AN ACUTE BOUT OF MODERATE-INTENSITY AEROBIC EXERCISE ENHANCES REAPPRAISAL AND REDUCES EMOTIONAL REACTIVITY TO ANXIETY-RELATED STIMULI IN INDIVIDUALS WITH ELEVATED ANXIETY SENSITIVITY

By

Kenan G. Sayers

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Psychology – Master of Arts

2024

ABSTRACT

Anxiety disorders are the most common mental disorders in the U.S. and rates have been steadily increasing in young adults (18-25 years old). Anxiety sensitivity (AS) is a transdiagnostic risk factor that can be modified through intervention. Exercise has been shown to be an effective treatment for AS, but how exercise leads to these changes in AS remains unknown. Thus, the purpose of this study was to examine whether cognitive reappraisal is a mechanism that explains exercise induced changes in AS. Using a randomized within-subjects crossover design in a sample of 27 college-aged females with elevated AS, measures of reappraisal and AS were assessed before and after 20-min of either an acute bout of moderate intensity aerobic exercise or a cognitively engaging control condition during two separate, counterbalanced sessions. A computer-based electroencephalogram (EEG) reappraisal task was used to assess reappraisal, which was indexed by the late-positive potential (LPP) amplitude. Contrary to expectations, results showed a significant increase in LPP amplitude for reappraisal trials after the exercise intervention compared to the control. Interestingly, however, results showed a significant decrease in LPP amplitude while participants passively viewed anxiety-related images following exercise compared to the control. No significant changes in AS were observed in either group. Thus, the results confirm that an acute bout of aerobic exercise leads to changes in purported mechanisms of action in AS – namely, increased cognitive reappraisal and decreased emotional reactivity – despite the lack of immediate reductions in self-reported AS symptom.

ACKNOWLEDGEMENTS

I would like to express my appreciation to my Thesis Committee, Dr. Jason Moser, Dr. Matthew Pontifex, and Dr. Katy Thakkar, for challenging me, encouraging me, and supporting me throughout this process. I want to give special thanks to Dr. Pontifex for allowing me to use his lab to run my study. I'm sincerely grateful.

TABLE OF CONTENTS

Introduction

Anxiety disorders affect 19.1% of the population yearly, making them the most common psychiatric disorders (National Alliance on Mental Illness, n.d.). Anxiety has been steadily increasing in all U.S. adults, with a particularly rapid increase occurring in the young adult population (ages 18-25; Goodwin et al., 2020). Anxiety sensitivity (AS), defined as the fear of experiencing arousal related body sensations based on catastrophic beliefs that these sensations could be dangerous (Reiss et al., 1986), has been identified as a key transdiagnostic risk and maintenance factor for anxiety pathology (Schmidt et al., 2010; Boswell et al., 2013; Blakey et al., 2017; Baek et al., 2019; Ojalehto et al., 2021; Warren et al., 2021). Importantly, AS is malleable and thus has been a focus of treatment research in recent years. In particular, several studies have examined the effects of exercise interventions on AS, showing positive effects with just brief, acute bouts of aerobic exercise (Broman-Fulks et al., 2015; LeBouthillier & Asmundson, 2015; Mason & Asmundson, 2018). However, little research has explored the mechanisms involved in exercise's salutary effects on AS. The current study investigates whether cognitive reappraisal might be a mechanism whereby exercise improves AS, using a combined self-report and EEG approach.

Several biological and psychological theories have been proposed to explain the mechanisms involved in exercise's effects on anxiety. One theory that has gained continuous support is that exercise promotes cognitive reappraisal, or the ability to change the salience and meaning of a stimulus, through interoceptive exposure. Interoceptive exposure involves exposing an individual to their fears (e.g., increased heart rate) to induce anxiety and challenge catastrophic beliefs (increased heart rate = heart attack) in a safe situation where they can learn that anxiety symptoms naturally decrease and feared outcomes do not occur (e.g., increased heart rate ≠ heart attack). Catastrophic or threat appraisals of physiological sensations (e.g., increased heart rate = heart attack) are a core aspect of AS, and research has shown that modifying these appraisals is critical to reducing AS (Kashdan et al., 2008; Hilchey & Clark, 2014). Interoceptive exposure is a common evidence-based technique for modifying appraisals of physiological sensations and is a recommended therapeutic treatment technique for AS (Taylor, 2019).

