Journal of Sport & Exercise Psychology, 2008, 30, 392-410

The Anxiolytic Effects of Exercise: A Meta-Analysis of Randomized Trials and Dose–Response Analysis

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A meta-analysis was conducted to examine the effects of exercise on anxiety. Because previous meta-analyses in the area included studies of varying quality, only randomized, controlled trials were included in the present analysis. Results from 49 studies show an overall effect size of −0.48, indicating larger reductions in anxiety among exercise groups than no-treatment control groups. Exercise groups also showed greater reductions in anxiety compared with groups that received other forms of anxiety-reducing treatment (effect size = −0.19). Because only randomized, controlled trials were examined, these results provide Level 1, Grade A evidence for using exercise in the treatment of anxiety. In addition, exercise dose data were calculated to examine the relationship between dose of exercise and the corresponding magnitude of effect size.

Keywords: physical activity, mental health, anxiety

Anxiety is a mental disorder that has been estimated to affect approximately 8.3% of the U.S. adult population (Myers et al., 1984). Briefly, anxiety has been defined as an unpleasant emotional state, which is often accompanied by fatiguing or exhausting physiological symptoms (Greist & Jefferson, 2000). Anxiety disorders vary in degree of severity from periods of mild discomfort to panic disorder, and common symptoms include rapid heart rate, sweating, nausea, chills, trembling, hyperventilation, a fear of doing something uncontrolled, and a fear of death. The onset of an anxiety attack can arise from cues (phobias) or "out of the blue" (spontaneous) (Greist & Jefferson).

Of the roughly 18 million adults affected by an anxiety disorder, it has been estimated that only 23% are receiving treatment. Common treatments for anxiety disorders are similar to those for clinical depression; it has been shown that 75% of people who are affected by clinical depression are also affected by anxiety disorder (Myers et al., 1984). The two most common treatments for these disorders are various drug treatments (antidepressants) and psychotherapy. The use of drugs and psychotherapy to treat anxiety disorders, however, has drawn criticism. Common side effects that accompany antidepressants include weight gain, hyperglycemia,

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hyperlipidemia, sexual dysfunction, and elevated blood pressure (Gardner, Baldessarini, & Waraich, 2005). Recently, antidepressant drugs classified as selective serotonin reuptake inhibitors have been linked to increased risk for suicide or suicidal thoughts in both children and adults (Ludwig & Marcotte, 2005).

In addition to these unwanted side effects, Andrews, Sanderson, Corry, and Lapsley (2000) have described the need for more treatments for depression due to the high percentage (approx. 50%) of people who may be clinically depressed but are not receiving treatment. Because a large percentage of people who have some type of anxiety disorder are not receiving treatment, the need for more forms of treatment for depression that was described by Andrews can be extended to include anxiety disorders as well. Given these criticisms, there is a general interest in finding new methods of treatment for anxiety disorders that are effective and widely accessible, and lack unwanted side effects. One potential method of treatment that has generated a large amount of research is exercise (Moore & Blumenthal, 1998).

The effects of exercise on anxiety have been examined by previous meta-analyses (Calfas & Taylor, 1994; Kugler, Seelbach, & Kruskemper, 1994; Landers & Petruzzello, 1994; Long & Van Stavel, 1995; McDonald & Hodgdon, 1991; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991; Schlicht, 1994). All these meta-analyses reported that exercise was related to decreases in anxiety. More specifically, in the Petruzzello et al. study, dependent measures of anxiety were divided into three categories: self-reported state anxiety, self-reported trait anxiety, and psycho-physiological measures of anxiety. While the effect sizes for all three categories indicated that exercise was associated with a reduction in anxiety, effect sizes ranged from 0.24 for state anxiety and 0.34 for trait anxiety, to 0.56 for psycho-physiological measures of anxiety. Results from moderator variables in this study showed that studies using random assignment to groups had higher effect sizes than other methods of subject assignment for measures of trait anxiety. This same finding, however, was not seen for measures of state anxiety and psycho-physiological measures of anxiety. Additional results from the analysis of moderator variables showed that exercise was significantly better than other types of treatment (i.e., relaxation or meditation) for reducing trait anxiety and psycho-physiological measures of anxiety. These effect sizes were small in magnitude (0.31 and 0.15, respectively).

Results from the Long and Van Stavel (1995) meta-analysis were similar to those of Petruzzello et al. The overall effect sizes in this analysis were 0.45 for within-group studies and 0.36 for studies that used a contrast group. Both of these effect sizes indicate a moderate reduction in anxiety, and fall within the range that was seen by Petruzzello et al. Moderator variable results from this quantitative review also showed that higher effect sizes (0.64 for within-group studies and 0.44 for contrast group studies) resulted from studies that used random assignment to groups.

