Review

META-ANALYSIS OF ACUTE EXERCISE EFFECTS ON STATE ANXIETY: AN UPDATE OF RANDOMIZED CONTROLLED TRIALS OVER THE PAST 25 YEARS

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Background: ***One prominent and well-cited meta-analysis published nearly 25 years ago reported that an acute or single bout of exercise reduced state anxiety by approximately ¼ standard deviation. We conducted a meta-analysis of randomized controlled trials (RCTs) published after that meta-analysis for updating our understanding of the acute effects of exercise on state anxiety.*** **Methods:** ***We searched PubMed, EBSCOHost, Medline, PsycINFO, ERIC, and ScienceDirect for RCTs of acute exercise and state anxiety as an outcome. There were 36 RCTs that met inclusion criteria and yielded data for effect size (ES) generation (Cohen's d). An overall ES was calculated using a random effects model and expressed as Hedge's g.*** **Results:** ***The weighted mean ES was small (Hedge's g = 0.16, standard error (SE) = 0.06), but statistically significant (P < 0.05), and indicated that a single bout of exercise resulted in an improvement in state anxiety compared with control. The overall ES was heterogeneous and post hoc, exploratory analyses using both random- and fixed-effects models identified several variables as moderators including sample age, sex and health status, baseline activity levels, exercise intensity, modality and control condition, randomization, overall study quality, and the anxiety measure (P < 0.05).*** **Conclusion:** ***The cumulative evidence from high quality studies indicates that acute bouts of exercise can yield a small reduction in state anxiety. The research is still plagued by floor effects associated with recruiting persons with normal or lower levels of state anxiety, and this should be overcome in subsequent trials. Depression and Anxiety 32:624–634, 2015.***

Key words: ***anxiety; mood; exercise; acute; review***

INTRODUCTION

Nearly 25 years ago a defining meta-analysis was published regarding the effects of acute and chronic exercise on anxiety.[1] Of note, that meta-analysis reported an effect size (ES) of nearly ¼ standard deviation (SD) supporting a small, but statistically significant reduction in state anxiety following an acute bout of exercise.[1] The meta-analysis has subsequently become one of the most cited papers for supporting the anxiolytic benefits of acute exercise (331 citations on Web of Science as of February 25, 2015), but requires an update considering advances in study methodology and approaches that have occurred over the past two decades. For example, the authors included studies using both experimental and nonexperimental designs, and the studies with nonexperimental designs did not include a control group that accounts for major threats of internal validity such as passage of time and repeated test administration.[2] Researchers have further recognized that the previous research often was plagued by inclusion of persons with low levels of baseline state anxiety thereby causing a floor effect in pre-exercise anxiety scores.[3] Researchers have subsequently either recruited persons with

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anxiety proneness[4] or adopted an approach for experimentally manipulating pre-exercise anxiety (e.g., caffeine consumption[5]). Such approaches seemingly avoid floor effects in pre-exercise anxiety and should yield larger effects of acute exercise on state anxiety.

There are additional reasons to update the meta-analysis on acute exercise and state anxiety. One reason is the increased focus on resistance training and its influence on state anxiety over the past 25 years. The previous meta-analysis reported no improvement in state anxiety with nonaerobic forms of acute exercise, but there were limited numbers of high quality studies that focused on this modality of acute exercise. The examination of resistance training on state anxiety is important considering the ever-increasing focus on this modality for public health benefits. There further has been increasing acceptance and focus on exercise as an approach for mood management[6, 7], yet there is considerably less focus on exercise for the management of anxiety symptoms and clinical anxiety disorders compared with depressive disorders. An updated meta-analysis might provide a stronger basis for future applications of acute exercise for specifically managing anxiety symptoms.

We performed a meta-analysis examining the effect of acute exercise compared with control for improving state anxiety in adults. We further examined the features of the participants (e.g., age, health and fitness status, high vs. low trait anxiety) and studies (e.g., exercise modality, duration, and intensity) as possible moderator variables. This is timely considering the increasing prevalence of clinical and subclinical anxiety in society and the importance of providing an updated estimate that accounts for advances in scientific design and methods and change in societal focus and prescription of resistance exercise compared with aerobic exercise.

METHODS

This meta-analysis was conducted consistent with the meta-analysis of observational studies in epidemiology (MOOSE) framework,[8] and a visual description of our step-by-step methods is provided in Fig. 1. The literature search and the extraction of data were conducted by two authors (I.E. and T.A.G.) and all of the steps were overseen by the other two authors (R.W.M. and S.J.P.). We conducted a search of the following electronic databases: PubMed, EBSCOHost, Medline, PsycINFO, ERIC, and ScienceDirect, using the keywords "exercise," "anxiety," "acute exercise," "state anxiety," "one bout of exercise," and "trait anxiety. We included randomized controlled trials (RCTs) that were published in 1990 and after for two reasons; first, a meta-analysis of those published earlier was already quantitatively reviewed by Petruzzello et al.[1] and second, we aimed to minimize variation due to any poorly controlled extraneous factors related to study design by including only high-quality RCTs in our analysis. We initially retrieved a total of 383 articles and 286 of them were excluded due to following reasons: duplicates, review articles, and lack of anxiety outcome measures, or an appropriate exercise manipulation. We searched the bibliographies of the retrieved articles,[9] as well as the bibliographies of relevant chapters in more recently published books on anxiety and exercise,[7, 10] and ultimately we reviewed a total of 131 articles in detail, including the 34 articles identified through the bibliography search (see Fig. 1). Of these, those without an appropriate control group or randomization/counterbalance were excluded. If the papers did not include sufficient information for calculating ES, we contacted the authors for further information. We were unable to reach some of these authors[11] and other authors did not have the data available any longer.[12–15] We included RCTs (i.e., studies that compared bouts of exercise vs. no-treatment control and stated assigning participants to conditions randomly or in a counterbalanced fashion) and that administered reliable and valid measures of anxiety symptoms (e.g., Spielberger State-Trait Anxiety Inventory (STAI), Profile of Mood States (POMS) Tension subscale, Activation-Deactivation Adjective Check List (AD-ACL) Tension subscale) as an outcome assessment pre-post intervention. We did not include RCTs that administered nonanxiety specific scales (e.g., Positive and Negative Affect Schedule (PANAS),[16] Feeling Scale (FS)[17]). This resulted in a total of 36 RCTs[4, 5, 18–51] that were included in the meta-analysis (see Table 1).

