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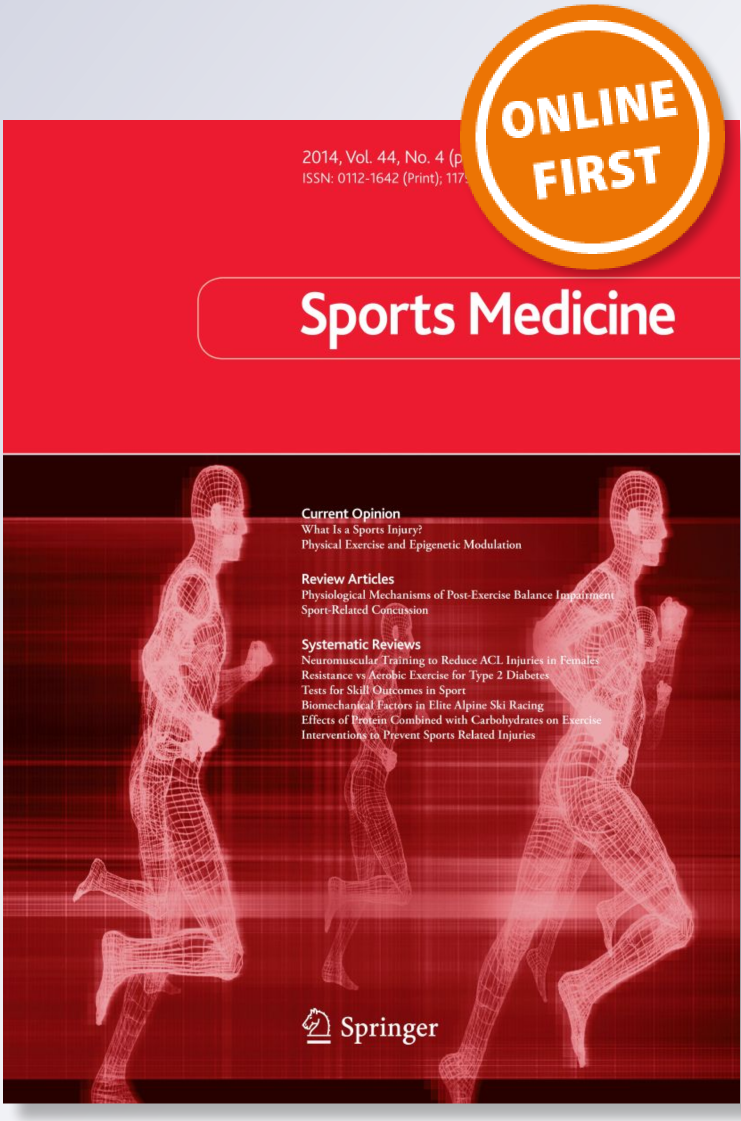

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SYSTEMATIC REVIEW

The Effects of Resistance Exercise Training on Anxiety: A Meta-Analysis and Meta-Regression Analysis of Randomized Controlled Trials

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Abstract

Background The salutary effects of resistance exercise training (RET) are well established, including increased strength and function; however, less is known regarding the effects of RET on mental health outcomes. Aerobic exercise has well-documented positive effects on anxiety, but a quantitative synthesis of RET effects on anxiety is needed.

Objectives To estimate the population effect size for resistance exercise training (RET) effects on anxiety and to determine whether variables of logical, theoretical, and/or prior empirical relation to anxiety moderate the overall effect.

Methods Thirty-one effects were derived from 16 articles published before February 2017, located using Google Scholar, MEDLINE, PsycINFO, PubMed, and Web of Science. Trials involved 922 participants (mean age = 43 ± 21 years, 68% female/32% male) and included both randomization to RET ($n = 486$) or a non-active control condition ($n = 436$), and a validated anxiety outcome measured at baseline, mid-, and/or post-intervention. Hedges' *d* effect sizes were computed and random effects models were used for all analyses. Meta-regression quantified the extent to which participant and trial characteristics moderated the mean effect.

Results RET significantly reduced anxiety symptoms ($\Delta = 0.31$, 95% CI 0.17–0.44; $z = 4.43$; $p < 0.001$). Significant heterogeneity was not indicated ($Q_T(30) = 40.5$, $p > 0.09$; $I^2 = 28.3\%$, 95% CI 10.17–42.81); sampling error accounted for 77.7% of observed variance. Larger effects were found among healthy participants ($\Delta = 0.50$, 95% CI 0.22–0.78) compared to participants with a physical or mental illness ($\Delta = 0.19$, 95% CI 0.06–0.31, $z = 2.16$, $p < 0.04$). Effect sizes did not significantly vary according to sex ($\beta = -0.31$), age ($\beta = -0.10$), control condition ($\beta = 0.08$), program length ($\beta = 0.07$), session duration ($\beta = 0.08$), frequency ($\beta = -0.10$), intensity ($\beta = -0.18$), anxiety recall time frame ($\beta = 0.21$), or whether strength significantly improved ($\beta = 0.19$) (all $p \geq 0.06$).

Conclusions RET significantly improves anxiety symptoms among both healthy participants and participants with a physical or mental illness. Improvements were not moderated by sex, or based on features of RET. Future trials should compare RET to other empirically-supported therapies for anxiety.

Key Points

Resistance exercise training significantly improves anxiety symptoms, and improvements were not moderated by sex or based on features of the resistance exercise training.

Larger effects were derived from studies of healthy participants compared to participants with a physical or mental illness; nonetheless, RET significantly reduced anxiety among otherwise healthy participants and participants with an illness.

