Review Article

Anxiety Reducing Effects of Physical Activity in Adolescents and Young Adults

Revisiting the Evidence

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Abstract: This systematic review provides an overview of the current literature on the effects of physical activity (PA) as an intervention to treat anxiety symptoms in adolescents and young adults. Three searches (March and May 2022; July 2024) focusing on RCTs using a PA intervention of at least moderate intensity were carried out in PubMed, PsycInfo, SportDiscus, and Google Scholar. Studies were screened, and risk of bias was assessed for all included studies. In total 2,521 studies were retrieved, and 14 RCTs were retained. Studies were compared based on several criteria, such as type of exercise, intensity, delivery mode, PA alone or as add-on treatment. Results suggest that PA is more effective compared to inactive control conditions. Intensity (moderate or high) or type of exercise (aerobic or resistance training) requirements for anxiolytic effects are less clear. Participants with elevated anxiety scores benefit more from PA interventions than those with low anxiety scores. We conclude that PA is a promising intervention to treat anxiety in adolescents and young adults. Heterogeneity between studies is high, and many present methodological shortcomings. Little is known about the underlying mechanisms responsible for anxiety-reducing effects. To advance research, more high-quality studies are needed to develop effective and personalized PA interventions.

Keywords: adolescents, young adults, physical activity, anxiety disorder, psychological intervention

Anxiety disorders are amongst the most common mental disorders in adolescents and young adults (Niermann et al., 2021; Parodi et al., 2022). They have a negative impact on academic performance, development, social and health functioning, and they increase the risk of developing secondary mental health problems (e.g., depression) (Asselmann & Beesdo-Baum, 2015; Mojtabai et al., 2015). Prospective longitudinal studies have shown that anxiety disorders in childhood and adolescence significantly predict homotypic and heterotypic continuity of disorders into adulthood (Asselmann & Beesdo-Baum, 2015). Lifetime prevalence rates are up to 30% for any anxiety disorder in this age group and present an early age of onset, with almost 75% of anxiety and fear-related disorders emerging before the age of 25 (Asselmann & Beesdo-Baum, 2015; Solmi et al., 2022).

Given the chronic and recurrent course of anxiety and the high risk of developing comorbid mental disorders (i.e., depression), early detection and treatment are crucial (Hill, Waite & Creswell, 2016). The most researched and empirically supported treatments for anxiety are Cognitive Behaviour Therapy (CBT), pharmacotherapy (selective serotonin reuptake inhibitors) or a combination of both. Currently, these approaches represent the recommended treatments for anxiety disorders for adolescents and young adults (Hill et al., 2016; Wehry, Beesdo-Baum, Hennelly, Connolly & Strawn, 2015). Nevertheless, these treatments have several disadvantages. For example, some individuals respond better to CBT than others. Approximately 40% keep their anxiety disorder diagnosis after treatment, and CBT interventions are not always more effective than active control interventions (Hill et al., 2016). Long waiting lists and high therapy costs reduce accessibility to CBT treatment. Shortcomings of pharmacological treatments for anxiety include side-effects, leading to treatment resistance and low treatment adherence (Henriksson et al., 2022; Hill et al., 2016; Stonerock et al., 2015).

There is growing evidence that exercise interventions are viable alternatives treatment options for adults with high anxiety or anxiety disorders (Aylett et al., 2018; Stonerock et al., 2015). For younger people, the available literature on anxiety-reducing effects of physical activity (PA) is limited. Biddle and Asare (2011) found positive associations between levels of PA and mental health outcomes (lower depression and anxiety, higher cognitive functioning, and self-esteem). The methodological quality of studies,

however, is weak. Evidence concerning the effects of lack of PA is clearer, as no PA is associated with poorer mental health. This is supported by the data from the World Health Survey indicating an association between low PA levels and increased anxiety (Stubbs, Koyanagi, et al., 2017).

In their updated review, Biddle et al. (2019), address the issue whether causality can be established between the positive associations between PA and mental health outcomes in children and adolescents. They found strong evidence for cognitive functioning and partial evidence for depression.

The most recent meta-analysis investigating the effects of PA-based interventions on anxiety in young clinical and non-clinical populations was conducted by Carter et al. (2021). In their review, they included only randomized controlled trials (RCTs) involving PA, motivational interventions, coaching, mindfulness, and behavior-based, individual- and group-based interventions. They found positive medium-sized effects on anxiety for PA compared to minimal or no intervention, and a small effect compared with attention-control groups. Compared to other mental health enhancing interventions, PA was not more effective in the non-clinical groups but seemed to be more effective in clinical groups (Carter et al., 2021).

Notwithstanding the results of this recent meta-analysis, the conclusions that can be drawn are limited due to a number of shortcomings. First, there are only few high-quality randomized trials, investigating PA as an intervention for anxiety in adolescents and young adults (Vögele, 2019). Second, there are methodological inconsistencies in these studies, including the use of varying definitions of PA, heterogeneity in length, duration, type and intensity of exercise, assessed with a range of instruments (e.g., wearable devices, self-report) reducing comparability between studies. Third, many of the studies included by Carter et al. (2021), which showed anxiety-reducing effects, involved mindfulness-based physical activities. Mindfulness exercises such as Yoga, tai chi or qigong typically involve low to moderate physical movements, relaxation techniques, with an emphasis on the present moment and being nonjudgemental towards thoughts and experiences during practice (So et al., 2020). It could be argued that the underlying mechanisms, such as insight, exposure and non-attachment, inherent to all mindfulness-based interventions and relaxation techniques are responsible for the reduction of anxiety (Brown et al., 2007), which may well differ from the mechanisms underlying the effects of PA. Supporting this notion, there is evidence for significant differences in effects between mindfulness-based interventions compared to aerobic and resistance exercise (Bridle et al., 2012).

In summary, it remains unclear from Carter et al. (2021) what role PA plays in reducing anxiety levels in children and adolescents, given that their review included a significant proportion of studies using a combination of interventions, some of which involved PA at intensity levels considered to be too low to achieve any health benefits (Bull et al., 2020). The first aim of the current paper concerns, therefore, a review of RCTs focusing on PA interventions of at least moderate intensity (> 3 metabolic equivalent of task, MET), so as to draw firmer conclusions on the usefulness of PA interventions in reducing anxiety in adolescents and young adults. The second aim was to update the review by Carter et al. (2021).

Method

This systematic review adheres to PRISMA guidelines.

Inclusion Criteria

Studies were eligible for this review if the participant age range was between 13 and 30 years, as anxiety disorders present an early age of onset and anxiety and fear-related disorders emerge during that period, with a lifetime prevalence of up to 30% for any anxiety disorder in this age group (Asselmann & Beesdo-Baum, 2015; Solmi et al., 2022). We included studies which investigated the effects of PA interventions on reducing anxiety symptoms. PA can be defined as "any bodily movement produced by skeletal muscles that results in the expenditure of energy" (Caspersen et al., 1985, p. 126). The intervention should involve PA of at least moderate intensity (> 3 MET), to be able to attribute any anxiety reducing effects to the changes associated with PA of sufficient intensity to achieve physical and mental health benefits (World Health Organization, 2020). Studies needed to include at least one standard outcome measure of anxiety (primary or secondary), and the effect of PA on the reduction of anxiety symptoms had to be analyzed. Only RCTs and papers in English language were retained.

Exclusion Criteria

We excluded studies investigating PA interventions for mental health problems other than anxiety or depression, and studies that were designed to improve mental health for people with intellectual disabilities. Studies that did not report an analysis on the effect of PA on reducing anxiety symptoms were not retained. Studies with a single session of PA or where anxiety was induced prior or after the PA were excluded (e.g., Lindheimer et al., 2017). Studies that included mindfulness exercises were excluded as PA intensity levels were deemed not high enough to justify the categorization of the intervention as PA and the

mechanisms involved in any anxiety-reducing effects, therefore, to differ from those involved in PA. Non-RCTs were also excluded.

Search History

A systematic review of the literature was carried out to retrieve studies that investigated the anxiolytic effects of PA in adolescents and young adults. In total three searches were conducted. The first search included the databases PubMed, PsycInfo and Google Scholar with the following combination of search terms:

> (adolescent or youth or young people or teenager) AND ("anxiety disorders" or "anxiety disorder*" or "social anxiety" or "generalized anxiety" or anxiety or "paediatric anxiety disorder" or SAD or GAD) AND (exercise or "exercise therapy" or sport or "physical activity").

In addition to the more specified databases PubMed and PsycInfo, Google Scholar was chosen as a search tool to provide a wider coverage of the extant literature, as it searches a wide range of scholarly literature across many disciplines and many sources (articles, books, theses, etc.).

For PubMed, the available MESH terms for "adolescent", "anxiety disorders" and "exercise" were used. The results were further filtered for RCTs using the filter in the respective databases. For Google Scholar the following search query was used: (("Randomized control test"|RCT) (Adolescent|youth|teenager) ("anxiety disorder") (Exercise|Sport|"Exercise Therapy"|"physical activity") -adult). The first search was conducted in March 2022.

After evaluating the first search, search terms were revised and updated to perform a more specified second search in the databases PubMed, PsycInfo, and SportDiscus. A combination of the following search terms were used for the second search:

> (adolescents or young adults or students) AND (physical activity or physical exercise or exercise therapy) AND (anxiety symptoms or anxiety disorder or anxiety) AND (randomized controlled trials or rtc or randomized control trials) NOT (mindfulness or yoga).

In PubMed the available MESH terms were used. The second search was conducted in May 2022, and it differed from the first search in the inclusion of the term "students" and the exclusion of the terms "mindfulness" and "yoga". Both searches included published articles in journals in English up to May 2022. The searches were carried out by the first author.

To update the present review, the searches were carried out again in the same databases in July 2024. The search yielded 1,616 results. None of the articles on which title and abstract screening had been conducted, met the inclusion criteria for the present review. Twelve publications were assessed in more detail, and were subsequently excluded due to the sample being out of age range (5), non-RCT (6), review (1), no PA intervention (1).

Study Selection

Studies were included into Zotero and Rayyan (https://www.rayyan.ai), a freely available software and tool to screen and organize studies for systematic reviews. First, title and abstract were screened for relevance and later the full texts were consulted to further select studies. In case of uncertainties, the two authors resolved any ambiguities by discussion.

Risk of Bias

Methodological quality of included studies was independently assessed by the two authors using the Cochrane tool (www.riskofbias.info) for individual and cluster RCTs (Sterne et al., 2019).

Results

Study Selection

In total 2,521 articles were retrieved from which 61 were duplicates. After title and abstract screening, a further 2,080 articles were excluded. After full-text screening, a further 366 studies were not retained. In total, 14 studies were included in this review. An overview of the exclusion process is shown in the PRISMA flow-diagram in Figure 1 (Page et al., 2021).