To evaluate the efficacy of exercise in the treatment of anxiety disorders, it is useful to examine the criteria for grading treatment recommendations that have been refined by Guyatt, Cook, Sackett, Eckman, and Pauker (1998). Based upon these criteria, a treatment that achieves Level 1, Grade A status receives the highest level of recommendation. In order for evidence to reach Level 1, Grade A status, the following criteria must be met: The evidence must come from randomized, controlled trials; there must be a high benefit-to-risk ratio; the results must be clear cut; and the evidence must come from a large sample. Large-scale randomized trials are often extremely costly and time consuming to conduct and are therefore rare. Level 1, Grade A evidence, however, can also be achieved through meta-analysis by combining results of Level 2 studies, which are smaller randomized, controlled trials (Guyatt et al.).

Because only 13 of the 104 studies in the Petruzzello et al. meta-analysis, and 15 of the 40 studies in the Long and Van Stavel meta-analysis were randomized, controlled trials, they fail to establish Level 1, Grade A evidence. Therefore, the purposes of this study were to update and strengthen earlier meta-analytic findings, and to establish Level 1, Grade A evidence for using exercise as a treatment for anxiety by including only randomized, controlled trials in the analysis.

Dose–Response Analysis

In the quest to satisfy all of Hill's (1965) criteria for causation, there have been several attempts to find evidence of a dose–response relationship between exercise and the associated mental health benefits. Much of this evidence has been summarized by Dunn, Trivedi, and O'Neal (2001). This article, however, argues that even though there is evidence to suggest a dose–response relationship between exercise and mental health benefits, much of this evidence comes from Grade B and Grade C studies, which consist of mainly correlational evidence. There have also been more recent studies that provide support for the existence of a dose–response relationship in this area (Dunn, Trivedi, Kampert, Clark, & Chambliss, 2002; Galper, Madhukar, Barlow, Dunn, & Kampert, 2006), which also provide correlational evidence. Two randomized, controlled trials (Dunn, Trivedi, Kampert, Clark, & Chambliss, 2005; Singh et al., 2005) have shown evidence of a dose relationship with regards to mental health. Dunn et al. examined four exercise groups, each of which were assigned an energy expenditure (either 17.5 $kcal \cdot kg^{-1} \cdot week^{-1}$ or 7.0 $kcal \cdot kg^{-1} \cdot week^{-1}$) and an exercise frequency (either 3 or 5 days per week). Results showed that both of the higher-dose groups showed significantly lower depression scores after the 12-week intervention than the lower-dose groups, regardless of exercise frequency. Results from Singh et al. showed that older adults who completed a higher-intensity weight training program showed significantly less depression postintervention than older adults who completed a lower-intensity weight training program.

Although the aforementioned evidence provides some support for a dose–response relationship between exercise and improved mental health, further evidence is required to strengthen this link. A secondary purpose of this study, therefore, was to provide additional evidence in support of a dose–response relationship between exercise and improved mental health by examining this relationship in the randomized, controlled studies that were collected for the meta-analysis.

Hypotheses

Hypothesis 1. Exercise groups show significantly greater reductions in anxiety than no-treatment and placebo control groups, as indicated by an overall effect size that is significantly different from zero. Based on results from previous meta-analyses, it is predicted that the overall effect size is moderate in magnitude.

Hypothesis 2. Based upon findings from Petruzzello et al. meta-analysis, it is predicted that exercise groups show greater reductions in anxiety than groups who underwent a different form of anxiety-reducing treatment. In addition, it is predicted that this effect size will be small in magnitude.

Hypothesis 3. Dose of exercise ($kcal \cdot kg^{-1} \cdot week^{-1}$) predicts a significant amount of variance in effect size.

Method

Literature Search

An electronic literature search was conducted using the following databases: PubMed, SportDiscus, PsycInfo, and Dissertation Abstracts International. This search was conducted using various combinations of the following terms: *exercise, physical activity, physical exercise, running, jogging, walking, weight lifting, weight training, anxiety, anxiety disorder, and mental health*. In addition, references from previous meta-analyses, narrative reviews, and all studies that were located were referenced by hand for possible studies that met the inclusion criteria.

Inclusion Criteria

Only randomized, controlled studies that included a self-report measure of anxiety as a dependent variable were included in the analysis. Psycho-physiological measures were not included in the meta-analysis because very few randomized, controlled studies employed these measures. Studies also had to include an exercise condition that did not include another form of treatment, i.e., exercise plus psychotherapy or drug therapy, as an independent variable. The analysis was also limited to studies in the English language that were available as of January 2006.