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1 Introduction

Anxiety is a pervasive public health problem for which treatment success remains limited. Although anxiety may be an adaptive response to a perceived threat, anxiety can develop into maladaptive symptoms and ultimately an anxiety disorder if symptoms become severe and chronic [1]. Approximately 15% of the US population reports frequently experiencing anxiety (e.g., symptoms on more than 15 days during the prior month), and those with frequent anxiety symptoms are more likely to report poor health, poor sleep, mental distress, pain, and activity limitations [2], and report lower levels of physical activity [3]. Anxiety disorders are highly prevalent, frequently comorbid with other chronic physical and mental illnesses, and have been associated with impaired health-related quality of life, poor treatment outcomes in chronic illness, and increased rate of adverse health behaviors [2, 4]. Additionally, anxiety disorders are among the leading causes of disability, quantified as years lived with disability, in both high and low/middle income countries [5]. However, anxiety remains poorly treated by traditional frontline therapies, including selective serotonin reuptake inhibitors (SSRIs) and cognitive-behavioral therapy [6, 7]; thus, there is continued interest in efficacious alternative and adjunct treatment options, including exercise training.

The available evidence supports the anxiolytic effects of acute exercise [8] and exercise training among otherwise healthy adults [9], adults with a chronic illness [10], and anxiety disorder patients [11, 12]. For example, recent meta-analytic evidence demonstrated a statistically significant, moderate improvement in anxiety symptoms among people with a current diagnosis of an anxiety and/or stress-related disorder [12]. However, although aerobic exercise training (AET) has well-established effects on anxiety that are comparable to other empirically-supported treatments, the anxiolytic effects of resistance exercise training (RET) remain understudied [13]. RET is exercise training primarily designed to increase skeletal muscle mass, strength, power, and endurance [14]. Although RET interventions are less studied than AET, previous evidence indicated that short-term RET may be an effective adjuvant or augmentation treatment with minimal risk of adverse events or negative side effects to ameliorate worry symptoms, the hallmark of generalized anxiety disorder [15]. RET has also demonstrated additional positive effects on other outcomes such as pain intensity, metabolic syndrome, depressive symptoms, feelings of fatigue, self-esteem, and sleep [13].

Though previous literature reviews have summarized the effects of RET on anxiety across different population samples [13], to date there has been no quantitative synthesis of the available empirical evidence, particularly randomized controlled trials (RCTs). In addition, given recently highlighted issues of focusing on aggregated effect size alone [16, 17], there is a need to identify potentially important sources of variability in the overall effect of RET on anxiety to guide future intervention development. Thus, the key objectives of the systematic review, meta-analysis, and meta-regression analysis reported here were to:(a) estimate the overall population effect size for RET effects on anxiety derived from RCTs, (b) determine the extent to which variables of logical, theoretical, and/or prior empirical relation to anxiety and RET effects on anxiety moderate the overall effect, and (c) compare the effect of differing exercise interventions in RCTs in which participants were randomized to an RET intervention, AET intervention, or non-active control condition.

2 Methods

2.1 Evidence Acquisition

The current systematic review with meta-analysis and meta-regression analysis was conducted in accordance with the recommendations and guidelines of the PRISMA group [18].

2.2 Data Sources and Searches

Articles published before February 2017 were identified using Google Scholar, MEDLINE, PsycINFO, PubMed, and Web of Science. Keywords used included combinations of “strength training,” “resistance training,” and “weight training” with “anxiety.” Supplementary searches of relevant systematic reviews and meta-analyses [11, 12, 19–21] and searches of the reference lists within cited articles were also performed manually.

2.3 Study Selection/Inclusion Criteria

Inclusion criteria were: (a) English language peer-reviewed publications, (b) randomized allocation to either a RET intervention or a non-active control condition, and (c) an anxiety outcome measured at baseline and at mid- and/or post-intervention. Investigations were excluded that (a) included exercise as one part of a multicomponent intervention but did not include the additional component in a comparison condition, and/or (b) compared RET only with an active treatment. Figure 1 provides a flowchart of study selection.

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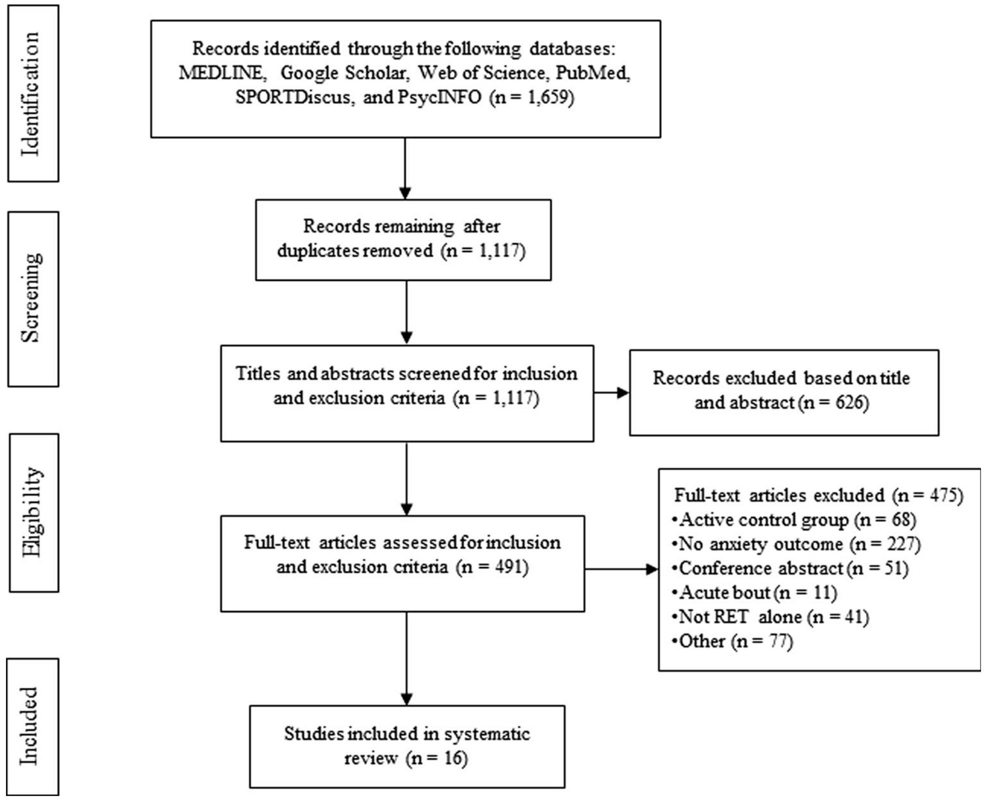