A total of 61 studies were excluded because participants' age was outside the defined age range (13–30 years). Another study presented outcome variables that were not comparable to the outcome variables of most other studies included in the review, such as in van Dijk-Lokkart et al. (2016), where components of the main outcome included procedural and treatment anxiety in young cancer patients. Another study was excluded as the PA intervention represented physical movement in the context of physiotherapy and, therefore, did not meet the PA requirements as defined for the current review (Andias et al., 2018). Two studies were excluded as no conclusion on the anxiety reducing effect of PA could be drawn from the intervention description (Zheng et al., 2021) and where the motivation of external circumstances strongly interfered with the anxiety outcome measures (Richards et al., 2014). For one study

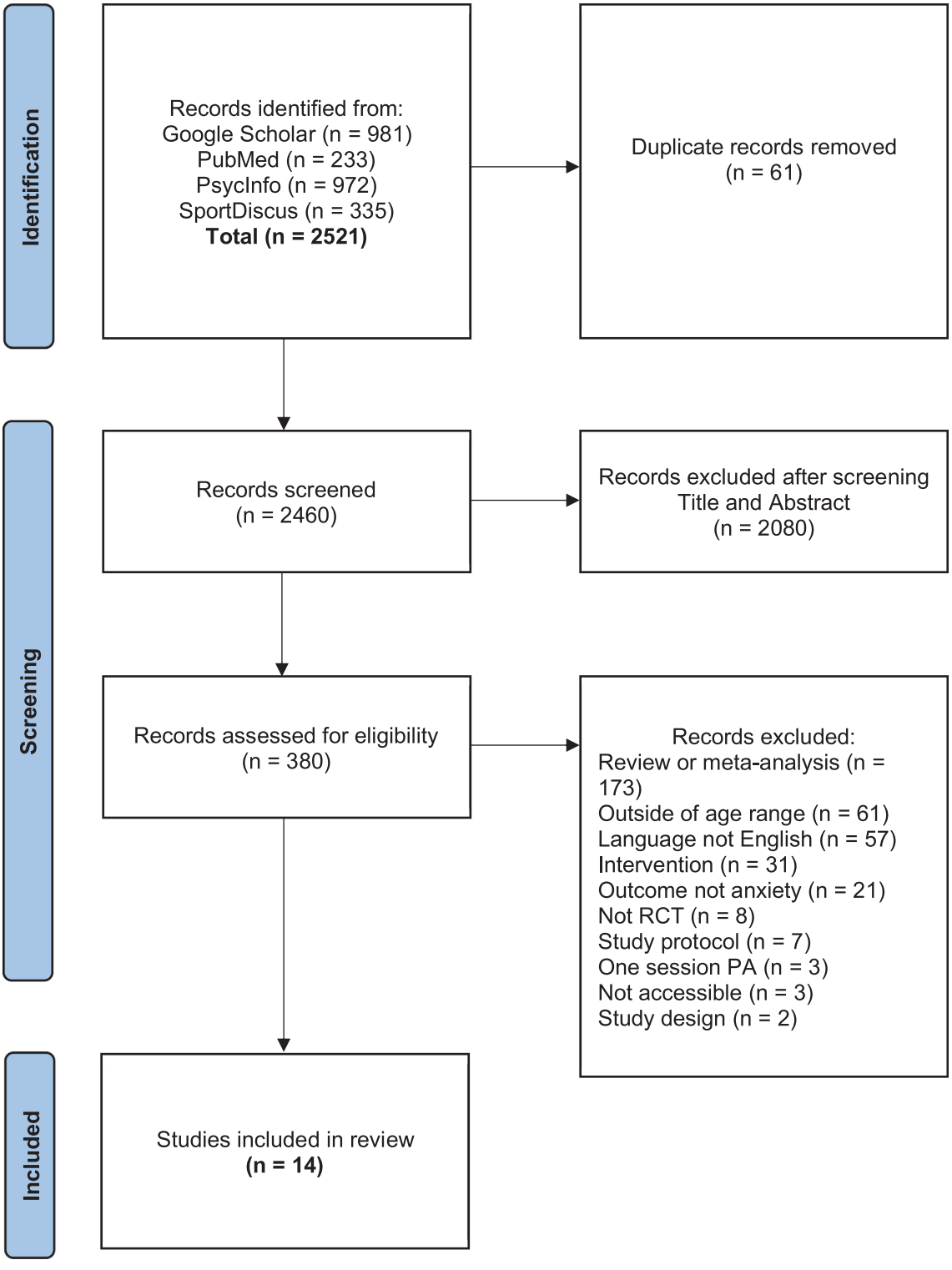

Figure 1. Prisma flow diagram.

methods and results were only available as an abstract (Crocker & Grozelle, 1991).

The studies included in Carter et al. (2021) were also reviewed, based on the inclusion criteria of the present review to check if they would fall within the scope of this review. Of the 22 studies included, 12 studies were excluded because they investigated mindfulness-based interventions; for two studies, only the abstracts were available (Jelalian et al., 2011; Sabourin et al., 2016), another two studies included participants outside of the age range of the current

review (Mailey et al., 2010; Smits et al., 2008), and one publication was not accessible (McEntee, 1995). Two studies were excluded, because they comprised PA, which was not intended as a training (Melnyk et al., 2009, 2013), but were part of a CBT-based intervention. Three studies (Maurer et al., 2020; Norris et al., 1992; Parker et al., 2016) included in Carter et al. (2021) met the inclusion criteria.

Study Characteristics

The included studies are summarized in ESM 1, Table E1.

Designs

Randomization was carried out at an individual level in 12 of the 14 included studies. Two studies used cluster randomization (Bonhauser et al., 2005; Lima et al., 2022) as these studies investigated school-based PA interventions, where classes (Bonhauser et al., 2005) and schools (Lima et al., 2022) constituted clusters.

Four studies compared a PA intervention with an inactive control group, providing a routine health education class (Broman-Fulks & Storey, 2008; Sabourin et al., 2015; J. Zhang et al., 2021; Y. Zhang et al., 2021) or social relaxation activities (Philippot et al., 2022) and one with a passive control group with no activity (Maurer et al., 2020). Three studies compared the PA intervention to an active control group by continuing PA as usual (Bonhauser et al., 2005; Eather et al., 2019; Lucibello et al., 2019). Two of these also had a waitlist group (Eather et al., 2019; Y. Zhang et al., 2021). One study compared the PA intervention to a placebo intervention through implicitly activating positive beliefs and emphasizing that exercise induces beneficial psychological and physiological changes (Lucibello et al., 2020), two studies compared a high and a low intensity group (Fidelix et al., 2019; Norris et al., 1992), with Norris et al. (1992) further comparing them with a flexibility and a control group. One study conducted a 2×2 factorial RCT with the factors Problem Solving Therapy (PST) versus Supportive Counseling and behavioral activation PA versus lifestyle psychoeducation (Parker et al., 2016). One study compared doubling physical education classes alone or plus a workshop for teachers with usual physical education classes and workshops for teachers alone. The workshop for teachers focused on pedagogical and health related topics that should be incorporated in physical education classes (Lima et al., 2022).

Sample

The number of participants ranged from 35 to 1,296, age ranged between 12 and 30 years with a mean age between 14.6 and 22.8 years across all included studies. Two studies had a only female sample (Sabourin et al., 2015; Y. Zhang et al., 2021).

Five studies included university students (Broman-Fulks & Storey, 2008; Eather et al., 2019; Lucibello et al., 2019, 2020; Sabourin et al., 2015), four studies involved adolescent secondary school students (Bonhauser et al., 2005; Lima et al., 2022; Norris et al., 1992; J. Zhang et al., 2021), one study recruited young female adolescents from a community sample (Y. Zhang et al., 2021), one included obese adolescents (Fidelix et al., 2019) and comprised adolescents inpatients (Philippot et al., 2022), and one including help-seeking individuals with a clinical caseness (92%) (Parker et al., 2016). Three studies defined high and low anxiety symptom severity subgroups using measurement tool specific cut-off rates (Lucibello et al., 2019, 2020; Sabourin et al., 2015); two included participants with higher anxiety severity symptoms (Broman-Fulks & Storey, 2008; J. Zhang et al., 2021); one included only participants with self-reported characteristics of anxiety and stress (Y. Zhang et al., 2021) and four made no differentiation between anxiety severity (Eather et al., 2019; Lima et al., 2022; Maurer et al., 2020; Norris et al., 1992).

Regarding PA at baseline, three studies comprised low active participants (> 150 min of moderate to vigorous PA) (Broman-Fulks & Storey, 2008; Lucibello et al., 2019, 2020); one included sedentary females (Y. Zhang et al., 2021) and one recruited sedentary healthy individuals (Maurer et al., 2020). In one, participants showed very low cardiovascular fitness (Philippot et al., 2022); one study differentiated between physical active and non-active participants (Bonhauser et al., 2005), and four studies made no differentiation between PA levels at baseline (Eather et al., 2019; Lima et al., 2022; Sabourin et al., 2015; J. Zhang et al., 2021).

Outcome Measures and Outcome Data Selection

Anxiety was assessed with self-report instruments, and one study used a physiological measure (Lucibello et al., 2020). For self-report questionnaires, three studies used the State and Trait Anxiety Inventory (STAI; Spielberger et al., 1983; see Fidelix et al., 2019; Maurer et al., 2020; Philippot et al., 2022), three studies used the short version of the STAI (Marteau & Bekker, 1992; see also Eather et al., 2019; Lucibello et al., 2019), with one (Y. Zhang et al., 2021) using the Chinese version (Zsido et al., 2020); three studies used the Beck Anxiety Inventory (BAI; Beck et al., 1988; see Lucibello et al., 2019, 2020; Parker et al., 2016); two studies used the Self-rating Anxiety Scale (SAS; Zung, 1971), whereas one used the Chinese version

(J. Zhang et al., 2021). One study used the Social Anxiety Scale for adolescents (Inderbitzen-Nolan & Walters, 2000; see also Lima et al., 2022); two studies used the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) (Bonhauser et al., 2005; Philippot et al., 2022) and one study used the Anxiety Sensitivity Index (ASI; Peterson & Reiss, 1992) (Sabourin et al., 2015) and one the revised version of the ASI (Taylor & Cox, 1998) (Broman-Fulks & Storey, 2008). One study used the Multiple Affect Adjective Check List (Zuckerman et al., 1964; see also Norris et al., 1992). One study measured proinflammatory cytokines blood levels as a marker of chronic inflammation, which is debated as a biomarker for General Anxiety Disorder (Lucibello et al., 2020).

In the present review, both studies that assessed anxiety as a primary or as a secondary outcome were included. Anxiety was the primary outcome in nine studies (Broman-Fulks & Storey, 2008; Fidelix et al., 2019; Lucibello et al., 2019, 2020; Maurer et al., 2020; Norris et al., 1992; Parker et al., 2016; Sabourin et al., 2015; J. Zhang et al., 2021) and the secondary outcome in four studies (Bonhauser et al., 2005; Eather et al., 2019; Lima et al., 2022; Y. Zhang et al., 2021). Moreover, Philippot et al. (2022) investigated the HADS as primary and the STAI as secondary outcome.

