JAMA Pediatrics | Original Investigation

Physical Activity Interventions to Alleviate Depressive Symptoms in Children and Adolescents
A Systematic Review and Meta-analysis

Francesco Recchia, MSc; Joshua D. K. Bernal, BSc; Daniel Y. Fong, PhD; Stephen H. S. Wong, PhD; Pak-Kwong Chung, DPE; Derwin K. C. Chan, PhD; Catherine M. Capio, PhD; Clare C. W. Yu, PhD; Sam W. S. Wong, DPT; Cindy H. P. Sit, PhD; Ya-Jun Chen, PhD; Walter R. Thompson, PhD; Parco M. Siu, PhD

IMPORTANCE Depression is the second most prevalent mental disorder among children and adolescents, yet only a small proportion seek or receive disorder-specific treatment. Physical activity interventions hold promise as an alternative or adjunctive approach to clinical treatment for depression.

OBJECTIVE To determine the association of physical activity interventions with depressive symptoms in children and adolescents.

DATA SOURCES PubMed, CINAHL, PsycINFO, EMBASE, and SPORTDiscus were searched from inception to February 2022 for relevant studies written in English, Chinese, or Italian.

STUDY SELECTION Two independent researchers selected studies that assessed the effects of physical activity interventions on depressive symptoms in children and adolescents compared with a control condition.

DATA EXTRACTION AND SYNTHESIS A random-effects meta-analysis using Hedges *g* was performed. Heterogeneity, risk of bias, and publication bias were assessed independently by multiple reviewers. Meta-regressions and sensitivity analyses were conducted to substantiate the overall results. The study followed the PRISMA reporting guideline.

MAIN OUTCOMES AND MEASURES The main outcome was depressive symptoms as measured by validated depression scales at postintervention and follow-up.

RESULTS Twenty-one studies involving 2441 participants (1148 [47.0%] boys; 1293 [53.0%] girls; mean [SD] age, 14 [3] years) were included. Meta-analysis of the postintervention differences revealed that physical activity interventions were associated with a reduction in depressive symptoms compared with the control condition (g = −0.29; 95% CI, −0.47 to −0.10; P = .004). Analysis of the follow-up outcomes in 4 studies revealed no differences between the physical activity and control groups (g = −0.39; 95% CI, −1.01 to 0.24; P = .14). Moderate study heterogeneity was detected (Q = 53.92; df = 20; P < .001; I^2 = 62.9% [95% CI, 40.7%-76.8%]). The primary moderator analysis accounting for total physical activity volume, study design, participant health status, and allocation and/or assessment concealment did not moderate the main treatment effect. Secondary analyses demonstrated that intervention (ie, <12 weeks in duration, 3 times per week, unsupervised) and participant characteristics (ie, aged ≥13 years, with a mental illness and/or depression diagnosis) may influence the overall treatment effect.

CONCLUSIONS AND RELEVANCE Physical activity interventions may be used to reduce depressive symptoms in children and adolescents. Greater reductions in depressive symptoms were derived from participants older than 13 years and with a mental illness and/or depression diagnosis. The association with physical activity parameters such as frequency, duration, and supervision of the sessions remains unclear and needs further investigation.

Editorial

Supplemental content

Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Parco M. Siu, PhD, Division of Kinesiology, School of Public Health, The University of Hong Kong, Pokfulam, Hong Kong 852, China (pmsiu@hku.hk).

JAMA Pediatr. doi:10.1001/jamapediatrics.2022.5090
Published online January 3, 2023.

Depression is the second most prevalent mental disorder among children and adolescents, with an estimated prevalence rate of 6.2% globally.[1] Early childhood depression is associated with severe adverse outcomes, including difficulties with social functioning, poor mental and physical health, and suicide.[2,3] The incidence of depressive symptoms at a young age is a strong predictor of future mental disorders, as it has been shown that up to 67% of youth with depressive symptoms are at risk of developing full-syndrome depressive or anxiety disorders in adulthood.[4-6]

The available clinical practice guidelines suggest the use of psychotherapy and/or pharmacotherapy to alleviate depressive symptoms in children and adolescents.[7-9] However, both approaches have limitations that can reduce treatment adherence. Lack of time, fear of stigmatization, parental mistrust of the therapist, and no perceived need for treatment can be strong barriers to childhood psychotherapy,[10] whereas adverse effects, including sleep disturbances, gastrointestinal distress, and even suicide, have been associated with antidepressant use in pediatric patients.[11] Data from a national survey in the US indicated that only 34% of community-dwelling children and adolescents seek and receive disorder-specific treatment or help from the mental health sector.[12] Data from previous surveys are even more alarming, as they showed that nearly 80% of children and adolescents needing mental health treatment did not receive appropriate medical care.[13] There is an urgent need to explore novel treatment approaches that can be safely, feasibly, and widely implemented in the daily routine of children and adolescents with depression. Physical activity interventions are potential complementary or alternative treatments for depression in youth, as they have been shown to alleviate depressive symptoms in adults[14,15] and have been endorsed by international guidelines (eg, European Psychological Association, the UK National Institute of Health and Care Excellence, Canadian Network for Mood and Anxiety Treatments) as an official treatment for adult depression.[16-18] Furthermore, physical activity is generally safer and more accessible than other clinical depression treatments.

Previous meta-analyses have attempted to synthesize the potential benefits of physical activity on depressive symptoms in younger cohorts,[19-22] but several limitations undermine the interpretation of the findings. Three of these reviews excluded studies of participants with somatic or psychiatric comorbidities, which can seriously challenge the generalizability of the results to everyday settings.[20-22] Children and adolescents with depression are at high risk of developing comorbidities, as research has shown that up to 75% of children with depression reported a comorbid anxiety disorder and up to 57% developed attention-deficit disorder.[23,24] In addition, all reviews based their results on generally small sample sizes, with the largest review including 15 studies in its analysis.[20]

With this systematic review and meta-analysis, we aimed to gather a wider range of studies to provide critical insight into the association between physical activity interventions and depressive symptoms in children and adolescents. Furthermore, we aimed to identify possible participant- and trial-related characteristics that might moderate the overall treatment effect.

Key Points

Question Can physical activity interventions alleviate depressive symptoms in children and adolescents?