Fig. 1 Flowchart of study selection. *RET* resistance exercise training

2.4 Data Extraction and Quality Assessment

Data were extracted from included studies into an SPSS file by two authors (BG, MPH) and cross-checked for inter-observer reliability. Data extracted included participant and trial characteristics, adherence and compliance, and exercise effects on outcomes of logical, theoretical, and/or prior empirical relation to anxiety symptoms and/or exercise effects on anxiety symptoms, including sex, age, health status, control condition, program length, session duration, frequency, intensity, supervision, outcomes assessed, anxiety measures utilized, and strength changes. Discrepancies were resolved by consensus.

2.5 Study Quality Assessment

Two authors (BG and MPH) independently assessed study quality (scored 0–15), utilizing the widely-used Detsky Scale [22], amended to include research design, randomization methods, control condition, outcome measures, adherence, and report of exercise intervention characteristics. Higher scores indicated better study quality. Quality assessment scores were not used as weights or moderators in the analysis because of the potential disparity in results that depends on the specific quality scale used [23]. A table identifying the individual scores of included studies is presented in Electronic Supplementary Material Table S1.

2.6 Effect Size Calculation

Hedges' *d* effect sizes were calculated by subtracting the mean change in the comparison condition from the mean change in the RET condition, and dividing this difference by the pooled standard deviation of baseline scores. Effect sizes were adjusted for small sample size bias and calculated such that a larger reduction of anxiety symptoms among those in the RET group resulted in a positive effect size [24]. Two-way (effects $\times$ raters) intraclass correlation coefficients (ICCs) for absolute agreement were calculated to examine inter-rater reliability for effect sizes. The initial ICCs were >0.90; discrepancies were resolved by consensus resulting in identical effects across extractors. When means and standard deviations were not reported, these were estimated from reported 95% confidence intervals (CIs) [25, 26], or estimated from the largest other study that used the same anxiety measure [27, 28].

2.7 Data Synthesis and Analysis

Meta-regression was used as the overall analysis of moderator effects. This technique reduces the probability of type I error by computing concurrent estimates of independent effects by multiple moderators on the variation in effect size across trials. Random effects models were used with macros (SPSS MeanES, MetaReg; SPSS, Inc,

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Armonk, NY, USA) to aggregate mean effect size delta (Δ) and to test variation in effects according to moderator variables [24, 29]. Consistency and heterogeneity were evaluated with the I^2 statistic and Cochrane's Q statistic, respectively [30]. If sampling error, calculated by subtracting the observed variance from the population variance, accounted for less than 75% of the observed variance, heterogeneity was indicated [24]. To assess potential publication bias (i.e., smaller studies showing larger effects), Egger's regression [31] and Begg's rank correlation [32] analyses were performed, as well as visual inspection of a funnel plot. The number of unpublished or unretrieved studies of null effect that would diminish the significance of observed effects to $p > 0.05$ was estimated as fail-safe $N+$ [33].

2.8 Univariate Meta-Regression Analyses

Moderators were selected based on theoretical, practical, and/or prior empirical relation with anxiety and/or exercise effects on anxiety. Random effects models were used to calculate mean effect sizes (Δ) and 95% CIs for continuous and categorical moderator variables [29]. In addition, each continuous and categorical moderator was included in random effects univariate meta-regression analysis with maximum-likelihood estimation [24, 29]. Definitions for each moderator and associated levels are presented in Table 1.

3 Results

3.1 Study Characteristics

Thirty-one effects were derived from 16 studies of 922 participants (RET = 486, control = 436); all effects were included in the main analysis. Table 2 presents relevant characteristics of the included studies. Anxiety was the primary outcome in nine studies (23 effects) [27, 34–42]. The mean sample age was 43 ± 21 years, and 68% of participants randomized were female. The mean intervention length was 11 weeks; and intervention frequency ranged from 2 to 5 days per week. Ten studies (18 effects) evaluated participants with either a physical [25–28, 34, 35, 43, 44] or mental [36, 41] illness. RET interventions were either fully supervised by various health professionals [25, 27, 34–37, 39, 42, 43, 45], included a combination of supervised and unsupervised sessions [26, 28, 38, 44], or did not report supervision status [40, 41]. Adherence or compliance was reported in four of the 16 (25%) studies [35, 36, 43, 44]. Of the 12 remaining studies that did not report adherence or compliance, three reported attendance rates [25, 42, 45], which ranged from 87.5 to 97.5%. Among the four studies that reported adherence, the mean (SD) exercise training adherence rate was 74% (18%). The most frequently used anxiety measure was the trait subscale of the State-Trait Anxiety Inventory ($k = 6$) [34, 36, 39–42, 46].

