Gauri A. Oka, Kalyani Deshmukh, Pritam Halder, Divya Ilanchoorian and Aravind P. Gandhi*

A systematic review and meta-analysis to determine the effect of pranayama in reducing anxiety and stress in adolescents

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Abstract

Background: Pranayama has garnered increasing attention in recent years due to its potential therapeutic effects on mental and physical health. However, a lack of age-specific synthesis of its efficacy, especially among adolescents, highlights the need for focused evaluation in this population. Therefore, this study aims to systematically review and meta-analyze (SRMA) the effectiveness of pranayama in reducing stress and anxiety in adolescents.

Methods: A systematic search was done on four databases, namely, the Cochrane Library, Medline (PubMed), Embase, and Web of Science, for articles published between 1st January 2015 and 31st December 2024. Independent screening of the articles was done by two reviewers, and duplicates were removed using NESTED Knowledge. Quality assessment of the studies was done using Cochrane and the JBI tools. A meta-analysis was undertaken in "Comprehensive Meta-Analysis (CMA)" software, and heterogeneity was evaluated using the I^2 statistic.

Results: Eighteen studies were included in this SRMA of which 11 were RCTs and 7 were quasi-experimental studies. The overall standardized mean difference (SMD) was −1.166 [95 % CI: −1.979 to −0.353], indicating a moderate effect on stress reduction in favor of deep breathing. GRADE assessment revealed very low certainty of evidence due to serious concerns in the risk of bias, inconsistency, and imprecision domains.

Conclusions: Integrating pranayama into adolescents' daily lives can help reduce their anxiety and stress levels. Rigorous research is required to generate good quality scientific evidence in this field.

Keywords: pranayama; deep breathing; stress; anxiety; adolescents

Introduction

Pranayama is a yogic breathing practice involving controlled breathing techniques and has garnered increasing attention in recent years due to its potential therapeutic effects on mental and physical health [1]. Increased stress and anxiety may occur during adolescence, a crucial developmental stage marked by profound physical, emotional, and psychological changes. The prevalence estimates of stress and anxiety disorders among adolescents are alarmingly high, to the extent that 20 % of them have severe anxiety symptoms at some time throughout their adolescence [2]. The detrimental impact of stress and anxiety on academic performance, social relationships, and overall well-being is well known. There is an urgent need for effective interventions that can be easily integrated into the lives of youngsters. Pranayama is an integral component of yoga, deeply rooted in ancient Indian philosophy. It encompasses different techniques to regulate the breath, thereby influencing the mind and body. Pranayama practices are believed to enhance self-awareness, promote relaxation, and emotional regulation [3]. Researchers have explored the efficacy of pranayama as a non-pharmacological intervention for managing stress and anxiety among adolescents. According to preliminary research, consistent practice may result in significant decrease in anxiety and improvement in mood [4]. However, the existing literature is characterized by considerable variability in study designs, sample sizes, and methodological rigor, which makes it difficult to draw definitive conclusions. The mechanisms behind the impact

***Corresponding author: Dr Aravind P. Gandhi**, Assistant Professor, Department of Community Medicine, All India Institute of Medical Sciences (AIIMS), Nagpur, India, E-mail: aravindsocialdoc@gmail.com. https://orcid.org/0000-0003-3898-5450
Gauri A. Oka, Research Consultant, Central Research and Publication Unit, Bharati Vidyapeeth Deemed University Medical College, Pune, India, E-mail: gauri.oka@bharatividyapeeth.edu. https://orcid.org/0000-0003-3425-8512
Kalyani Deshmukh, Technical Resource Centre, Centre for Evidence based Guidelines, All India Institute of Medical Sciences, Nagpur, India, E-mail: deshmukhkalyanip@gmail.com. https://orcid.org/0009-0009-7125-4896
Pritam Halder, Department of Community Medicine and School of Public Health, PGIMER Chandigarh, Chandigarh, India, E-mail: rynedann@gmail.com. https://orcid.org/0009-0008-2407-6807
Divya Ilanchoorian, Public Health (International Health), Directorate General of Health Services, New Delhi, India, E-mail: div.ilan12@gmail.com