Findings This systematic review and meta-analysis included 21 studies involving 2441 participants. The results indicate that physical activity interventions were associated with significant reductions in depressive symptoms compared with the control condition.

Meaning The available evidence supports physical activity interventions as an alternative or adjunctive approach to alleviate depressive symptoms in children and adolescents, substantiating the beneficial influence of physical activity on the mental health of pediatric populations.

Methods

This meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered at the International Prospective Register of Systematic Reviews (CRD42021287944).

Search Strategy and Selection Criteria

We searched PubMed, CINAHL, PsycINFO, EMBASE, and SPORTDiscus from inception to February 2022 for relevant articles written in English, Chinese, or Italian. The search terms used are available in eAppendix 1 in the Supplement. References of previous meta-analyses were also examined. Two authors (F.R. and J.D.K.B.) independently scrutinized each study using preestablished criteria. Any disagreement on the inclusion of a study was arbitrated by a third author (P.M.S.) and resolved by consensus.

We included published randomized clinical trials (RCTs) and studies with a quasi-experimental design (nonrandomized clinical trials [NRCTs]) investigating the effects of an aerobic-type physical activity intervention on depressive symptoms in children and adolescents (aged <19 years). Aerobic-type physical activity was defined using World Health Organization guidelines as "an activity in which the body's large muscle groups move in a rhythmic manner for a sustained period of time."[25(p1452)] The intervention could be conducted in a laboratory setting or integrated as part of a school curriculum and could be implemented as monotherapy or added to the current physical education routine, as an education component, or to treatment as usual. We included studies that implemented a control condition in the form of no treatment, waiting list, education/attention control, or treatment as usual. Only studies with an intervention that was at least 4 weeks long were included. To increase the generalizability of the results, studies with participants with somatic or psychiatric disorders were also included.

Table 1. Study Characteristics

Source	Age, mean (SD or range), y	Sex[a]	Participant characteristics	Control	Intensity	Duration, wk
Bonhauser et al,[35] 2005	15.5 (0.9)	Mixed	Low socioeconomic status	Usual care	V	40
Daley et al,[36] 2006	13.1 (11.0-15.2)	Mixed	Obesity	Usual care	L/M	8
Goldfield et al,[37] 2015	15.6 (1.4)	Mixed	Obesity	No intervention	L/M	22
Hughes et al,[38] 2013	17.0 (16.1-17.9)	Mixed	Depression	Stretching	V	12
Lin et al,[39] 2020	12.6 (0.6)	Mixed	Subthreshold mood syndromes	Attention control	L/M	12
Mohammadi,[40] 2011	NR	Mixed	Depression	No intervention	NR	8
Nabkasorn et al,[41] 2006	18.8 (0.7)	Female	Depressive symptoms	Waiting list	L/M	8
Norris et al,[42] 1992	16.8 (NR)	Mixed	Healthy	No intervention	L/M - V	10
Olive et al,[43] 2019	8.1 (0.4)	Mixed	Midrange socioeconomic status	Usual care	V	144
Peng et al,[44] 2015	14.2 (2.4)	Mixed	Left-behind school children	No intervention	L/M	12
Petty et al,[45] 2009	9.35 (1.1)	Mixed	Overweight	No intervention	V	13
Romero-Pérez et al,[46] 2020	10.0 (0.8)	Mixed	Obesity	Usual care	NR	20
Roshan et al,[47] 2011	16.9 (0.9)	Female	Depression	No intervention	L/M	6
Roth et al,[48] 1987	18.9 (1.3)	Mixed	Stressful life events	No intervention	V	11
Silva et al,[49] 2020	12.0 (1.5)	Mixed	ADHD	No intervention	NR	8
Talakoub et al,[50] 2012	17.4 (2.2)	Female	T1D	No intervention	L/M	6
Weintraub et al,[51] 2008	9.9 (0.7)	Mixed	Obesity	Attention control	V	26
Williams et al,[52] 2019	9.7 (0.9)	Mixed	Overweight	Attention control	V	35
Wunram et al,[53] 2018	15.9 (1.2)	Mixed	Depression	Usual care	NR	6
Yu et al,[54] 2020	9.8 (0.7)	Mixed	Obesity	Usual care	V	30
Zhang and Ji,[55] 2021	14.4 (2.2)	Mixed	Depression	Usual care	V	16

Abbreviations: ADHD, attention-deficit/hyperactivity disorder; L/M, low to moderate; NR, not reported; T1D, type 1 diabetes; V, vigorous.

[a] Mixed indicates both boys and girls.

Main Outcome

The primary outcome was depressive symptoms as assessed using a validated depression rating scale at the end of the intervention period and at the last available follow-up. For studies using multiple scales, observer-rated scales were preferred over self-reported scales. If more than 1 depression scale was reported, we chose the most commonly used scale to reduce heterogeneity.

Data Extraction

Two investigators (F.R. and J.D.K.B.) independently extracted relevant data from the selected studies using preestablished criteria. For each study, sample size, depressive symptoms mean scores, and SDs were extracted to calculate the effect size. When relevant data were not clearly reported, we contacted the authors. When authors were unresponsive or unreachable, we used previously validated methods to extract means and SD; namely, data were computed from the *P* values or CIs provided in the study or from the included graphs.[26] Data from multiarm trials were combined and added as a single comparison group.[26] Inconsistencies in the data extraction between the 2 investigators were resolved by consensus after consulting with a third investigator (P.M.S.).

Additional information regarding participant and trial characteristics was collected to determine their association with physical activity interventions and depressive symptoms. These characteristics included participants' age, sex, and health status; intervention frequency, intensity, duration, and overall volume; type of control; whether the intervention was supervised and used as monotherapy or as an integrated part of an education program; and whether intention-to-treat outcomes were available. Data on race and ethnicity were not collected as they were not within the objectives of this study.