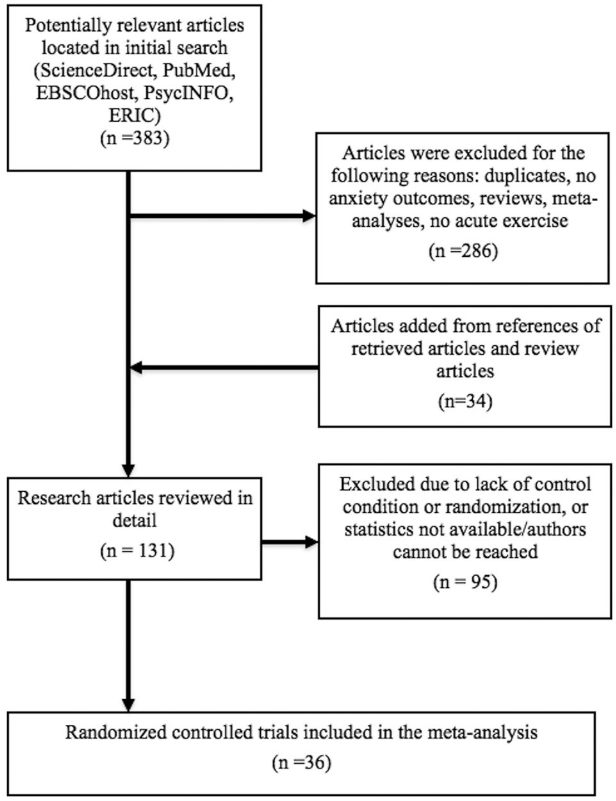

Figure 1. Flow diagram of study selection.

DATA ANALYSIS

We computed ESs expressed as Cohen's *d*.[52] To do this, we computed the mean change from before to after the exercise bout and subtracted the mean change of the control session. The resulting difference in mean change between the conditions was then divided by the pooled baseline SD for the conditions. The ESs were calculated so that a positive ES indicated an improvement in mean state anxiety scores after exercise, whereas a negative ES indicated a worsening of mean state anxiety scores in the exercise condition compared with control. Separate ESs were calculated per dependent variable (i.e., some studies had multiple anxiety outcomes) as well as per type of exercise (i.e., some studies had more than one type of exercise training modality or condition). The overall analysis itself took place using a single ES per study (i.e., an average ES when there was more than

TABLE 1. Study characteristics for the 36 studies included in the analyses

Reference	(Number of Effects)	Exercise control	Design (condition order)	Exercise mode/ intensity/duration	Type of anxiety manipulation	State anxiety measure	Sample size (F/M)	Mean Age (SD)	Health status	Baseline activity levels	State anxiety assessment time point (postexercise)
Arent et al. 2005	6	Alternative task	Within-subjects, counterbalanced	Resistance training/low, moderate, high/NR	None	20-item STAI, AD-ACL	31 ($F = 16$)	M = 22 (0.7), $F =$ 20.8 (0.5)	Healthy	Active	0–5, 15, 30, 45, 60 min
Arent et al. 2007	24	Alternative task	Within-subjects, counterbalanced	Resistance training/ moderate/ 30 min	None	10-item STAI, AD-ACL	23 (Male)	18–23[a]	NR	Active	5,15,30,60, 90,120 min
Bartholomew 1999	8	Alternative task	Between-subjects, randomized	Resistance training/ high/ 20 min	Mood manipulation	20-item STAI	35 (Male)	E = 23.2 (1.9) C = 23.6 (2.8)	NR	Active	5, 15, 30, 45 min
Bartholomew et al. 2005	3	Quiet rest	Between-subjects, randomized	Treadmill/ moderate/ 30 min	High baseline anxiety	POMS	40 ($F = 25$)	38.1 (18–55) [a]	MDD	Sedentary	5, 30, 60 min
Breus and O'Connor 1998	2	True control	Within-subjects, randomized	Cycle ergometer/ light/ 20 min	High baseline anxiety	20-item STAI	14 (Female)	19.9 (2.6)	Healthy	Sedentary	20 min
Brown et al. 1993	1	Quiet rest	Within-subjects, randomized	Cycle ergometer/ self-selected/ variable	High baseline TA	20-item STAI	10 ($F = 5$)	24.9 (5.8)	Moderate disability or injury	Sedentary	2–3 min
Butki et al. 2001	2	Quiet rest	Within-subjects, counter balanced	Treadmill/ moderate/ 20 min	None	10-item STAI	12 (Male)	24.1 (4.3)	Healthy	Active	5, 20 min
Cox 2004	8	True control	Within-subjects, randomized, counterbalanced	Treadmill/ moderate or high/ 30 min	None	20-item STAI	24 (Female)	29.2 (2.1)	Iron deficiency	Active	5, 30, 60, 90 min
Fallon and Hausenblas 2005	4	Quiet rest	Between-subjects, randomized	Treadmill/ low/ 20 min	Stressor stimulus	VAS	63 (Female)	19.8 (1.14)	NR	Active	0 min, 2 min
Focht 2002	16	Quiet rest	Within-subjects, randomized, counterbalanced	Resistance training/ low or moderate	High baseline anxiety	20-item STAI	19 (Female)	20.6 (3.1)	NR	NR	0, 20, 60, 120 min
Focht and Hausenblas 2001	2	Quiet rest	Within-subjects, randomized, counterbalanced	Stairmaster, rowing or cycle ergometer/ high/ 20 min	High baseline anxiety	20-item STAI	50 (Female)	19.9 (1.6)	NR	NR	0 min, 30 min
Focht and Hausenblas 2003	8	Quiet rest	Within-subjects, randomized, counterbalanced	Cycle ergometer/ moderate/ 20 min	High baseline anxiety	20-item STAI	30 (Female)	20.2 (1.7)	NR	NR	5, 60, 120, 180 min
Focht et al. 2000	10	Alternative task	Between-subjects, randomized	Resistance training/ moderate or high/ 30 min	None	20-item STAI	54 (Female)	21.2 (2.3)	Healthy	Active	0 min, 20, 60, 120, 180 min
Glazer and O'Connor 1992	8	Quiet rest	Within-subjects, randomized, counterbalanced	Treadmill/ low or moderate/ 20 min	None	20-item STAI, POMS	18 (Female)	25.15 (4.4)	Bulimia nervosa	Active	10, 20 min
Julian et al. 2012	2	Alternative task	Between-subjects, randomized	Treadmill/ low/20 min	High baseline anxiety	20-item STAI	112 ($F = 91$)	19.75 (2.3)	Mood disorder	NR	0, 5, 12 min

