for males[43]. Another possible explanation could be that boys are more likely to participate in team sports, which foster socialization and emotional growth, and contribute to a reduction in depressive symptoms[44,45].

Heterogeneity in our meta-analysis was mainly originated from factors including data source and follow-up period. As for data source, subgroup analysis demonstrated a protective effect of PA in both school-based and community-based studies while the effect was greater in the latter. Previous research in this field has consistently confirmed that PA interventions, regardless of school-based[46] or community-based[47], show significant potential to reduce the risk of depression among youth. Our study, while largely supporting the previous findings, suggests promotion of PA in a community setting bring more benefits. Regarding follow-up period, we found a stronger association in studies with longer follow-up period, in line with the quality assessment criteria recommended by NOS, suggesting that outcomes can be more accurately captured and assessed with adequate follow-up time[23].

Adolescence to early adulthood is a critical developmental period when PA levels start to decline[27] and depression commences or increases[48]. Strategies aimed at maintaining PA participation from adolescence or even childhood have great potential for reducing the morbidity and subsequent treatment burden of

depression. The WHO guidelines recommend adolescents engaging in at least 60 minutes of moderate to vigorous intensity PA daily to maintain good health[49]. Moreover, evidence suggests that sport participation during adolescence rather than overall PA, is linked to a reduced risk of depression in adulthood[50]. Therefore, we also encourage further exploration of duration and types of PA (such as team sports, aerobic exercise, or outdoor play) and their potential impact on future depression. Unfortunately, estimating the optimal volume and types of PA in our meta-analysis is challenging due to insufficient data. To address this issue, public health policies should work to foster PA competence, facilitate lifelong engagement in PA, and ensure opportunities to participate in different types of PA. Additionally, given its minimal cost and easy implementation, PA can serve as an adjunctive therapy in clinical practice[51].

Limitations

The present meta-analysis has several limitations to be acknowledged. First, all the studies analyzed utilized self-report questionnaires to assess PA, which may introduce recall bias and reduce the objectivity of collected data. This also reflects a broader limitation in the PA literature, where studies often lack consistency in using standardized tools with established reliability and validity. Second, our study did not consider the specific characteristics of depression recurrence, which might weaken the robustness of results. Although we only analyzed studies involving non-depressed adolescents at the baseline, it is crucial to recognize the possibility of selection bias.

Conclusions

To summarize, our study revealed a negative association of early life PA—in adolescence —with the development of depression in adulthood. Our findings not only fill the quantitative evidence gap regarding this topic, but also emphasize the importance of policies aimed at PA promotion with a special focus on early life. Further research in this field should involve well-established prospective evidence, considering specific aspects such as duration, frequency, and type of PA to determine its optimal pattern for preventing depression.

Author contributions

X.J. and M.F. supervised the study. X.J., M.F., Q.D. and J.H. conceived of the study. Q.D., J.H., P.Y., R.X., L.S., J.Z., X.Z., C.X., C.Q., Y.Q., T.H., X.S., B.Y., T.Y., J.Z., and S.Z. did the analyses. Q.D., J.H., M.F., and X.J. drafted the manuscript. All authors contributed to the interpretation of the findings, critically revised the paper, and had final responsibility for the decision to submit for publication.

Funding

This study was supported by the Young Scientists Fund of the National Natural Science Foundation of China (8220121746), the Recruitment Program for Young Professionals of China, the Promotion Plan for Basic Medical Sciences and the Development Plan for Cutting-Edge Disciplines, Sichuan University, and other Projects from West China School of Public Health and West China Fourth Hospital, Sichuan University. The funder had no role in study design, data collection, analysis, interpretation, writing of the report, or the