Moderator Variable Coding

Each study that met the inclusion criteria was coded for both participant and design characteristics. The first author coded the studies, and the second author recoded the moderator variables from a random sample of 10 studies to examine coding reliability. Studies were coded as part of a clinical population or a nonclinical population, as determined by whether the participants were classified as clinically anxious, with or without clinical depression, according to DSM-IV (American Psychiatric Association, 1994) criteria. Effect sizes were also coded for gender, to examine whether exercise has a differential effect for men and women, or when interventions included both men and women. The final participant characteristic that was coded was mean participant age.

Design characteristics that were coded included the duration of the exercise intervention, type of exercise (aerobic, anaerobic, or a combination of the two), the frequency of exercise, the intensity of the exercise, and the duration of the exercise bout. For studies in which a range of intensities or bout durations were given (i.e., 60–70% VO_{2max} or 20–30 min of exercise), the lowest value of the range was used because this is the only level for which it can be assumed that every participant in the study reached. In addition, because there has been a great deal of interest in whether improvements in aerobic fitness are at least partially responsible for the mental health benefits of exercise (Etnier, Nowell, Landers, & Sibley, 2006), studies were coded for the average percentage improvement in VO_{2max} that was realized by the participants.

Effect Size Calculation

A single average effect size was calculated for studies that used multiple different measures of anxiety and studies that used multiple different exercise groups (i.e., one weight training group and one aerobic group). This treatment of effect size measures leads to independence of effect size values and gives each study in the analysis equal weight. Hedges's *g* was used as the measure of effect size in this meta-analysis, in which Hedges's $g = M_{\text{Experimental}} - M_{\text{Control}} / SD_{\text{Pooled}}$, where

$$SD_{\text{Pooled}} = \sqrt{\frac{(N_E - 1)SD_E^{\,2} + (N_C - 1)SD_C^{\,2}}{N_E + N_C - 2}}$$

Posttest means and standard deviations were used in effect size calculation. When means and standard deviations were not available, an effect size was calculated using *F*, *t*, and *r* values when available (Rosenthal, 1994). Because studies with large sample sizes yield more precise estimates of true population parameters than small studies, each standardized mean difference was multiplied by

$$[1 - \frac{3}{4N - 9}]$$

(Hedges & Olkin, 1985). Finally, based upon the recommendations of Hedges and Olkin (1985), along with Hunter and Schmidt (2004), a random effects model was used, and effect sizes were weighted by the inverse of the variance to calculate the overall effect size (Shadish & Haddock, 1994). In addition, gains effect sizes were calculated for exercise and control groups, in which case the calculation for effect size becomes $M_{\text{Post}} - M_{\text{Pre}} / SD_{\text{Pooled}}$ for each group, and

$$SD_{\text{Pooled}} = \sqrt{\frac{(N_{Pre} - 1)SD_{Pre}^{\,2} + (N_{Post} - 1)SD_{Post}^{\,2}}{N_{Pre} + N_{Post} - 2}}$$

Each effect size was coded such that a negative value indicates a reduction in anxiety. After calculation, effect sizes were divided into two categories: those that compared exercise to a no-treatment control group, and those that compared exercise to some other form of treatment for anxiety. In each case, a one-sample *t* test was used to compare the value of the overall effect to zero.

An overall *Q* value, which represents the total amount of variance among the set of effect sizes, was calculated to test for homogeneity of variance among the effect sizes. This value was tested against a χ^2 distribution, in which $df = k - 1$, where k = number of effect sizes. A significant Q value would indicate that the data are heterogeneous, and warrant the examination of moderator variables by partitioning the variance into Qw and Qb. Qb values are also tested against a χ^2 distribution, in which df = number of categories of the moderator variable − 1. A significant Qb value indicates that the moderator variable contributes to the variance among effect sizes. Weighted effect sizes and standard errors were then calculated for each category within the moderator variables, along with 95% confidence intervals (Hedges, 1994). For each moderator variable that revealed a significant Qb test, pairwise comparisons between all effect sizes were examined, which indicate whether the effect sizes are significantly different from one another (Hedges & Olkin, 1985).

Dose–Response Analysis

The volume of exercise used in each study was estimated in units of energy ($kcal \cdot kg^{-1} \cdot week^{-1}$) expended during exercise, assuming 5 kcal per milliliter of O_2 consumed. Total O_2 consumed per kilogram per week was calculated as

$$\text{Total } O_2 \text{ consumed} = (VO_{2max}) \times (\text{intensity}) \times (\text{bout duration}) \times (\text{frequency})$$

where total O_2 units are $mL \cdot kg^{-1} \cdot week^{-1}$, VO_{2max} units are $mL \cdot kg^{-1} \cdot min^{-1}$, average exercise bout intensity is in $\%VO_{2max}$, average bout duration is in minutes, and exercise frequency is number of exercise bouts per week. Only those studies reporting VO_{2max} were used, and pre- and postintervention VO_{2max} measurements were averaged in the calculation (Powers & Howley, 2003).