(*Continued*)

TABLE 1. Continued

Reference	(Number of Effects)	Exercise control	Design (condition order)	Exercise mode/ intensity/duration	Type of anxiety manipulation	State anxiety measure	Sample size (F/M)	Mean Age (SD)	Health status	Baseline activity levels	State anxiety assessment time point (postexercise)
Koltyn and Arbogast 1998	2	Quiet rest	Within-subjects, counterbalanced	Resistance training/ high/ 45 min	None	20-item STAI	13 ($F = 6$)	23 (5)	NR	Sedentary	10, 20 min
Kopp et al. 2012	4	Quiet rest	Between-subjects, randomized	Outdoor walking/ self-selected/ 20 min	None	AD-ACL tension	16 ($F = 11$)	55.3 (22.3)	Type 2 diabetes	Sedentary	5, 10, 15, 20 min
Lofrano et al. 2012	4	Quiet rest	Within-subjects, randomized	Treadmill/ moderate or high/ 350kcals	None	20-item STAI, POMS	8 (Male)	15.4 (2.06)	Obese	Sedentary	0 min
McAuley et al. 1996	1	Quiet rest	Within-subjects, randomized, counterbalanced	Cycle ergometer/ high/ 25 min	None	10-item STAI	34 ($F = 18$)	21.8 (2.27)	NR	Active	0 min, 15 min
Motl and Dishman 2004	2	Quiet rest	Within-subjects, counterbalanced	Cycle ergometer/ moderate/ 30 min	Caffeine	20-item STAI	16 (Female)	21.4 (2.3)	Healthy (low anxiety)	Active	10 min
Motl et al. 2004	4	Quiet rest	Within-subjects, counterbalanced	Cycle ergometer/ low or high/ 20 min	High baseline anxiety	20-item STAI	40 (Male)	38.8 (2.9)	Healthy	Active	10 min
Passos et al. 2010	3	True control	Between-subjects, randomized	Aerobic or resistance training/ moderate or high/ 50 min	None	20-item STAI	48 ($F = 12$)	44.4 (8)	Standalone insomnia	NR	180 min
Roth 1989	1	Quiet rest	Between-subjects, randomized	Cycle ergometer/ moderate/ 20 min	High baseline anxiety	POMS	80 ($F = 40$)	20.8 (3.5)	Healthy	Active and inactive	15 min
Roth et al. 1990	2	Quiet rest	Between-subjects, randomized	Cycle ergometer/ moderate/ 10 min	High baseline anxiety	POMS	57 (Female)	20.5 (2.3)	Healthy	NR	9 min
Smith 2013	6	True control	Within-subjects, randomized counterbalanced	Cycle ergometer/ moderate/ 40 min	Stressor stimulus	20-item STAI, Arousal Scale	36 ($F = 15$)	22.6 (3.3)	Healthy	Active	15, 45 min
Smith et al. 2002	2	Quiet rest	Within-subjects, counterbalanced	Cycle ergometer/ low or high/ 25 min	Stressor stimulus	20-item STAI	24 (Female)	22 (2)	Healthy	NR	20 min
Smits et al. 2009	2	Quiet rest	Between-subjects, randomized	Treadmill/ moderate/ 30 min	CO_2 challenge	API	92 ($F = 52$)	19.4 (1.3)	Healthy	NR	~15 seconds
Strohle et al. 2005	3	Quiet rest	Within-subjects, randomized	Treadmill/ high/ 30 min	CCK-4 injection	API	15 ($F = 6$)	26.4 (3.8)	Panic disorder	NR	5, 15 min
Strohle et al. 2009	12	Quiet rest	Between-subjects, randomized	Treadmill/ high/ 30 min	CCK-4 injection	API, Somatic Arousal Scale	24 ($F = 18$)	31.4 (11.5)	Panic disorder	NR	5, 15 min
Szabo et al. 1993	2	Alternative task	Within-subjects, counterbalanced	Cycle ergometer/ moderate/ 30 min	Stressor stimulus	POMS, 10-item STAI	9 (Male)	31.6 (9.6)	Healthy	Active	NR
Tate and Petruzzello 1995	20	True control	Within-subjects, randomized	Cycle ergometer/ moderate or high/ 30 min	None	10-item STAI	20 ($F = 5$)	22.6 (3.3)	NR	Active	NR

(*Continued*)