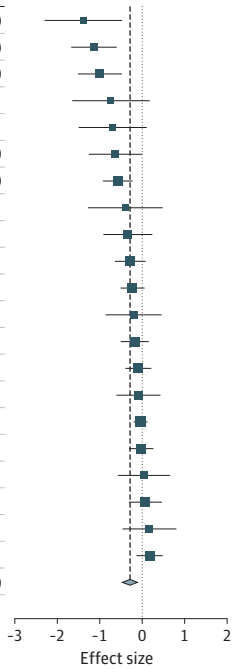
Risk-of-Bias Assessment

Risk of bias was assessed using the Cochrane risk-of-bias tool for randomized trials.[27] Two investigators (F.R. and J.D.K.B.) independently assessed each study as having low risk of bias, some concerns, or high risk of bias. Any discrepancies between the 2 evaluations were resolved by consensus after consulting a third investigator (P.M.S.). The criteria used for the risk-of-bias assessment are available in eAppendix 2 in the Supplement.

Data Analysis

The meta-analysis was performed using R, version 4.2.0 (R Foundation for Statistical Computing). To account for variations in the included studies regarding participants and instruments used to assess depressive symptoms, a random-effects model (Hartung-Knapp method) was used to calculate pooled estimates (Hedges *g*) and the 95% CI. Hedges *g* was calculated from the postintervention or follow-up means, SDs, and sample sizes for each comparison of interest. A negative effect size indicates a beneficial effect of the physical activity intervention compared with the control condition. Cochran *Q* test was used to assess between-study heterogeneity. Higgins I^2 statistic was used to define the percentage of variability that was due to between-study heterogeneity rather than sam-

Figure. Forest Plot of the Distribution of Effect Sizes After Physical Activity Intervention



pling error. The I^2 values of 25%, 50%, and 75% were taken to represent low, moderate, and high levels of heterogeneity, respectively.[28]

The overall effect of the physical activity interventions on reducing depressive symptoms was used to calculate the number needed to treat.[29] Publication bias was assessed by a visual examination of the funnel plot symmetry and by Egger regression test, for which $P < .10$ indicates significant publication bias.[30] Sensitivity analyses were conducted by recalculating the effect size after excluding potential outliers. We defined outliers as studies with an effect size where the 95% CI did not overlap with the 95% CI of the aggregated effect size.[31]

Meta-regressions were performed to assess the influence of potential moderators on the overall effect size to explain any possible heterogeneity. Four primary moderators were chosen a priori: total physical activity volume, participants' health status, whether the allocation and/or assessments were concealed, and whether the study was an RCT or NRCT. We chose these moderators based on their possible associations with physical activity, depressive symptoms, or both and because previous meta-analyses on exercise for depressive symptoms in adults showed significant associations with similar moderators.[32,33] Multiple linear regression analyses using a mixed-effects model with maximum likelihood estimation were performed using the 4 primary moderators.[34] Univariable analyses were performed to explore whether the potential participant and trial characteristics moderated the overall effect. The threshold for significance was a 2-sided $P < .05$. Definitions of all moderators and the codes used for each level are included in eTable 1 in the Supplement.

Results

The database search identified 9153 unique records. After assessment of titles and abstracts, 104 full texts were screened, and 21 studies involving 2441 participants were included in the meta-analysis.[35-55] A visual description of the search results is available in the PRISMA flowchart in eFigure 1 in the Supplement.

Study Characteristics

A summary of the characteristics of the included studies is presented in **Table 1**. Of the 21 studies included, 17 were RCTs,[36-41,43-49,51,52,54,55] and 4 were NRCTs,[35,42,50,53] and included 2441 participants (1148 [47.0%] boys; 1293 [53.0%] girls). The mean (SD) age of participants at baseline was 14 (3) years. Eighteen studies[35-40,42-46,48,49,51-55] included both boys and girls, and 3 studies[41,47,50] included female participants only.

Twelve studies included participants with a somatic or psychiatric disorder, such as depression, obesity, attention deficit hyperactivity disorder, and diabetes.[36-38,40,46,49-51,53-55] The mean duration of the prescribed physical activity program was 22 weeks (range, 6-144 weeks). The frequency of the physical activity sessions ranged from 2 to 5 days per week, with 3 days per week being the most commonly used frequency (8 studies[35,36,38,40,47,48,50,55]). The mean duration of the physical activity sessions was 50 minutes (range, 30-120 minutes). Most interventions were fully supervised (16 studies[35-37,39,41-43,45,47-49,51-55]), and 2 did not report any supervision.[40,50] Physical activity was prescribed as a monotherapy in 17 studies[35,38-53] and implemented in a multimodal intervention in 4 studies.[36,37,54,55] More information regarding the interventions of the included studies is available in eTable 2 in the Supplement.

Mean Effect Size, Heterogeneity, and Bias

A visual representation of the distribution of the study effect sizes is provided in the **Figure**. Seventeen of the 21 effect sizes (81%) were smaller than 0, indicating larger reductions in depressive symptoms for physical activity interventions.[35-38,40,41,43-45,47-53,55] The physical activity interventions had a mean effect size of −0.29 (95% CI, −0.47 to −0.10; $P = .004$). Overall, the reduction in depressive symptoms after a physical activity intervention resulted in a number needed to treat of 6.

Only 4 studies[36,48,52,53] assessed the effects of physical activity interventions on depressive symptoms at follow-up. The mean follow-up period postintervention was 21 weeks (range, 6-48 weeks). No association of physical activity interventions with depressive symptoms was detected at follow-up ($g = −0.39$; 95% CI, −1.01 to 0.24; $P = .14$) (eFigure 2 in the Supplement).

There was evidence of moderate heterogeneity at postintervention ($Q = 53.92$; $df = 20$; $P < .001$; $I^2 = 62.9\%$ [95% CI, 40.7%-76.8%]) and at follow-up ($Q = 7.85$; $df = 3$; $P = .04$; $I^2 = 61.8\%$ [95% CI, 0.0%-87.2%]). Egger regression test revealed significant funnel plot asymmetry (intercept, −1.87 [95%

Table 2. Primary Moderator Analysis

Primary moderator	β (95% CI)	SE	*P* value
Participant health status	−0.16 (−0.44 to 0.13)	0.15	.28
Total physical activity volume	0.00 (−0.00 to 0.00)	0.00	.07
Allocation and/or assessment concealment	0.08 (−0.19 to 0.36)	0.14	.56
Study design	0.14 (−0.21 to 0.49)	0.18	.42

CI, −3.20 to −0.55]; t = −2.77; P = .01) (eFigure 3 in the Supplement). Three outliers were detected. The differences in effect sizes may be attributed to different research designs[40,50] or a different study intervention.[47] We conducted sensitivity analyses after excluding these studies, resulting in a smaller effect size that remained significant (g = −0.15; 95% CI, −0.26 to −0.03; P = .02; I^2 = 25.8% [95% CI, 0.0%-58.1%]). Risk of bias was determined to be low in 6 studies,[36,38,51-54] moderate in 13 studies,[35,37,39-41,43-48,50,55] and high in 2 studies[42,49] (eFigure 4 in the Supplement). We repeated the analyses after removing studies with high risk of bias, which did not change the overall effect size (g = −0.29; 95% CI, −0.48 to −0.10; P = .005; I^2 = 65.4% [95% CI, 43.7%-78.7%]).