3.2 Mean Effect Delta, Heterogeneity, and Publication Bias

An annotated table and forest plot of the distribution of effects are presented in Table 2 and Fig. 2, respectively. Twenty-seven of 31 effects (87.1%) were larger than zero. The mean effect size Δ was 0.31 (95% CI 0.17–0.44; $z = 4.43$; $p < 0.001$). Significant heterogeneity was not indicated ($Q_{T(30)} = 40.5$, $p > 0.09$; $I^2 = 28.3\%$, 95% CI 10.17–42.81), and sampling error accounted for 77.7% of observed variance. The mean quality score was 11.4 ± 1.9 with a range of 9–15. Egger's regression did not indicate publication bias (intercept = 0.47, SE = 0.59, $p \geq 0.43$), and Begg's rank correlation failed to reach significance (Kendall's tau = −0.25, $p > 0.05$). The fail-safe number of effects was 151, and a funnel plot (Electronic Supplementary Material Table S2) did not indicate publication bias.

3.3 Univariate Meta-Regression Analyses

Planned contrasts showed that larger effects were derived from studies in which participants were healthy (Δ = 0.50, 95% CI: 0.22–0.78) compared to physically- or mentally-ill participants (Δ = 0.19, 95% CI: 0.06–0.31, $z = 2.16$, $p < 0.04$). Effect sizes did not significantly vary according to planned contrasts for sex ($\beta = -0.31$), age ($\beta = -0.10$), control condition ($\beta = 0.08$), program length ($\beta = 0.07$), session duration ($\beta = 0.08$), frequency ($\beta = -0.10$), intensity ($\beta = -0.18$), supervision ($\beta = 0.06$), primary outcome ($\beta = 0.29$), anxiety recall time frame ($\beta = 0.21$), or if the intervention resulted in a significant improvement in strength ($\beta = 0.19$) (all $p \geq 0.07$). Results of the univariate moderator analyses for each moderator are presented in Table 3. Mean effect size Δ, 95% CI, the number of effects (k), and contrast p value are provided for each level of each moderator.

Of note, 11 effects were derived from five of the included studies that provided a comparison of RET with an AET intervention arm. Data were extracted from these studies to facilitate sub-analyses between RET and AET in those studies, and are presented in Table 4. Effects were similar for the RET interventions (Δ = 0.13, 95% CI 0.03–0.29) and AET interventions (Δ = 0.18, 95% CI 0.03–0.33) in comparison to the control groups. When directly comparing the effects of RET to AET, with RET serving as the intervention group and AET serving as the control group in Hedges' d calculations, no significant

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Table 1 Definitions for each moderator and associated levels

Effect moderator	Definition
Sex	
Female	Participants were female only
Mixed	Participants were both male and female
Male	Participants were male only
Age (years)	
<25	Participants were less than 25 years of age
25–54	Participants were aged 25–54 years
55+	Participants were 55 years of age or older
Health	
Healthy	Participants were healthy
Physical illness	Participants had a physical illness (cancer, obesity, ischemic stroke, etc.)
Mental illness	Participants had a mental illness (GAD, chemical dependence)
Control	
No treatment	There was no treatment for the control group
Usual care	The control group was provided usual care
Wait list	The control group was assigned to a wait-list
Program (weeks)	
<12	The program lasted less than 12 weeks
12+	The program lasted 12 weeks or more
Session (min)	
<60	The exercise session lasted less than 60 min
60+	The exercise session lasted 60 min or more
Frequency (days/week)	
2	The exercise program was conducted twice per week
3	The exercise program was conducted three times per week
Intensity	
Moderate	Relative intensity: 50–80% 1RM, 12–16 RPE or authors reported exercise was of a moderate intensity
Vigorous	Vigorous intensity: ≥80% 1RM, >16 RPE, or authors reported exercise was of a vigorous intensity
Supervised	
Combination	The program was a combination of supervised and unsupervised exercise
Yes	The program was supervised
Primary outcome anxiety	
No	The primary outcome of the study was not anxiety
Yes	The primary outcome of the study was anxiety
Recall	
State	Reported anxiety symptoms at the moment of testing
Trait	Reported anxiety symptoms recalled from a time frame greater than 7 days
Significant improvement in strength	
Yes	The confidence interval corresponding to the Hedges' *d* effect size for strength change did not encompass zero
No	The confidence interval corresponding to the Hedges' *d* effect size for strength change encompassed zero
Not reported	The authors did not measure or report strength changes

GAD generalized anxiety disorder, *RM* repetition maximum, *RPE* rate of perceived exertion

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Table 2 Relevant characteristics of the included studies