Exercise is a unique method to reduce AS because unlike other exposure-based techniques for anxiety (e.g., breathing through a straw (induces shortness of breath) or spinning in a chair (induced dizziness)), exercise can induce several physiological sensations simultaneously (e.g., sweating, shortness of breathing, increased heart rate, etc.). Several studies have demonstrated exercise's efficacy as an interoceptive exposure. Important to the aims of the current project, research has shown that exercise, both chronic and acute bouts, can reduce AS (Stathopoulou et al., 2006; Smits et al., 2008; LeBouthillier & Asmundson, 2015; Sabourin et al., 2016; Mason & Asmundson, 2018; Plag et al., 2019; O'Neill & Dogra, 2020), presumably because it may function as an interoceptive exposure that induces feared physiological sensations (e.g., increased heart rate, sweating, etc.; Sabourin et al., 2015; Bischoff et al., 2018). Further, exercise is recommended as a naturalistic exposure for individuals with high AS, which refers to exposure to daily tasks or activities that have been avoided or endured with dread because of the associated sensations (Craske & Barlow, 1993). Thus, exercise and related interoceptive exposures can induce a learning process whereby physiologic sensations are reappraised as less threatening in individuals with high AS.

While research has investigated the efficacy of exercise for reducing anxiety and transdiagnostic factors, such as AS, studies directly testing whether reappraisal might serve as a mechanism in reducing AS are lacking. One way to evaluate mechanisms of interventions like exercise is through event-related potentials (ERPs), signals derived from human EEG that assess how people react to specific stimuli with millisecond precision. One ERP used to assess appraisals of threatening stimuli is the late positive potential (LPP), an ERP component that is associated with emotional reactivity and arousal (Hajcak & Foti, 2020; Hajcak et al., 2010; MacNamara et al., 2022). The LPP has been used in prior studies of anxiety and reappraisal processes. For example, Allan et al. (2019) found that the LPP to AS-related images was larger in females who reported greater AS symptoms. Moreover, the amplitude of the LPP is sensitive to the appraisal of emotional stimuli such that more threatening appraisals are associated with larger LPPs and less threatening appraisals are associated with smaller LPPs (for a review see MacNamara et al., 2022). Specifically, when people are instructed to view negative images from a more immersed or personal perspective, the LPP amplitude is increased (Moser et al., 2009) whereas when people are instructed to view images from a more distanced or impersonal perspective the LPP amplitude is decreased (Qi et al., 2017). Further, habitual reappraisal is associated with reduced LPP amplitude to negative images (Moser et al., 2014), even in the absence of explicit emotion regulation instructions (Harrison & Chassy, 2017). Thus, the LPP is an ideal index to use to examine the effects of exercise on appraisal processes in AS.

Therefore, the primary aim of this study was to examine cognitive reappraisal as a mechanism of change following exercise for people with elevated AS. This study utilized an acute bout of exercise paradigm to directly test whether exercise leads to increased reappraisal of anxiety-related stimuli in individuals with elevated AS. Importantly, the use of ERP data, specifically the LPP, allows for the direct testing of the reappraisal mechanism, a mechanism that has yet to be examined in the exercise and AS literature. We hypothesized that exercise is a form of interoceptive exposure that will lead individuals with elevated AS to reappraise threatening stimuli more effectively. Successful reappraisal will be operationalized as a decrease in LPP amplitude to anxiety-related images during reappraisal trials. We predicted there would be a decrease in this reappraisal modulated LPP amplitude from pre-intervention to post-intervention timepoints in the exercise condition, but not the control condition. Second, we predicted significant reductions in self-report scores of AS in the exercise group but not the control condition. As an exploratory aim, we predicted that reappraisal success, as measured by the LPP, would mediate the positive effect of exercise on AS.

Method

Participants

Analyses were conducted on a sample of 27 college-aged females (mean age: 19.59 ± 1.60, 27 female) from Michigan State University. Participants were recruited via flyer advertisements posted in the community and on social media platforms (Facebook and Snapchat) as well as Michigan State University's Psychology research participant pool. The screening battery consisted of 1) the Physical Activity Readiness Questionnaire (Thomas et al., 2007) to assess physical health and ensure it was safe for each individual to participate in exercise, 2) the Anxiety Sensitivity Index-3 (Taylor et al., 2007) to assess levels of anxiety sensitivity, and 3) the Godin Leisure-Time Physical Activity Questionnaire (GLTPAQ: Godin, 2011) to assess self-reported activity levels of each prospective participant. To be enrolled in the study, participants had to score a 23 or greater on the Anxiety Sensitivity Index-3. The cut-off score of 23 was selected based on recent research that individuals with scores at or above 23 on the ASI-3 are classified as having elevated anxiety sensitivity (Allan et al., 2014a, 2014b). Moreover, participants were included if they denied all items on the PAR-Q, indicating they were healthy to engage in exercise. Finally, the GLTPAQ was used to determine self-reported physical activity. Those with a score of 85 or lower, indicating they did not engage in significant exercise, were included in the study. An original sample of 49 participants were recruited and completed both sessions at the time of analyses. However, only individuals who had enough EEG data for all 4 time points were included in the study. Timepoints were excluded if: 1) they had too many electrodes removed during pre-processing to be able to run proper analyses, and 2) if 5 or more reappraise negative or view negative trials were removed during pre-processing during any of the 4 time points. All experimental protocols were approved by the Institution Review Board at Michigan State University and all methods were carried out in accordance with those protocols and relevant guidelines and regulations regarding the use of human subjects. Demographic data is provided in Table 1.