Moderator Analyses

The primary moderator analysis did not show significant moderation effects (QM = 8.12, df = 4, P = .09; R^2 = 49.0%; QE = 39.32, P = .001; I^2 = 42.8%) (**Table 2**). Total physical activity volume, study design, participant health status, and allocation and/or assessment concealment did not moderate the main treatment effect. Results of the secondary analyses are summarized in **Table 3**. In brief, interventions showed greater benefits in participants aged 13 years or older and those with a mental illness and/or depression diagnosis. Participant sex, supervision, and frequency and duration of the intervention also moderated the overall effect.

Discussion

In this meta-analysis, we investigated the association of physical activity interventions with depressive symptoms in children and adolescents. The results showed that physical activity interventions produced greater reductions in depressive symptoms compared with the control conditions. However, these differences were not detected after a mean follow-up of 21 weeks, possibly due to the limited number of studies with follow-up outcomes.

Comorbid psychiatric conditions develop in up to 90% of children and adolescents with depression, and 2 comorbid conditions develop in up to 50%.[24] As such, pediatric depression is often underdiagnosed and undertreated, with research showing that only 50% of children and adolescents with depression receive an adequate diagnosis before reaching adulthood.[56] Physical activity, particularly aerobic exercise, is suitable for children, as it is a major component of most sports activities and can easily be implemented in physical education classes. Increased levels of physical activity can reduce the risk of cardiovascular disease,[57] which is the leading cause of death in individuals with depression,[58] and improve executive function,[59] which is greatly impaired in youth with depression.[60] Most of the studies in this systematic review and meta-analysis involved a supervised school intervention targeted at increasing students' physical activity levels through a wide range of activities, including sport games and simple aerobic exercises (eg, running, jumping). The findings of this systematic review and meta-analysis strengthen the role of physical activity for depressive symptom management and highlight the potential of structured physical education programs in primary and secondary schools for improving the mental health of children and adolescents.

While the association between physical activity and depression is strong,[61,62] the mechanisms underlying the antidepressant properties of physical activity remain unclear. Potential pathways include the activation of the endocannabinoid system to stimulate the release of endorphins,[63] an increase in the bioavailability of brain neurotransmitters (eg, serotonin, dopamine, noradrenaline) that are reduced with depression,[64] and long-term changes in brain plasticity.[65] Psychosocial and behavioral hypotheses have also been made, asserting that physical activity can lead to improvements in self-perception, social interactions, and self-confidence.[65] However, the depressive phenomenology is multifaceted, including cognitive, emotional, interpersonal, and somatic symptoms,[66] and isolating the effects that physical activity has on specific symptoms is seemingly impossible due to individual variability. Evidence on the benefits of physical activity in conjunction with traditional depression treatments is even more sparse, though it seems that physical activity can enhance the treatment of cognitive and affective symptoms in depression.[67] Furthermore, the combination of physical activity and pharmacotherapy may reduce relapse risk, improve adherence to antidepressants, and promote better management of adverse effects compared with pharmacotherapy alone.[67] The benefits of physical activity are not restricted to depression treatment but extend to various health domains, including psychiatric, neurologic, cognitive, somatic, and psychosocial.[68] Therefore, a combination of biologic, psychological, and psychosocial factors may mediate the relationship between physical activity and depression. More research is warranted to explain whether and how these mechanisms moderate the effect of physical activity and whether these changes are also present in younger populations.

Our moderator analyses showed that participants with a mental illness and/or a clinical diagnosis of depression benefitted more from the physical activity interventions compared with those who were healthy or had a physical illness. Similar results were observed in a meta-analysis on exercise for adult depression.[14] As the authors concluded, participants showed greater depressive symptoms at baseline and

Table 3. Secondary Analyses

Moderator	K	Hedges *g* (95% CI)	I^2, %	*P* value[a]	
				Moderator	Contrast
Sex					
Both males and females	18	−0.19 (−0.35 to −0.04)	49	.01	.03
Female	3	−0.90 (−2.26 to 0.45)	64	.10	
Age, y					
<13	8	−0.05 (−0.18 to 0.09)	6	.44	.002
≥13	13	−0.44 (−70 to −0.19)	62	.003	
Health status					
Healthy	9	−0.09 (−0.18 to −0.00)	0	.05	
Physical illness	6	−0.22 (−0.71 to 0.28)	74	.31	<.001
Mental illness	6	−0.74 (−1.01 to −0.47)	0	<.001	
Depression diagnosis					
Yes	5	−0.75 (−1.09 to −0.41)	0	.004	<.001
No	16	−0.13 (−0.28 to 0.01)	41	.07	
Monotherapy					
Yes	17	−0.33 (−0.55 to −0.11)	63	.006	.39
No	4	−0.16 (−0.68 to 0.35)	71	.38	
Supervision					
Fully supervised	16	−0.17 (−0.33 to −0.02)	44	.03	
Partially supervised	3	−0.20 (−1.01 to 0.61)	44	.40	<.001
Not supervised	2	−1.06 (−1.95 to −0.18)	0	.04	
Control					
Usual care	7	−0.11 (−0.38 to 0.16)	59	.34	
No intervention	9	−0.50 (−0.87 to −0.13)	67	.01	.11
Attention	4	−0.13 (−0.54 to 0.28)	7	.38	
Waiting list	1	−0.34 (−0.91 to 0.23)	NA	.25	
Study design					
RCT	17	−0.25 (−0.43 to −0.06)	37	.01	.56
NRCT	4	−0.42 (−1.31 to 0.47)	81	.23	
Intention to treat					
Yes	6	−0.15 (−0.30 to 0.01)	0	.06	.12
No	15	−0.36 (−0.62 to −0.10)	72	.01	
Frequency, d/wk					
2	5	−0.06 (−0.25 to 0.12)	5	.39	
3	8	−0.57 (−1.00 to −0.14)	74	.02	.03
≥4	8	−0.19 (−0.43 to 0.04)	51	.09	
Session, min					
<45	10	−0.27 (−0.54 to −0.01)	49	.04	.83
≥45	11	−0.31 (−0.61 to −0.01)	72	.04	
Duration, wk					
<12	9	−0.58 (−0.96 to −0.20)	59	.008	.01
≥12	12	−0.12 (−0.27 to 0.02)	37	.08	
Intensity					
Low to moderate	7	−0.41 (−0.89 to 0.08)	67	.09	
Vigorous	10	−0.13 (−0.31 to 0.04)	41	.11	.65
Not reported	4	−0.53 (−1.32 to 0.25)	75	.12	