TABLE 1. Continued

Reference	(Number of Effects)	Exercise control	Design (condition order)	Exercise mode/ intensity/duration	Type of anxiety manipulation	State anxiety measure	Sample size (F/M)	Mean Age (SD)	Health status	Baseline activity levels	State anxiety assessment time point (postexercise)
Tieman et al. 2002	8	Alternative task	Within-subjects, randomized	Cycle ergometer/ low or high/ 20 min	High baseline anxiety	20-item STAI	26 (Male)	24.5 (5)	NR	Active and sedentary	NR
Vancampfort et al. 2011	2	Quiet rest	Between-subjects, randomized	Yoga or treadmill/ moderate/ 30 min	None	20-item STAI	40 ($F = 18$)	32.2 (8.8)	Schizophrenia	NR	0 min
Van Landuyt et al. 2000	3	Alternative task	Between-subjects, randomized	Cycle ergometer/ moderate/ 30 min	None	AD-ACL tension	82 ($F = 19$)	19.9 (1.4)	NR	Active	0, 10, 20 min
Youngstedt et al. 1993	4	Quiet rest	Within-subjects, counterbalanced	Cycle ergometer/ high/ 20 min	Stressor stimulus	20-item STAI	9 (Male)	26 (5.8)	Healthy	Active	1, 10, 20 min
Youngstedt et al. 1998	3	Quiet rest	Within-subjects, counterbalanced	Cycle ergometer/ moderate/ 60 min	Caffeine	20-item STAI	9 (Male)	25.1 (3.8)	NR	Active	10, 20 min

STAI, Spielberger state-trait anxiety inventory; POMS, profile of mood states; AD-ACL, activation-deactivation adjective check list; NR, not reported; F, female; M, male; E, exercise; C, control; SD, standard deviation.
[a]Range.

one ES computed by the software). This was necessary as multiple ESs from the same study are not independent.[53] The lack of independence can bias the standard error (SE) for judging the significance of the overall ES and multiple ESs from one study bias the overall ES disproportionately compared with the studies that have a single ES.[54]

The ESs along with the associated SEs were entered into the Comprehensive Meta-analysis Software (Version 2.0, Biostat, Englewood, New Jersey). We used a random-effects model for computing the overall or mean ES as this model assumes that the samples come from populations with different ESs and the true effect differs between studies.[54] We further computed a 95% confidence interval (CI) around the mean ES. An overall Q value and I^2 value were calculated to test for homogeneity of variance among ESs. The Q value is a measure of variance among the ESs and a statistically significant ($P < .05$) sum of the squares of each ES about the weighted mean (Q) indicates heterogeneity. The I^2 value represents the magnitude of the heterogeneity where a larger number indicates larger heterogeneity.

We further performed post hoc, exploratory moderator analyses based on the categorical variables of exercise modality (cycle ergometer, treadmill, resistance, or rowing/stairclimbing), anxiety measurement scale (20-item STAI vs. 10-item STAI vs. POMS vs. AD-ACL vs. API), duration, and intensity of exercise (20 min or less vs. longer than 20 min), exercise intensity (low vs. moderate vs. high), anxiety manipulation (none vs. activity-induced vs. agent-induced), trait anxiety levels of the sample (high vs. low, as reported by the study authors), anxiety outcome assessment time points (immediate/within 5 min postexercise vs. delayed), sample age (25 or younger/college students vs. older than 25 year/noncollege students), type of exercise control (true control vs. rest vs. alternate activity), design (between vs. within), condition order (random vs. counterbalanced vs. both), sample size (35 or fewer vs. more than 35 participants), and study quality based on the 11-item Physiotherapy Evidence Database (PEDro) scale[55,56] (6 or higher vs. lower than 6). A cut-off score of 6 was selected for categorization of studies with regards to quality as this is a score previously established as a benchmark for a "good quality" RCT.[55] Those variables were selected a priori based on the moderators addressed by the previous meta-analyses on the topic [1] or new opportunities for moderators based on the focus of research over the past 25 years. The moderator of anxiety manipulation was selected in an attempt to compare the effects from studies using samples with above vs. within normal levels of anxiety. However, not all studies provided baseline characteristics with regards to anxiety levels and furthermore, not all included scales with established cut-off points for distinguishing sub- vs. supranormal anxiety levels. Therefore, only those that reported such information were included in this particular categorization. The selected moderators were then categorized based on the number of studies available within each category (i.e., at least two, preferably three studies per category).

We conducted moderator analyses using both random- and fixed-effects models; this provided a more comprehensive profile of the moderator analysis outcome. We used a random-effects model as this accounted for the correlation between the ESs of the subgroups within each study as a considerable number of the studies had more than one outcome (e.g., multiple anxiety scales, assessment time points, experimental groups or exercise conditions).[57] This prevents overestimation of the power and allows for the most conservative estimation of the true ESs per study. We repeated the same analyses under the assumptions of the fixed-effects model in an attempt to better partition the significant heterogeneity in our overall ES. Under the fixed-effects model, it is assumed that the ES heterogeneity is due to unobserved random, but systematic, sources and can be explained by variables captured in the coding protocol.[57] We sought to apply this model as a supplement to the random-effects model to avoid potentially underestimating the ESs and missing important moderators that could inform future research on acute exercise and state anxiety.

The quality of studies included in the meta-analysis were established using the PEDro scale[55,56] for RCTs. Two authors (I.E. and T.A.G.) coded each of the studies and any discrepancies were discussed and resolved resulting in the reported PEDro scores. Scores on the PEDro range between 0 and 10, with higher scores indicating higher quality of methodology, and have been used previously in reviews of exercise training.[58,59] As dictated by the literature on the guidelines on PEDro scoring,[55] item 1 is not included in computing the overall score, therefore resulting in a score out of 10, instead of 11. All studies inevitably received a score of 0 on items 5 and 6 (i.e., blinding of subjects and the therapists to the conditions, respectively), based on the obvious difficulty of blinding to exercise training. On the other hand, studies that utilized a counterbalanced design received a score of 1 on item 2 (i.e., randomization to conditions) as counterbalancing is considered an acceptable method of attempting to control for bias in the trials. For item 4 (i.e., group similarity at baseline), the prognostic indicators that were taken into account for assessment were those related to mood (e.g., anxiety, depression) and physical activity (e.g., fitness levels, habitual activity levels). To that effect, if the authors did not report whether such baseline scores were significantly different, a difference of ½ SD between groups at baseline was considered clinically different;[60] therefore, those studies received a score of 0 on this item (see Table 2).