Study	Measure	Intensity	Duration (weeks)	Participant characteristics	Control	Sex	Age (years)	Hedges' *d* (ES ± 95% CI)
Aidar et al. [34]	STAI-S	Moderate	12	Ischemic stroke	Usual care	Mixed	43–60	0.26 (−0.55 to 1.06)
Aidar et al. [34]	STAI-T	Moderate	12	Ischemic stroke	Usual care	Mixed	43–60	0.24 (−0.57 to 1.04)
Courneya et al. [43]	STAI-S	Moderate	Mid-treatment	Breast-cancer	Usual care	Female	25–78	0.16 (−0.15 to 0.46)
Courneya et al. [43]	STAI-S	Moderate	Post-treatment	Breast-cancer	Usual care	Female	25–78	0.08 (−0.23 to 0.38)
Damush et al. [45]	MHFI-A	Moderate	8	Elderly	Wait list	Female	62–74	0.29 (−0.21 to 0.79)
Goldfield et al. [35]	BRUMS-T	Moderate	22	Obese adolescents	No treatment	Mixed	14–18	0.14 (−0.18 to 0.46)
Herring et al. [36]	POMS-T	Moderate	2	GAD	Wait list	Female	18–37	0.62 (−0.28 to 1.51)
Herring et al. [36]	STAI-T	Moderate	2	GAD	Wait list	Female	18–37	0.14 (−0.74 to 1.02)
Herring et al. [36]	POMS-T	Moderate	4	GAD	Wait list	Female	18–37	0.15 (−0.72 to 1.03)
Herring et al. [36]	STAI-T	Moderate	4	GAD	Wait list	Female	18–37	0.36 (−0.52 to 1.25)
Herring et al. [36]	POMS-T	Moderate	6	GAD	Wait list	Female	18–37	1.05 (0.12 to 1.99)
Herring et al. [36]	STAI-T	Moderate	6	GAD	Wait list	Female	18–37	0.52 (−0.37 to 1.41)
Herring et al. [28]	HADS-A	Moderate	12	Morbidly obese	Usual care	Mixed	24–68	−0.49 (−1.47 to 0.49)
Lau et al. [27]	HADS-A	Vigorous	6	Obese adolescents	Usual care	Mixed	10–17	0.41 (−0.25 to 1.07)
Martins et al. [37]	POMS-T	Moderate	16	Elderly	No treatment	Mixed	65–95	−0.34 (−0.89 to 0.20)
Norvell et al. [38]	SCL-90	Moderate	16	Law enforcement personnel	Wait list	Male	25–40	1.17 (0.38 to 1.96)
Nyberg et al. [25]	HADS-A	Moderate	8	COPD	Other	Mixed	61–74	0.34 (−0.26 to 0.09)
O'Reilly et al. [26]	HADS-A	Low	36	People with knee pain	No treatment	Mixed	40–80	0.14 (−0.15 to 0.43)
Rahmani-Nia et al. [39]	STAI-S	Moderate	8	Untrained college students	No treatment	Not reported	20–23	0.43 (−0.19 to 1.06)
Rahmani-Nia et al. [39]	STAI-T	Moderate	8	Untrained college students	No treatment	Not reported	20–23	0.32 (−0.30 to 0.95)
Tsutsumi et al. [40]	STAI-T	Moderate	12	Elderly	No treatment	Female	60–86	1.50 (0.59 to 2.40)
Tsutsumi et al. [40]	STAI-S	Moderate	12	Elderly	No treatment	Female	60–86	0.87 (0.03 to 1.70)
Tsutsumi et al. [40]	POMS-T	Moderate	12	Elderly	No treatment	Female	60–86	0.63 (−0.19 to 1.45)
Tsutsumi et al. [40]	STAI-T	Vigorous	12	Elderly	No treatment	Female	60–86	0.89 (0.05 to 1.73)
Tsutsumi et al. [40]	STAI-S	Vigorous	12	Elderly	No treatment	Female	60–86	0.64 (−0.18 to 1.46)
Tsutsumi et al. [40]	POMS-T	Vigorous	12	Elderly	No treatment	Female	60–86	0.85 (0.01 to 1.68)
Vizza et al. [44]	DASS-21	Moderate	12	Polycystic ovarian syndrome	Usual care	Female	21–32	0.53 (−0.58 to 1.64)
Vlachopoulou et al. [41]	STAI-S	Moderate	8	Chemically dependent	No treatment	Male	22–43	−0.75 (−1.76 to 0.26)
Vlachopoulou et al. [41]	STAI-T	Moderate	8	Chemically dependent	No treatment	Male	22–43	0.82 (−0.20 to 1.83)
Zanuso et al. [42]	POMS-T	Vigorous	12	Elderly	Wait list	Mixed	65–78	0.07 (−0.81 to 0.94)
Zanuso et al. [42]	STAI-T	Vigorous	12	Elderly	Wait list	Mixed	65–78	−0.08 (−0.96 to 0.80)

POMS-T profile of mood states-tension, *SCL-90* hopkins symptom checklist, *STAI-T* State-Trait Anxiety Inventory-Trait, *STAI-S* State-Trait Anxiety Inventory-State, *MHFI-A* Mental Health Functioning Index-Anxiety, *HADS-A* Hospital Anxiety and Depression Scales-Anxiety, *DASS-21* Depression Anxiety and Stress Scale-21, *BRUMS-T* Brunel Mood Scale-Tension, *GAD* generalized anxiety disorder, *COPD* chronic obstructive pulmonary disease, *ES* effect size, *CI* confidence intervals