Abbreviations: NA, not applicable; NRCT, nonrandomized clinical trial; RCT, randomized clinical trial.

[a] The moderator *P* value indicates the *P* value for the pooled estimate effect of the subgroup defined by the level of the moderator; the contrast *P* value indicates the *P* value of the effect of the moderator in the corresponding meta-regression.

may have had more potential for improvement than those whose symptoms were not indicative of a depression diagnosis. Our findings suggest that physical activity interventions may be particularly helpful in children and adolescents with elevated depressive symptoms.

Physical activity had greater benefits in participants aged 13 years or older than in younger participants. A recent cohort study reported that between the ages of 12 and 16 years, the physical activity levels of children start to decrease while sedentary time increases, and this was associated with more de-

pressive symptoms.[69] It is possible that younger children are sufficiently active to be desensitized to additional physical activity, whereas their older and more sedentary counterparts might be more responsive to the intervention.

Three physical activity sessions per week and interventions that were shorter than 12 weeks induced greater benefits on depressive symptoms compared with other frequencies and durations. These findings are reflected in the results of previous meta-analyses on the association between physical activity and depression,[61,70] suggesting that increasing amounts of physical activity may not translate into greater reductions in depressive symptoms. A recent cross-sectional study found a U-shaped association between physical activity frequency and mental health, such that 10 to 15 sessions per month induced the greatest mental health improvements.[71] In contrast, there is evidence that increasing amounts of physical activity have beneficial effects on mental health.[72] With regard to overall intervention duration, Bailey et al[73] discussed the challenges in maintaining long-term benefits in interventional studies with children and adolescents and described the factors and skills needed to preserve these benefits. Securing participants' attention throughout a trial can be difficult, and researchers may need to consider loss of interest in the intervention as a potential factor influencing the treatment effect. More research is needed to explain these findings and to establish the optimal physical activity parameters for depressive symptom management.

We found differences in the effect sizes of studies involving female-only participants and studies with unsupervised interventions compared with studies on both males and females and studies with supervised or partially supervised interventions. These findings are surprising and may be attributed to a discrepancy among the number of studies used to assess each moderator. Eighteen studies included boys and girls[35-40,42-46,48,49,51-55] and 3 included female participants only,[41,47,50] and 16 studies[35-37,39,41-43,45,47-49,51-55] reported fully supervised interventions, whereas 2 did not report any supervision.[40,50] Among the studies recruiting females only and the studies with unsupervised interventions, all but 1 were identified as potential outliers because of their substantially larger effect sizes.[40,47,50] Thus, their effect sizes may have been overestimated and may have influenced our estimate of the true difference between moderators.

Limitations

This study has some limitations. First, we did not screen for study quality in our inclusion criteria, and it is possible that poorly conducted studies may have influenced the overall results. Second, there was a notable lack of complete reporting regarding participant and trial characteristics. Specifically, information regarding the blinding of participants and assessors, exercise intensity, exercise type, and degree of supervision was often absent and had to be extrapolated from the article, requested from authors, or otherwise excluded from the analyses. Future research should include more rigorous reporting of study design and characteristics to allow for the analysis of potential moderators on the treatment effects. Third, because of the exploratory nature of our univariable meta-regression analyses, other confounding variables could not be controlled for, which limits the interpretation of our findings and warrants further validation.

Conclusions

The results of this systematic review and meta-analysis suggest that physical activity interventions can alleviate symptoms of depression in children and adolescents. Results were corroborated by stringent sensitivity and moderator analyses that revealed greater reductions in depressive symptoms in participants aged 13 years or older and in those with a mental illness and/or depression diagnosis. Future studies should investigate the influence of physical activity parameters such as frequency, duration, and supervision of the sessions to determine the optimal dose and mode of delivery of the intervention for depressive symptom management.

ARTICLE INFORMATION

Accepted for Publication: September 21, 2022.

Published Online: January 3, 2023. doi:10.1001/jamapediatrics.2022.5090

Author Affiliations: Division of Kinesiology, School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong, China (Recchia, Bernal, Siu); School of Nursing, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong, China (Fong); Department of Sports Science and Physical Education, Faculty of Education, The Chinese University of Hong Kong, Hong Kong, China (S. H. S. Wong, Sit); Department of Sport, Physical Education and Health, Faculty of Social Sciences, Hong Kong Baptist University, Hong Kong, China (Chung); Department of Early Childhood Education, Faculty of Education and Human Development, The Education University of Hong Kong, Hong Kong, China (Chan, Capio); Department of Rehabilitation Sciences, Faculty of Health and Social Sciences, The Hong Kong Polytechnic University, Hong Kong, China (Yu); Physical Fitness Association of Hong Kong, Hong Kong, China (S. W. S. Wong); Department of Maternal and Child Health, School of Public Health, Sun Yat Sen University, Guangzhou, China (Chen); College of Education and Human Development, Georgia State University, Atlanta (Thompson).

Author Contributions: Mr Recchia had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Recchia, Bernal, Fong, S. H. Wong, Chung, Chan, Capio, S. W. Wong, Chen, Siu.
Acquisition, analysis, or interpretation of data: Recchia, Bernal, Yu, Sit, Chen, Thompson, Siu.
Drafting of the manuscript: Recchia, S. H. Wong, Thompson, Siu.
Critical revision of the manuscript for important intellectual content: Recchia, Bernal, Fong, Chung, Chan, Capio, Yu, S. W. Wong, Sit, Chen, Siu.
Statistical analysis: Recchia, Fong, S. H. Wong, Chen, Siu.
Obtained funding: Chan, Capio, Siu.
Administrative, technical, or material support: Chan, Thompson, Siu.
Supervision: Fong, S. W. Wong, Chen, Siu.