decision for submission.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Evaluation IoHMa. Global Health Data Exchange (GHDx). 2019. https://ghdx.healthdata.org/gbd-2019.
2. Collishaw S. Annual research review: Secular trends in child and adolescent mental health. *Journal of child psychology and psychiatry, and allied disciplines* 2015; **56**(3): 370-93.
3. Thapar A, Eyre O, Patel V, Brent D. Depression in young people. *Lancet (London, England)* 2022; **400**(10352): 617-31.
4. Rush AJ, Trivedi MH, Wisniewski SR, et al. Acute and longer-term outcomes in depressed outpatients requiring one or several treatment steps: a STAR*D report. *The American journal of psychiatry* 2006; **163**(11): 1905-17.
5. Thornicroft G, Chatterji S, Evans-Lacko S, et al. Undertreatment of people with major depressive disorder in 21 countries. *The British journal of psychiatry : the journal of mental science* 2017; **210**(2): 119-24.
6. Chisholm D, Sweeny K, Sheehan P, et al. Scaling-up treatment of depression and anxiety: a global return on investment analysis. *The lancet Psychiatry* 2016; **3**(5): 415-24.
7. Santarsieri D, Schwartz TL. Antidepressant efficacy and side-effect burden: a quick guide for clinicians. *Drugs in context* 2015; **4**: 212290.
8. Pearce M, Garcia L, Abbas A, et al. Association Between Physical Activity and Risk of Depression: A Systematic Review and Meta-analysis. *JAMA psychiatry* 2022; **79**(6): 550-9.
9. Sha JHQDL. Physical activity and risk of depression in adolescents: a systematic review and meta-analysis of prospective observational studies. 2024.
10. Patton GC, Sawyer SM, Santelli JS, et al. Our future: a Lancet commission on adolescent health and wellbeing. *Lancet (London, England)* 2016; **387**(10036): 2423-78.
11. Redig L, Feter N, Dumith SC, Domingues MR, Rombaldi AJ. Physical Inactivity From Childhood to Adolescence and Incident Depression. *Am J Prev Med* 2022; **62**(2): 211-8.
12. Murray RM, Sabiston CM, Doré I, Bélanger M, O'Loughlin JL. Association between pattern of team sport participation from adolescence to young adulthood and mental health. *Scand J Med Sci Sports* 2021; **31**(7): 1481-8.
13. da Silva BGC, Menezes AMB, Gonçalves H, et al. Physical Activity During Adolescence and Mental Health in Early Adulthood: Findings From the 1993 Pelotas Birth Cohort Study. *J Phys Act Health* 2023; **20**(9): 860-7.
14. Hoegh Poulsen P, Biering K, Andersen JH. The association between leisure time physical activity in adolescence and poor mental health in early adulthood: a prospective cohort study. *BMC Public Health* 2016; **16**: 3.
15. Korczak DJ, Madigan S, Colasanto M. Children's Physical Activity and Depression: A Meta-analysis. *Pediatrics* 2017; **139**(4).
16. García-Hermoso A, Ezzatvar Y, Ramírez-Vélez R, López-Gil JF, Izquierdo M. Trajectories of 24-h movement guidelines from middle adolescence to adulthood on depression and suicidal ideation: a 22-year follow-up study. *Int J Behav Nutr Phys Act* 2022; **19**(1): 135.
17. Kandola A, Lewis G, Osborn DPJ, Stubbs B, Hayes JF. Depressive symptoms and objectively measured physical activity and sedentary behaviour throughout adolescence: a prospective cohort study. *The lancet Psychiatry* 2020; **7**(3): 262-71.
18. Sagatun A, Søgaard AJ, Bjertness E, Selmer R, Heyerdahl S. The association between weekly hours of physical activity and mental health: a three-year follow-up study of 15-16-year-old students in the city of Oslo, Norway. *BMC Public Health* 2007; **7**: 155.
19. (WHO) WHO. Adolescent Health. https://www.who.int/health-topics/adolescent-health/#tab=tab_1.
20. Belcher BR, Zink J, Azad A, Campbell CE, Chakravartti SP, Herting MM. The Roles of Physical Activity, Exercise, and Fitness in Promoting Resilience During Adolescence: Effects on Mental Well-Being and Brain Development. *Biological psychiatry Cognitive neuroscience and*