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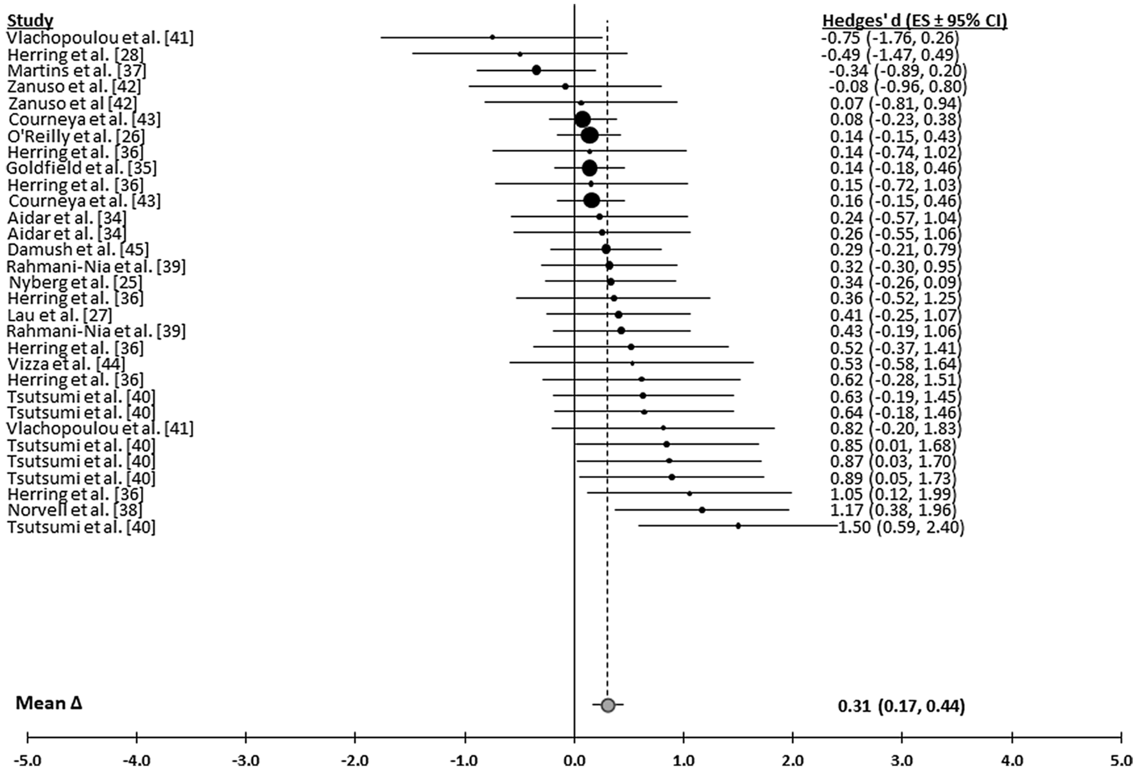

Fig. 2 Forest plot of unweighted distribution of Hedges' *d*

differences were found ($\Delta = -0.07$, 95% CI -0.22 to 0.09).

4 Discussion

The cumulative evidence reviewed here suggests that RET has a small-to-moderate statistically significant, positive effect on anxiety symptoms. The magnitude of the overall mean effect ($\Delta = 0.31$) provides quantitative support for the anxiolytic effect of RET previously reported in a narrative review [13], and is similar to previously reported effects of AET on anxiety symptoms among primarily healthy adults ($g = 0.40$) [47] and chronically ill patients ($\Delta = 0.29$) [19], depressive symptoms among chronically ill patients ($d = 0.30$) [10], pain among patients with osteoarthritis ($g = 0.38$) [48], and on feelings of energy and fatigue among adults ($d = 0.37$) [49]. Lowered anxiety symptoms found among RET participants in the studies reviewed here, expressed as a function of absolute risk reduction [50], resulted in a number-needed-to-treat of approximately 7. The number-needed-to-treat of 7 indicates that anxiety symptom reductions could be expected to occur for at least one of every seven participants who would engage in RET comparable to the RET programs reviewed herein. These preliminary findings should be interpreted with some caution, as the 16 RCTs collectively included less than 1000 participants.

There has been continued interest in the comparative effectiveness of aerobic and resistance exercise training, but limited evidence is available from RCTs in which the effects of multiple exercise modes have been quantified and compared in a single study sample. Among the sub-sample of studies that allowed comparison of the anxiolytic effects of RET and AET in the same study population, AET and RET resulted in similar magnitude improvements in anxiety symptoms. Specifically, no significant differences were found between the anxiolytic effects of RET and AET, providing support for both exercise modes as short-term interventions to improve anxiety outcomes [36]. Notably, of the sub-sample of studies that did allow comparison of the effects of RET and AET, only one RCT reported matching RET and AET conditions to relevant features of the exercise stimulus [15]. There are clear challenges in matching AET and RET interventions, particularly given differences in the inherent structure and organization of bouts of resistance exercise and aerobic exercise. Thus, future trials may benefit from comparing the anxiolytic effects of RET and AET interventions that have been matched with respect to multiple features of the exercise stimulus, including total work completed during the exercise bout and perceptual responses during the time actively engaged in exercise.