Measures

Anxiety Sensitivity Index-3 (ASI-3; Taylor et al., 2007) is a validated 18-item measure that is used in both athlete and non-athlete populations to assess levels of anxiety sensitivity. There are 3 subscales: Physical Concerns, Cognitive Concerns, and Social Concerns. Each subscale has 6 questions that correspond to each scale. The Physical Concerns subscale includes questions that assess somatic sensations such as “When my stomach is upset, I worry that I might be seriously ill” and “It scares me when my heart beats rapidly.” The Cognitive Concerns subscale includes questions that assess one’s beliefs about cognitive related experiences, such as “When I feel ‘spacey’ or spaced out I worry that I may be mentally ill” and “When I have trouble thinking clearly, I worry that there is something wrong with me.” The Social Concerns subscale assesses one’s beliefs about social situations and includes items such as “When I begin to sweat in a social situation, I fear people will think negatively of me” and “When I tremble in the presence of others, I fear what people might think of me.” Total scores range from 0 to 72 with each question having 5 answer options that range in value from 0 (Very Little) to 4 (Very Much). Scores are calculated by summing all 18 items with higher scores indicating higher anxiety sensitivity. This measure has been shown to be reliable and valid in adult populations (Taylor et al., 2007; Kemper et al., 2011; Jardin et al., 2018).

Stimuli

Neutral images were taken from the International Affective Picture System (IAPS; Center for the Study of Emotion and Attention, 1999; pictures used: 5510, 6150, 7002,7003, 7004, 7009, 7017, 7021, 7025, 7026, 7035, 7041, 7052, 7055, 7056, 7059, 7080, 7100, 7150, 7160, 7211, 7235,7700, 7950). The neutral images consisted of everyday household items. AS-related images included images that related to one of the three AS subscales and were taken directly from Allan et al., (2019). Images relating to the physical concerns subscale included scenes of individuals experiencing physical symptoms of anxiety (i.e., man with his hand on his chest as if he were having a heart attack). Images related to the social concerns subscale included scenes of individuals with observable symptoms of anxiety (i.e., man sweating in public in the absence of exercise). Images relating to the cognitive concerns subscale included scene of individuals who appeared to be unable to control their thoughts or experiencing cognitive dyscontrol (i.e., woman yelling while holding her head in her hands). Participants viewed 24 AS-related images and 24 neutral images.

Reappraisal Task

For the reappraisal task, participants viewed AS-related images and neutral images and were prompted to either passively view the images or reappraise the images (see Moser et al., 2014 for similar methods). For the passive viewing conditions, participants saw the prompt “View Negative” for AS-related images or “View Neutral” for neutral images. During these trials, participants were instructed to simply view the images and allow any emotions to arise without trying to change them. Neutral stimuli were primarily included so as to reduce habituation to the AS-related images, as well as provide a break from the AS-related content. For the reappraisal trials (AS-related images only), participants saw the prompt "Reappraise Negative" and were instructed to view the image acknowledging that the reactions they were having would pass and that they would be alright. These instructions explicitly told the participants that they were not instructed what to feel, but rather provide instructions on how to think about the images. Further, participants were instructed to minimize their movement and to put their full attention on the screen for the duration of each trial. There were no reappraisal trials for neutral stimuli as is typical for reappraisal research (e.g., Moser et al., 2014) because changing reactions to stimuli that evoke no emotion is generally considered confusing or irrelevant. Full reappraisal task instructions can be found in Appendix A.

ERP Recording

EEG activity was recorded from 64 electrode sites (Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz, Fp1/2, F7/5/3/1/2/4/6/8, FT7/8, FC3/1/2/4, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, P7/5/3/1/2/4/6/8, O1/2) arranged in an extended montage based on the International 10-10 system (Chatrian et al., 1985) using a Neuroscan Quik-Cap (Compumedics, Inc., Charlotte, NC). Recordings were referenced to averaged mastoids (M1, M2), with AFz serving as the ground electrode. Additional electrodes were placed above and below the left orbit and on the outer canthus of both eyes to monitor electrooculographic (EOG) activity with a bipolar recording. Continuous data were digitized at a sampling rate of 1000 Hz and amplified 500 times with a DC to 70 Hz filter using a Neuroscan SynAmps RT Amplifier. The EEG data was then imported into EEGLAB (Delorme & Makeig, 2004) and prepared for temporal ICA decomposition. Data more than 2 s prior to the first event marker and 2 s after the final event marker were removed to restrict computation of