RESULTS

Table 1 provides the sample and exercise characteristics per study. Overall, 194 ESs were retrieved from the 36 published RCTs that included a total sample of 1233 persons. Figure 2 provides a visual description of the average ES per study. The distribution of ESs had slight negative skewness (g1 = −.77, SE = .39) and slight positive kurtosis (g2 = 1.28, SE = .77). Twenty-seven of the 36 ESs from the studies were greater than zero (i.e., 75%). The funnel plot of the average ESs from the 36 studies suggested against publication bias. The overall weighted mean ES was 0.16 (SE = 0.06, 95% CI = 0.05–0.27, $z = 2.81$, $P < .05$). This reflects a statistically significant, but small effect in favor of acute exercise for improving state anxiety compared with the control condition. The weighted mean ES was heterogeneous ($Q = 166.50$, df = 35, $P < .001$, $I^2 = 78.98$). This indicates that the variation among studies was greater than expected due to random chance and supported the subgroup moderator analyses.

Regarding methodological quality, 12 of 36 studies received a score of 6 or higher on the PEDro scale; individual PEDro item scores for each study are provided in Table 1. The score of 6 has been previously determined as the cut-off point for a high quality study (i.e., Level I evidence).[55] Regarding baseline scores on the measures of anxiety symptoms, samples in 12 of the studies had scores above the threshold for average anxiety levels as reported/assessed by the authors. We were unable to make such determination of baseline anxiety levels if the study used an anxiety measure without established anxiety threshold cut-off scores (e.g., POMS, 10-item STAI, AD-ACL).

We conducted post hoc analyses using categorical moderator variables to further examine heterogeneity in the overall ES. Point estimates, SEs, and significant values for the Q_b statistic are provided in Table 3. Based on the random-effects model, we only identified age category as a significant moderator variable ($P < .001$). Older age (i.e., 25 and older) was associated with a larger positive effect of exercise than being younger (see Table 3). Based on the fixed-effects model, the moderator variables that yielded a statistically significant effect were type of exercise control, condition order, overall study quality, intensity and modality, age, sex, health status, anxiety measurement scale, and baseline activity levels. The following categories yielded the larger effects with regards to study characteristics: quiet rest control condition, a PEDro score of 6 or higher, using a randomized counterbalanced design, the 10-item STAI, treadmill/walking exercise, and high intensity exercise. With regards to sample characteristics, being older (i.e., 25 and older), female, having a nonpsychiatric disease, and being physically sedentary yielded the largest positive effects of exercise (see Table 3).

We estimated the possible clinical importance of the overall ES by determining the success/failure rate of acute exercise on reducing state anxiety compared with the no-exercise control condition based on the binomial ES. We converted the overall mean ES of 0.16 into a correlation coefficient ($r = 0.08$). The chance of treatment success was determined as $(0.5 + r/2)100$, and the chance of treatment failure was determined as $(0.5 - r/2)100$. This resulted in 54% chance of success (i.e., a reduction in anxiety symptoms) and 46% chance of failure for a single bout of exercise on improving anxiety symptoms.

DISCUSSION

The results of the current meta-analysis suggested that acute exercise sessions improved anxiety symptoms in the overall sample and this improvement corresponded to a small improvement (i.e., ES = 0.16) in anxiety scores compared with control. The results further indicated substantial heterogeneity of the overall ES, thereby indicating significant variation across the 36 RCTs. The exploratory, categorical moderator analyses, particularly using the fixed-effects model, suggested that type of exercise control, anxiety measure, sample age, health and physical activity status at baseline, higher overall study quality (i.e., PEDro score of 6 or higher), exercise mode and condition order were associated with larger effects of acute exercise on state anxiety (i.e., reductions).

Our results are complementary of those reported in the previous meta-analysis of Petruzzello et al.[1] Indeed, their meta-analysis reported an overall ES of 0.24 (SE = 0.04), and this corresponds with a ¼ SD improvement in state anxiety levels. Collectively, both meta-analyses are suggesting that acute bouts of exercise have a small, but reliable effect on state anxiety, and this effect is slightly smaller when examined in the context of RCTs.

TABLE 2. Individual and overall PEDro scores for all studies included in the analyses