Conflict of Interest Disclosures: None reported.

Funding/Support: This work was supported by grant 17182461 from the Health and Medical Research Fund of the Food and Health Bureau, Hong Kong Special Administrative Region Government and the Seed Fund for Basic Research of The University of Hong Kong.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Additional Contributions: The authors thank Edwin Chin, PhD, The Chinese University of Hong Kong, for the technical advice provided for the conduct of this study. He did not receive compensation for his contribution.

REFERENCES

1. Erskine HE, Baxter AJ, Patton G, et al. The global coverage of prevalence data for mental disorders in children and adolescents. *Epidemiol Psychiatr Sci*. 2017;26(4):395-402. doi:10.1017/S2045796015001158

2. Windfuhr K, While D, Hunt I, et al; National Confidential Inquiry into Suicide and Homicide by People with Mental Illness. Suicide in juveniles and adolescents in the United Kingdom. *J Child Psychol Psychiatry*. 2008;49(11):1155-1165. doi:10.1111/j.1469-7610.2008.01938.x

3. Maughan B, Collishaw S, Stringaris A. Depression in childhood and adolescence. *J Can Acad Child Adolesc Psychiatry*. 2013;22(1):35-40.

4. Klein DN, Shankman SA, Lewinsohn PM, Seeley JR. Subthreshold depressive disorder in adolescents: predictors of escalation to full-syndrome depressive disorders. *J Am Acad Child Adolesc Psychiatry*. 2009;48(7):703-710. doi:10.1097/CHI.0b013e3181a56606

5. Fergusson DM, Horwood LJ, Ridder EM, Beautrais AL. Subthreshold depression in adolescence and mental health outcomes in adulthood. *Arch Gen Psychiatry*. 2005;62(1):66-72. doi:10.1001/archpsyc.62.1.66

6. Keenan K, Hipwell A, Feng X, et al. Subthreshold symptoms of depression in preadolescent girls are stable and predictive of depressive disorders. *J Am Acad Child Adolesc Psychiatry*. 2008;47(12):1433-1442. doi:10.1097/CHI.0b013e3181886eab

7. Guideline Developmental Panel for the Treatment of Depressive Disorders. APA Clinical practice guideline for the treatment of depression across three age cohorts. Guideline development panel for the treatment of depressive disorders. American Psychiatric Association. 2019. Accessed September 15, 2022. https://www.apa.org/depression-guideline/guideline.pdf

8. National Institute for Health and Clinical Excellence. Depression in children and young people: identification and management. NICE guideline [NG134]. 2019. Accessed September 15, 2022. https://www.nice.org.uk/guidance/ng134

9. MacQueen GM, Frey BN, Ismail Z, et al; CANMAT Depression Work Group. Canadian Network for Mood and Anxiety Treatments (CANMAT) 2016 clinical guidelines for the management of adults with major depressive disorder: section 6. special populations: youth, women, and the elderly. *Can J Psychiatry*. 2016;61(9):588-603. doi:10.1177/0706743716659276

10. Gopalan G, Goldstein L, Klingenstein K, Sicher C, Blake C, McKay MM. Engaging families into child mental health treatment: updates and special considerations. *J Can Acad Child Adolesc Psychiatry*. 2010;19(3):182-196.

11. Dwyer JB, Bloch MH. Antidepressants for pediatric patients. *Curr Psychiatr*. 2019;18(9):26-42F.

12. Avenevoli S, Swendsen J, He JP, Burstein M, Merikangas KR. Major depression in the national comorbidity survey-adolescent supplement: prevalence, correlates, and treatment. *J Am Acad Child Adolesc Psychiatry*. 2015;54(1):37-44.e2. doi:10.1016/j.jaac.2014.10.010

13. Kataoka SH, Zhang L, Wells KB. Unmet need for mental health care among U.S. children: variation by ethnicity and insurance status. *Am J Psychiatry*. 2002;159(9):1548-1555. doi:10.1176/appi.ajp.159.9.1548

14. Schuch FB, Vancampfort D, Richards J, Rosenbaum S, Ward PB, Stubbs B. Exercise as a treatment for depression: a meta-analysis adjusting for publication bias. *J Psychiatr Res*. 2016;77:42-51. doi:10.1016/j.jpsychires.2016.02.023

15. Kvam S, Kleppe CL, Nordhus IH, Hovland A. Exercise as a treatment for depression: a meta-analysis. *J Affect Disord*. 2016;202:67-86. doi:10.1016/j.jad.2016.03.063

16. Stubbs B, Vancampfort D, Hallgren M, et al. EPA guidance on physical activity as a treatment for severe mental illness: a meta-review of the evidence and position statement from the European Psychiatric Association (EPA), supported by the International Organization of Physical Therapists in Mental Health (IOPTMH). *Eur Psychiatry*. 2018;54:124-144. doi:10.1016/j.eurpsy.2018.07.004

17. National Institute for Health and Clinical Excellence. *Depression in Adults: Recognition and Management*. National Institute for Health and Clinical Excellence; 2009.