of pranayama on anxiety and stress are multifaceted. Research indicates that controlled breathing can activate the parasympathetic nervous system, leading to a state of relaxation [5]. This activation may result in reduced cortisol levels, thereby mitigating the physiological reactions occurring in response to stress [6]. Furthermore, pranayama has been shown to enhance the vagal tone, leading to improved emotional well-being and resilience against stressors [7]. These physiological changes may contribute to the observed psychological benefits of pranayama. Despite the promising evidence supporting pranayama's role in alleviating stress and anxiety, there remains a lack of comprehensive reviews synthesizing the available data specifically focused on adolescents. Most existing reviews have primarily concentrated on adult populations or have not differentiated between various age groups [8]. This gap in the literature underscores the necessity for a "systematic review and meta-analysis (SRMA)" that specifically examines the impact of pranayama on stress and anxiety in adolescents, systematically evaluating the current body of evidence. In addition to assessing overall efficacy, it is crucial to explore potential moderators that may influence the outcomes of pranayama interventions, as factors such as frequency and duration of practice, type of pranayama technique employed, and baseline anxiety and stress levels may all play significant roles in determining the effectiveness [9].

Methodology

This SRMA was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Table S1).

Inclusion criteria

Studies in English that were either "randomized controlled trials (RCTs)" or quasi-experimental in design were included. Observational studies (cross-sectional, cohort, case-control), case reports, case series, letters, communications, editorials, abstracts, and conference proceedings were excluded. Studies on adolescents (aged 10–19 years) were included if the intervention was yogic breathing (*pranayama*), regardless of the type, frequency, or duration. , and the outcome measured was stress and/or anxiety measured using standard validated instruments. Studies involving adolescents with comorbidities were excluded. Studies were included if the intervention was compared with no treatment, placebo, or any other form of physical or breathing exercise. Studies employing any co-intervention were eligible if the same was employed across all the groups studied (Table S2).

Outcome variables

Change in stress and/or anxiety levels of adolescents.

Search strategy

Electronic databases, namely, the "Cochrane Library, Medline (PubMed), Embase, and Web of Science", were searched for articles published between 1st January 2015 and 31st December 2024, with detailed search strings provided as a supplementary file (Table S3). Screening: After removing duplicate records, the title and abstract screening were carried out by two reviewers independently (GO and KD), and eligible studies were identified. Discrepancies when encountered were addressed through adjudication or by involving a third reviewer (AG) where necessary. Subsequently, GO and KD screened the full texts of the included articles independently. The discrepancies were resolved through adjudication with the third reviewer (AG).

Data extraction

Data extraction was done using a predesigned data extraction form. Details on the study participants, intervention and control arms, stress and anxiety as the outcomes, and their measures were extracted independently by two reviewers (GO and KD). This was followed by need-based adjudication and involvement of a third reviewer (AG) where discrepancies were encountered. Following this, an independent risk of bias assessment was conducted by the same two reviewers using the Cochrane "Risk of Bias tool (RoB 2)" for RCTs, and the JBI tool for quasi experimental studies.

Statistical analysis

To estimate pooled outcomes, a random-effects model based on maximum likelihood estimation was applied. The variability between studies was done using the I^2 statistic, prediction intervals were also determined to capture the range of likely effects [10]. While Doi plots and the "Luis Furuya-Kanamori (LFK)" index were planned to assess publication bias, they were not used due to the smaller number of studies eligible for meta-analysis. "Comprehensive Meta-Analysis (CMA)" software was used for all

statistical analyses [11, 12]. A correlation coefficient of 0.5 was assumed between pre- and post-intervention stress levels. To examine the stability of the results, sensitivity analyses were also performed using correlation values of 0.1 and 0.9.

Certainty of evidence

GRADEpro software was used to evaluate the certainty of the pooled estimate of each outcome, following the "Grading of Recommendations, Assessment, Development, and Evaluations (GRADE)" methodology [13].