In terms of outcomes, six studies investigated the effects of PA on anxiety symptom severity (Bonhauser et al., 2005; Lucibello et al., 2019, 2020; Norris et al., 1992; Parker et al., 2016; Philippot et al., 2022), five studies examined PA intervention effects on state and trait anxiety (Eather et al., 2019; Fidelix et al., 2019; Lucibello et al., 2019; Philippot et al., 2022; Y. Zhang et al., 2021), two studies on anxiety sensitivity (Broman-Fulks & Storey, 2008; Sabourin et al., 2015) and one study on social anxiety (Lima et al., 2022).

Intervention Characteristics

Four studies included a combination of psychological counseling and PA (Fidelix et al., 2019; Philippot et al., 2022; Sabourin et al., 2015; J. Zhang et al., 2021). Fidelix et al. (2019) combined psychological, clinical, and nutritional counseling with PA. In Philippot et al. (2022) participants were inpatients in a psychiatric hospital receiving usual psychological care and PA was an add-on treatment. J. Zhang et al. (2021) combined psychological counseling intervention to improve overall psychological resilience with outdoor PA and in Sabourin et al. (2015) participants received group cognitive behavioral therapy before the exercise intervention. One study combined Problem Solving Therapy and Supportive Counseling with behavioral activation PA (Parker et al., 2016).

Five studies included aerobic PA (running, brisk walking and cycling) (Broman-Fulks & Storey, 2008; Lucibello et al., 2019; Maurer et al., 2020) and team sports (Bonhauser et al., 2005) or aerobic exercise to music (Norris et al., 1992). Three studies included HIIT, in form of online courses (Y. Zhang et al., 2021), cycling (Lucibello et al., 2020) and a variety of resistance and body weight training design (Eather et al., 2019) and two studies did not specify the PA intervention (Lima et al., 2022; Parker et al., 2016). In the majority of the studies, the PA intervention was carried out in a group setting, four studies chose an individual setting (Broman-Fulks & Storey, 2008; Maurer et al., 2020; Parker et al., 2016; Sabourin et al., 2015), and two studies did not report on the format (Fidelix et al., 2019; Lucibello et al., 2019).

PA was supervised, except in two studies (Parker et al., 2016; Sabourin et al., 2015). Supervision was carried out by a member of the research team in six studies, by an exercise professional in three studies (Philippot et al., 2022; J. Zhang et al., 2021; Y. Zhang et al., 2021) and by physical education teachers in two studies (Bonhauser et al., 2005; Lima et al., 2022).

PA intensity was reported in ten studies. From those, seven studies based PA intensity on a percentage of the maximum heart rate (Broman-Fulks & Storey, 2008; Eather et al., 2019; Lucibello et al., 2019, 2020; Maurer et al., 2020; Norris et al., 1992; J. Zhang et al., 2021) ranging from 50% to 95%. Maximum heart rate was determined by a cardiorespiratory fitness test at baseline in two studies (Lucibello et al., 2019, 2020), using the formula (220 – age) in two studies (Broman-Fulks & Storey, 2008; Norris et al., 1992), one study performed a graded exercise test with the participants (Maurer et al., 2020), and no details provided in Eather et al. (2019) and J. Zhang et al. (2021). One study used the heart rate reserve (HRR) to determine PA intensity (Philippot et al., 2022). Here, 40–59% of the HRR was targeted, indicating a moderate intensity. Fidelix et al. (2019) measured PA intensity by measuring individual ventilatory threshold (VT), with 1 VT accounting for high intensity, and 80% of 1VT representing low intensity. Lastly, in one study (Y. Zhang et al., 2021), participants rated their perceived exertion (RPE) using the BORG RPE-Scale, ranging from 1 to 10, with a target of 6 to 8, representing a high intensity level of PA (Williams, 2017).

PA intervention duration ranged from 2 to 40 weeks, with an average duration of 14.2 weeks. PA frequency per week ranged from one to four sessions, while most carried out PA three times per week. Session duration varied from 8 to 90 min, with an average of 40.6 min. In one study, the sessions were isocaloric with a target of 350 kcal. After measuring the individual workload, exercise session duration was calculated for each participant resulting in a mean

session duration of 38.40 (4.36) min for the high intensity group and 52.30 (6.52) min for the low intensity group (Fidelix et al., 2019).

Risk of Bias

The individual evaluation of risk of bias for the respective study is illustrated in Table 1 and the percentage of different biases across the included studies is shown in Figure 2, providing an overall indication of the risk of bias. Risk of bias was rated as "low", "some concerns" or "high" according to the Cochrane assessment tool (Sterne et al., 2019). The overall risk of bias was judged medium to high across all studies. Main reasons for "some concerns" or "high" ratings, were missing detailed information on the randomization process and allocation concealment before randomization, blinding researchers and participants, participants from the intervention group spending more time with the researcher potentially influencing the outcome and possible deviations from the intended intervention especially when participants were unsupervised.

Study Results Overview

The findings of the included studies are summarized in Table 2. For those studies that did not calculate effect sizes, effect sizes were calculated with the available data provided in the respective studies (*). We calculated these effect sizes in an attempt to make the results of studies comparable.

The overall picture of findings across all included studies is very mixed: some studies report no effects at all (Eather et al., 2019; Lima et al., 2022; Philippot et al., 2022), while others describe large effect sizes in reducing anxiety (e.g., Broman-Fulks & Storey, 2008; Lucibello et al., 2019, 2020; Norris et al., 1992).

Nevertheless, Philippot et al. (2022) found that over the course of the study, both groups (IG and CG) showed reduced HADS anxiety scores, possibly resulting from the general clinical environment, suggesting that PA did not significantly contribute to the improvement. Similarly, Parker et al. (2016), who added PA to their psychological interventions (including PST and Supportive Counseling), found no significant differences between groups in regard to anxiety symptoms. Parker et al. (2016) found an overall reduction of BAI anxiety scores in all groups, indicating that PA did not play a crucial role in reducing anxiety. Maurer et al. (2020), could not demonstrate any effects of PA on state and trait anxiety. As these studies included PA as an adjunct treatment, it is impossible to disentangle the effects of PA from those of the other interventions, which might explain their null findings with respect to PA.

Bonhauser et al. (2005) report significant reductions of anxiety symptoms in the PA group, indicating that PA reduced anxiety. In Broman-Fulks and Storey (2008), anxiety sensitivity was reduced after the first session and remained stable, indicating that one session of aerobic exercise can reduce anxiety sensitivity (ES = large). Interestingly, Lucibello et al. (2019) found that participants with high anxiety scores (BAI score $\geq$ 11) benefitted most from PA and that the degree of the effect increased as training progressed (ES = large). This effect could not be found in the low anxiety severity group (BAI $\leq$ 10).

In another study, Lucibello et al. (2020), compared a HIIT intervention to a placebo-control group. Both intervention groups showed significantly reduced anxiety (ES = large), suggesting that PA was not more effective than the placebo PA, but still reduced anxiety symptoms. The authors also investigated resting-state proinflammatory cytokines as immunological markers of anxiety, but no changes in either group could be found. Interestingly, they found that anxiety levels, is assessed by the BAI, moderated cardiorespiratory fitness improvement. Only those with low levels of anxiety (BAI $\leq$ 10) in the HIIT group improved cardiovascular fitness, while those with high levels of anxiety did not, even though the participants trained with similar workload and exercise intensity (Lucibello et al., 2020).

Sabourin et al. (2015), found that participants with high anxiety sensitivity levels showed significantly reduced anxiety sensitivity levels (ES = large) in response to a running intervention. In contrast, low anxiety sensitivity individuals did not, indicating that people with higher anxiety levels benefit more from running than those with low anxiety levels. The authors interpret these effects in terms of interoceptive exposure therapy. In an online-based HIIT intervention combined with health education compared to health education only, a main effect of time on anxiety was found (ES = medium) but no significant treatment or interaction effects. Still, anxiety symptom reductions in the PA condition were greater than in the control group (Y. Zhang et al., 2021).

The study by J. Zhang et al. (2021) compared psychological counseling paired with outdoor PA with a routine health education intervention. Results showed that both groups significantly reduced anxiety (ES = small), with the PA group presenting greater improvements than the control group, indicating that a combination of psychological counseling and outdoor activity is more effective than health education alone.

Fidelix et al. (2019) compared high and moderate intensity training combined with a multidisciplinary behavioral intervention (clinical, psychological and nutritional counseling) in obese adolescents. Their results yielded significant reductions in trait anxiety for both groups, with the high

Table 1. Risk of bias assessment for each included study

	D1a	D1b	D2	D3	D4	D5	Overall
Bonhauser et al. (2005)	⚠	✓	✓	✓	⚠	⚠	⚠
Broman-Fulks & Storey (2008)	✗	n.a.	✗	✗	✗	⚠	✗
Eather et al. (2019)	✓	n.a.	✓	✓	✓	✓	✓
Fidelix et al. (2019)	✓	n.a.	⚠	⚠	✓	✓	⚠
Lima et al. (2022)	⚠	✓	⚠	✓	⚠	⚠	⚠
Lucibello et al. (2019)	⚠	n.a.	✓	✓	✗	⚠	✗
Lucibello et al. (2020)	⚠	n.a.	✓	✓	✗	⚠	✗
Maurer et al. (2020)	⚠	n.a.	✗	✗	⚠	⚠	✗
Norris et al. (1992)	⚠	n.a.	✗	✗	⚠	⚠	✗
Parker et al. (2016)	✓	n.a.	⚠	✓	⚠	⚠	⚠
Philippot et al. (2022)	✓	n.a.	✓	✓	✓	✓	✓
Sabourin et al. (2015)	⚠	n.a.	✗	✓	✗	✓	✗
J. Zhang et al. (2021)	✓	n.a.	✓	✓	⚠	⚠	⚠
Y. Zhang et al. (2021)	✓	n.a.	✓	✓	✓	⚠	⚠

Note. D1a = bias arising from the randomization process; D1b = Bias arising from the identification or recruitment of participants into clusters (only relevant for cluster RCTs); D2 = bias due to deviations from intended interventions; D3 = bias due to missing outcome data; D4 = bias in measurement of the outcome; D5 = bias in selection of the reported result; Overall = overall judgement of the risk of bias for the respective studies (Sterne et al., 2019).

intensity training presenting a larger effect size (ES = large) than the moderate intensity group (ES = small). No significant effect on state anxiety could be demonstrated. This indicates that high intensity training may be beneficial in terms of reductions in trait anxiety, at least for this sample.

Lastly, Norris et al. (1992), who also compared high and moderate intensity aerobic activities, found that high intensity training was more effective in reducing anxiety than moderate intensity training (ES = large) over time.

Taken together these results suggest that PA interventions may result in reduced anxiety, depending on the initial anxiety level (those higher in anxiety benefit more) and on intensity levels (higher training intensities are associated with larger reductions in trait anxiety). Suggested mechanisms include exposure to interoceptive signals during PA.

Discussion

This paper aimed at providing a systematic review of RCTs focusing on PA interventions of at least moderate intensity to reduce anxiety in adolescents and young adults.

Overall, the results indicate that PA is a promising intervention as a stand-alone or add-on treatment for anxiety in adolescents and young adults. The results of several studies suggest that PA is more effective when compared to inactive or no-treatment control groups (Bonhauser et al., 2005; Broman-Fulks & Storey, 2008; Lucibello et al., 2020), although there are also other reports not supporting this finding (Eather et al., 2019; Lima et al., 2022; Maurer et al., 2020).