After calculating exercise dose, the data were examined for outliers. Any exercise dose that was greater than three standard deviations away from the mean were considered outliers, and were removed from the analysis. Pearson's product–moment correlation was then calculated between exercise dose and the corresponding effect sizes for the exercise groups. In addition, regression analysis was used to further examine the relationship between exercise dose and effect size.

Results

Exercise Versus No-Treatment Controls

A total of 140 studies were located for possible inclusion in the analysis. Of these 140 studies, 63 met inclusion criteria, and 43 had sufficient information for calculation of effect sizes. Corresponding authors from the remaining 20 studies were contacted and asked to provide additional data that would allow for effect size calculation. Correspondence was received from a number of authors, six of whom were able to provide sufficient data for effect size calculation, resulting in 49 studies in the final analysis. In total, 3,566 individuals participated in the 49 studies that were included in the analysis. The overall weighted effect size was –0.48 (95% confidence intervals –0.63, –0.33), which is significantly different from zero. This indicates that people in exercise groups experienced 1/2 of a standard deviation larger reduction in anxiety than people in control groups. The average standard deviation on the State Trait Anxiety Inventory (Spielberger & Krasner, 1988), which was the most commonly used measure in these studies, was 7.13 points. An effect size of –0.48 indicates that, on average, anxiety scores for people in exercise groups will drop 3.42 more points than people in nonexercising control groups.

Moderator Variables

The mean intercoder reliability rate (Cronbach's α) was found to be 0.93, and the test for homogeneity of variance was found to be significant, $Q = 136.67$, $p < .001$, thus warranting the examination of moderator variables. Only three *Qb* values were found to be significant, and pairwise comparisons revealed four significant differences between moderator variable categories: Unpublished studies had significantly higher effect sizes than published studies, participants who were 31–45 years old had significantly higher effect sizes than those who were 45 years and above, and participants who exercised 3–4 times per week had significantly higher effect sizes than those who exercised 1–2 times per week or 5+ times per week.

Further analysis of moderator variables revealed that four group effect sizes were found to be nonsignificantly different from zero: The effect sizes for participants who were under 18, for participants who exercised either 1–2 times per week or 5+ times per week, and for those who had fitness improvements of 6–10%. It should be noted, however, that all four of these categories, along with many others, contain few effect sizes. More randomized trials in such areas may reveal significant moderators of the relationship between exercise and anxiety in the future. Further results from the analysis of moderator variables are presented in Table 1.

Gains Effect Sizes

Forty-two studies included enough information for calculation of gains effect sizes. The overall weighted gains effect size for control groups was –0.08, (95% CI = –0.13, –0.04). The overall weighted gains effect size for exercise groups was –0.43, (95% CI = –0.46, –0.36).

File Drawer Test

A file drawer test (Hunter & Schmidt, 2004) was conducted to examine the potential impact of unpublished studies that were not included in the meta-analysis. This test revealed that it would take 120 missing randomized, controlled trials, all showing null results, to reduce the magnitude of the overall effect size to –0.15, which, under the current confidence intervals, would be a nonsignificant effect. Furthermore, the fact that unpublished studies had higher effect sizes in this meta-analysis shows that the potential for publication bias in this area is small.

Exercise Versus Other Treatments

A total of 27 randomized, controlled trials compared an exercise group to some other form of treatment for anxiety. The types of treatment that were compared with exercise are listed in Table 2. These studies resulted in 28 effect sizes, a population of 1,924 participants, and an overall effect size of –0.19. This effect size was found to be significantly different from zero, $t(27) = -2.21$, $p < .05$, indicating that