Ethics

Ethics review is not applicable since this is a systematic review of already published studies.

Results

Study selection

An efficient two-stage screening was done by two independent reviewers (GO and KD). Nested Knowledge was used for the proper management of all the studies extracted. Searching through the selected databases yielded 1,476 records. After removing duplicates and applying the exclusion criteria, 119 full-text studies were reviewed. For the final analysis, 18 records were included, of which 11 were RCTs and 7 were quasi-experimental studies (6 studies employed the before-after design and 1 was a non-randomized comparative study) (Figure 1).

Characteristics of the included studies

The final eligible studies were from the USA, European countries, namely Poland, Germany, Portugal, and Greece, and Asian countries, namely South Korea, Indonesia, India, and Malaysia. The interventions were not homogeneous across studies. A total of 2,007 and 1,530 participants belonged to the exposed and control groups, respectively. The various interventions included in the 11 RCTs [14–24] and 7 [25–31] quasi-experimental studies were various breathing exercises, including diaphragmatic breathing, deep breathing, abdominal breathing, pranayama, and app-guided breathing [14, 24]. Few studies reported the effect of specific types of breathing exercises like Kapalbhati, Nadi Shuddhi, Savitri Pranayama, and Anulom Vilom. Tellas et al. [19] and Wilson et al. [29] studied the effect of high-frequency breathing exercise, whereas Rodrigues et al. [20] studied the impact of deep breathing as a part of Quigong exercise. The durations and frequencies of the interventions varied from 2 to 12 weeks and from two times to several times per day (as described by Okado et al.). The most common intervention was deep breathing or pranayama (Table 1).

The anxiety scales used across the included studies were "State-Trait Anxiety Inventory (STAI)", "Patient Health Questionnaire – Somatization, Anxiety, and Depression (PHQ-SADS)", "Spielberger's State Trait Anxiety Inventory – State (STAI-S)", "State-Trait Anxiety Inventory for Children (STAIC)", and DASS 21 (Supplementary Table S4). The Perceived Stress Scale, "Psychological Social Well-Being Index (PWI-SF)", Trier Social Stress Test, subjective stress levels via ratings, Medical Students Stressor Questionnaire, "ADOlescence Stress Scale (ADOSS)", Stress questionnaire designed by the International Stress Management Association, and Stress management subscale of the "Health-promoting Lifestyle Profile II (HPLP-II)" were used for evaluating stress. Salivary cortisol and alpha-amylase levels were also used as surrogate markers of stress [17, 18].

Results of analysis

Deep breathing and its effect on stress

The pooled estimate shows that deep breathing significantly reduces stress levels compared to the pre-intervention period, over a 1–4 month period [15, 24]. Overall standardized mean difference (SMD) is −1.166 [95 % CI: −1.979 to −0.353], revealing a moderate effect in favor of deep breathing (Supplementary Figure 2). However, there was a substantial heterogeneity among the studies (I^2=74.46 %). Sensitivity analysis at correlation coefficients of 0.1 and 0.9 did not change the significance of the results obtained (Supplementary Figure 1). The leave-one-out sensitivity analysis showed that the study by Kim et al. appeared to influence the results notably, and when it was removed, the overall effect remained statistically significant [15] (Supplementary Figure 3).

Narrative synthesis

Okado et al. [14] conducted a pilot study on the impact of short-term relaxation training on preventing stress-related problems, involving 132 participants who completed an in-person research session. A significant decline in anxiety scores was