A combination of psychological and PA interventions showed small to large effects on reducing anxiety. In most of these studies, the intervention group was compared to a health education control group (J. Zhang et al., 2021; Y. Zhang et al., 2021), where both groups reported reductions in anxiety symptoms, albeit to a larger extent in the PA condition. This indicates that combining psychological treatment with PA seems to be more effective than routine health education alone. A recent review (Thomas et al., 2020) concluded a positive effect on psychological outcomes, when psychological interventions are combined with exercise or theory-based (e.g., behavioral activation) PA alone, for various mental health conditions in adults. One study included in this review (Parker et al., 2016), found that simple psychological interventions with PA based on behavioral activation were more effective than the psychological interventions combined with lifestyle education for depression, but not for anxiety. However, one major shortcoming of this study is that PA was measured through self-reports, an assessment which is known for its poor validity and reliability (Helmerhorst et al., 2012). Self-report measures of PA should always be complemented by an objective measure of PA, for example, heart rate or physical movement, monitored – for example – with wearables.

Nevertheless, the evidence remains equivocal as findings suggest that PA as add-on treatment is just as effective as theory-based PA alone (Thomas et al., 2020). This raises the question which one is more effective. If both are equally effective, then PA may provide an effective alternative affording physiological health benefits as well. Due to the small number of studies, high heterogeneity between them

Table 2. Study results overview

Author	Outcome	Findings	Result	Reported Effect size
Bonhauser et al. (2005)	Anxiety symptoms	Sig. reduction of anxiety symptoms	Mean difference between IG and CG is sig. – 0.94, 95% CI (–1.43 to –0.45), $p < .001$	Not reported
Broman-Fulks & Storey (2008)	ASI	Simple effect for session for the EG in reducing anxiety sensitivity	$F(7, 77) = 10.48$, $p < .001$, $\eta^2_p = .49$	$\eta^2_p = .49$, ES = large
Eather et al. (2019)	STAI	No sig. effects measured for anxiety outcome	Change: –0.2 (–1.5 – 1.1) (95% CI) $p = 0.709$	$d = .02$ – no sig. effect
Fidelix et al. (2019)	STAI	STAI -Trait – both groups decreased sig. STAI – State – no significant changes	STAI – Trait: sig. $p < .01$ STAI – State: not sig. $p = .21$	d (HIG): .82, ES: large d (LIG): .31, ES: small d (HIG): .26, ES: small – not sig. d (LIG): .11, ES small – not sig.
Lima et al. (2022)	Social Anxiety	No sig. effect found for reduction of social anxiety	Not reported	Not reported
Lucibello et al. (2019)	STAI	Main effect of group	$F(1, 51) = 19.72$, $p < .001$, $R^2 = .29$	$d = 1.28$*, ES = large $d = 1.42$*, ES = large
		Main effect of anxiety severity (high vs. low)	$F(8, 50) = 3.22$, $p = .05$, $R^2 = .34$	$d = 2.14$*, ES = large
		Post hoc – high anxiety subgroup significantly reduced state anxiety following exercise, and magnitude increased with training	$F(8, 26) = 3.60$, $p = .006$, $R^2 = .53$ $F(8, 23) = 3.82$, $p = .005$, $R^2 = .57$	$d = 2.27$*, ES = large
Lucibello et al. (2020)	BAI	Main effect of time: HIIT and PLACEBO were both effective in reducing anxiety symptoms Cardiorespiratory response moderated by anxiety	$p < .001$, $\eta^2_p = .51$ $r(22) = -0.42$, $p = .04$	$\eta^2_p = .51$, ES = large $d = .93$*, ES = large
Maurer et al. (2020)	STAI	Decrease in STAI scores in both groups but not significant No sig. changes over time and between groups for BAI	IG: $r = -0.44$, $p = .08$ CG: $r = -0.49$, $p = .12$	$d = 49$*, ES = medium – not sig. $d = .61$*, ES = medium – not sig.
Norris et al. (1992)	Multiple Affect Adjective Check List	Groups main effect for anxiety Post hoc analysis: high intensity group showed sig. lower scores than moderate intensity group	$F(3, 56) = 3.52$, $p < .05$ $p < .05$	$\eta^2_p = .16$**, ES = large $d = 1.65$*, ES = large
Parker et al. (2016)	BAI	No sig. time by intervention arm interaction for BAI, no effect of physical activity	$F(2, 119) = 0.88$, $p = .417$ $t(139.4) = 0.55$, $p = .584$	Not reported Not reported
		No sig. changes between groups from baseline Overall reduction of anxiety scores over the course of the study	$F(2, 121) = 109.43$, $p < .001$	$\eta^2_p = .64$**, ES = large
Philippot et al. (2022)	HADS-A (primary outcome PO) No statistical sig. treatment effects STAI (secondary outcome SO)	No sig. changes between groups (PO) reduction of HADS-A scores in both groups	$p > .05$ no added value from physical exercise benefit from treatment as usual	No sig. effect found
Sabourin et al. (2015)	ASI	High AS participants sig. reduced ASI scores Low AS participants did not reduce ASI scores sig.	$t(17) = 2.25$, $p < .05$ $t(9) = 1.71$, $p =$ NS	$d = 1.09$*, ES = large
J. Zhang et al. (2021)	SAS	Sig. decreases of scores in both groups in anxiety scores Decreases greater in IG than in CG	$p < .001$ for both groups baseline to post intervention comparison IG – CG comparison, $p = .018$; stronger decreases in IG	$d = .24$*, ES = small
Y. Zhang et al. (2021)	STAI	Main sig. effect of time on anxiety No significant treatment effects Greater changes of anxiety in IG than CG	$F = 7{,}73$, $p < .001$, $\eta^2_p = .11$ $M_{diff} = -4{,}73$, $p = .002$, 95% CI (–7.30 to –2.15)	$\eta^2_p = .11$, ES = medium

Note. *Author calculated effect sizes Cohen's d using formula and conversion table provided in Howitt and Cramer (2020) in chapter 36. Effect sizes are considered small ($d = .2$), medium ($d = .5$) and large ($d = .8$), as suggested by Cohen (1988). For the $\eta^{2,}$ the following effect sizes are considered small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$), also suggested by Cohen (1988). **η^2_p was calculated by using the *F*-value and degrees of freedom (Lakens, 2013).

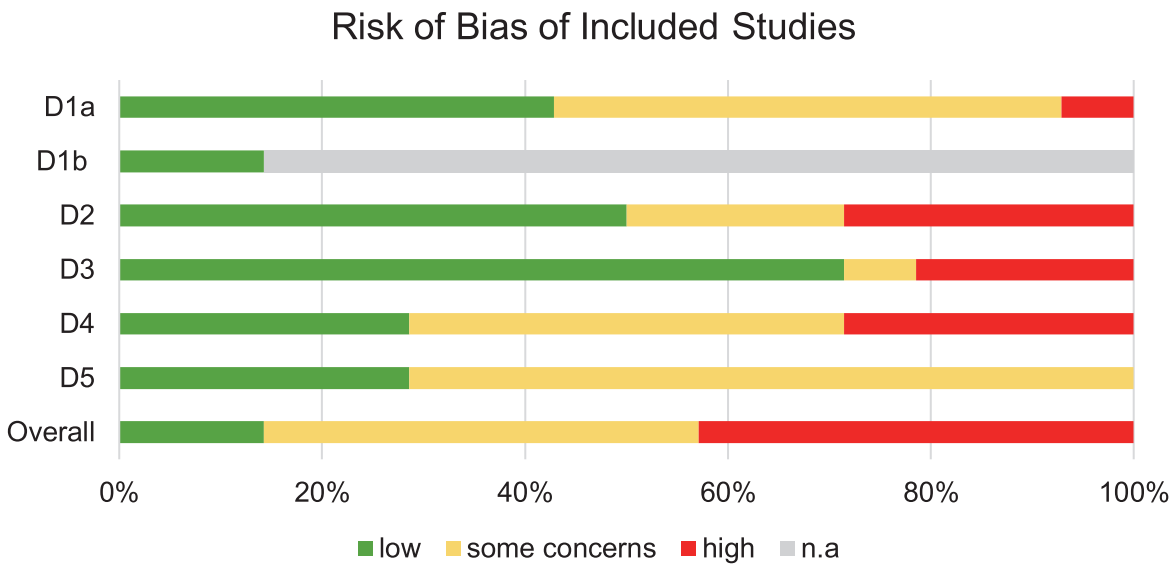

Figure 2. Risk of bias of included studies. D1a = bias arising from the randomization process; D1b = Bias arising from the identification or recruitment of participants into clusters (only relevant for cluster RCTs); D2 = bias due to deviations from intended interventions; D3 = bias due to missing outcome data; D4 = bias in measurement of the outcome; D5 = bias in selection of the reported result; Overall = overall judgment of the risk of bias (Sterne et al., 2019).

and methodological shortcomings, no firm conclusions can be drawn at this time (Thomas et al., 2020). Future research should specifically compare the effects of PA interventions alone with psychological interventions to reduce anxiety, and their combination. Especially in the field of anxiety, evidence is scarce for adolescents and adults, and more high-quality studies are needed.

Intensity

PA intensity levels are also important for any anxiety reducing effects. In the present review, most studies reported intensities (10 out of 14 studies), and both moderate and high intensities could be associated with positive outcomes for anxiety. Overall, high intensity seems to be more effective than moderate intensity, although this could not be confirmed in all studies (Eather et al., 2019). Unfortunately, only two studies (Fidelix et al., 2019; Norris et al., 1992), compared moderate intensity training directly with high intensity training. Fidelix et al. (2019) showed that high and moderate intensity training produce large and small effect sizes respectively, indicating that high intensity training may be superior over moderate intensity training exercise. In a similar vein, Norris et al. (1992) showed that high intensity training was more effective than moderate intensity training, suggesting that for adolescents a certain exercise intensity is required to produce anxiety reducing effects. Carter et al. (2021) were unable to draw any conclusions on the recommended intensity level. In adult populations with anxiety disorders, the evidence indicates that high intensity is more effective compared to low intensity PA (Aylett et al., 2018). Nevertheless, this conclusion was based on only five studies, and others have also criticized the lack of studies reporting PA intensity (Stubbs, Vancampfort, et al., 2017). In contrast, Henriksson et al. (2022) showed low, moderate and high intensities to be all effective in decreasing anxiety symptoms. Findings from a cross-sectional study indicate that PA intensity effects differ for men and women, while optimal intensity for men is higher and for women is lower (Asztalos et al., 2010). Future studies should investigate the optimal intensity for anxiety reducing effects of PA and consider potentially moderating factors such as gender, age, motivation and initial fitness level.