neuroimaging 2021; **6**(2): 225-37.
21. Lockhart S, Sawa A, Niwa M. Developmental trajectories of brain maturation and behavior: Relevance to major mental illnesses. *Journal of pharmacological sciences* 2018; **137**(1): 1-4.
22. Lu J, Huang YQ, Liu ZR, Cao XL. Validity of Chinese Version of the Composite International Diagnostic Interview-3.0 in Psychiatric Settings. *Chinese medical journal* 2015; **128**(18): 2462-6.
23. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol* 2010; **25**(9): 603-5.
24. Wu W, Tong Y, Zhao Q, Yu G, Wei X, Lu Q. Coffee consumption and bladder cancer: a meta-analysis of observational studies. *Sci Rep* 2015; **5**: 9051.
25. Omagari K, Sakaki M, Tsujimoto Y, et al. Coffee consumption is inversely associated with depressive status in Japanese patients with type 2 diabetes. *Journal of clinical biochemistry and nutrition* 2014; **55**(2): 135-42.
26. Dogo SH. The effect of some estimators of between-study variance on random-effects meta-analysis. *Science World Journal* 2017; (Vol. 12 No. 2 (2017)).
27. Olds T, Wake M, Patton G, et al. How do school-day activity patterns differ with age and gender across adolescence? *The Journal of adolescent health : official publication of the Society for Adolescent Medicine* 2009; **44**(1): 64-72.
28. Howie EK, McVeigh JA, Smith AJ, et al. Physical activity trajectories from childhood to late adolescence and their implications for health in young adulthood. *Prev Med* 2020; **139**: 106224.
29. Firth J, Solmi M, Wootton RE, et al. A meta-review of "lifestyle psychiatry": the role of exercise, smoking, diet and sleep in the prevention and treatment of mental disorders. *World psychiatry : official journal of the World Psychiatric Association (WPA)* 2020; **19**(3): 360-80.
30. Schuch FB, Vancampfort D, Firth J, et al. Physical Activity and Incident Depression: A Meta-Analysis of Prospective Cohort Studies. *The American journal of psychiatry* 2018; **175**(7): 631-48.
31. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ (Clinical research ed)* 2017; **358**: j4008.
32. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ (Clinical research ed)* 1997; **315**(7109): 629-34.
33. Stavrakakis N, Roest AM, Verhulst F, Ormel J, de Jonge P, Oldehinkel AJ. Physical activity and onset of depression in adolescents: a prospective study in the general population cohort TRAILS. *J Psychiatr Res* 2013; **47**(10): 1304-8.
34. McKercher C, Sanderson K, Schmidt MD, et al. Physical activity patterns and risk of depression in young adulthood: a 20-year cohort study since childhood. *Social psychiatry and psychiatric epidemiology* 2014; **49**(11): 1823-34.
35. Kaseva K, Rosenström T, Hintsa T, et al. Trajectories of Physical Activity Predict the Onset of Depressive Symptoms but Not Their Progression: A Prospective Cohort Study. *Journal of sports medicine (Hindawi Publishing Corporation)* 2016; **2016**: 8947375.
36. Jerstad SJ, Boutelle KN, Ness KK, Stice E. Prospective reciprocal relations between physical activity and depression in female adolescents. *J Consult Clin Psychol* 2010; **78**(2): 268-72.
37. Agans JP, Johnson SK, Lerner RM. Adolescent Athletic Participation Patterns and Self-Perceived Competence: Associations With Later Participation, Depressive Symptoms, and Health. *Journal of research on adolescence : the official journal of the Society for Research on Adolescence* 2017; **27**(3): 594-610.
38. Bursnall P. The relationship between physical activity and depressive symptoms in adolescents: a systematic review. *Worldviews on evidence-based nursing* 2014; **11**(6): 376-82.
39. Rodriguez-Ayllon M, Cadenas-Sánchez C, Estévez-López F, 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 medicine (Auckland, NZ)* 2019; **49**(9): 1383-410.
40. Mammen G, Faulkner G. Physical activity and the prevention of depression: a systematic review of prospective studies. *Am J Prev Med* 2013; **45**(5): 649-57.
41. Buchan MC, Romano I, Butler A, Laxer RE, Patte KA, Leatherdale ST. Bi-directional relationships between physical activity and mental health among a large sample of Canadian youth: a sex-stratified analysis of students in the COMPASS study. *Int J Behav Nutr Phys Act* 2021; **18**(1): 132.
42. Asztalos M, De Bourdeaudhuij I, Cardon G. The relationship between physical activity and