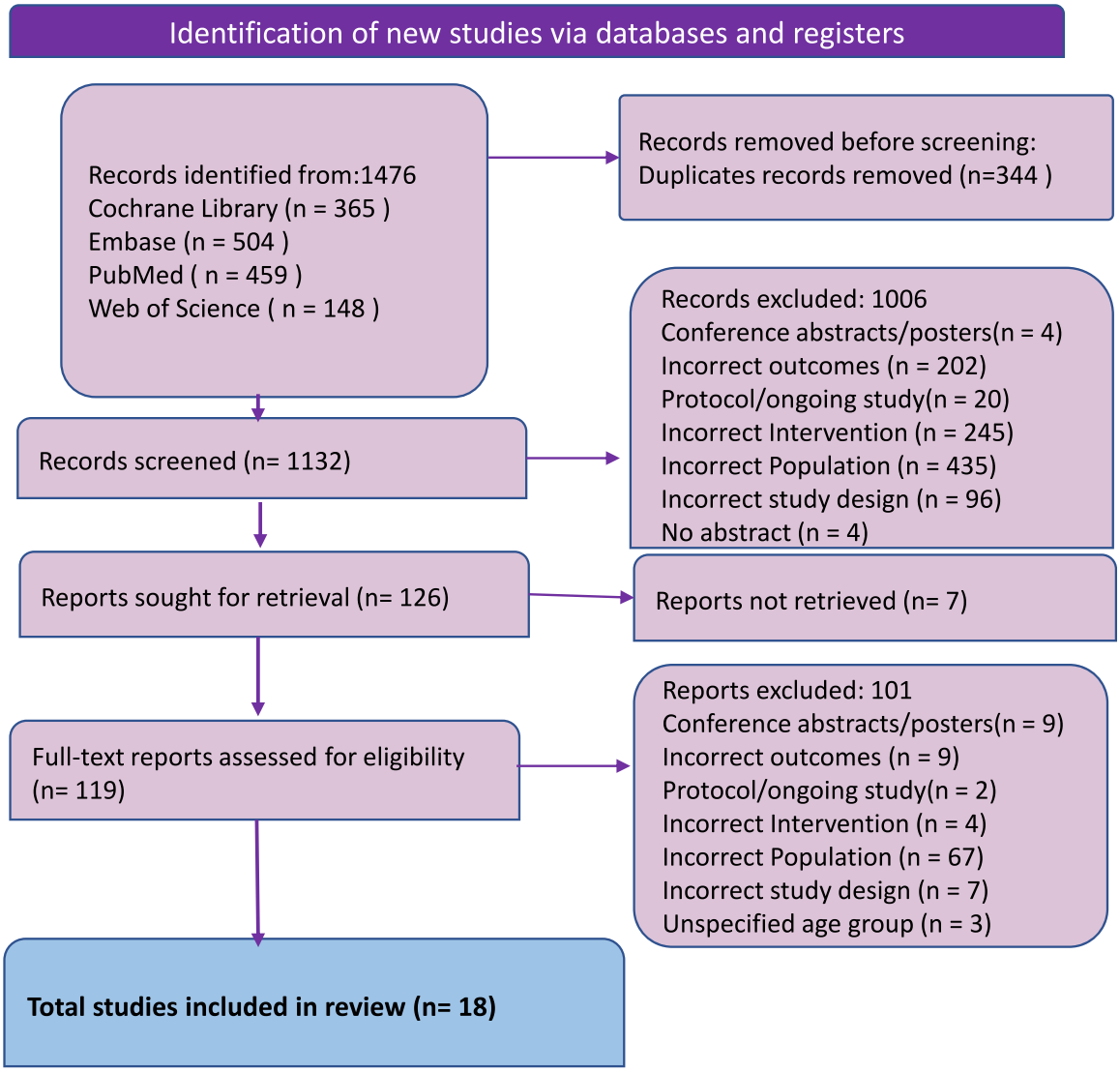

Figure 1: PRISMA diagram for selection of the studies.

observed after a one-on-one diaphragmatic breathing training session among male athletes in this pilot study, which used a stress management tool consisting of rhythmic breathing. In the RCT conducted for 21 days, the mean anxiety levels of the intervention group significantly decreased (mean change = −4; $p<0.001$), whereas the control group showed no substantial change ($p=0.817$). In addition, compared to the control group, athletes who underwent biofeedback training showed notable and statistically significant improvements in heart rate variability, as well as substantial changes in alpha asymmetry and theta and alpha brain wave power spectra [16]. Khng et al. [22], Ranjani et al. [18], Nebhinani et al. [26], Ariga et al. [25], and Okado et al. [14] reported the effects of deep breathing on anxiety and stress levels. Nebhinani et al. observed a significant reduction in academic, interpersonal, social, and group activity-related stressors. The total stress score declined from 53.27 (±21.42) to 44.30 (±20.42) after three months of deep breathing exercises [26].