Type of Physical Activity and Duration

Concerning the type of PA and duration of intervention, there was considerable heterogeneity across the included studies. Aerobic and resistance training (equipment and bodyweight) or a combination of both, team sports and outdoor activities were all part of intervention protocols. Overall, aerobic and resistance training or a combination show promising results in reducing anxiety symptoms, although Eather et al. (2019) and Philippot et al. (2022) could not demonstrate this. A recent narrative review made the same observation (Camilleri, 2022). Similarly, for depressive adolescents mostly aerobic exercise and a combination of aerobic and resistance training shows positive effects in reducing depressive symptoms (Wang et al., 2022; Wegner

et al., 2020). Future studies should compare aerobic training with resistance training and a combination of both to identify the best type of activity for reducing anxiety.

For adult samples, results support beneficial effects of both aerobic exercise (Aylett et al., 2018) and resistance training (Gordon et al., 2017) in reducing anxiety. Results indicate that aerobic exercise is only effective when compared to waitlist or placebo control, but not when compared to other control conditions (Bartley et al., 2013). A possible explanation for these mixed findings is that aerobic and resistance training may affect different anxiety-disorder symptoms and underlying constructs, with resistance training affecting a larger range of anxiety-related factors than aerobic training (LeBouthillier & Asmundson, 2017). In their study of adults with anxiety-related disorders, aerobic training was effective in reducing general psychological distress, anxiety, and stress, while resistance training reduced disorder-specific symptoms, anxiety sensitivity, distress tolerance and tolerance of uncertainty (LeBouthillier & Asmundson, 2017). This suggests that there may be differential effects of the type of exercise on anxiety facets, and that, therefore, choosing the appropriate type of PA depends on the targeted constructs for improvement. Future research should investigate if those findings hold in adolescent populations, as evidence is still scarce.

Frequency

In terms of duration, frequency of session and length of intervention, in the present review these averaged 40.6 min per session, mostly 3 times per week for an average length of 14.2 weeks. This is in line with usually reported intervention and session lengths, ranging from 8 to 14 weeks and 20 to 30 min per session (Ströhle, 2008). In a systematic review on depression Wang et al. (2022) suggested 30 min per session, 4 times a week for 6 weeks for depressive adolescents and 75 to 120 min, 3 times a week for 8 weeks for adolescents with depressive symptoms for optimal results. It remains to be seen if this can be replicated for anxiety disorders. Up to date, there is no consensus on the concept of administration of PA interventions for mental health issues, as it is often not controlled for (Biddle et al., 2019). A possible guideline for this could be the recommended times by the WHO (Bull et al., 2020), with an average of 60 min of moderate to vigorous PA per day for adolescents and 150 to 300 min per week for adults.

Clinical vs. Non-Clinical Samples

A comparison of the effectiveness of PA intervention for non-clinical and clinical populations is not trivial, as it depends on the definition of the clinical status. In standard clinical practice and research, mental disorders and clinical caseness is determined based on the results of diagnostic instruments (questionnaires and structured interviews), which are based on classification systems (DSM-5 or ICD-11). Those classification systems provide predefined symptom criteria that need to be fulfilled to diagnose a specific mental disorder (Newson et al., 2020). However, among the wide range of available assessment tools, there is high heterogeneity and inconsistency (Newson et al., 2020). Thus, the assessment result depends on the chosen tool, the questions asked in an interview, and the kind of symptoms (e.g., behavioral, cognitive or physical symptoms) assessed (Newson et al., 2020).

As clinical significance is often operationalized based on questionnaire results, in terms of symptom severity, participants can be categorized into non-clinical, sub-clinical, or clinical groups by using questionnaire specific cut-off scores. Such cut-off-scores, however, draw a line between normality and psychopathology, and people with subthreshold levels may not receive adequate treatment, as they do not meet the necessary score for a diagnosis (Balázs et al., 2013; Helmchen & Linden, 2000). Additionally, inpatients in a clinical institution can be considered to have a clinical status, as they have been diagnosed with a mental disorder and/or comorbidities which may not necessarily be an anxiety disorder.

All these points may distort the determination of clinical status and introduce challenges in comparing research studies, aiming at developing effective treatments (Newson et al., 2020). This issue is apparent from the studies included in this review. Only two studies included a clinical sample, one with participants seeking help (Parker et al., 2016) and one comprised of inpatients (Philippot et al., 2022) already admitted for the treatment of anxiety and depression symptoms. In Philippot et al. (2022), it was not specified whether the participants were diagnosed with an anxiety disorder or depression, plus they did present comorbidities. No significant treatment effect for PA could be found, but both groups showed reductions in anxiety symptoms. It remains unclear from this study whether the PA intervention was indeed ineffective, as all participants, received multidisciplinary treatment, and control participants were allowed to participate in physical activities available at the hospital possibly interfering with the results (Philippot et al., 2022). Parker et al. (2016), who included help-seeking individuals with different mental disorders, provided participants with a psychological intervention (PST or Supportive Counseling) combined with behavioral activation PA or lifestyle psychoeducation, but significant changes in anxiety could be demonstrated across intervention arms. Due to this combination of interventions and the

poor measurement of PA, it is hard to isolate the effect of PA on anxiety.

The other studies in this review included non-clinical samples. Some studies, however, created subgroups by anxiety symptom severity (Broman-Fulks & Storey, 2008; Lucibello et al., 2019, 2020; Sabourin et al., 2015; J. Zhang et al., 2021) to investigate the effects of PA on high or low anxiety symptom severity. In Broman-Fulks and Storey (2008), participants presented a score above the non-clinical mean, and in Lucibello et al. (2019, 2020), high anxiety participants presented a functionally relevant anxiety score. Some of those participants may have fulfilled the criteria for an anxiety disorder and thus may have had a clinical status. This shows that a clear definition of the clinical status of participants needs to be provided and applied systematically to be able to compare the studies.

Anxiety Symptom Severity

The results of the current review suggest that participants with high anxiety symptom severity benefit more from PA interventions than low anxiety individuals when compared to an inactive control group. This is in line with Carter et al. (2021). Nevertheless, when PA is compared to a placebo or health education group the results show that both reduced anxiety symptoms in high anxiety individuals (Lucibello et al., 2020; J. Zhang et al., 2021). This is in contrast to Carter et al. (2021), who conclude that PA interventions are more effective in clinical populations. This could also not be supported by Philippot et al. (2022). A very small number of studies have investigated the effect of PA for general and clinical populations of children and adolescents, with mixed results (Biddle et al., 2019; Carter et al., 2021). For adults diagnosed with an anxiety disorder, results are also inconclusive, as some indicate significant effects of PA on reductions in anxiety (Aylett et al., 2018; Stubbs, Vancampfort, et al., 2017) and others do not (Bartley et al., 2013).

The non-significance of effects for PA in low level anxiety populations (Eather et al., 2019; Lucibello et al., 2019) can be explained by the floor effect. Participants presenting already low levels of anxiety at baseline, do not leave much room for further reductions (Ensari et al., 2015), potentially resulting in an effect size bias to the disadvantage of PA.

Additionally, the included studies that yielded no effect size investigated anxiety as a secondary outcome, indicating that anxiety levels might have already been low within the sample. Future research should compare non-clinical with clinical participants diagnosed with an anxiety disorder or distinguish between low and high anxiety individuals within a study and compare the effect of PA in reducing anxiety in those specific target groups.

Delivery Mode of Physical Activity

The majority of the included studies used group-based interventions, while four opted for individual delivery (Broman-Fulks & Storey, 2008; Maurer et al., 2020; Parker et al., 2016; Sabourin et al., 2015), whereas two did not specify delivery mode (Fidelix et al., 2019; Lucibello et al., 2019). In a study investigating the transdiagnostic effects of group-based exercise interventions for a range of mental disorders in adults, the intervention was effective in reducing global symptom severity, specifically in anxiety symptom severity (Zeibig et al., 2021). Nevertheless, it remains unclear if group-based exercise interventions are preferable to individually delivered interventions. Evidence for established clinical-psychological interventions (CBT) is inconsistent, as Zhou et al. (2019) found group-delivered CBT to be more effective in reducing anxiety than non-CBT interventions and control conditions. Conversely, in their meta-analysis on the effectiveness of psychological therapies for anxiety disorders in adolescents, Baker et al. (2021), concluded that the delivery format did not significantly moderate anxiety outcomes. In this regard, future research should investigate the moderating effect of group-based and individual intervention delivery formats.

Underlying Mechanisms

In terms of the mechanisms underlying any potential effects of PA on anxiety levels, several factors have been put forward including effects on neurotransmitters (e.g., dopamine), anti-inflammatory properties, cognitive restructuring of symptoms, positive self-belief, self-efficacy, and mastery (see Asmundson et al., 2013; Carter et al., 2021; Kandola et al., 2018). Nevertheless, none of the studies included in this review, specifically investigated the potential mechanisms underlying any anxiety reducing effects, with perhaps the one exception of Sabourin et al. (2015) who interpret these effects in terms of interoceptive exposure therapy. Our current understanding of the specific physiological and psychological mechanisms at play is still very limited and needs more attention in future research (Asmundson et al., 2013; Carter et al., 2021; Kandola et al., 2018).

It is noteworthy that the benefits of PA go well beyond a possible reduction in anxiety. Regular exercise has a positive impact on physical health, that current psychological treatments do not provide. People with high levels of anxiety are at an elevated risk for comorbid mental disorders, physical health issues and increased mortality (Kandola & Stubbs, 2020). On the one hand, people that are physically inactive have higher odds of anxiety (Stubbs, Koyanagi, et al., 2017). On the other hand, people with anxiety also have lower cardiorespiratory fitness, and are, therefore,

again at higher risk for cardiovascular disease (Lucibello et al., 2020). Regular PA is associated with reduced cardiometabolic risk factors and other physical health outcomes. Consistent engagement in PA from childhood until young adulthood, predicts higher activity levels in adulthood (Daniels et al., 2011). Therefore, an emphasis on the importance of PA and its many benefits should be part of any psychological intervention treating anxiety.

Methodological Quality Issues

A major issue in the research of the anxiety reducing effects of PA concerns the overall low methodological quality of the included studies, also noted in previous reviews (Biddle et al., 2019). Many of the studies involved only small samples and sometimes an uneven distribution of males and females (Eather et al., 2019). Many studies did not control for PA outside of the intervention setting, having a potential influence on the outcome (Broman-Fulks & Storey, 2008). Further, the studies are very heterogeneous and present a large range in the duration, frequency, and length of intervention, the type of PA and outcome measures. Some studies included PA as an add-on treatment for anxiety, where it is very hard to isolate the part of the anxiolytic effect for which PA is responsible if any. Comparability across studies is, therefore, very limited. Additionally, none of the studies was able to draw conclusions on the longer-lasting effects of PA on anxiety, as no longer-term follow-up measurements were carried out. Equally important is the possible distortion of results due to self-report and response bias (Rosenman et al., 2011).

Compared to the research on the effects of PA on anxiety, depression has received much more attention, and studies more conclusively confirm PA to be a viable alternative treatment for depression (Carter et al., 2016; Vögele, 2019). As mentioned by Biddle et al. (2019), research on the effects of PA on anxiety seems to have stagnated. The findings of this review support this, as only a very small number of studies exist on this topic. Potentially, publication bias, more specifically selection bias, is involved. PA as treatment for depression might have received more attention due to its stronger and larger research base. Positive effects seem to be more consistent than with anxiety, despite the fact that both anxiety disorders and depression are comorbid in adolescents, with anxiety occurring before depression (Essau, 2003).