ICA components to task-related activity. The continuous data was filtered using a 0.05 Hz high-pass 2nd order Butterworth IIR filter to remove slow drifts (Pontifex, Gwizdala, et al., 2017), and the mastoids electrodes were removed prior to ICA decomposition. ICA decomposition was performed using the extended infomax algorithm to extract sub-Gaussian components using the default settings called in the MATLAB implementation of this function in EEGLAB with the block size heuristic (floor[sqrt(EEG.pnts/3)]) drawn from MNE-Python (Gramfort et al., 2013). Following the ICA decomposition, the eyeblink artifact components were identified using the icablinkmetrics function (Pontifex, Miskovic, et al., 2017) and the EEG data was reconstructed without the eyeblink artifact.

Following removal of the eye blink components, stimulus-locked epochs were created from –3,000 to 6,000 ms around the image, baseline corrected using the -500 to 0 ms pre-stimulus period and filtered using a zero phase shift low-pass filter at 30 Hz. Trials with artifact exceeding ±100 µV were rejected. To ensure the integrity of the signal, stimulus-locked epochs were visually inspected blind to the experimental condition and time point prior to computing mean waveforms. Following visual inspection, the mean number of trials included in the waveforms was 23.9 ± 0.3 trials for view-neutral trials, 12.0 ± 1.0 trials for view-negative trials, and 12.0 ± 1.0 trials for reappraise-negative trials. Given the well-established nature of the LPP elicited in response to this task, a nine-channel region-of-interest centering around the topographic maxima of the LPP (i.e., the CP1/Z/2, P1/Z/2, PO3/Z/4 electrodes) was created. LPP amplitude was evaluated from these regions of interest on view-neutral, view-negative, and reappraise-negative trials as the mean amplitude within a 400 to 700 ms, 700 to 1000 ms, and 1000 to 6000 ms window following the onset of the image.

Procedure

Using a within-participants design, participants came to the Health Behaviors and Cognition Laboratory at Michigan State University on two separate days to complete their sessions. On the first day, participants complete the informed consent and put on a Bluetooth heart rate sensor (Mio Link®, Mio Global, Canada). While their EEG cap was being fitted and prepped, participants completed a demographics questionnaire and a pre-intervention battery that included the ASI-3 and State-Trait Anxiety Inventory-State (STAI-S).

After completing the questionnaires and fitting the EEG cap, the participants completed the reappraisal task. Then, participants were randomly assigned to one of two session orders (day 1: sitting, day 2: exercise; or day 1: exercise, day 2: sitting) with each intervention (exercise/sitting) lasting 20 minutes. During each session, participants watched 20 minutes of a neutral video to reduce their attention to non-exercise related stimuli. Heart rate was recorded every two minutes during the exercise session using a Bluetooth heart rate sensor along with OMNI ratings of perceived exertion (RPE; 0 = no exertion – 10 = maximal exertion) (Robertson et al., 2000) and ratings of affect (-5 = Awful – 5 = Great). After the session, participants completed the reappraisal task and completed a post-intervention survey that consisted of the ASI-3 and STAI-S. (See Figure 1).

Statistical Analysis

All data analyses were performed in R Version 4 (R Core Team, 2019) utilizing a familywise alpha level of $p = 0.05$. To assess the effects of exercise on reappraisal, the difference in LPP amplitude between reappraise-negative and view-negative trials was examined using a 2 (Mode: control, exercise) × 2 (Time: pretest, posttest) × 3 (Window: 400, 700, 1000) univariate repeated measures multi-level model including the random intercept for Partid. A similar analysis was then conducted to assess the effects of exercise on emotional reactivity using the difference in LPP amplitude between view-negative and view-neutral trials. Analyses were conducted using the lme4 (Bates et al., 2023), lmerTest (Kuznetsova et al., 2020), MuMIn (Bartoń, 2023), emmeans (Lenth et al., 2024), and Rmimic (Pontifex, 2024) packages in R version 4.3.2.

The multi-level model analyses were performed using the Rmimic (Pontifex, 2020) package which provides a standardized implementation wrapper and automated post-hoc decompositions utilizing the lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and emmeans (Lenth et al., 2017) packages in R with Kenward-Roger degrees of freedom approximations and Benjamini-Hochberg false discovery rate control = 0.05 for post-hoc decompositions. Cohen's f^2 and d with 95% confidence intervals were computed as standardized measures of effect size, using appropriate variance corrections for within-subject (d_{rm}) comparisons (Lakens, 2013).