Table 1 Moderator Variables of the Relationship Between Exercise and Anxiety

df	*Qb*	Category	*k*	Effect size	*SE*	95% CI
		Gender				
2	1.86	Mixed	37	–0.41	0.04	–0.50, –0.33*
		Male	6	–0.53	0.14	–0.81, –0.25*
		Female	6	–0.31	0.09	–0.49, –0.12
		Age				
3	8.28*	<18	3	–0.18	0.16	–0.49, 0.12
		18–30	10	–0.50	0.08	–0.66, –0.34*
		31–45	17	–0.51[a]	0.07	–0.65, –0.37*
		>45	17	–0.31[b]	0.06	–0.42, –0.19*
		Population				
1	0.44	Clinical	3	–0.52	0.18	–0.87, –0.17*
		Nonclinical	46	–0.40	0.04	–0.47, –0.32*
		Type of exercise				
2	4.03	Aerobic	44	–0.40	0.04	–0.48, –0.32*
		Anaerobic	1	–1.15	0.40	–0.37, –1.94*
		Combined	2	–0.52	0.16	–0.83, –0.21*
		Intervention duration				
3	2.74	Acute bout	8	–0.39	0.10	–0.59, –0.18*
		4–9 weeks	8	–0.59	0.11	–0.81, –0.36*
		10–14 weeks	14	–0.40	0.07	–0.53, –0.26*
		15 + weeks	18	–0.38	0.06	–0.49, –0.27*
		Frequency				
2	16.37*	1–2 times/week	5	–0.16[a]	0.10	–0.34, 0.03
		3–4 times/week	32	–0.51[b]	0.05	–0.42, –0.61*
		5+ times/week	3	–0.13[a]	0.13	–0.38, 0.12
		Exercise bout duration				
2	2.67	1–30 min	23	–0.41	0.05	–0.51, –0.30*
		31–60 min	16	–0.31	0.06	–0.44, –0.19*
		61–90 min	3	–0.61	0.20	–0.99, –0.22*
		Exercise intensity				
1	0.89	Moderate†	13	–0.31	0.07	–0.44, –0.17*
		Hard††	15	–0.40	0.06	–0.47, –0.32*
		VO_{2max} improvements				
2	0.59	1–5% increase	3	–0.26	0.12	–0.48, –0.02*
		6–10% increase	4	–0.22	0.15	–0.52, 0.06
		11% + increase	11	–0.33	0.07	–0.48, –0.19*
		Sources				
1	4.48*	Journal	41	–0.37 [a]	0.04	–0.45, –0.29*
		Unpublished	8	–0.61 [b]	0.11	–0.82, –0.40*

Note. Differing superscripts indicate that pairwise comparisons revealed significant differences between the effect sizes.

*$p < .05$.

†Moderate = 40–59% VO_{2max}/HRR or 55–69% HR max.

††Hard = 60–84% VO_{2max}/HRR or 70–89% HR max.

Table 2 Effect Sizes of Types of Treatment Compared With Exercise

Treatment	*k*	Effect size
Cognitive/behavioral therapy	2	0.00
Group therapy	3	–0.09
Light exercise (stretching, yoga)	6	–0.15
Relaxation/meditation	9	–0.23
Stress management education	5	–0.45
Pharmacotherapy	2	0.11
Music therapy	1	–0.05
Total:	28	–0.19*

*One-sample t test, $p < .05$

exercise is slightly, yet significantly, better at reducing anxiety than other common forms of treatment. Exercise was found to be equal to, or better than, all of the other forms of treatment except pharmacotherapy; the effect size for pharmacotherapy was 0.11, which is considered to be very small. Further results from this analysis are summarized in Table 2.

Studies With Insufficient Data

There were 14 randomized, controlled trials that examined the effects of exercise on anxiety for which no effect size was able to be calculated. Of these 14 studies, 12 showed results indicating that participation in exercise resulted in lower anxiety scores when compared with controls. Nine of these 12 studies showed results that were statistically significant ($p < .05$), whereas the other three showed nonsignificant anxiety reductions in exercise groups compared with control groups.

Dose–Response Analysis

Twelve of the randomized, controlled trials provided adequate information to examine a dose–response relationship. Because some of the studies included multiple exercise groups, there were a total of 21 "doses" of exercise that could be examined in this analysis. One outlier was excluded from the analysis; the exercise dose for this study was more than 4 standard deviations above the mean. Pearson's product–moment correlation between exercise dose and effect size was found to be nonsignificant, $r = .00$. Multiple regression analysis revealed that a quadratic trend explained the largest amount of variance, R^2 *Multiple* = 0.185, but this model was not statistically significant, $F(2, 18) = 1.92$, $p > .05$. The trend in the data showed that effect size magnitude increased as exercise approached a dose of 12.5 $kcal \cdot kg^{-1} \cdot week^{-1}$, and then began to decrease as exercise dose increased. These data are displayed in Figure 1.