An incomplete description and implementation of a control condition protocol may affect the reported effects of an intervention. It has been recognized that the effect of the intervention group is highly dependent on the selected control group (Mohr et al., 2009, 2014). In a meta-analysis, Mohr et al. (2014) found that the choice of the control group exerts a large influence on the later reported effects of psychological treatments for depression. Waitlist and treatment as usual control groups yielded the largest trial effects, whereas placebo and active control groups produced smaller effects in favor of the psychological intervention (Mohr et al., 2014). Similar observations can be made when analyzing the results of the studies included in this review. In Lucibello et al. (2019), a PA intervention was compared to PA as usual group and found large effect sizes in favor of the intervention, whereas in Lucibello et al. (2020), a placebo control group was compared with the PA intervention, where both groups significantly reduced anxiety symptoms. Researchers should be aware of this when deciding on and implementing control groups. Thus, future studies should provide a detailed description of the control conditions, which would improve our understanding of the origin of possible anxiety-reducing effects of PA.

The risk of bias in the included studies is substantial. A higher risk of bias reduces the confidence that true treatment effects have been demonstrated by the studies (Viswanathan et al., 2012). Main issues in the included studies concerned unreported information on the randomization process and allocation concealment before randomization, and on blinding researchers and participants, that possibly influenced effect sizes. Blinding participants partaking in the PA intervention, however, may be challenging, due to the nature of the intervention (Parker et al., 2016). To improve methodological quality of studies in the future, efforts should be made properly to report information on randomization and to blind participants and researchers accordingly.

While evidence for the positive effects of PA on reducing anxiety symptoms is promising, these shortcomings highlight the fact that more high-quality RCTs, which constitute the gold-standard in effectiveness research (Hariton & Locascio, 2018), are needed to close the existing research gap. Suggested areas of focus are length, duration, frequency, and type of PA (aerobic vs. resistance training) optimal for reducing anxiety symptoms. For this we suggest to design PA interventions in compliance with WHO-guidelines (Bull et al., 2020). Furthermore, studies with non-clinical and clinical populations, PA as stand-alone or add-on treatment with long-term follow-up are required. Moreover, a better understanding of the underlying mechanisms responsible for the anxiety reducing effects of PA needs more research. Future research should also investigate any moderating effects of gender, individual beliefs, fitness level, targeted symptoms and different anxiety disorders. All this is needed to establish *prescription*-like PA to reduce anxiety.

Limitations

The present review has several limitations. First, the searches were conducted in a limited number of databases.

It cannot be ruled out, therefore, that not all existing studies could be retrieved. Similarly, as we did not carry out an extensive grey-literature search, a grey-literature bias cannot be excluded. Second, only studies published in English were included. To improve this, future reviews should include studies publications in other languages, in addition to English. Third, the appropriate application of the RoB2 tool is highly complex, time-consuming, and subjective, as the judgment of bias is dependent on the reviewer's methodological knowledge and expertise, with previously reported interrater reliability being very low (17% same judgments) (Minozzi et al., 2020). In the present review only one author conducted the RoB assessment, thus no inter-rater comparison can be provided. This constitutes a source of bias influencing the conclusions drawn in the review. Fourth, the present review focused on adolescents and young adults, reducing the generalizability of results to other age groups. In addition, this age range is characterized by potential developmental differences, which may well influence the efficacy and effectiveness of PA interventions.

Conclusion

PA as a treatment for adolescents and young adults is promising. Many findings indicate that PA is a viable adjunct treatment for anxiety for adolescents and young adults. PA interventions are easily accessible alternative to the currently available psychological and pharmacological therapies that are often time-consuming, expensive, and with undesired side effects. In addition, being physically active has a positive impact on overall health and should therefore alone be considered in all psychological treatment. The research field is still in its early stages, and future high-quality studies are needed on the exact duration, frequency and type of activity that is required to achieve anxiolytic effects. Furthermore, little is known about the possible underlying mechanisms responsible for anxiety reducing effects. Acquiring more knowledge is crucial to be able to develop effective and personalized PA interventions to treat anxiety in adolescents and young adults. Most importantly, future investigations should prioritize research areas such as comparative effectiveness studies, mechanistic research, and intervention optimization strategies.

Electronic Supplementary Materials

The following electronic supplementary material is available with this article at https://doi.org/10.1027/2512-8442/a000168

ESM 1. Study characteristics.

References

Andias, R., Neto, M., & Silva, A. G. (2018). The effects of pain neuroscience education and exercise on pain, muscle endurance, catastrophizing and anxiety in adolescents with chronic idiopathic neck pain: A school-based pilot, randomized and controlled study. *Physiotherapy Theory and Practice, 34*(9), 682–691. https://doi.org/10.1080/09593985.2018.1423590

Asmundson, G. J. G., Fetzner, M. G., DeBoer, L. B., Powers, M. B., Otto, M. W., & Smits, J. A. J. (2013). Let's get physical: A contemporary review of the anxiolytic effects of exercise for anxiety and its disorders. *Depression and Anxiety, 30*(4), 362–373. https://doi.org/10.1002/da.22043

Asselmann, E., & Beesdo-Baum, K. (2015). Predictors of the course of anxiety disorders in adolescents and young adults. *Current Psychiatry Reports, 17*(2), Article 7. https://doi.org/10.1007/s11920–014-0543-z

Asztalos, M., De Bourdeaudhuij, I., & Cardon, G. (2010). The relationship between physical activity and mental health varies across activity intensity levels and dimensions of mental health among women and men. *Public Health Nutrition, 13*(8), 1207–1214. https://doi.org/10.1017/S1368980009992825

Aylett, E., Small, N., & Bower, P. (2018). Exercise in the treatment of clinical anxiety in general practice–a systematic review and meta-analysis. *BMC Health Services Research, 1/8*(1), Article 559. https://doi.org/10.1186/s12913–018-3313–5

Baker, H. J., Lawrence, P. J., Karalus, J., Creswell, C., & Waite, P. (2021). The effectiveness of psychological therapies for anxiety disorders in adolescents: A meta-analysis. *Clinical Child and Family Psychology Review, 24*(4), 765–782. https://doi.org/10.1007/s10567-021-00364-2

Balázs, J., Miklósi, M., Keresztény, Á., Hoven, C. W., Carli, V., Wasserman, C., Apter, A., Bobes, J., Brunner, R., Cosman, D., Cotter, P., Haring, C., Iosue, M., Kaess, M., Kahn, J., Keeley, H., Marusic, D., Postuvan, V., Resch, F., & Saiz, P. A. (2013). Adolescent subthreshold-depression and anxiety: Psychopathology, functional impairment and increased suicide risk. *Journal of Child Psychology & Psychiatry, 54*(6), 670–677. https://doi.org/10.1111/jcpp.12016

Bartley, C. A., Hay, M., & Bloch, M. H. (2013). Meta-analysis: Aerobic exercise for the treatment of anxiety disorders. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 45*, 34–39. https://doi.org/10.1016/j.pnpbp.2013.04.016

Beck, A. T., Epstein, N., Brown, G., & Steer, R. A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology, 56*(6), 893–897. https://doi.org/10.1037/0022-006X.56.6.893

Biddle, S. J. H., & Asare, M. (2011). Physical activity and mental health in children and adolescents: A review of reviews. *British Journal of Sports Medicine, 45*(11), 886–895. https://doi.org/10.1136/bjsports-2011-090185

Biddle, S. J. H., Ciaccioni, S., Thomas, G., & Vergeer, I. (2019). Physical activity and mental health in children and adolescents: An updated review of reviews and an analysis of causality. *Psychology of Sport and Exercise, 42*, 146–155. https://doi.org/10.1016/j.psychsport.2018.08.011

Bonhauser, M., Fernandez, G., Püschel, K., Yañez, F., Montero, J., Thompson, B., & Coronado, G. (2005). Improving physical fitness and emotional well-being in adolescents of low socioeconomic status in Chile: Results of a school-based controlled trial. *Health Promotion International, 20*(2), 113–122. https://doi.org/10.1093/heapro/dah603

Bridle, C., Spanjers, K., Patel, S., Atherton, N. M., & Lamb, S. E. (2012). Effect of exercise on depression severity in older people: Systematic review and meta-analysis of randomised controlled

trials. *The British Journal of Psychiatry, 201*(3), 180–185. https://doi.org/10.1192/bjp.bp.111.095174

Broman-Fulks, J. J., & Storey, K. M. (2008). Evaluation of a brief aerobic exercise intervention for high anxiety sensitivity. *Anxiety, Stress, and Coping, 21*(2), 117–128. https://doi.org/10.1080/10615800701762675

Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical foundations and evidence for its salutary effects. *Psychological Inquiry, 18*(4), 211–237. https://doi.org/10.1080/10478400701598298

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., & Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Camilleri, N. (2022). An evaluation of the evidence of physical activity as a treatment for anxiety. *Malta Medical Journal, 34*(1), 87–93. https://www.mmsjournals.org/index.php/mmj/article/view/403

Carter, T., Morres, I. D., Meade, O., & Callaghan, P. (2016). The effect of exercise on depressive symptoms in adolescents: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 55*(7), 580–590. https://doi.org/10.1016/j.jaac.2016.04.016

Carter, T., Pascoe, M., Bastounis, A., Morres, I. D., Callaghan, P., & Parker, A. G. (2021). The effect of physical activity on anxiety in children and young people: A systematic review and meta-analysis. *Journal of Affective Disorders, 285*, 10–21. https://doi.org/10.1016/j.jad.2021.02.026

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126–131.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge Academic. https://doi.org/10.4324/9780203771587

Crocker, P. R., & Grozelle, C. (1991). Reducing induced state anxiety: Effects of acute aerobic exercise and autogenic relaxation. *The Journal of Sports Medicine and Physical Fitness, 31*(2), 277–282.