Given a sample size of 27 participants and beta of 0.20 (i.e., 80% power), the present research design theoretically had sufficient sensitivity to detect conventional t-test differences exceeding d = .49 (with a two-sided alpha) as computed using G*Power 3.1.2 (Faul et al., 2007).

Results

The racial and ethnic distribution of the sample was: 0 (0%) American Indian or Alaska Native, 1 (3.70%) Asian, 1 (3.70%) Black or African American, 1 (3.70%) Hispanic or Latino (Non-White), 0 (0%) Native Hawaiian or Other Pacific Islander, 23 (85.20%) White or Caucasian, 1 (3.70%) biracial or of other ethnicities.

LPP Data

Exercise on Reappraisal LPP

Analyses revealed an interaction of Mode × Time, $F(1, 285) = 9.0$, $p = 0.003$, $f^2 = 0.64$ [95% CI: 0.17 to 1.71].

Post-hoc decomposition of the Mode × Time interaction was conducted by examining the effect of Time within each Mode. In line with our hypothesis, no significant differences were observed between Posttest (0.2 ± 3.2) and Pretest (0.7 ± 2.4); $t(285) = 0.9$, $p = 0.38$, $d_{rm} = 0.25$ [95% CI: -0.31 to 0.81] LPP amplitudes in the control condition. Contrary to our hypothesis, a significant increase, rather than decrease, in LPP amplitude was observed between Posttest (1.8 ± 7.6) and Pretest (-0.5 ± 3.3) in the exercise condition; $t(285) = 3.4$, $p < 0.001$, $d_{rm} = 0.98$ [95% CI: 0.40 to 1.56]. (See Figure 3).

Secondary post-hoc decomposition of the Mode × Time interaction was conducted by examining the effect of Mode within each Time. For Pretest: No significant differences were observed between Control (0.7 ± 2.4) and Exercise (-0.5 ± 3.3); $t(285) = 1.8$, $p = 0.071$, $d_{rm} = 0.58$ [95% CI: -0.05 to 1.22]. For Posttest: The difference between Control (0.2 ± 3.2) and Exercise (1.8 ± 7.6) was statistically significant; $t(285) = 2.4$, $p = 0.016$, $d_{rm} = 0.56$ [95% CI: 0.11 to 1.01].

Exploratory Analysis: Exercise on Emotional Reactivity LPP

There was an interaction of Mode × Time, $F(1, 285) = 9.6$, $p = 0.002$, $f^2 = 0.21$ [95% CI: 0.0 to 0.64]. Post-hoc decomposition of the Mode × Time interaction was conducted by examining the effect of Time within each Mode. For Control: No significant differences were observed between Posttest (1.8 ± 3.0) and Pretest (2.4 ± 2.5); $t(285) = 1.2$, $p = 0.24$, $d_{rm} = 0.20$ [95% CI: -0.13 to 0.53]. For Exercise: The difference between Posttest (-0.5 ± 6.1) and Pretest (2.4 ± 2.8) was statistically significant; $t(285) = 5.6$, $p < 0.001$, $d_{rm} = 1.45$ [95% CI: 0.93 to 1.98]. Secondary post-hoc decomposition of the Mode × Time interaction was conducted by examining the effect of Mode within each Time. For Pretest: No significant differences were observed between Control (2.4 ± 2.5) and Exercise (2.4 ± 2.8); $t(285) = 0.1$, $p = 0.9$, $d_{rm} = 0.02$ [95% CI: -0.38 to 0.42]. For Posttest: The difference between Control (1.8 ± 3.0) and Exercise (-0.5 ± 6.1) was statistically significant; $t(285) = 4.3$, $p < 0.001$, $d_{rm} = 0.97$ [95% CI: 0.52 to 1.42]. (See Figure 3).

Mediation Analysis

Mediation analyses were conducted using the mediation (Tingley et al., 2014) and Rmimic (Pontifex, 2024) packages in R version 4.3.2. (See Figure 2 for the full mediation model).

Unstandardized indirect effects were computed using 1000 quasi-Bayesian approximation-based samples. The relationship between Condition and ASI-3 was not mediated by reappraisal (Proportion Mediated = 1.7% [95% CI: -250.7% to 201.5%]; Average Causal Mediation Effect = -0.08 [95% CI: -0.99 to 0.77], $p = 0.9$; Average Direct Effect = -0.82 [95% CI: -3.49 to 1.83], $p = 0.53$).Thus, the results do not support our hypothesis that reappraisal would mediate the relationship between exercise and changes in AS.

Self-Report Measures

ANOVA and t-tests were conducted using IBM SPSS Statistics (Version 28). Full descriptives for the self-report repeated measures variables can be found in Table 2.