18. Ravindran AV, Balneaves LG, Faulkner G, et al; CANMAT Depression Work Group. Canadian Network for Mood and Anxiety Treatments (CANMAT) 2016 clinical guidelines for the management of adults with major depressive disorder: section 5. complementary and alternative medicine treatments. *Can J Psychiatry*. 2016;61(9):576-587. doi:10.1177/0706743716660290

19. Brown HE, Pearson N, Braithwaite RE, Brown WJ, Biddle SJ. Physical activity interventions and depression in children and adolescents: a systematic review and meta-analysis. *Sports Med*. 2013;43(3):195-206. doi:10.1007/s40279-012-0015-8

20. Wang X, Cai ZD, Jiang WT, Fang YY, Sun WX, Wang X. Systematic review and meta-analysis of the effects of exercise on depression in adolescents. *Child Adolesc Psychiatry Ment Health*. 2022;16(1):16. doi:10.1186/s13034-022-00453-2

21. Oberste M, Medele M, Javelle F, et al. Physical activity for the treatment of adolescent depression: a systematic review and meta-analysis. *Front Physiol*. 2020;11:185-185. doi:10.3389/fphys.2020.00185

22. Carter T, Morres ID, Meade O, Callaghan P. The effect of exercise on depressive symptoms in adolescents: a systematic review and meta-analysis. *J Am Acad Child Adolesc Psychiatry*. 2016;55(7):580-590. doi:10.1016/j.jaac.2016.04.016

23. Angold A, Costello EJ. Depressive comorbidity in children and adolescents: empirical, theoretical, and methodological issues. *Am J Psychiatry*. 1993;150(12):1779-1791. doi:10.1176/ajp.150.12.1779

24. Birmaher B, Brent D, Bernet W, et al; AACAP Work Group on Quality Issues. Practice parameter for the assessment and treatment of children and adolescents with depressive disorders. *J Am Acad Child Adolesc Psychiatry*. 2007;46(11):1503-1526. doi:10.1097/chi.0b013e318145ae1c

25. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*. 2020;54(24):1451-1462. doi:10.1136/bjsports-2020-102955

26. Higgins JPT, Thomas J, Chandler J, et al, eds. *Cochrane Handbook for Systematic Reviews of Interventions* (updated February 2021). Cochrane; 2021.

27. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:l4898. doi:10.1136/bmj.l4898

28. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557-560. doi:10.1136/bmj.327.7414.557

29. Furukawa TA, Leucht S. How to obtain NNT from Cohen's d: comparison of two methods. *PLoS One*. 2011;6(4):e19070-e19070. doi:10.1371/journal.pone.0019070

30. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629-634. doi:10.1136/bmj.315.7109.629

31. Viechtbauer W, Cheung MW. Outlier and influence diagnostics for meta-analysis. *Res Synth Methods*. 2010;1(2):112-125. doi:10.1002/jrsm.11

32. Gordon BR, McDowell CP, Hallgren M, Meyer JD, Lyons M, Herring MP. Association of efficacy of resistance exercise training with depressive symptoms: meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry*. 2018;75(6):566-576. doi:10.1001/jamapsychiatry.2018.0572

33. Herring MP, Puetz TW, O'Connor PJ, Dishman RK. Effect of exercise training on depressive symptoms among patients with a chronic illness: a systematic review and meta-analysis of randomized controlled trials. *Arch Intern Med*. 2012;172(2):101-111. doi:10.1001/archinternmed.2011.696

34. Wilson DB, Lipsey MW. *Practical Meta-analysis*. Sage; 2001.

35. Bonhauser M, Fernandez G, Püschel K, et al. Improving physical fitness and emotional well-being in adolescents of low socioeconomic status in Chile: results of a school-based controlled trial. *Health Promot Int*. 2005;20(2):113-122. doi:10.1093/heapro/dah603

36. Daley AJ, Copeland RJ, Wright NP, Roalfe A, Wales JK. Exercise therapy as a treatment for psychopathologic conditions in obese and morbidly obese adolescents: a randomized, controlled trial. *Pediatrics*. 2006;118(5):2126-2134. doi:10.1542/peds.2006-1285

37. Goldfield GS, Kenny GP, Alberga AS, et al. Effects of aerobic training, resistance training, or both on psychological health in adolescents with obesity: the HEARTY randomized controlled trial. *J Consult Clin Psychol*. 2015;83(6):1123-1135. doi:10.1037/ccp0000038

38. Hughes CW, Barnes S, Barnes C, Defina LF, Nakonezny P, Emslie GJ. Depressed Adolescents Treated with Exercise (DATE): a pilot randomized controlled trial to test feasibility and establish preliminary effect sizes. *Ment Health Phys Act*. 2013;6(2):119-131. doi:10.1016/j.mhpa.2013.06.006

39. Lin K, Stubbs B, Zou W, et al. Aerobic exercise impacts the anterior cingulate cortex in adolescents with subthreshold mood syndromes: a randomized controlled trial study. *Transl Psychiatry*. 2020;10(1):155. doi:10.1038/s41398-020-0840-8

40. Mohammadi M. A study and comparison of the effect of team sports (soccer and volleyball) and individual sports (table tennis and badminton) on

depression among high school students. *Aust J Basic Applied Sci*. 2011;5(12):1005-1011.

41. Nabkasorn C, Miyai N, Sootmongkol A, et al. Effects of physical exercise on depression, neuroendocrine stress hormones and physiological fitness in adolescent females with depressive symptoms. *Eur J Public Health*. 2006;16(2):179-184. doi:10.1093/eurpub/cki159

42. Norris R, Carroll D, Cochrane R. The effects of physical activity and exercise training on psychological stress and well-being in an adolescent population. *J Psychosom Res*. 1992;36(1):55-65. doi:10.1016/0022-3999(92)90114-H

43. Olive LS, Byrne D, Cunningham RB, Telford RM, Telford RD. Can physical education improve the mental health of children? the LOOK study cluster-randomized controlled trial. *J Educ Psychol*. 2019;111(7):1331-1340. doi:10.1037/edu0000338

44. Peng S, Qi A, Yuan F. Experimental study on the effects of exercise prescription on the mental health of left-behind school children in rural areas. *Rev Argent Clin Psicol*. 2015;24:267-276.

45. Petty KH, Davis CL, Tkacz J, Young-Hyman D, Waller JL. Exercise effects on depressive symptoms and self-worth in overweight children: a randomized controlled trial. *J Pediatr Psychol*. 2009;34(9):929-939. doi:10.1093/jpepsy/jsp007

46. Romero-Pérez EM, González-Bernal JJ, Soto-Cámara R, et al. Influence of a physical exercise program in the anxiety and depression in children with obesity. *Int J Environ Res Public Health*. 2020;17(13):E4655. doi:10.3390/ijerph17134655

47. Roshan VD, Pourasghar M, Mohammadian Z. The efficacy of intermittent walking in water on the rate of MHPG sulfate and the severity of depression. *Iran J Psychiatry Behav Sci*. 2011;5(2):26-31.