Daniels, S. R., Pratt, C. A., & Hayman, L. L. (2011). Reduction of risk for cardiovascular disease in children and adolescents. *Circulation, 124*(15), 1673–1686. https://doi.org/10.1161/CIRCULATIONAHA.110.016170

Eather, N., Riley, N., Miller, A., Smith, V., Poole, A., Vincze, L., Morgan, P. J., & Lubans, D. R. (2019). Efficacy and feasibility of HIIT training for university students: The Uni-HIIT RCT. *Journal of Science and Medicine in Sport, 22*(5), 596–601. https://doi.org/10.1016/j.jsams.2018.11.016

Ensari, I., Greenlee, T. A., Motl, R. W., & Petruzzello, S. J. (2015). Meta-analysis of acute exercise effects on state anxiety: An update of randomized controlled trials over the past 25 years. *Depression and Anxiety, 32*(8), 624–634. https://doi.org/10.1002/da.22370

Essau, C. A. (2003). Comorbidity of anxiety disorders in adolescents. *Depression & Anxiety (1091–4269), 18*(1), 1–6. https://doi.org/10.1002/da.10107

Fidelix, Y., Lofrano-Prado, M. C., Fortes, L. S., Hill, J. O., Caldwell, A. E., Botero, J. P., & do Prado, W. L. (2019). Aerobic training performed at ventilatory threshold improves psychological outcomes in adolescents with obesity. *Journal of Physical Activity & Health, 16*(10), 851–856. https://doi.org/10.1123/jpah.2018-0193

Gordon, B. R., McDowell, C. P., Lyons, M., & Herring, M. P. (2017). The effects of resistance exercise training on anxiety: A meta-analysis and meta-regression analysis of randomized controlled trials. *Sports Medicine, 47*(12), 2521–2532. https://doi.org/10.1007/s40279-017-0769-0

Gordon, B. R., McDowell, C. P., Lyons, M., & Herring, M. P. (2021). Resistance exercise training among young adults with analogue generalized anxiety disorder. *Journal of Affective Disorders, 281*, 153–159. https://doi.org/10.1016/j.jad.2020.12.020

Hariton, E., & Locascio, J. J. (2018). Randomized controlled trials – The gold standard for effectiveness research. *BJOG: An International Journal of Obstetrics and Gynaecology, 125*(13), 1716. https://doi.org/10.1111/1471–0528.15199

Helmchen, H., & Linden, M. (2000). Subthreshold disorders in psychiatry: Clinical reality, methodological artifact, and the double-threshold problem. *Subthreshold Disorders in Psychiatry, 41*(2, Supplement 1), 1–7. https://doi.org/10.1016/S0010–440X(00)80001–2

Helmerhorst, H. H. J., Brage, S., Warren, J., Besson, H., & Ekelund, U. (2012). A systematic review of reliability and objective criterion-related validity of physical activity questionnaires. *International Journal of Behavioral Nutrition and Physical Activity, 9*(1), Article 103. https://doi.org/10.1186/1479–5868-9–103

Henriksson, M., Wall, A., Nyberg, J., Adiels, M., Lundin, K., Bergh, Y., Eggertsen, R., Danielsson, L., Kuhn, H. G., Westerlund, M., David Åberg, N., Waern, M., & Åberg, M. (2022). Effects of exercise on symptoms of anxiety in primary care patients: A randomized controlled trial. *Journal of Affective Disorders, 297*, 26–34. https://doi.org/10.1016/j.jad.2021.10.006

Hill, C., Waite, P., & Creswell, C. (2016). Anxiety disorders in children and adolescents. *Paediatrics and Child Health, 26*(12), 548–553. https://doi.org/10.1016/j.paed.2016.08.007

Howitt, D., & Cramer, D. (2020). *Understanding statistics in psychology with SPSS 8th edition*. Pearson Education.

Inderbitzen-Nolan, H. M., & Walters, K. S. (2000). Social anxiety scale for adolescents: Normative data and further evidence of construct validity. *Journal of Clinical Child Psychology, 29*(3), 360–371. https://doi.org/10.1207/S15374424JCCP2903_7

Jelalian, E., Sato, A., & Hart, C. N. (2011). The effect of group-based weight-control intervention on adolescent psychosocial outcomes: Perceived peer rejection, social anxiety, and self-concept. *Children's Health Care, 40*(3), 197–211. https://doi.org/10.1080/02739615.2011.590391

Kandola, A., & Stubbs, B. (2020). Exercise and anxiety. In J. Xiao (Ed.), *Physical exercise for human health* (pp. 345–352). Springer. https://doi.org/10.1007/978–981-15–1792-1_23

Kandola, A., Vancampfort, D., Herring, M., Rebar, A., Hallgren, M., Firth, J., & Stubbs, B. (2018). Moving to beat anxiety: Epidemiology and therapeutic issues with physical activity for anxiety. *Current Psychiatry Reports, 20*(8), Article 63. https://doi.org/10.1007/s11920–018-0923-x

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, Article 863. https://doi.org/10.3389/fpsyg.2013.00863

LeBouthillier, D. M., & Asmundson, G. J. G. (2017). The efficacy of aerobic exercise and resistance training as transdiagnostic interventions for anxiety-related disorders and constructs: A randomized controlled trial. *Journal of Anxiety Disorders, 52*, 43–52. https://doi.org/10.1016/j.janxdis.2017.09.005

Lima, R. A., de Barros, M. V. G., Bezerra, J., Dos Santos, S. J., Monducci, E., Rodriguez-Ayllon, M., & Soares, F. C. (2022). Universal school-based intervention targeting depressive symptoms in adolescents: A cluster randomized trial. *Scandinavian Journal of Medicine & Science in Sports, 32*(3), 622–631. https://doi.org/10.1111/sms.14115

Lindheimer, J. B., O'Connor, P. J., McCully, K. K., & Dishman, R. K. (2017). The effect of light-intensity cycling on mood and working memory in response to a randomized, placebo-controlled design. *Psychosomatic Medicine, 79*(2), 243–253.

Lucibello, K. M., Paolucci, E. M., Graham, J. D., & Heisz, J. J. (2020). A randomized control trial investigating high-intensity interval training and mental health: A novel non-responder phenotype related to anxiety in young adults. *Mental Health and Physical Activity, 18*, Article 100327. https://doi.org/10.1016/j.mhpa.2020.100327

Lucibello, K. M., Parker, J., & Heisz, J. J. (2019). Examining a training effect on the state anxiety response to an acute bout of exercise in low and high anxious individuals. *Journal of Affective Disorders, 247*, 29–35. https://doi.org/10.1016/j.jad.2018. 12.063

Mailey, E. L., Wójcicki, T. R., Motl, R. W., Hu, L., Strauser, D. R., Collins, K. D., & McAuley, E. (2010). Internet-delivered physical activity intervention for college students with mental health disorders: A randomized pilot trial. *Psychology, Health & Medicine, 15*(6), 646–659. https://doi.org/10.1080/13548506.2010.498894

Marteau, T. M., & Bekker, H. (1992). The development of a six-item short-form of the state scale of the Spielberger State – Trait Anxiety Inventory (STAI). *British Journal of Clinical Psychology, 31*(3), 301–306. https://doi.org/10.1111/j.2044-8260.1992.tb00997.x

Maurer, A., Deckert, S., Levenig, C., Schörkmaier, T., Stangier, C., Attenberger, U., Hasenbring, M., & Boecker, H. (2020). Body image relates to exercise-induced antinociception and mood changes in young adults: A randomized longitudinal exercise intervention. *International Journal of Environmental Research and Public Health, 17*(18), Article E6801. https://doi.org/10.3390/ijerph17186801

McEntee, D. J. (1995). *Cognitive group therapy and exercise in the treatment of anxiety and stress*. University of Massachusetts Amherst.

Melnyk, B. M., Jacobson, D., Kelly, S., Belyea, M., Shaibi, G., Small, L., O'Haver, J., & Marsiglia, F. F. (2013). Promoting healthy lifestyles in high school adolescents: A randomized controlled trial. *American Journal of Preventive Medicine, 45*(4), 407–415. https://doi.org/10.1016/j.amepre.2013.05.013

Melnyk, B. M., Jacobson, D., Kelly, S., O'Haver, J., Small, L., & Mays, M. Z. (2009). Improving the mental health, healthy lifestyle choices, and physical health of Hispanic adolescents: A randomized controlled pilot study. *The Journal of School Health, 79*(12), 575–584. https://doi.org/10.1111/j.1746-1561.2009.00451.x

Minozzi, S., Cinquini, M., Gianola, S., Gonzalez-Lorenzo, M., & Banzi, R. (2020). The revised Cochrane risk of bias tool for randomized trials (RoB 2) showed low interrater reliability and challenges in its application. *Journal of Clinical Epidemiology, 126*, 37–44. https://doi.org/10.1016/j.jclinepi.2020.06.015

Mohr, D. C., Ho, J., Hart, T. L., Baron, K. G., Berendsen, M., Beckner, V., Cai, X., Cuijpers, P., Spring, B., Kinsinger, S. W., Schroder, K. E., & Duffecy, J. (2014). Control condition design and implementation features in controlled trials: A meta-analysis of trials evaluating psychotherapy for depression. *Translational Behavioral Medicine, 4*(4), 407–423. https://doi.org/10.1007/s13142-014-0262-3

Mohr, D. C., Spring, B., Freedland, K. E., Beckner, V., Arean, P., Hollon, S. D., Ockene, J., & Kaplan, R. (2009). The selection and design of control conditions for randomized controlled trials of psychological interventions. *Psychotherapy and Psychosomatics, 78*(5), 275–284. https://doi.org/10.1159/000228248

Mojtabai, R., Stuart, E. A., Hwang, I., Eaton, W. W., Sampson, N., & Kessler, R. C. (2015). Long-term effects of mental disorders on educational attainment in the National Comorbidity Survey ten-year follow-up. *Social Psychiatry and Psychiatric Epidemiology, 50*(10), 1577–1591. https://doi.org/10.1007/s00127-015-1083-5

Newson, J. J., Hunter, D., & Thiagarajan, T. C. (2020). The heterogeneity of mental health assessment. *Frontiers in Psychiatry, 11*, Article 76. https://doi.org/10.3389/fpsyt.2020. 00076

Niermann, H. C. M., Voss, C., Pieper, L., Venz, J., Ollmann, T. M., & Beesdo-Baum, K. (2021). Anxiety disorders among adolescents and young adults: Prevalence and mental health care service utilization in a regional epidemiological study in Germany. *Journal of Anxiety Disorders, 83*, Article 102453. https://doi.org/10.1016/j.janxdis.2021.102453

Norris, R., Carroll, D., & Cochrane, R. (1992). The effects of physical activity and exercise training on psychological stress and well-being in an adolescent population. *Journal of Psychosomatic Research, 36*(1), 55–65. https://doi.org/10.1016/0022-3999(92)90114-h

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *British Medical Journal, 372*, Article n71. https://doi.org/10.1136/bmj.n71

Parker, A., Hetrick, S., Jorm, A., Mackinnon, A., McGorry, P. D., Yung, A. R., Scanlan, F., Stephens, J., Baird, S., Moller, B., & Purcell, R. (2016). The effectiveness of simple psychological and physical activity interventions for high prevalence mental health problems in young people: A factorial randomized controlled trial. *Journal of Affective Disorders, 196*, 200–209. https://doi.org/10.1016/j.jad.2016.02.043

Parodi, K. B., Holt, M. K., Green, J. G., Porche, M. V., Koenig, B., & Xuan, Z. (2022). Time trends and disparities in anxiety among adolescents, 2012–2018. *Social Psychiatry and Psychiatric Epidemiology, 57*(1), 127–137. https://doi.org/10.1007/s00127-021-02122-9

Peterson, R. A., & Reiss, S. (1992). *Anxiety sensitivity index manual* (revised, 2nd ed.). International Diagnostic Services.