Anxiety Sensitivity

To examine changes in AS based on Mode, a 2(Time: Pretest vs. Posttest) x 2(Mode: Exercise vs. Control) repeated measures ANOVA was conducted using IBM SPSS Statistics (Version 28). A significant main effect of Mode was observed $F(1, 26) = 7.677$, $p = .010$, $\eta_p{}^2 = .228$ on self-reported scores of AS (ASI-3). ASI-3 scores were lower in the exercise group irrespective of time-point. There was not a significant main effect of time $F(1, 26) = .274$, $p = .605$, $\eta_p{}^2 = .010$ or a condition by time interaction $F(1, 26) = .441$, $p = .512$, $\eta_p{}^2 = .017$. Thus, our hypothesis that significant reductions in AS scores would be observed in the exercise group but not the control group was not supported.

Manipulation checks

To confirm that we achieved a moderate intensity workout with our exercise intervention, two independent samples t-tests were conducted using IBM SPSS Statistics (Version 28) examining ratings of perceived exertion (RPE) and heart rate (HR). There were significant differences in HR $t(52) = -16.13$, $p < .001$, $d = -4.39$, [95% CI: -5.38 to -1.38] and RPE $t(52) = -5.51$, $p < .001$, $d = 1.44$, [95% CI: -2.95 to -1.38] between the exercise and control groups. This demonstrates that the exercise group provided participants with higher physiological activation and required greater physical exertion than the control group. No differences in self-report ratings of affect were observed between groups $t(52) = -.264$, $p = .793$, $d = -.072$, [95% CI: -.605 to .462]. See Table 3 for full descriptives.

Discussion

The primary aim of this study was to directly examine whether reappraisal is a mechanism of change for exercise induced changes in AS in individuals with elevated AS. Reappraisal success was determined by changes in LPP amplitude on reappraise negative trials compared to view negative trials. Contrary to our hypothesis, mean differences in LPP amplitudes to negative stimuli on reappraise trials were larger in the exercise condition than in the control condition. Thus, these results do not support our second hypothesis that exercise would lead to greater reductions in AS scores than the control. Further, reappraisal did not mediate the relationship between exercise and changes in AS scores. In an exploratory analysis, we did find that the LPP to negative versus neutral images during passive viewing was reduced following exercise compared to the control session.

Our first hypothesis that exercise is a form of interoceptive exposure that will lead individuals with elevated AS to reappraise threatening stimuli more effectively resulting in reduced LPP was not supported. Unexpectedly, the reappraisal LPP (i.e., reappraise negative – view negative) increased following exercise compared to the control session. Despite being unexpected, this finding is in line with other studies of anxiety that have shown an enlargement of the LPP following a successful course of cognitive behavioral therapy (Leutgeb et al., 2009; 2012; Moser et al., 2014). The authors attribute this potentiation of the LPP to an increase in engagement with the stimuli – i.e., reduced avoidance – which is undergirded by research demonstrating that the LPP is a measure of engagement with emotionally relevant stimuli (Hajcak & Foti, 2020). That is, it may be that following exercise, participants high in AS are better able to think differently about the stimuli in a less threatening way because they engage more strongly with the stimuli, allowing for greater reappraisal. Interestingly, we also found that the LPP to view negative trials decreases following exercise compared to the control condition. This finding is consistent with prior research that found that exercise can reduce emotional reactivity to negative stimuli as measured by LPP amplitude (Tartar et al., 2018). Together with the reappraisal LPP results, our data point to the possibility that exercise both increases cognitive engagement with emotional stimuli to facilitate reappraisal and decreases natural emotional reactivity.

Another explanation for the increased LPP on reappraise trials may involve exercise's effects on cognition. There is extensive support in the literature for a positive effect of acute exercise on cognition (for reviews see Basso & Suzuki, 2017; Pontifex, 2019), including in individuals with anxiety (Pontifex et al., 2021). Specifically, acute moderate-intensity aerobic exercise has been shown to free up cognitive resources and improve working memory (Pontifex et al., 2009; Quelhas Martins et al., 2013). Thus, the enhanced LPP in the exercise condition may be due to the fact that exercise improved working memory, which allowed participants to engage more strongly with the stimuli. This proposed explanation is supported by research demonstrating that exercise can promote stimulus engagement (Brush et al., 2020; Gomez-Pinilla & Hillman, 2014).