Pranayama interventions such as Anulom Vilom, Kapalbhati, and Savitri pranayama were used in several studies to assess their effects on stress and anxiety [21, 27, 28, 31]. Practicing pranayama for 5 min, three times a week, led to a reduction in stress scores from 9.42 (±2.80) to 3.96 (±1.04). A significant decrease in stress and anxiety-related difficulties was observed after a two-week follow-up. The pranayama group's mean "Perceived Stress Scale (PSS)" score was significantly lower than that of the control group both immediately before the test and after the training ($p<0.05$) [28]. In both, an RCT [19] and a quasi-experimental study [29], high-frequency yoga breathing was used as an intervention to evaluate its effects on anxiety and stress. It was found that the STAI-S score decreased from 37.59 (±10.51)

Table 1: Characteristics of included studies.

Sr no	Author, year	Study design	Study setting, region	Intervention	Sample size (intervention group)	Sample size (control group 1)	Sample size (control group 2)	Sample size (control group 3)	Duration of intervention (frequency)
1	Okado et al., 2020 [14]	RCT	Public university, California, USA	Diaphragmatic breathing	44 (Diaphragmatic breathing training with handout)	43 (Existing relaxation strategy)	44 (Existing relaxation strategy with handout)	81 (Online only, no face-to-face contact)	2 weeks (several times a day)
2	Kim et al., 2024 [15]	RCT	Metro city, South Korea	Ten minutes of breathing exercise both before and after the program	16 (Wind instrument and choral training group)	17 (Choral training group)	17 (Listening to music that helps with emotional relaxation)	NA	12 weeks (2 times a week, 120 min per session)
3	Dziembowska et al., 2015 [16]	RCT	Psychophysiology laboratory, Poland	Abdominal breathing through pursed lips	20 (Abdominal breathing through pursed lips)	21 (Nothing)	NA	NA	3 weeks (10 sessions in 3 weeks, 20 min per session)
4	Ariga et al., 2015 [25]	Quasi-experimental, non RCT	University, Medan, Indonesia	Deep breathing	20 (Deep breathing)	20 (NA)	NA	NA	NA
5	Schleicher et al., 2024 [17]	RCT	District Hospital, Germany	Breathing exercises integrated into smartphones as a health app	36	37 (Natural relaxation)	NA	NA	NA
6	Nebhinani et al., 2024 [26]	Quasi-experimental, pre-post	Institute of National Importance, Rajasthan, India	Deep breathing	100	NA	NA	NA	2 weeks with 8 modules of 1 h each
7	Ranjani et al., 2023 [18]	Cluster RCT	Schools at Chennai and New Delhi, India	Pranayama or deep breathing	996	1,004 (45-min Educational session on healthy living)	NA	NA	17 Sessions over 5 months (10-min session once a week)
8	Adhikari et al., 2023 [27]	Quasi-experimental, pre-post	University, Madhya Pradesh, India	Anulom-vilom and Kapalbhati	50	NA	NA	NA	8 weeks (5 min 3 times a week)
9	Lagare et al., 2023 [28]	Quasi-experimental, non-RCT	Government Medical College, Kolhapur, India	Kapalbhati and Yogic Shwasan, followed by Nadi Shuddhi, Bhastrika and Bhramari	30	120 (Nothing)	NA	NA	12 weeks (20 min a day 6 days a week)
10	Telles et al., 2019 [19]	RCT	School, India	High-frequency yoga breathing,	61	NA	NA	NA	NA
11	Wilson et al., 2015 [29]	Quasi-experimental, pre-post	School, Boston	High-frequency yoga breathing,	85	NA	NA	NA	6–8 weeks (At least 30 min a week)
12	Wang et al., 2024 [30]	Quasi-experimental, pre-post	Public college, Malaysia	Abdominal breathing	31	NA	NA	NA	5 weeks (60-min sessions 3 times a week)