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Table 3 Summary of univariate moderator analyses

Effect moderator	Contrast weights	Effects (*k*)	Δ	95% CI	Contrast *p* value
Sex					
Female	−1	16	0.44	0.24 to 0.63	0.07
Mixed	0.5	10	0.11	−0.06 to 0.27	
Male	0.5	5	0.43	−0.11 to 0.96	
Age (years)					
<25	0.5	10	0.31	0.11 to 0.51	0.56
25–54	0.5	8	0.26	−0.03 to 0.55	
55+	−1	12	0.40	0.13 to 0.66	
Health					
Healthy	1	13	0.50	0.22 to 0.78	0.03
Physical illness	−0.5	10	0.15	0.02 to 0.29	
Mental illness	−0.5	8	0.37	0.01 to 0.73	
Control					
No treatment	1	13	0.40	0.13 to 0.66	0.62
Usual care	−0.5	6	0.12	−0.08 to 0.32	
Wait list	−0.5	10	0.41	0.16 to 0.67	
Program (weeks)					
<12	−1	14	0.28	0.18 to 0.50	0.68
12+	1	15	0.42	0.15 to 0.70	
Session (min)					
<60	−1	22	0.29	0.15 to 0.42	0.63
60+	1	7	0.33	−0.08 to 0.74	
Frequency (days/week)					
2	−1	8	0.41	0.13 to 0.70	0.56
3	1	21	0.34	0.17 to 0.54	
Intensity					
Moderate	1	24	0.31	0.14 to 0.47	0.27
Vigorous	−1	6	0.47	0.14 to 0.80	
Supervised					
Combination	−1	5	0.10	−0.44 to 0.65	0.77
Yes	1	20	0.20	0.08 to 0.32	
Primary outcome anxiety					
No	−1	8	0.16	0.01 to 0.31	0.07
Yes	1	23	0.42	0.22 to 0.61	
State vs. trait					
State	−1	22	0.27	0.12 to 0.43	0.17
Trait	1	9	0.42	0.16 to 0.69	
Significant improvement in strength					
Yes	1	21	0.37	0.20 to 0.54	0.24
No	−0.5	2	0.18	−0.07 to 0.43	
Not reported	−0.5	8	0.20	−0.17 to 0.56	

CI confidence interval

4.1 Health

As anxiety symptoms can negatively impact treatment outcomes [51], a growing body of research, including six studies reviewed here [25, 28, 34–36, 44], has examined the effects of exercise on anxiety symptoms among participants with a physical or mental illness. The finding that larger positive effects were found in studies of healthy participants in comparison to participants with a physical or mental illness is consistent with previous meta-analytic

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Table 4 Sub-analysis comparing RET and AET

Study	Measure	Duration (weeks)	RET Hedges' *d* (ES ± 95% CI)	AET Hedges' *d* (ES ± 95% CI)	RET vs. AET Hedges' *d* (ES ± 95% CI)
Herring et al. [36]	POMS-T	2	0.62 (−0.28 to 1.15)	0.58 (−0.32 to 1.47)	−0.06 (−0.94 to 0.81)
Herring et al. [36]	STAI-T	2	0.14 (−0.74 to 1.02)	0.15 (−0.73 to 1.02)	0.01 (−0.86 to 0.89)
Herring et al. [36]	POMS-T	4	0.15 (−0.72 to 1.03)	0.21 (−0.67 to 1.09)	−0.09 (−0.96 to 0.79)
Herring et al. [36]	STAI-T	4	0.36 (−0.52 to 1.25)	0.47 (−0.43 to 1.36)	−0.08 (−0.96 to 0.79)
Herring et al. [36]	POMS-T	6	1.05 (0.18 to 1.99)	0.73 (−0.18 to 1.63)	0.15 (−0.73 to 1.03)
Herring et al. [36]	STAI-T	6	0.52 (−0.37 to 1.41)	0.54 (−0.36 to 1.43)	0.05 (−0.82 to 0.93)
Herring et al. [28]	HADS-A	12	−0.49 (−1.47 to 0.49)	0.03 (−0.94 to 1.00)	−0.43 (−1.41 to 0.55)
Martins et al. [37]	POMS-T	16	−0.34 (−0.89 to 0.20)	0.12 (−0.42 to 0.65)	−0.49 (−1.07 to 0.09)
Courneya et al. [43]	STAI-S	Mid-treatment	0.16 (−0.15 to 0.46)	0.19 (−0.12 to 0.50)	−0.05 (−0.36 to 0.26)
Courneya et al. [43]	STAI-T	Post-treatment	0.29 (−0.21 to 0.79)	0.10 (−0.21 to 0.41)	−0.07 (−0.38 to 0.24)
Goldfield et al. [35]	BRUMS-T	22	0.14 (−0.18 to 0.46)	0.17 (−0.15 to 0.49)	0.03 (−0.29 to 0.35)
			RET mean Δ = 0.13 (−0.03 to 0.29)	AET mean Δ = 0.18 (0.03 to 0.33)	RET vs. AET mean Δ = −0.07 (−0.22 to 0.09)

RET resistance exercise training, *AET* aerobic exercise training, *POMS-T* Profile of Mood States-Tension, *STAI-T* State-Trait Anxiety Inventory-Trait, *STAI-S* State-Trait Anxiety Inventory-State, *HADS-A* Hospital Anxiety and Depression Scales-Anxiety, *BRUMS-T* Brunel Mood Scale-Tension, *ES* effect size, *CI* confidence interval

findings of exercise effects on anxiety in non-clinical participants [47] and among patients [19], although these reviews investigated exercise interventions of all types. Previous evidence has supported small-to-moderate improvements in anxiety among non-clinical populations of otherwise healthy adults ($d = 0.40$) [47]. The slightly larger effect (0.50 vs. 0.40) found in the present analyses among healthy participants may be due in part to the current focus on only RCTs of RET compared to a non-active comparison condition. The present findings of small-magnitude improvements among participants with an illness are consistent, albeit slightly smaller, than previously reported findings [19]. However, previous reviews of exercise training effects on anxiety among patients included only a single effect for RET. Additionally, the present findings showed no significant differences in RET effects between participants with a physical versus mental illness, though the magnitude of improvement among those with a mental illness was non-significantly larger. Caution should be exercised when considering these findings because six of eight effects (75%) were derived from a single trial of RET among young women with generalized anxiety disorder (GAD) [36]. However, given that the present findings highlighted larger effects of RET on anxiety among healthy participants and effects of similar magnitude were derived from a RCT of patients with GAD, future studies focusing on otherwise healthy adults with elevated, sub-clinical, or prodromal anxiety symptoms may be particularly informative.