48. Roth DL, Holmes DS. Influence of aerobic exercise training and relaxation training on physical and psychologic health following stressful life events. *Psychosom Med*. 1987;49(4):355-365. doi:10.1097/00006842-198707000-00004

49. Silva LAD, Doyenart R, Henrique Salvan P, et al. Swimming training improves mental health parameters, cognition and motor coordination in children with attention deficit hyperactivity disorder. *Int J Environ Health Res*. 2020;30(5):584-592. doi:10.1080/09603123.2019.1612041

50. Talakoub S, Gorbani S, Hasanpour M, Zolaktaf V, Amini M. Impact of exercise on affective responses in female adolescents with type I diabetes. *Iran J Nurs Midwifery Res*. 2012;17(6):434-439.

51. Weintraub DL, Tirumalai EC, Haydel KF, Fujimoto M, Fulton JE, Robinson TN. Team sports for overweight children: the Stanford Sports to Prevent Obesity Randomized Trial (SPORT). *Arch Pediatr Adolesc Med*. 2008;162(3):232-237. doi:10.1001/archpediatrics.2007.43

52. Williams CF, Bustamante EE, Waller JL, Davis CL. Exercise effects on quality of life, mood, and self-worth in overweight children: the SMART randomized controlled trial. *Transl Behav Med*. 2019;9(3):451-459. doi:10.1093/tbm/ibz015

53. Wunram HL, Hamacher S, Hellmich M, et al. Whole body vibration added to treatment as usual is effective in adolescents with depression: a partly randomized, three-armed clinical trial in inpatients. *Eur Child Adolesc Psychiatry*. 2018;27(5):645-662. doi:10.1007/s00787-017-1071-2

54. Yu HJ, Li F, Hu YF, et al. Improving the metabolic and mental health of children with obesity: a school-based nutrition education and physical activity intervention in Wuhan, China. *Nutrients*. 2020;12(1):E194. doi:10.3390/nu12010194

55. Zhang JLS, Ji W. Exercise intervention improves the quality of life, anxiety, and depression of adolescent depression patients. *Int J Clin Exp Med*. 2021;14(2):1292-1300.

56. Zuckerbrot RA, Cheung A, Jensen PS, Stein REK, Laraque D; GLAD-PC STEERING GROUP. Guidelines for Adolescent Depression in Primary Care (GLAD-PC): part I. practice preparation, identification, assessment, and initial management. *Pediatrics*. 2018;141(3):e20174081. doi:10.1542/peds.2017-4081

57. Gutin B, Yin Z, Humphries MC, Barbeau P. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. *Am J Clin Nutr*. 2005;81(4):746-750. doi:10.1093/ajcn/81.4.746

58. Correll CU, Solmi M, Veronese N, et al. Prevalence, incidence and mortality from cardiovascular disease in patients with pooled and specific severe mental illness: a large-scale meta-analysis of 3,211,768 patients and 113,383,368 controls. *World Psychiatry*. 2017;16(2):163-180. doi:10.1002/wps.20420

59. Best JR. Effects of physical activity on children's executive function: contributions of experimental research on aerobic exercise. *Dev Rev*. 2010;30(4):331-551. doi:10.1016/j.dr.2010.08.001

60. Wagner S, Müller C, Helmreich I, Huss M, Tadić A. A meta-analysis of cognitive functions in children and adolescents with major depressive disorder. *Eur Child Adolesc Psychiatry*. 2015;24(1):5-19. doi:10.1007/s00787-014-0559-2

61. 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):550-559. doi:10.1001/jamapsychiatry.2022.0609

62. Schuch FB, Vancampfort D, Firth J, et al. Physical activity and incident depression: a meta-analysis of prospective cohort studies. *Am J Psychiatry*. 2018;175(7):631-648. doi:10.1176/appi.ajp.2018.17111194

63. Brellenthin AG, Crombie KM, Hillard CJ, Koltyn KF. Endocannabinoid and mood responses to exercise in adults with varying activity levels. *Med Sci Sports Exerc*. 2017;49(8):1688-1696. doi:10.1249/MSS.0000000000001276

64. Lin TW, Kuo YM. Exercise benefits brain function: the monoamine connection. *Brain Sci*. 2013;3(1):39-53. doi:10.3390/brainsci3010039

65. Kandola A, Ashdown-Franks G, Hendrikse J, Sabiston CM, Stubbs B. Physical activity and depression: towards understanding the antidepressant mechanisms of physical activity. *Neurosci Biobehav Rev*. 2019;107:525-539. doi:10.1016/j.neubiorev.2019.09.040

66. Kennedy SH. Core symptoms of major depressive disorder: relevance to diagnosis and treatment. *Dialogues Clin Neurosci*. 2008;10(3):271-277. doi:10.31887/DCNS.2008.10.3/shkennedy

67. Guerrera CS, Furneri G, Grasso M, et al. Antidepressant drugs and physical activity: a possible synergism in the treatment of major depression? *Front Psychol*. 2020;11:857. doi:10.3389/fpsyg.2020.00857

68. Pedersen BK, Saltin B. Exercise as medicine—evidence for prescribing exercise as therapy in 26 different chronic diseases. *Scand J Med Sci Sports*. 2015;25(suppl 3):1-72. doi:10.1111/sms.12581

69. 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. *Lancet Psychiatry*. 2020;7(3):262-271. doi:10.1016/S2215-0366(20)30034-1

70. Kim SY, Jeon SW, Shin DW, Oh KS, Shin YC, Lim SW. Association between physical activity and depressive symptoms in general adult populations: an analysis of the dose-response relationship. *Psychiatry Res*. 2018;269:258-263. doi:10.1016/j.psychres.2018.08.076

71. Xu P, Huang Y, Hou Q, et al. Relationship between physical activity and mental health in a national representative cross-section study: its variations according to obesity and comorbidity. *J Affect Disord*. 2022;308:484-493. doi:10.1016/j.jad.2022.04.037

72. Hamer M, Stamatakis E, Steptoe A. Dose-response relationship between physical activity and mental health: the Scottish Health Survey. *Br J Sports Med*. 2009;43(14):1111-1114. doi:10.1136/bjsm.2008.046243

73. Bailey D, Duncan GJ, Odgers CL, Yu W. Persistence and fadeout in the impacts of child and adolescent interventions. *J Res Educ Eff*. 2017;10(1):7-39. doi:10.1080/19345747.2016.1232459