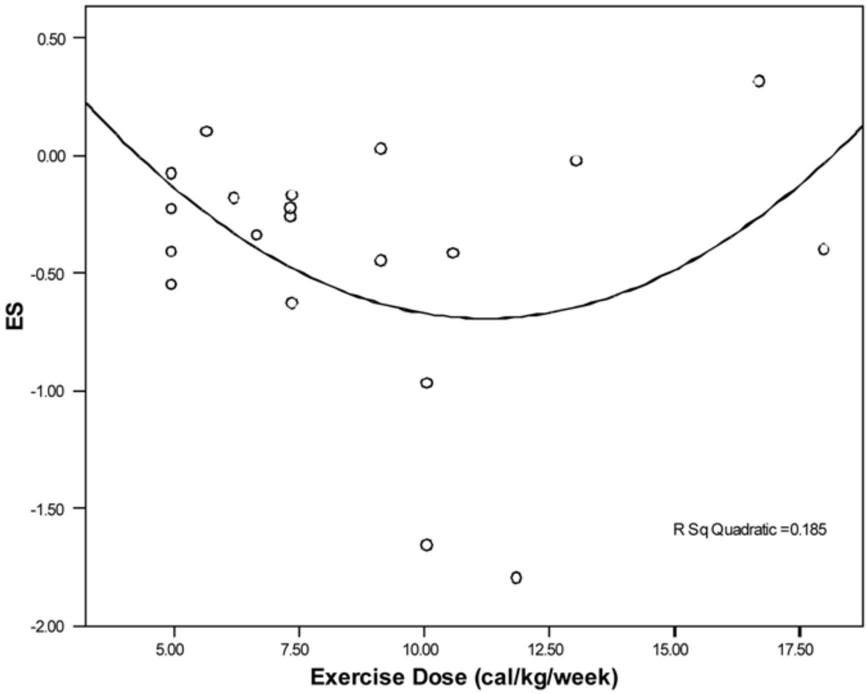

Figure 1 — The relationship between exercise dose and effect size.

Discussion

The effect size of –0.48 for exercise groups compared with control groups represents Level 1, Grade A evidence for using exercise as a treatment for anxiety disorders. These results indicate that exercise alone can be effective at reducing anxiety because none of these studies included groups that combined exercise with some other form of treatment. In addition, the comparison of exercise to other forms of treatment revealed that exercise is as effective, and nearly as effective as the two most common treatments for anxiety disorders—psychotherapy and pharmacotherapy, respectively. This finding supports the use of exercise as one of the frontline treatments for anxiety. In addition, research in the area of depression has shown that the combination of pharmacotherapy and exercise is also effective for reducing depression, and may therefore be effective for reducing anxiety as well (Blumenthal et al., 1999).

As mentioned earlier, self-report questionnaires were the only measure of anxiety included in this meta-analysis. Self-report measures are often criticized for potential bias in the form of behavioral artifacts. It may be worthwhile to note, therefore, that the results of this meta-analysis are supported by animal literature. Animal research is able to provide an unbiased look at some of the mental variables that have shown an association with exercise. For example, mice that are depressed and anxious tend to show less free-roaming behavior, less sexual activity, and gain weight, which are also common symptoms of humans who are depressed and/or anxious. After an exercise training program, these animals will show behavioral changes, such as more free roaming, more sexual activity, and weight loss, which are considered to be unbiased measures of changes in anxiety and/or depression. (Landers & Arent, 2007).

The overall effect size that was found in this meta-analysis is similar, yet slightly larger, than the effect sizes that were found in previous meta-analyses. This is consistent with findings from earlier meta-analyses that showed larger effect sizes for studies that used random assignment to groups, which is one marker of study quality. Attrition rates may provide another indication of study quality. The average attrition rate for exercise groups in this meta-analysis was 7.1%, whereas the average attrition rate for control groups was 4.4%. The attrition rates indicate that the randomized, controlled trials in the analysis were high-quality studies, and also show that exercise is an effective, viable option for alleviating symptoms of anxiety. The majority of the population in this study, however, was not receiving clinical treatment, and future studies should focus on exercise among those with clinically diagnosed anxiety disorders.

The analysis of moderator variables indicates the strength and consistency of the results. It should also be noted that reductions in anxiety occurred with minimal improvements in VO_{2max}; also notable, however, is the increase in effect size that occurred as fitness improvements increased to 11% or higher improvement. These results show that exercise can be useful for reducing symptoms of anxiety in practically any population, and in any dose. The different effect sizes that were seen at varying exercise frequencies are likely a result of the small number of studies in the 1–2 times per week and 5+ times per week categories. The data for participants 31 to 45 years old compared with participants 45 years old and above, however, comes from a larger number of studies. Although the pairwise comparisons revealed this difference to be statistically significant, the significance of this difference in an applied setting is minimal. Exercise was effective in both of these groups, and the effect sizes are similar in magnitude. Even though these results could be interpreted as simply showing that something is better than nothing, the comparison of exercise to other treatments, such as stress management and education, provides a refutation to this interpretation.