mental health varies across activity intensity levels and dimensions of mental health among women and men. *Public Health Nutr* 2010; **13**(8): 1207-14.
43. Black JE, Isaacs KR, Anderson BJ, Alcantara AA, Greenough WT. Learning causes synaptogenesis, whereas motor activity causes angiogenesis, in cerebellar cortex of adult rats. *Proceedings of the National Academy of Sciences of the United States of America* 1990; **87**(14): 5568-72.
44. McMahon EM, Corcoran P, O'Regan G, et al. Physical activity in European adolescents and associations with anxiety, depression and well-being. *Eur Child Adolesc Psychiatry* 2017; **26**(1): 111-22.
45. Pluhar E, McCracken C, Griffith KL, Christino MA, Sugimoto D, Meehan WP, 3rd. Team Sport Athletes May Be Less Likely To Suffer Anxiety or Depression than Individual Sport Athletes. *Journal of sports science & medicine* 2019; **18**(3): 490-6.
46. Andermo S, Hallgren M, Nguyen TT, et al. School-related physical activity interventions and mental health among children: a systematic review and meta-analysis. *Sports medicine - open* 2020; **6**(1): 25.
47. Buechner H, Toparlak SM, Ostinelli EG, et al. Community interventions for anxiety and depression in adults and young people: A systematic review. *The Australian and New Zealand journal of psychiatry* 2023; **57**(9): 1223-42.
48. Birmaher B, Ryan ND, Williamson DE, et al. Childhood and adolescent depression: a review of the past 10 years. Part I. *Journal of the American Academy of Child and Adolescent Psychiatry* 1996; **35**(11): 1427-39.
49. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine* 2020; **54**(24): 1451-62.
50. Brunet J, Sabiston CM, Chaiton M, et al. The association between past and current physical activity and depressive symptoms in young adults: a 10-year prospective study. *Ann Epidemiol* 2013; **23**(1): 25-30.
51. Heinzel S, Schwefel M, Sanchez A, et al. Physical exercise training as preceding treatment to cognitive behavioral therapy in mild to moderate major depressive disorder: A randomized controlled trial. *J Affect Disord* 2022; **319**: 90-8.

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Table 1. Characteristics of included studies.

First author	Year	Country	Data source	Sample size (Case)	Male (%)	Age, y	Follow-up, y	Exposures		Outcomes ascertainment	Covariates	NOS
								PA parameter	Measure			
Agans, J. P.	2017	USA	School	5,961 (NR)	2,283 (38.3)	13.1 ± 0.9	7.0	Change and frequency	One single question about how frequently they participated in various athletic activities	CES-D	Sex, ethnicity and maternal education.	6
da Silva, B. G.	2023	Brazil	Community	3,247 (93)	1,514 (46.6)	11.0	11.0	Change, duration and frequency	Questions about duration and weekly frequency of PA	MINI	Sex, skin color, family income at birth, maternal schooling at birth, BMI, screen time, and mental health disorder.	9
Garcia, H. A.	2022	USA	School	7,069 (1,418)	3,055 (43.2)	15.4 ± 1.3	22.0	Change and frequency	Questions about weekly frequency of MVPA	CES-D-5	Sex, age, ethnicity, parental income, and alcohol consumption.	7
Hoegh, P. P.	2016	Denmark	Community	1,589 (NR)	702 (44.0)	14.0 ~ 15.0	6.0	Change and duration	One single item about exercise duration per week	CES-DC ≥ 3	BMI, mental health, yearly household income, and highest household education.	4
Howie, E. K.	2020	Australia	Community	1628 (NR)	848 (52.1)	8.0 ~ 17.0	14.0	Change	A single-item was used to create an ordinal activity score	DASS-21	Sex and current PA.	5
Jerstad, S. J.	2010	USA	School	496 □30□	0 (0.0)	13.0 ± 0.7	6.0	Number	Modified version of the PYAS about total number of PA	K-SADS	Baseline depression, body satisfaction, bulimic symptoms, social support, and previous year BMI percentile.	8
Kaseva, K.	2016	Finland	Community	2,224 (NR)	1764 (49.1)	10.4 ± 5.0	32.0	PA factor scores	Self-administered questionnaires	BDI-II	Sex, age, BMI, childhood negative emotionality, socioeconomic factors, previous depressive symptoms, social support, and smoking status.	9
McKercher, C.	2014	Australia	School	1,630 (142)	759 (46.6)	9.0 ~ 15.0	20.0	Change, duration and	Questions about past-week frequency and duration of school	CIDI	Self-reported health status and language spoken at home in childhood, number of	7