Reference	1[c]	2	3	4	5	6	7	8	9	10	11	Total
Arent et al. 2005	1	1[a]	0	0	0	0	0	1	1	1	1	5
Arent et al. 2007	1	1[a]	0	0	0	0	0	1	1	1	1	5
Bartholomew 1999	1	1[a]	0	0	0	0	0	1	1	1	1	5
Bartholomew et al. 2005	1	1	0	1	0	0	0	1	1	1	1	6
Breus and O'Connor et al. 1998	1	1	0	0	0	0	0	0	0	1	1	3
Brown et al. 1993	0	1[a]	0	1	0	0	0	1	1	1	1	6
Butki et al. 2001	1	1[a]	0	1	0	0	0	1	1	1	1	6
Cox et al. 2004	1	1[a]	0	0	0	0	0	1	1	1	1	5
Fallon and Hausenblas 2005	1	1	0	0[b]	0	0	0	1	1	1	1	5
Focht 2002	0	1	0	0[b]	0	0	0	1	1	1	1	5
Focht and Hausenblas 2001	1	1	0	0	0	0	0	1	1	1	1	5
Focht and Hausenblas 2003	1	1	0	1	0	0	0	1	1	1	1	6
Focht et al. 2000	0	1	0	1	0	0	0	1	1	1	1	6
Glazer and O'Connor 1992	1	1	0	0	0	0	0	1	1	1	1	5
Julian et al. 2012	1	1	0	1	0	0	0	1	1	1	0	5
Koltyn and Arbogast 1998	0	1	0	1	0	0	0	1	1	1	1	6
Kopp et al. 2012	1	1	0	1	0	0	0	1	1	1	0	5
Lofrano et al. 2012	0	1	0	0	0	0	0	1	1	1	1	5
McAuley 1996	0	1[a]	0	1	0	0	0	1	1	1	1	6
Motl and Dishman 2004	1	1	0	0[b]	0	0	0	1	1	1	1	5
Motl et al. 2004	1	1[a]	0	0[b]	0	0	0	1	1	1	1	5
Passos et al. 2010	1	1	0	0	0	0	0	1	1	1	1	5
Roth 1989	1	1	0	1	0	0	0	1	0	1	1	5
Roth et al. 1990	1	1	0	0	0	0	0	1	0	1	1	4
Smith 2013	1	1[a]	0	1	0	0	0	1	1	1	1	6
Smith et al. 2002	1	1[a]	0	1	0	0	0	1	0	1	1	5
Smits et al. 2009	1	1	0	0	0	0	0	1	0	1	1	4
Strohle et al. 2005	1	1	0	1	0	0	1	1	1	1	1	7
Strohle et al. 2009	1	1	0	1	0	0	1	1	0	1	1	6
Szabo et al. 1993	0	1	0	0	0	0	0	1	1	1	1	5
Tate and Petruzzello 1995	0	1	0	1	0	0	0	1	1	1	1	6
Tieman et al. 2002	0	1	0	0[b]	0	0	0	0	0	1	1	3
Vancampfort et al. 2011	1	1	1	1	0	0	0	1	1	1	1	7
Van Landuyt et al. 2000	0	1	0	1	0	0	0	1	0	1	1	5
Youngstedt et al. 1993	1	1	0	0	0	0	0	1	1	1	1	5
Youngstedt et al. 1998	0	1	0	0	0	0	0	0	1	1	1	4

[a]Counterbalanced design.
[b]Baseline differences due to separation of participants into groups.
[c]Item 1 is not included in the calculation of the overall score as per instructions.[55]

Such evidence supports statements, conclusions, and recommendations for the utilization of acute exercise for managing the daily manifestations of state anxiety in adults.

The main analysis further indicated substantial heterogeneity in the overall ES. To that end, we included random-effects and fixed-effects analyses for examining study and sample characteristics that yielded the large heterogeneity of our overall ES. Importantly, the random-effects model represents a more conservative approach for examining moderators of the overall ES, whereas the fixed-effects model is less conservative as it assumes that the across-samples variation is similar.[55] The random-effects model identified age as having significant effects, whereas the fixed-effects model indicated several additional moderators (i.e., assignment order, overall study quality, type of exercise control, modality and intensity, sex, baseline health and physical activity levels, anxiety assessment scale type). Our random-effects moderator analyses suggested that older age yields a larger effect for acute exercise (i.e., greater anxiety reduction; $P < .001$). The fixed-effects moderator analyses further suggested that using a randomized counterbalanced design, a PEDro score of 6 or higher, a quiet rest control condition, high exercise intensity, the treadmill as a modality, the 10-item STAI for state anxiety assessment; with female, sedentary and diseased samples yielded larger effects for acute exercise. Such differences should be confirmed and cross-validated in subsequent research on acute exercise and state anxiety. Overall, the results of the moderator analyses are insightful, but should be interpreted with caution considering the small