Philippot, A., Dubois, V., Lambrechts, K., Grogna, D., Robert, A., Jonckheer, U., Chakib, W., Beine, A., Bleyenheuft, Y., & De Volder, A. G. (2022). Impact of physical exercise on depression and anxiety in adolescent inpatients: A randomized controlled trial. *Journal of Affective Disorders, 301*, 145–153. https://doi.org/10.1016/j.jad.2022.01.011

Richards, J., Foster, C., Townsend, N., & Bauman, A. (2014). Physical fitness and mental health impact of a sport-for-development intervention in a post-conflict setting: Randomised controlled trial nested within an observational study of adolescents in Gulu, Uganda. *BMC Public Health, 14*, Article 619. https://doi.org/10.1186/1471-2458-14-619

Rosenman, R., Tennekoon, V., & Hill, L. G. (2011). Measuring bias in self-reported data. *International Journal of Behavioural & Healthcare Research, 2*(4), 320–332. https://doi.org/10.1504/IJBHR.2011.043414

Sabourin, B. C., Stewart, S. H., Watt, M. C., & Krigolson, O. E. (2015). Running as interoceptive exposure for decreasing anxiety sensitivity: Replication and extension. *Cognitive Behaviour Therapy, 44*(4), 264–274. https://doi.org/10.1080/16506073.2015.1015163

Sabourin, B. C., Watt, M. C., Krigolson, O. E., & Stewart, S. H. (2016). Two interventions decrease anxiety sensitivity among high anxiety sensitive women: Could physical exercise be the key? *Journal of Cognitive Psychotherapy, 30*(2), 131–146. https://doi.org/10.1891/0889-8391.30.2.131

Smits, J. A. J., Berry, A. C., Rosenfield, D., Powers, M. B., Behar, E., & Otto, M. W. (2008). Reducing anxiety sensitivity with

exercise. *Depression and Anxiety, 25*(8), 689–699. https://doi.org/10.1002/da.20411

So, W. W. Y., Lu, E. Y., Cheung, W. M., & Tsang, H. W. H. (2020). Comparing mindful and non-mindful exercises on alleviating anxiety symptoms: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 17*(22), Article 8692. https://doi.org/10.3390/ijerph17228692

Solmi, M., Radua, J., Olivola, M., Croce, E., Soardo, L., Salazar de Pablo, G., Il Shin, J., Kirkbride, J. B., Jones, P., Kim, J. H., Kim, J. Y., Carvalho, A. F., Seeman, M. V., Correll, C. U., & Fusar-Poli, P. (2022). Age at onset of mental disorders worldwide: Large-scale meta-analysis of 192 epidemiological studies. *Molecular Psychiatry, 27*(1), 281–295. https://doi.org/10.1038/s41380-021-01161-7

Spielberger, C., Gorsuch, R., Lushene, R., Vagg, P., & Jacobs, G. (1983). *Manual for the State-Trait Anxiety Inventory (Form Y1–Y2)* (Vol. IV). Consulting Psychologists Press.

Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H.-Y., Corbett, M. S., Eldridge, S. M., Emberson, J. R., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T., … Higgins, J. P. T. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. *British Medical Journal, 366*, Article l4898. https://doi.org/10.1136/bmj.l4898

Stonerock, G. L., Hoffman, B. M., Smith, P. J., & Blumenthal, J. A. (2015). Exercise as treatment for anxiety: Systematic review and analysis. *Annals of Behavioral Medicine: A Publication of the Society of Behavioral Medicine, 49*(4), 542–556. https://doi.org/10.1007/s12160–014-9685–9

Ströhle, A. (2008). Physical activity, exercise, depression and anxiety disorders. *Journal of Neural Transmission, 116*(6), 777–784. https://doi.org/10.1007/s00702–008-0092-x

Stubbs, B., Koyanagi, A., Hallgren, M., Firth, J., Richards, J., Schuch, F., Rosenbaum, S., Mugisha, J., Veronese, N., Lahti, J., & Vancampfort, D. (2017). Physical activity and anxiety: A perspective from the World Health Survey. *Journal of Affective Disorders, 208*, 545–552. https://doi.org/10.1016/j.jad.2016.10.028

Stubbs, B., Vancampfort, D., Rosenbaum, S., Firth, J., Cosco, T., Veronese, N., Salum, G. A., & Schuch, F. B. (2017). An examination of the anxiolytic effects of exercise for people with anxiety and stress-related disorders: A meta-analysis. *Psychiatry Research, 249*, 102–108. https://doi.org/10.1016/j.psychres.2016.12.020

Taylor, S., & Cox, B. J. (1998). An expanded anxiety sensitivity index: Evidence for a hierarchic structure in a clinical sample. *Journal of Anxiety Disorders, 12*(5), 463–483. https://doi.org/10.1016/s0887-6185(98)00028-0

Thomas, J., Thirlaway, K., Bowes, N., & Meyers, R. (2020). Effects of combining physical activity with psychotherapy on mental health and well-being: A systematic review. *Journal of Affective Disorders, 265*, 475–485. https://doi.org/10.1016/j.jad.2020.01.070

van Dijk-Lokkart, E. M., Braam, K. I., van Dulmen-den Broeder, E., Kaspers, G. J. L., Takken, T., Grootenhuis, M. A., Streng, I. C., Bierings, M., Merks, J. H., van den Heuvel-Eibrink, M. M., Veening, M. A., & Huisman, J. (2016). Effects of a combined physical and psychosocial intervention program for childhood cancer patients on quality of life and psychosocial functioning: Results of the QLIM randomized clinical trial. *Psycho-Oncology, 25*(7), 815–822. https://doi.org/10.1002/pon.4016

Viswanathan, M., Ansari, M. T., Berkman, N. D., Chang, S., Hartling, L., McPheeters, M., Santaguida, P. L., Shamliyan, T., Singh, K., Tsertsvadze, A., & Treadwell, J. R. (2012). Assessing the risk of bias of individual studies in systematic reviews of health care interventions. In Agency for Healthcare Research Quality. (Ed.), *Methods Guide for Effectiveness and Comparative Effectiveness Reviews* (pp. 1–36). Agency for Healthcare Research and Quality. https://effectivehealthcare.ahrq.gov/sites/default/files/pdf/assessing-the-risk-of-bias-in-systematic-reviews-of-health-care-interventions-01_0.pdf

Vögele, C. (2019). Die Rolle von Sport und Bewegung für die körperliche und psychische Gesundheit [The role of sport and exercise for physical and mental health]. In S. Schneider & J. Margraf (Eds.), *Lehrbuch der Verhaltenstherapie, Band 3: Psychologische Therapie bei Indikationen im Kindes- und Jugendalter* (pp. 967–977). Springer. https://doi.org/10.1007/978-3-662-57369-3_53

Wang, X., Cai, Z., Jiang, W., Fang, Y., Sun, W., & Wang, X. (2022). Systematic review and meta-analysis of the effects of exercise on depression in adolescents. *Child and Adolescent Psychiatry and Mental Health, 16*, Article 16. https://doi.org/10.1186/s13034-022-00453-2

Wegner, M., Amatriain-Fernández, S., Kaulitzky, A., Murillo-Rodriguez, E., Machado, S., & Budde, H. (2020). Systematic review of meta-analyses: Exercise effects on depression in children and adolescents. *Frontiers in Psychiatry, 11*, Article 81. https://doi.org/10.3389/fpsyt.2020.00081

Wehry, A. M., Beesdo-Baum, K., Hennelly, M. M., Connolly, S. D., & Strawn, J. R. (2015). Assessment and treatment of anxiety disorders in children and adolescents. *Current Psychiatry Reports, 17*(7), Article 52. https://doi.org/10.1007/s11920–015-0591-z

Williams, N. (2017). The Borg Rating of Perceived Exertion (RPE) scale. *Occupational Medicine, 67*(5), 404–405. https://doi.org/10.1093/occmed/kqx063

World Health Organisation. (2020). *WHO guidelines on physical activity and sedentary behaviour*. WHO. https://apps.who.int/iris/bitstream/handle/10665/336656/9789240015128-eng.pdf

Zeibig, J.-M., Seiffer, B., Sudeck, G., Rösel, I., Hautzinger, M., & Wolf, S. (2021). Transdiagnostic efficacy of a group exercise intervention for outpatients with heterogenous psychiatric disorders: A randomized controlled trial. *BMC Psychiatry, 21*(1), Article 331. https://doi.org/10.1186/s12888–021-03307-x

Zhang, J., Zhou, Z., & Zhang, W. (2021). Intervention effect of research-based psychological counseling on adolescents' mental health during the COVID-19 epidemic. *Psychiatria Danubina, 33*(2), 209–216. https://doi.org/10.24869/psyd.2021.209

Zhang, Y., Zhang, B., Gan, L., Ke, L., Fu, Y., Di, Q., & Ma, X. (2021). Effects of online bodyweight high-intensity interval training intervention and health education on the mental health and cognition of sedentary young females. *International Journal of Environmental Research and Public Health, 18*(1), Article E302. https://doi.org/10.3390/ijerph18010302

Zheng, Y., Wang, W., Zhong, Y., Wu, F., Zhu, Z., Tham, Y.-C., Lamoureux, E., Xiao, L., Zhu, E., Liu, H., Jin, L., Liang, L., Luo, L., He, M., Morgan, I., Congdon, N., & Liu, Y. (2021). A peer-to-peer live-streaming intervention for children during COVID-19 home-schooling to promote physical activity and reduce anxiety and eye strain: cluster randomized controlled trial. *Journal of Medical Internet Research, 23*(4), Article e24316. https://doi.org/10.2196/24316

Zhou, X., Zhang, Y., Furukawa, T. A., Cuijpers, P., Pu, J., Weisz, J. R., Yang, L., Hetrick, S. E., Del Giovane, C., Cohen, D., James, A. C., Yuan, S., Whittington, C., Jiang, X., Teng, T., Cipriani, A., & Xie, P. (2019). Different types and acceptability of psychotherapies for acute anxiety disorders in children and adolescents. *JAMA Psychiatry, 76*(1), 41–50. https://doi.org/10.1001/jamapsychiatry.2018.3070

Zigmond, A. S., & Snaith, R. P. (1983). The hospital anxiety and depression scale. *Acta Psychiatrica Scandinavica, 67*(6), 361–370. https://doi.org/10.1111/j.1600-0447.1983.tb09716.x

Zsido, A. N., Teleki, S. A., Csokasi, K., Rozsa, S., & Bandi, S. A. (2020). Development of the short version of the Spielberger State – Trait anxiety inventory. *Psychiatry Research, 291*, Article 113223. https://doi.org/10.1016/j.psychres.2020.113223

Zuckerman, M., Lubin, B., Vogel, L., & Valerius, E. (1964). *Multiple affect adjective check list* [Database record]. APA PsycTests. https://doi.org/10.1037/t06152-000

Zung, W. W. (1971). A rating instrument for anxiety disorders. *Psychosomatics, 12*(6), 371–379. https://doi.org/10.1016/S0033-3182(71)71479-0

History
Received November 22, 2023
Revision received September 10, 2024
Accepted November 14, 2024
Published online February 10, 2025

Publication Ethics
This systematic review adheres to PRISMA guidelines.

Authorship
Thierry Aumer: writing, original draft, data curation, review & editing; Claus Vögele: conceptualization, consulting, reviewing & editing. All others approved the final version of this article.

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