The findings from this study did not support our second hypothesis that exercise would lead to significant reductions in AS. These findings are inconsistent with prior research that demonstrated exercise's efficacy for reducing anxiety sensitivity (Stathopoulou et al., 2006; Smits et al., 2008; LeBouthillier & Asmundson, 2015; Sabourin et al., 2016; Mason & Asmundson, 2018; Plag et al., 2019; O'Neill & Dogra, 2020). The failure to replicate these findings may be due to the fact that that this design involved a single bout of exercise with no follow-up assessment of AS. Many of the studies investigating the effects of exercise on AS incorporated repeated bouts of exercise in their paradigms. However, results from LeBouthillier & Asmundson (2015) demonstrated a slight reduction in AS following an acute bout of exercise – quite a bit smaller than the effects of longer exercise programs (e.g., Smits et al., 2008). That said, LeBouthillier & Asmundson (2015) did find a continued gradual decline in AS a week out from the exercise session, suggesting that exercise has a delayed effect on AS such that immediate changes in AS are modest, but long-term reductions occur. Thus, it may be that if we followed our participants longer, we would observe a "sleeper" effect several days or weeks later.

There are several limitations that are worth discussing. One limitation is that the intervention consisted of a single bout of exercise, which means these results do not generalize to interventions that utilize repeated bouts of exercise. It's likely that long-term exercise interventions would have different effects on the psychophysiological and self-report data. Lastly, the study sample was 100% female and majority White (85.20%). Thus, these results do not generalize to other sexes or other racial or ethnically minoritized groups.

Future directions

One area for future research is to examine how exercise impacts the LPP in individuals who are clinically anxious. The participants in this study had high levels of AS according to the cutoffs developed by Allan and colleagues (2014a) but did not have to be diagnosed with an anxiety disorder. Thus, future research should examine the effects of exercise interventions on the LPP in individuals with anxiety disorders. Exercise has been shown to lead to positive changes in anxiety in individuals with various anxiety disorders (Asmundson et al., 2013). However, there hasn't been any research that looks at how exercise may influence the LPP in individuals with these disorders or changes in the LPP after exercise differ between anxiety disorders. This research could help determine if the anxiolytic effect of exercise in individuals with these disorders occurs via the same mechanism or via different mechanisms as those who score high on anxiety without receiving a diagnosis. This could ultimately aid in the clinical utility of exercise interventions by providing insight into how best to tailor exercise interventions based what mechanisms of action should be utilized for a client's presenting concerns.

Future research should also look at how long-term exercise programs, rather than single bouts, impact reappraisal responses using the LPP. A review by Asmundson and colleagues (2013) recommended that exercise interventions should last at least 10 weeks to provide meaningful changes in anxiety. Several studies have demonstrated that even single bouts of exercise can lead to reductions in anxiety (LeBouthillier & Asmundson, 2015; Mason & Asmundson, 2018), but longer exercise interventions can provide greater reductions (Asmundson et al., 2013). Thus, randomized controlled trials investigating how exercise impacts the LPP in individuals with anxiety should include longer exercise intervention paradigms.

Last, various exercise modalities and intensities should be examined when creating studies that examine exercise's effect on the LPP in anxious individuals. A large research base has been established investigating how different intensities and modalities impact anxiety. Reviews by Asmundson and colleagues (2013) and Strickland and Smith (2014) suggest that both aerobic and resistance training modalities, at various intensities, can lead to reductions in state and trait anxiety. Though there is a substantial and growing research base investigating exercise modalities and anxiety, there is no research examining how these interventions influence the LPP in anxious individuals. Understanding how different exercise modalities influence the LPP could give insights into how these interventions influence reappraisal and emotional reactivity. Thus, more research is needed using these exercise interventions, using various modalities and intensities, and psychophysiological measures, like the LPP.

Conclusion

The findings from this study demonstrate that acute aerobic exercise can reduce emotional reactivity to symptom-relevant stimuli in individuals with elevated anxiety sensitivity as evidenced by significant reductions in LPP amplitude from pre to post timepoints in the exercise condition but not the control condition. Contrary to the hypothesis, exercise led to increased LPP amplitude during reappraise trials after exercise compared to the control. The brief bout of exercise was also insufficient to effect measurable changes in AS symptoms. Together, the current findings demonstrate that a brief bout of aerobic exercise induces immediate changes in cognitive and emotional mechanisms relevant to AS, and in the absence of symptom reduction, point to the possibility that exercise may act as a "sleeper" on AS through its initial effects on emotional reactivity and regulation. Given the lack or research in this area, there are exciting avenues for future studies to examine this possibility in repeated measures longitudinal designs across a longer course of exercise sessions.