Although the three largest studies included in this analysis [26, 35, 43] focused on participants with either a physical or a mental illness, more trials are needed to confirm RET effects on anxiety among specific patient samples. Trials also should include appropriate and clear reporting of important trial characteristics such as adherence, compliance, and medication use. Medication use and adherence were both insufficiently reported in the case of included studies here. Adherence was reported only in trials of participants with an illness; those trials reported a mean adherence rate of 74% (18%) [35, 36, 43, 44]. Reporting of medication use was scarce and inconsistent, but may be particularly important given evidence that prescribed antidepressant medication use has been

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associated with poor adherence rates to exercise programs among patients [52].

Interestingly, some patient and trial characteristics, based on previous reports, that may influence the effects of RET on anxiety [13, 14, 19], including age, sex, type of control condition, program length, session duration, exercise intensity and frequency, and the timeframe of anxiety recall used, were not independently associated with the overall effect of RET on anxiety. Plausible explanations for these findings include lack of heterogeneity among included study methodologies and additional limitations of reviewed studies including small sample sizes. Notably, lack of heterogeneity in and poor reporting of features of the exercise stimulus, particularly exercise intensity and resistance exercise session duration, likely contributed to the current findings, and also precluded rigorous evaluation of total resistance exercise dose. Future trials would be strengthened by improved detail in reporting specific features of the resistance exercise stimulus to facilitate evaluation of the influence of total exercise dose on anxiety symptoms. It is also important to note that the purpose of the meta-regression analyses reported here was to examine participant characteristics and features of the RET stimulus that may moderate, or influence, and ideally could be manipulated to enhance, the effect of RET on anxiety symptoms. The purpose of these analyses was not to test whether those variables help to explain the effects of RET; that purpose requires trials that assess plausible mediators of RET effects.

The potential mechanisms by which RET affects anxiety remain poorly understood. Plausible mechanisms include social interaction, particularly within group RET interventions, and expectations for psychological benefits [53]. Less is known, however, regarding potential physiological adaptations to RET, which have predominately been hypothesized through animal models. These mechanisms include thermogenic responses [54] and neurological mechanisms including monoaminergic regulation [13]. However, it is clear that research examining plausible neurobiological adaptations to resistance exercise training is needed.

4.2 Future Research

Clear and complete information regarding adherence, compliance, attendance, session duration, and intensity is needed to provide a better understanding of what components of a RET intervention elicit the strongest anxiolytic effects. Compared to growing evidence of the antidepressant effects of exercise, there has been a comparative lack of methodologically rigorous studies of the anxiolytic effects of RET on anxiety. Furthermore, there is a critical lack of studies comparing RET and AET within the same study sample [15, 36, 37]. Researchers should attempt to match RET with AET as closely as possible on multiple relevant features of the exercise stimulus (e.g., frequency, intensity, time spent engaged in exercise, muscle groups exercised). When RET and AET conditions have been matched according to multiple important features of the exercise stimulus, RET elicited larger improvements in anxiety and other symptoms compared to the effects of AET, a finding that may have been due partly to differences in the perception of effort between the different exercise stimuli [36].

Though improved signs and symptoms of GAD have been reported following as little as 2 weeks of RET [36], the evidence regarding the effects of RET among individuals with an anxiety disorder, or in those with subclinical levels of anxiety, is limited. To the authors' knowledge, no RCT has examined RET effects on anxiety in those with subclinical or prodromal levels of anxiety. Given that individuals who display elevated subclinical symptoms are more likely to develop clinically significant psychopathology [55, 56], investigating the effects of RET among individuals with emerging signs and symptoms of an anxiety disorder may be particularly important.

The present findings support the efficacy of moderate-to-vigorous RET to improve anxiety symptoms among both healthy adults and adults with a physical or mental illness, and the feasibility of both short-term RET and AET interventions to improve signs and symptoms among adults with GAD has been supported [15]. However, implementing RET can potentially be more difficult than AET, as special equipment such as free weights, elastic bands, or resistance training equipment may be required. To minimize cost, RET interventions can be designed to use cost-free RET exercises, incorporating participants' body weight for resistance, including exercises such as squats, lunges, push-ups, and abdominal crunches. Nonetheless, the findings here support the positive effects of moderate-to-vigorous intensity RET interventions. Those effects did not significantly vary based on participant characteristics, features of the resistance exercise stimulus, or other features of the intervention, providing support for real-world implementation of diverse RET programs to improve anxiety symptoms among otherwise healthy adults and chronically ill adults.

5 Conclusion

The empirical evidence reviewed herein supports RET as a potential low-risk alternative or adjuvant therapy for anxiety symptoms. Significantly larger improvements were found among otherwise healthy participants compared to participants with a physical or mental illness; nonetheless,

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RET resulted in small-to-moderate improvements among both healthy participants and participants with an illness. Improvements were not moderated by sex, or based on features of RET. Future trials should compare RET to other empirically supported therapies for anxiety, examine plausible neurobiological mechanisms for the anxiolytic effects of RET, and more rigorously examine the optimal total resistance exercise dose required to improve anxiety.

Compliance with Ethical Standards

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