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								frequency	and extracurricular sport and exercise		live births, current occupation and age in adulthood, and depressed mood.	
Murray, R. M.	2021	Canada	School	733 (NR)	621 (48.0)	12.8 ± 0.6	8.0	Change	One single question about whether participated in any team sports outside school in the past 3 months	MDI	Sex, age, parental education, adolescent depression, adolescent stress and anxiety, and MVPA in young adulthood.	7
Redig, L.	2022	UK	Community	18,555 (1697)	9,593 (51.7)	16.0	¿ 11.0	Frequency	Face-to-face interview-administered paper-based questionnaire	Malaise Inventory ≥ 7	Sex, age, ethnicity, mother's education, mother's SES, mother's marital status at birth, mother's age at birth, mother's husband social class, birth order, sleep difficulty, smoking, alcohol consumption, BMI, internalizing symptoms, and highest educational achievement at age 50 years.	8
Stavrakakis, N.	2013	Netherlands	School	2,149 (140)	1,053 (49.0)	13.7 ± 0.5	5.0	Frequency and duration	Questions about frequency and duration of PA during an average week	CIDI	Ethnicity and SES.	6

BMI, Body Mass Index; BDI-II, Beck Depression Inventory; CES-D, Center for Epidemiological Studies Depression; CES-D-5, 5-item subscale of the Center for Epidemiologic Studies Depression scale; CES-DC, Center for Epidemiologic Studies Depression Scale for Children; CIDI, Composite International Diagnostic Interview; DASS-21, Depression Anxiety Stress Scales-short form; K-SADS, Affective Disorders and Schizophrenia for School-Age Children; MINI, Mini International Neuropsychiatric Interview; MVPA, Moderate-to-Vigorous Physical Activity; MDI, Major Depression Inventory; NOS, Newcastle-Ottawa Scale; NR, Not Reported; PA, Physical Activity; PYAS, Past Year Activity Scale; SES, Socioeconomic Status.

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Table 2. Subgroup analysis exploring the effects of PA on depression in different sex, data source, region, follow-up period, depression measurement, and NOS score.