Table 1: (continued)

Sr no	Author, year	Study design	Study setting, region	Intervention	Sample size (intervention group)	Sample size (control group 1)	Sample size (control group 2)	Sample size (control group 3)	Duration of intervention (frequency)
13	Rodrigues et al., 2024 [20]	RCT	School, Portugal	Qigong exercise	34	34 (Watching a TV documentary)	36 (Typical school duties)	NA	6 weeks (~8 sessions of 15–20 min each)
14	Parajuli et al., 2022 [21]	RCT	School, India	Breathing exercises and pranayama	45	44 (Physical exercise)	NA	NA	2 Months (1 h a day 4 days a week)
15	Khng et al., 2016 [22]	RCT	School, Singapore	Deep breathing	154	NA	NA	NA	NA
16	Bentley et al., 2022 [23]	Cluster RCT	Public high school, California, USA	Self-paced slow diaphragmatic breathing	25	18 (Treatment as usual)	NA	NA	5 weeks (3 times a week)
17	Nithiya Devi et al., 2018 [31]	Quasi-experimental, pre-post	Medical college hospital and research institute, Pondicherry, India	Savitri pranayama	250	NA	NA	NA	2 h (4 Cycles of 5 min each)
18	Dimou et al., 2013 [24]	RCT	University, Athens, Greece	Diaphragmatic breathing	30	30 (Nothing)	NA	NA	8 weeks (2 times a week)

to 32.46 (±10.10) after practicing the intervention for 6–8 weeks. It was not possible to conduct a meta-analysis for anxiety as an outcome variable due to the lack of a common outcome variable across the included studies.

Risk of bias

Out of the included RCTs, the quality assessment revealed a generally strong methodological quality, with most studies rated as having low risk or some concerns. Several studies, including Okado et al. [14], Kim et al. [15], and Dziembowska et al. [16], showed some concerns. Schleicher et al. [17] was the only study rated as having a high risk of bias overall, primarily due to a high risk in the domain of missing outcome data (Supplementary Figure 4, Supplementary Table S5). All seven quasi-experimental studies had an overall appraisal as good and hence were included in the SRMA (Supplementary Table S6).

Certainty in evidence

GRADE assessment revealed very low certainty in the effectiveness of the breathing exercise in reducing the stress in adolescents, primarily due to serious concerns in risk of bias, inconsistency, and imprecision domains (Supplementary Table S7).

Discussion

Deep breathing and pranayama interventions significantly reduce stress and anxiety over 1–4 months. This meta-analysis shows a moderate effect in favor of deep breathing (SMD = –1.166), though high heterogeneity exists (I^2=74.46 %). Sensitivity analysis confirms result stability, with Kim et al. having a notable impact on results [15].

According to studies by Okado et al. [10] and Nebhinani et al. [22], there is a substantial decrease in stress in several domains, such as social and academic stressors. Biofeedback trials showed improvements in brainwave activity and variability in heart rate among male athletes. In RCTs, anxiety scores significantly decreased ($p<0.001$), and stress levels were further reduced by pranayama techniques, including Anulom Vilom and Kapalbhati, which were practiced three times per week. Over a 6- to 8-week period, high-frequency yoga breathing interventions reduced STAI-S scores. Overall, there was strong evidence that organized breathwork was effective at reducing stress, and other trials confirmed long-term advantages.

An experimental study by Joshi et al. on the effect of Om chanting and Bhramari Pranayama found significant reductions in anxiety levels among adolescents after a 20-day intervention, daily for 25 min [32]. According to Singh et al., the effects of pranayama techniques on teenage mental health, 30 min daily for 12 weeks, using techniques like Anulom Vilom and Bhastrika, significantly lowered stress, anxiety, and depression [33]. According to a study by Goswami et al. evaluating the effects of yoga and pranayama on emotional intelligence and mental health in Rajasthan, teens who engaged in both practices reported less stress and higher emotional intelligence than those who did not [34].