TABLE 3. Results of the random- and fixed-effects moderator analyses

		Random effects			Fixed effects		
Moderator	Type (Number of studies)	Point estimate (SE)	*Z* value	*Q* statistic (df)	Point estimate (SE)	*Z* value	*Q* statistic (df)
Exercise control	True control (5)	0.18 (0.12)	1.48	5.77 (2)	0.12 (0.05)	2.42*	27.05 (2)**
	Quiet rest (23)	0.25 (0.07)	3.49		0.23 (0.04)	6.52**	
	Alternate activity (8)	−0.08 (0.12)	−0.67		−0.06 (0.05)	−1.44	
Design	Between (23)	0.14 (0.06)	2.44*	0.12 (1)	0.10 (0.03)	3.48**	1.33 (1)
	Within (13)	0.19 (0.13)	1.15		0.16 (0.05)	3.55**	
Condition Order	Random (19)	0.15 (0.10)	1.48	5.13 (2)	0.10 (0.04)	2.64	18.24 (2)*
	Counterbalanced (10)	0.05 (0.08)	0.57		−0.04 (0.0)	0.49	
	Both (7)	0.25 (0.04)	5.84**		0.25 (0.04)	5.84**	
Overall study quality	PEDro score <6 (24)	0.09 (0.07)	1.23	3.30 (1)	0.07 (0.03)	2.29*	5.52 (1)*
	PEDro score ≥6 (12)	0.31 (0.10)	3.14*	(*P* = .07)	0.19 (0.04)	4.86**	(*P* = .02)
Sex	Male (10)	0.07 (0.11)	1.03	2.09 (2)	0.00 (0.05)	0.01	13.49 (2)**
	Female (10)	0.23 (0.04)	5.45**		0.23 (0.04)	5.65**	
	Both (16)	0.16 (0.11)	1.45		0.08 (0.04)	2.21*	
Sample size	35 or less (20)	0.17 (0.08)	2.28*	0.05 (1)	0.11 (0.03)	3.32**	0.30 (1)
	More than 35 (16)	0.15 (0.09)	1.58		0.13 (0.04)	3.46**	
Age category	College students (24)	0.04 (0.06)	0.57	14.76 (1)**	0.03 (0.03)	1.11	43.50 (1)**
	25 years and up (11)	0.43 (0.08)	5.33**		0.42 (0.05)	8.01**	
Health status	Healthy (12)	0.13 (0.08)	1.67	5.58 (3)	0.13 (0.05)	2.72*	16.70 (3)**
	Psychiatric disease (4)	0.03 (0.35)	0.08		0.22 (0.11)	2.05*	
	Non-psychiatric disease (5)	0.30 (0.15)	1.98*		0.31 (0.07)	4.24**	
	Psychiatric and nonpsychiatric disease (2)	0.61 (0.20)	3.00*		0.61 (0.12)	5.18**	
Baseline activity levels	Sedentary (5)	0.35 (0.15)	2.29*	2.02 (1)	0.39 (0.09)	4.25**	10.13 (1)**
	Active (23)	0.12 (0.06)	1.99*		0.08 (0.03)	3.12*	
Exercise mode	Cycling (15)	0.11 (0.09)	1.28	1.44 (3)	0.06 (0.04)	1.45	10.61 (3)*
	Treadmill (12)	0.21 (0.13)	1.61		0.24 (0.05)	4.64**	
	Resistance (6)	0.06 (0.09)	0.63		0.05 (0.04)	1.18	
	Rowing/stairclimbing (2)	0.21 (0.12)	1.75		0.21 (0.12)	1.75	
Exercise intensity	Light (3)	0.08 (0.21)	0.36	3.42 (2)	0.08 (0.12)	0.65	17.15 (2)**
	Moderate (13)	0.12 (0.12)	1.20		0.03 (0.04)	0.82	
	High (7)	0.40 (0.12)	3. 30**		0.36 (0.07)	5.32**	
Exercise duration	20 min or less (18)	0.16 (0.06)	2.83*	0.00 (1)	0.15 (0.04)	4.15**	1.21 (1)
	>20 min (17)	0.16 (0.10)	1.58		0.10 (0.03)	2.95*	
State anxiety measure	20-item STAI (19)	0.21 (0.05)	4.77**		0.22 (0.04)	6.45**	19.62 (4)**
	10-item STAI (2)	0.38 (0.19)	2.03*		0.38 (0.19)	2.03*	
	API (3)	0.37 (0.46)	0.80	1.95 (4)	0.13 (0.12)	1.15	
	AD-ACL (2)	−0.22 (0.57)	−0.39		−0.29 (0.12)	−2.49*	
	POMS (3)	0.35 (0.18)	1.97*		0.31 (0.13)	2.48*	
Baseline anxiety level	Low (19)	0.16 (0.11)	1.48	0.00 (1)	0.12 (0.04)	3.20**	0.57 (1)
	High (11)	0.16 (0.05)	3.19**		0.16 (0.04)	3.71**	
Type of anxiety manipulation	None (15)	0.08 (0.10)	0.78	1.69 (3)	0.08 (0.04)	0.75	14.42 (3)
	High baseline TA (10)	0.16 (0.05)	2.99*		0.16 (0.04)	3.69**	
	Activity-induced (4)	0.22 (0.09)	2.46*		0.23 (0.08)	2.98*	
	Agent-induced (6)	0.35 (0.23)	1.51		0.30 (0.08)	3.55**	
Anxiety assessment time point	Immediate (2)	0.31 (0.17)	1.85	0.26 (2)	0.31 (0.17)	1.85	2.16 (2)
	Delayed (14)	0.21 (0.12)	1.82		0.20 (0.05)	3.94**	
	Multiple points (15)	0.22 (0.07)	3.08*		0.13 (0.03)	4.31**	

In the random-effects model, sample age indicated a statistically significant effect of exercise for older individuals ($P < .001$). In the fixed effects model, the following moderators were associated with a statistically significant effect: type of exercise control, order of conditions, PEDro score, sample age, baseline health status and activity levels, exercise mode and intensity, and type of anxiety measurement scale (*$P < .05$, ** $P < .001$)