Subgroup Analysis	No. of studies	Sample size	OR (95%CI)	*P*-value			$P_{interaction}$
Sex							
Overall	7	39,938	0.68 (0.53, 0.86)	¿0.01	77.4	0.07	
Boy	3	2,403	0.68 (0.48, 0.96)	0.03	47.1	0.04	0.59
Girl	4	2,940	0.81 (0.61, 1.08)	0.15	77.7	0.06	
Data source							
School	6	18,038	0.85 (0.73, 0.99)	0.04	72.0	0.02	0.04
Community	5	27,243	0.61 (0.47, 0.80)	¿0.01	72.6	0.06	
Region							
North America	4	14,259	0.86 (0.72, 1.03)	0.11	71.9	0.02	
Europe	4	5,962	0.62 (0.42, 0.90)	0.01	87.7	0.12	0.22
Oceania	2	21,813	0.68 (0.44, 1.04)	0.07	62.2	0.06	
Follow-up period (years)							
¿**11**	5	10,928	0.85 (0.71, 1.02)	0.08	75.3	0.03	0.05
≥**11**	6	34,353	0.62 (0.48, 0.81)	¿0.01	76.6	0.07	
Depression measure							
Diagnostic scale	8	38,255	0.72 (0.58, 0.88)	¿0.01	87.9	0.06	0.99
Interview	3	7,026	0.71 (0.47, 1.09)	0.12	75.8	0.10	
NOS score							
Moderate	4	11,327	0.79 (0.66, 0.95)	0.01	57.5	0.02	0.23
High	7	33,954	0.65 (0.50, 0.85)	¿0.01	88.2	0.08	

CI, confidence interval; No., Number; NOS, Newcastle-Ottawa Scale; OR, Odds Ratio; PA, Physical Activity.

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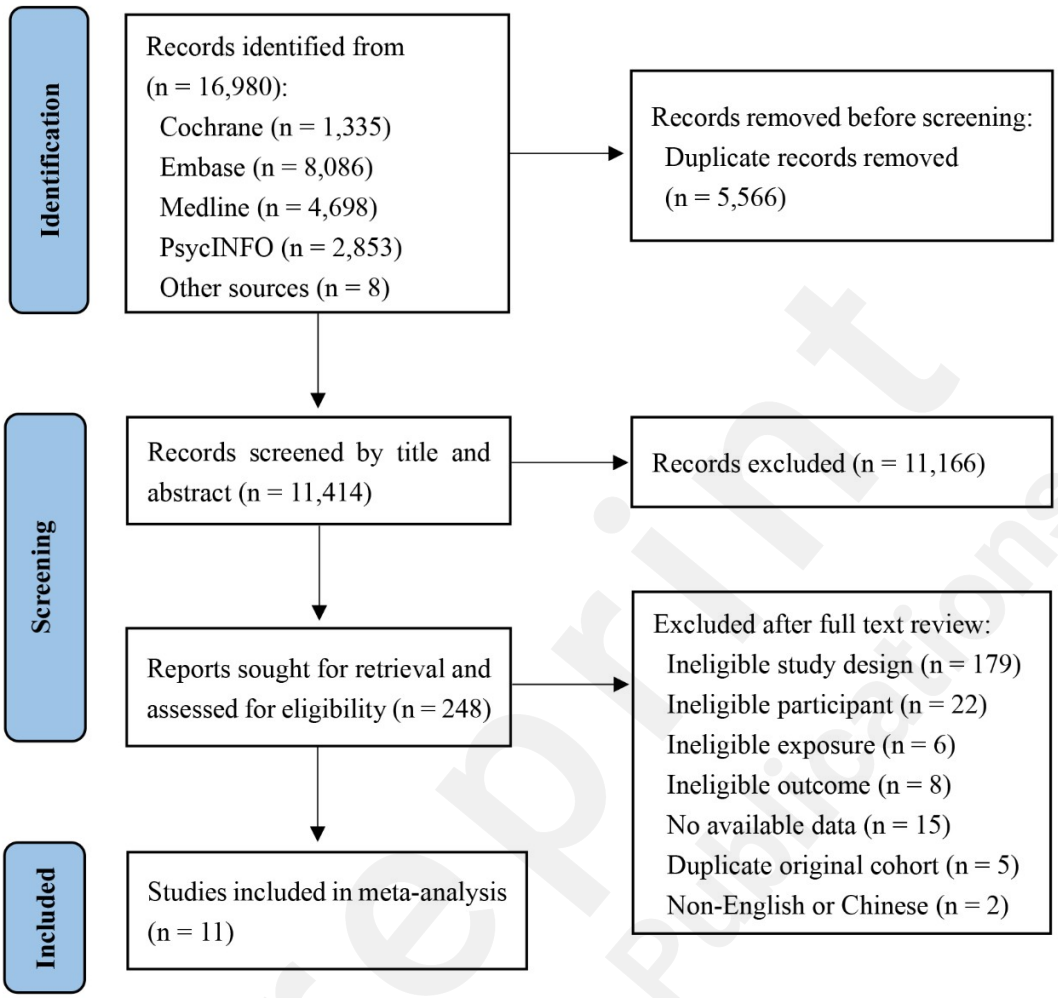

Figure 1. The overall flowchart of the identification, screening, and inclusion of studies.