Cramer et al. conducted an SRMA including eight RCTs that evaluated yoga's ability to reduce anxiety in adults diagnosed with an anxiety disorder. Practicing yoga, comprising both breathing and asanas, had greater effects on anxiety than active comparators (SMD = −0.86, p=0.02) and smaller but significant effects than no therapy (SMD = −0.43, p=0.008). Depression showed slight improvements (SMD = −0.35, p=0.03). However, only three RCTs showed safety data findings without additional hazards, and effects were equivocal for recognized anxiety disorders [35]. While showing the potential of yoga, Khajuria et al.'s comprehensive evaluation of the biological effects of yoga on stress reduction utilizing biosignals revealed a dearth of research regarding the underlying mechanisms [36]. Maity et al.'s meta-analysis assessed how well yoga performed to enhance the physical and mental health of medical and dental students. Analysis of 18 studies indicated that yoga was a useful intervention, with substantial reductions in heart rate, stress (0.77 reduction), anxiety (1.2 reduction), and diastolic (2.92 mmHg) and systolic (6.82 mmHg) blood pressure [37]. More high-quality studies are recommended to strengthen the role of breathing practices in anxiety and stress management.

Adolescents practicing breathing exercises and pranayama experience less stress and anxiety because of improved parasympathetic activity, a regulated autonomic nervous system, and lower cortisol levels [33]. Methods like Bhastrika pranayama regulate brain activity, lowering amygdala hyperactivity associated with stress, and Nadi Shodhana enhances oxygenation and emotional balance [38]. Pranayama promotes emotional control and resilience, which is proven to improve mental health [39].

The strength of this study is that it is the first systematic review and meta-analysis determining the efficacy and effectiveness of Pranayama and yogic breathing exercises in reducing anxiety and stress in adolescents globally, showcasing notable strengths such as adherence to PRISMA guidelines, a comprehensive dataset of 18 studies encompassing 3,537 adolescent participants (intervention group: 2007 and control group: 1,530) across diverse regions, and a long time frame (2015–2024).

The findings were further validated by thorough sensitivity and risk of bias testing. Generalizability and reliability are improved by the majority of high-quality studies having low risk/minor issues. Yet, some limitations nevertheless require careful consideration. Despite comprehensive sensitivity analyses, the substantial heterogeneity in pooled estimates (I^2=74.46 %) revealed variability among studies, most likely driven by differences in population dynamics, design, demographics, and diagnostic techniques/study instruments. Furthermore, estimations may have been impacted due to the exclusion of gray literature, unpublished studies, and studies published in languages other than English. Pooling results for anxiety using meta-analysis was not feasible due to the lack of a common outcome variable. GRADE assessment revealed very low certainty in the effectiveness of the breathing exercise in reducing stress in adolescents. Although these limitations do not diminish the validity of the study, they might affect the wider applicability.

Conclusions

Breathing techniques/Pranayama offer an effective means to improve adolescents' mental health. Pranayama's mind-body approach appears encouraging in current times when psychological and pharmacological treatments are commonly employed to manage stress and anxiety. In conclusion, the findings of this SRMA provide promise for incorporating pranayama as a useful intervention for reducing anxiety and stress in adolescents. There is a need for future studies that are rigorous in methodology to generate quality evidence in this area.

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Research ethics: Ethics review is not applicable since this is a systematic review of already published studies.

Informed consent: Informed consent was obtained from all individuals included in this study, or their legal guardians or wards.

Author contributions: Concept and design: GO, KD, DI, APG. Acquisition, analysis, or interpretation of data: GO, KD, DI, APG. Drafting of the manuscript: GO, KD, PH, DI, APG. Critical review of the manuscript for important intellectual content: GO, KD, PH, DI, APG. Supervision: APG.

Use of Large Language Models, AI and Machine Learning Tools: Nested Knowledge a semi-automated, AI-assisted platform for conducting systematic reviews and meta-analyses, was utilized to screen the studies.

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