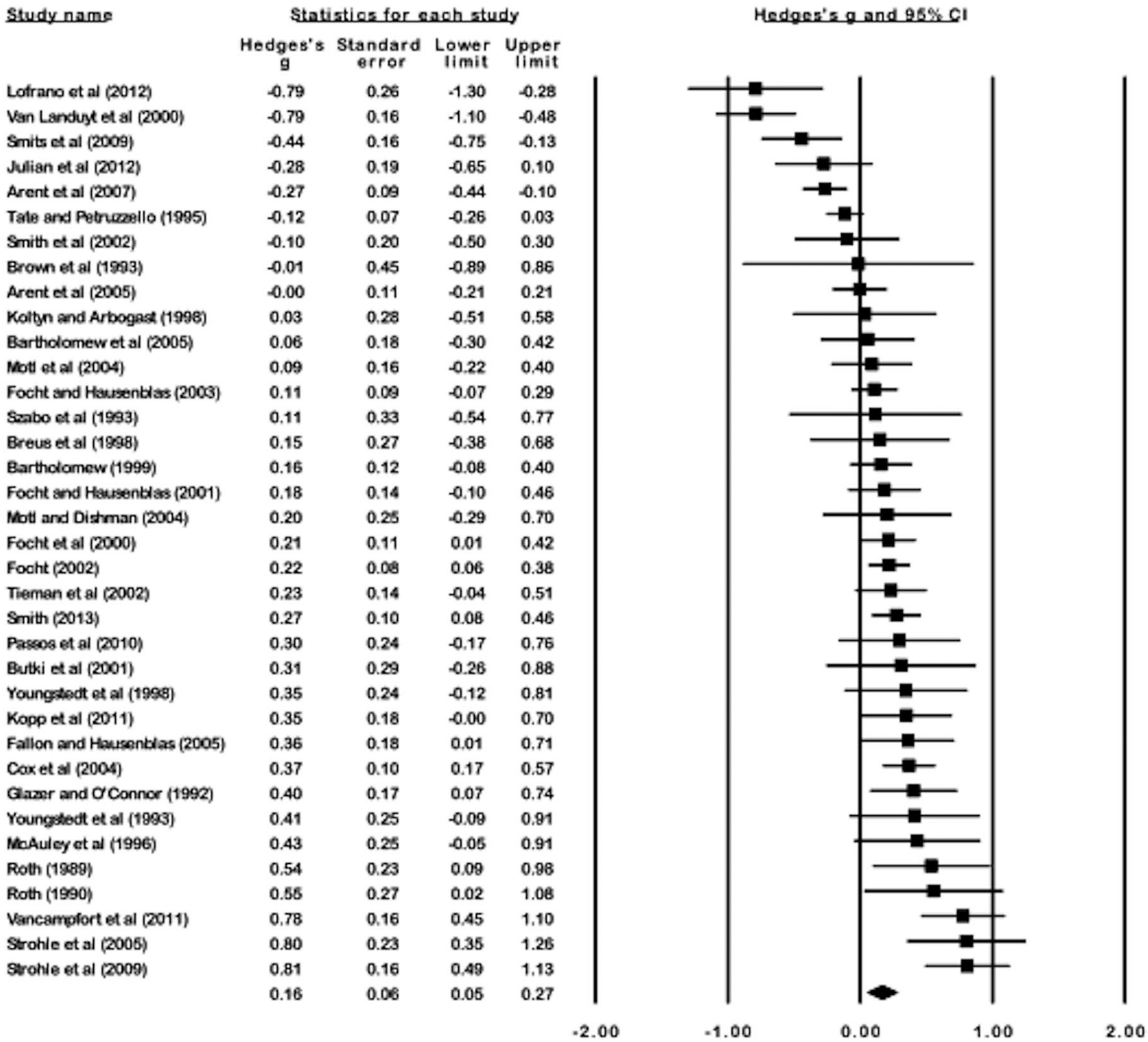

Figure 2. Summary of overall and individual effect sizes.

sample of studies included within some of the categories in the analysis.

There have been significant advances in the research on acute exercise and state anxiety over the past 25 years, such as inclusion of participants with anxiety disorders or high trait anxiety at baseline to avoid floor effects and consistent inclusion of exercise control conditions. Nevertheless, there are still major limitations of the existing research regarding acute exercise and state anxiety. One primary weakness of the existing research was identified during methodological quality assessment and indicated overall moderate quality of the published studies in acute exercise and anxiety measurement. Based on the PEDro scale cut-off score,[55] more than half of the studies received a score of 5 or higher (i.e., median score = 5), and there were only 12 studies with a score of 6 or higher (i.e., indicating good overall quality) (see Table 2). Nevertheless, issues regarding blinding of the assessors, participants, and therapists, and concealed allocation of participants were the main factors resulting in a loss of points on the PEDro scale (see Table 2). This raises the possibility that expectancy bias is inevitable in almost all of the studies. Consequently, the overall quality scores were inevitably lowered. Some of these issues (e.g., blinding of the assessors and concealed allocation) can be overcome in subsequent research; however, other issues (e.g., blinding of the participants and the therapists) are extremely difficult to overcome. In addition, some of the studies received a score of 0 on item 1 (i.e., reporting of the eligibility criteria) as these studies did not specify criteria for exclusion or inclusion. This could be due to either simply elimination of this piece of information, or that the study might not have had a systematic exclusion/inclusion criteria. Several studies received a score of 0 on item 4 (homogeneity of comparison groups at baseline) due to the a priori goal of comparing distinct group responses (e.g., high vs. low anxious individuals) and these are noted in Table 1. Finally, the need for improving methodological quality in future studies of exercise and acute anxiety is further emphasized considering the PEDro score category was a significant moderator in our fixed-effects post hoc analyses ($P = .02$) and almost statistically significant in our random-effects analysis at $P = .07$ (see Table 3).

We further note that only three studies used samples with clinical anxiety.[31,43,44] Therefore, these findings may not be sufficient to generalize to those with more severe anxiety symptoms or with a clinical anxiety disorder. This is an important limitation as studies with clinical populations yielded substantially higher ESs than others in our analyses, yet the overall values were not significant because there were so few studies and ESs. If these results are replicated in subsequent research, then it might have clinical implications. Clinicians might then consider recommending that people with anxiety symptoms or even clinical anxiety disorders engage in exercise training as an approach for potentially preventing and for alleviating their anxiety symptoms.

This meta-analysis is not without limitations. Most of the studies included the 20-item STAI as an assessment of state anxiety and so our results might be accordingly biased. Most of the studies included cycle ergometry as the mode of exercise and therefore other modalities were not as well represented (e.g., rowing, stairclimbing, yoga, etc.) in our analyses. Quiet rest was the most commonly applied exercise control condition in comparison to a true control (i.e., sitting on the exercise equipment without exercising) or an alternate activity (e.g., reading, watching videos) and therefore this may have biased the results of our analyses. Finally, unlike the meta-analysis of Petruzzello et al.,[1] we only included self-reported state anxiety as the outcome measure and decided against conducting additional moderator analyses on the physiological correlates of anxiety. There were not sufficient studies that included such measures and some measures are difficult to interpret as either normal physiological changes with exercise or a change in anxiety (e.g., heart rate variability).

Accordingly, we are in need of better-designed RCTs with the proper exercise manipulations and those conducted with samples having clinically diagnosed anxiety disorders, as opposed to convenience samples (i.e., college students). This recommendation will be further clarified in future RCTs with psychiatric populations to further delineate which factors might be most important in increasing their enjoyment of the activity and their subsequent adherence to the exercise regimen. Such investigations might further consider comparing exercise with cognitive behavioral therapy and anxiolytics for managing anxiety in clinical populations.

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