Some trends emerged in the analysis of moderator variables that may have reached statistical significance with more effect sizes in certain categories. For example, groups that exercised either 61–90 min per session experienced larger reductions in anxiety (effect size = –0.61) than groups who exercised for 1–30 or 31–60 min per session (effect sizes = –0.41, and –0.31, respectively). Despite the disparity between these effect sizes, the differences did not reach statistical significance. This trend seems to indicate that more exercise leads to greater reductions in anxiety, which led to the question of whether a dose–response relationship could be established from the randomized, controlled studies that were used in the analysis.

Although the R^2 in the dose–response analysis was relatively robust, explaining 18.5% of the variance in effect size, the quadratic trend did not show significance. The nadir of this curve occurs at approximately 12.5 kcal·kg^{-1}·week^{-1}, which is slightly lower than the current public health dose that has been recommended by the American College of Sports Medicine and Centers for Disease Control for physical health (Pate et al., 1995). Unfortunately, the sample size for the dose–response analysis was relatively small; only 24% (12/49) of the randomized, controlled trials that were included in the analysis provided adequate information to calculate an exercise dose. In addition, nearly half of the effect sizes in the meta-analysis were derived from studies that did not report the intensity of exercise used. Detailed information in more studies would likely have led to stronger conclusions to be drawn from the dose–response analysis in this study. Furthermore, if research in this area is to have any clinical significance, it is crucial that future studies provide both a clear description of the exercise paradigm that was used, and provide detailed information about the quantity of exercise that was used.

It should also be noted that the studies that were included in the meta-analysis used a fairly homogeneous set of interventions, as evidenced by the large discrepancies in the number of effect sizes in certain categories. For example, the majority of studies examined aerobic exercise in a nonclinical population, with a frequency of 3–4 times per week. Many of the moderator variables may have shown significant differences, and the dose response analysis may have been able to yield more conclusive results, had there been more variation among the exercise paradigms. Future research should attempt to fill some of the gaps that are present in the literature. Specifically, it may be beneficial to examine the effects of both low and maximal intensity exercise on anxiety, or for more studies to examine the effects of anaerobic exercise on anxiety in randomized, controlled trials. It is also crucial that future research be conducted with clinical populations. Clinical patients are the people who potentially have the most to gain from this type of research, and the effect size for clinical populations from this meta-analysis (−0.52) supports the recommendation to use exercise as a method of treatment for anxiety disorders. This effect size, however, is based upon only three studies, and additional studies with clinical populations would provide a much stronger recommendation.

Evidence showing that exercise can help alleviate anxiety and depression is fairly strong, but the methods by which exercise affects anxiety and depression remain largely unknown, providing another area of concentration for future research. There are numerous theories that have been proposed, both psychological and physiological. Some of the explanations, such as the thermogenic hypothesis, the time-out hypothesis, the Pitts–McClure hypothesis, and the behavioral artifact hypothesis have not been supported in the literature, and are no longer considered tenable (Landers & Arent, 2007). The literature investigating these hypotheses has been summarized by Landers and Arent (2001). There are many psychological theories that are still under investigation, including increases in self-esteem, self-concept, and self-efficacy. Physiological hypotheses that have been developed to explain the anxiolytic and antidepressive effects of exercise include the brain-derived neurotrophic factor hypothesis, the endorphin hypothesis, the endocannabinoid hypothesis, the hypothalamic-pituitary-adrenal axis hypothesis, and the norepinephrine hypothesis. These hypotheses remain tenable and are supported primarily by animal models, but a paucity of research has examined these hypotheses in humans (Landers & Arent, 2007).

Conclusions

In conclusion, the evidence presented in this meta-analysis provides support for using exercise for the alleviation of anxiety. Because only randomized, controlled trials were included in the analysis, this study presents Level 1, Grade A evidence for the use of exercise as a treatment for anxiety disorders. Although the dose–response analysis portion of this study does not show a definitive relationship between amount of exercise and reductions in anxiety, the quadratic shape of the curve may give a good indication of the relationship, and it is consistent with current physical activity recommendations. Future research in the area should focus on varied exercise paradigms, attempt to use a clinical population whenever possible, and attempt to examine multiple doses of exercise in an experimental setting. Research with humans into the mechanisms by which exercise can reduce anxiety may also be useful in the future.

References

Note. References preceded by an asterisk are listed in the appendix table that follows.