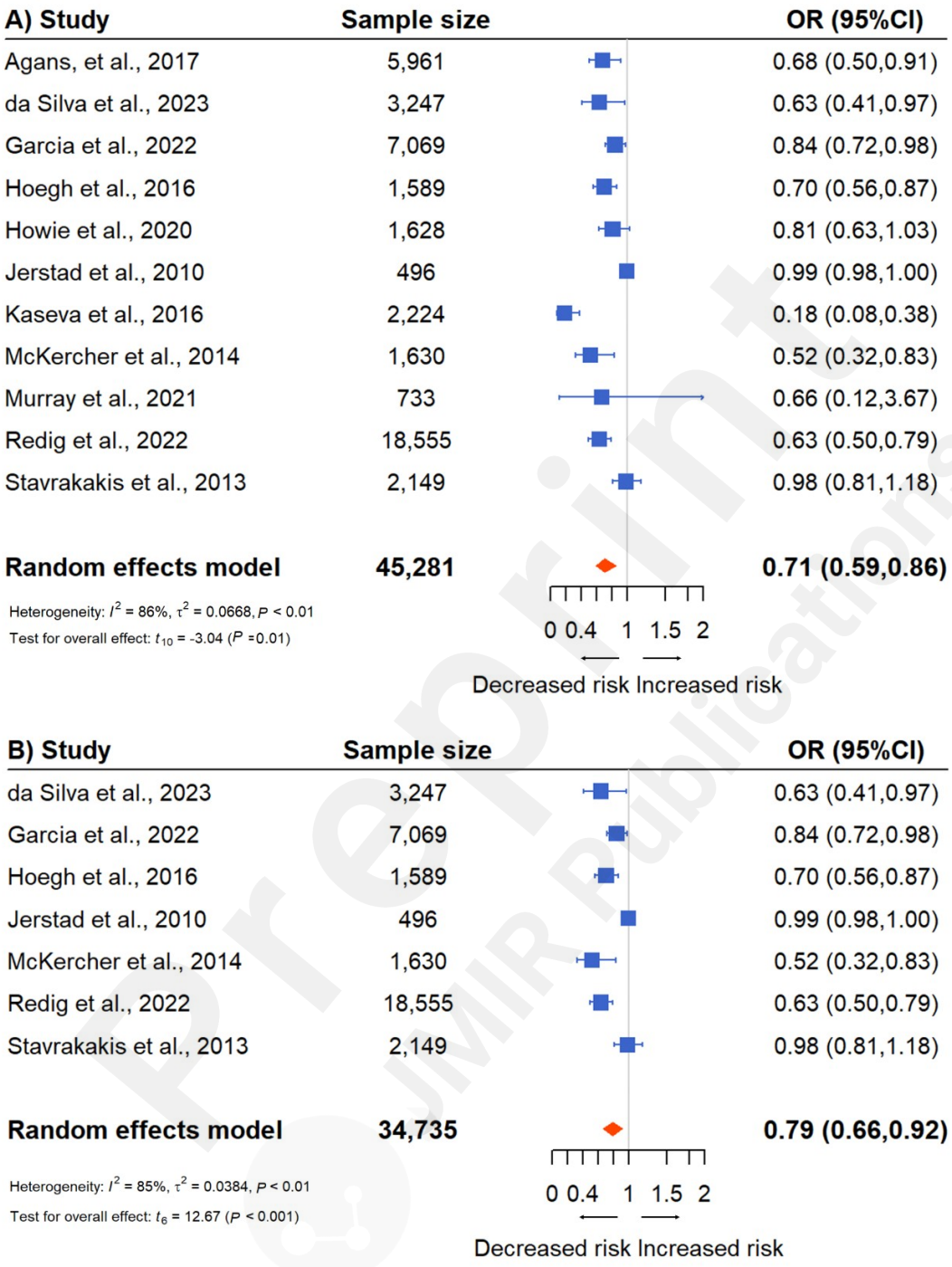

Figure 2. A) Meta-analyses of physical activity during adolescence and depression risk in adulthood. B) Sensitivity analysis of physical activity and depression risk after exclusion of beta effect estimates. CI, Confidence Incidence; OR, Odds Ratio.