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Manuscript submitted: January 18, 2007
Revision accepted: March 29, 2008

Appendix Table Characteristics of Studies Used in the Meta-Analysis

Author (year)[a]	Average corrected effect size	Exercise type	Age (mean or range)	*N*	Gender	Intervention duration (weeks)	Bout duration (minutes)	Frequency (times/week)
Antunes (2005)	−0.89	Aerobic	66.97	46	Male	24	20	3
Bahrke (1978)	0.29	Aerobic	51.9	75	Male	Acute	20	Acute
Bahrke (1985)	−0.13	Aerobic	10.7	65	Mixed	Acute	15	Acute
Bartholomew (2005)	0.04	Aerobic	38.1	40	Mixed	Acute	30	Acute
Berger (1988)	−0.35	Aerobic	19	153	Mixed	12	20	3
Blumenthal (1991)	−0.31	Aerobic	67	101	Mixed	16	30	3
Blumenthal (2005)	−0.33	Aerobic	63	142	Mixed	16	45	3
Broocks (1998)	−1.40	Aerobic	46	37	Mixed	10	NA	3
Brown (2001)	−0.54	Aerobic	42	104	Female	8	20	5
Castro (2002)	−0.18	Aerobic	62	85	Female	52	30	3
Cramer (1991)	−0.40	Aerobic	34	35	Mixed	15	45	5
Crocker (1991)	−1.33	Aerobic	20	85	Mixed	Acute	40	Acute
De Geus (1990)	−0.18	Aerobic	23.7	26	Male	7	90	4
Deivert (1990)[b]	−2.33	Aerobic	31	40	Mixed	8	20	3
DePalma (1989)[b]	−0.93	Aerobic	20.27	77	Mixed	12	20	3
DiLorenzo (1998)	−0.51	Aerobic	32	111	Mixed	12	24	4
Doan (1995)	−0.08	Aerobic	19	52	Mixed	Acute	15	Acute
Dugmore(1999)	−0.57	Combined	55	124	Mixed	52	NA	3
Eby (1984)[b]	0.08	NA	19–31	39	Mixed	NA	60	3
Emery (1998)	−0.28	Aerobic	66.6	74	Mixed	10	45–90	3–5
Gowans (2001)	−1.14	Aerobic	47	31	Mixed	23	30	3
Gowans (2002)	−0.92	Aerobic	47	31	Mixed	23	30	3
Hilyer (1982)	−0.39	Combined	15–18	43	Male	20	90	3
Jorgensen (1986)[b]	−0.27	Aerobic	36.4	11	Mixed	6	60	3
King (1989)	0.31	Aerobic	48	113	Mixed	24	50	5
King (1993)	−0.28	Aerobic	50–65	300	Mixed	52	40	3

(continued)

Appendix Table *continued*

Author (year)[a]	Average corrected effect size	Exercise type	Age (mean or range)	*N*	Gender	Intervention duration (weeks)	Bout duration (minutes)	Frequency (times/week)
Koukouvou (2004)	–1.74	Aerobic	52.5	26	Male	24	60	3
Lion (1978)	–0.55	Aerobic	NA	6	Mixed	8	NA	3
Lobitz (1983)	–0.99	Aerobic	36.5	18	Mixed	7	NA	3
Long (1984)	–1.02	Aerobic	39.9	73	Mixed	10	90	3
McEntee (1999)	–0.53	Aerobic	NA	70	Mixed	6	20	3
Newton (1991)	–0.41	Aerobic	<70	22	Mixed	10	60	3
Norris (1992)	–0.08	Aerobic	16.5	80	Mixed	10	25	2
Norvell (1993)	–1.15	Anaerobic	32.84	29	Male	16	20	3
Petajan (1996)	0.11	Aerobic	40	46	Mixed	15	50	3
Pierce (1993)	–0.25	NA	45	99	Mixed	16	50	3
Roth (1987)	–0.02	Aerobic	18.9	36	Mixed	11	30	3
Roth (1989)	–0.83	Aerobic	20.8	80	Mixed	Acute	20	Acute
Roth (1990)	0.07	Aerobic	20.5	57	Female	Acute	10	Acute
Setaro (1985)[b]	–1.38	Aerobic	18–35	75	Mixed	10	NA	2
Sorensen (1999)	–0.50	Aerobic	44.9	219	Mixed	52	60	3
Taylor (1991)[b]	–0.21	Aerobic	39.1	102	Female	6	20	3
Thaxton (1982)	–0.84	Aerobic	36	33	Mixed	Acute	30	Acute
Thorsen (2005)	0.10	Aerobic	39.1	111	Mixed	14	30	2
Van den Berg-Emons (2004)	–0.17	Aerobic	58.6	34	Mixed	12	60	2
Veale (1992)	–0.58	Aerobic	35.5	83	Mixed	12	NA	3
Williams (1997)	–0.15	Aerobic	71.7	187	Female	42	60	2
Wilson (1985)[b]	–1.28	Aerobic	31	34	Female	16	40	3
Zentner (1981)[b]	–0.12	Aerobic	41	40	Mixed	10	60	3

[a]The citations are found in the References section.

[b]All the articles were published in journals; the unpublished citations bear the superscript *b*.