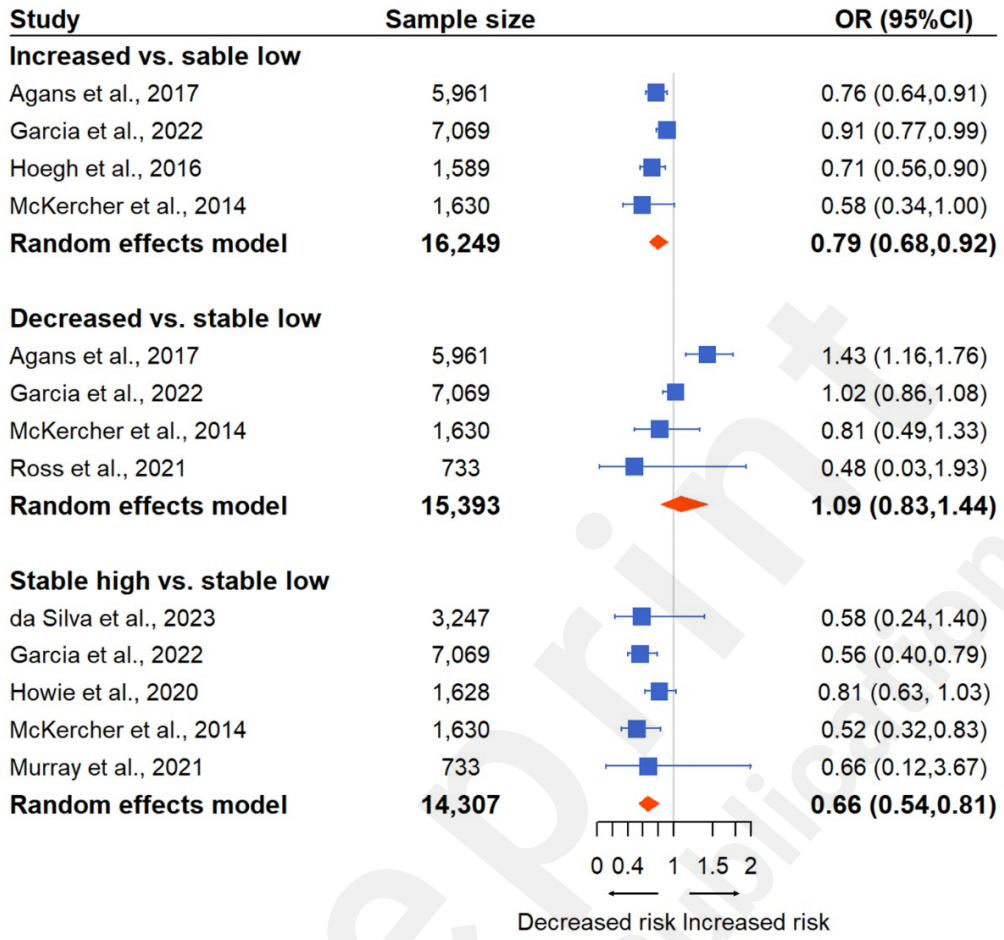

Figure 3. Meta-analyses of changes in physical activity during adolescence and depression risk in adulthood. CI, Confidence Incidence; OR, Odds Ratio.

Supplementary Files

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