REFERENCES

Allan, N. P., Judah, M. R., Albanese, B. J., Macatee, R. J., Sutton, C. A., Bachman, M. D., Bernat, E. M., & Schmidt, N. B. (2019). Gender differences in the relation between the late positive potential in response to anxiety sensitivity images and self-reported anxiety sensitivity. *Emotion*, *19*(1), 70–83. https://doi.org/10.1037/emo0000420

Allan, N. P., Raines, A. M., Capron, D. W., Norr, A. M., Zvolensky, M. J., & Schmidt, N. B. (2014a). Identification of anxiety sensitivity classes and clinical cut-scores in a sample of adult smokers: Results from a factor mixture model. *Journal of Anxiety Disorders*, *28*(7), 696–703. https://doi.org/10.1016/j.janxdis.2014.07.006

Allan, N. P., Korte, K. J., Capron, D. W., Raines, A. M., & Schmidt, N. B. (2014b). Factor mixture modeling of anxiety sensitivity: A three-class structure. *Psychological Assessment*, *26*(4), 1184–1195. https://doi.org/10.1037/a0037436

Asmundson, G. J. G., Fetzner, M. G., DeBoer, L. B., Powers, M. B., Otto, M. W., & Smits, J. A. J. (2013). LET'S GET PHYSICAL: A CONTEMPORARY REVIEW OF THE ANXIOLYTIC EFFECTS OF EXERCISE FOR ANXIETY AND ITS DISORDERS: Review: Exercise and Anxiety Reduction. *Depression and Anxiety*, *30*(4), 362–373. https://doi.org/10.1002/da.22043

Baek, I., Lee, E., & Kim, J. (2019). Differences in anxiety sensitivity factors between anxiety and depressive disorders. *Depression and Anxiety*, *36*(10), 968–974. https://doi.org/10.1002/da.22948

Bartón, K. (2023) MuMlm R Package.

Basso, J. C., & Suzuki, W. A. (2017). The Effects of Acute Exercise on Mood, Cognition, Neurophysiology, and Neurochemical Pathways: A Review. *Brain Plasticity*, *2*(2), 127–152. https://doi.org/10.3233/BPL-160040

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using **lme4**. *Journal of Statistical Software*, *67*(1). https://doi.org/10.18637/jss.v067.i01

Bischoff, S., Wieder, G., Einsle, F., Petzold, M. B., Janßen, C., Mumm, J. L. M., Wittchen, H.-U., Fydrich, T., Plag, J., & Ströhle, A. (2018). Running for extinction? Aerobic exercise as an augmentation of exposure therapy in panic disorder with agoraphobia. *Journal of Psychiatric Research*, *101*, 34–41. https://doi.org/10.1016/j.jpsychires.2018.03.001

Blakey, S. M., Abramowitz, J. S., Reuman, L., Leonard, R. C., & Riemann, B. C. (2017). Anxiety sensitivity as a predictor of outcome in the treatment of obsessive-compulsive disorder. *Journal of Behavior Therapy and Experimental Psychiatry*, *57*, 113–117. https://doi.org/10.1016/j.jbtep.2017.05.003

Boswell, J. F., Farchione, T. J., Sauer-Zavala, S., Murray, H. W., Fortune, M. R., & Barlow, D. H. (2013). Anxiety Sensitivity and Interoceptive Exposure: A Transdiagnostic Construct and Change Strategy. *Behavior Therapy*, *44*(3), 417–431. https://doi.org/10.1016/j.beth.2013.03.006

Broman-Fulks, J. J., Kelso, K., & Zawilinski, L. (2015). Effects of a Single Bout of Aerobic Exercise Versus Resistance Training on Cognitive Vulnerabilities for Anxiety Disorders. *Cognitive Behaviour Therapy*, *44*(4), 240–251. https://doi.org/10.1080/16506073.2015.1020448

Brush, C. J., Foti, D., Bocchine, A. J., Muniz, K. M., Gooden, M. J., Spaeth, A. M., Miller, M. W., & Alderman, B. L. (2020). Aerobic exercise enhances positive emotional reactivity in individuals with depressive symptoms: Evidence from neural responses to reward and emotional content. *Mental Health and Physical Activity*, *19*, 100339. https://doi.org/10.1016/j.mhpa.2020.100339

Chatrian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten Percent Electrode System for Topographic Studies of Spontaneous and Evoked EEG Activities. *American Journal of EEG Technology*, *25*(2), 83–92. https://doi.org/10.1080/00029238.1985.11080163

Craske, M. G., & Barlow, D. H. (2007). *Mastery of your anxiety and panic: Workbook* (4. ed). Oxford Univ. Press.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Ekkekakis, P., Zenko, Z., & Vazou, S. (2021). Do you find exercise pleasant or unpleasant? The Affective Exercise Experiences (AFFEXX) questionnaire. *Psychology of Sport and Exercise*, *55*, 101930. https://doi.org/10.1016/j.psychsport.2021.101930

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Giles, G. E., Cantelon, J. A., Eddy, M. D., Brunyé, T. T., Urry, H. L., Mahoney, C. R., & Kanarek, R. B. (2017). Habitual exercise is associated with cognitive control and cognitive reappraisal success. *Experimental Brain Research*, *235*(12), 3785–3797. https://doi.org/10.1007/s00221-017-5098-x

Godin, G. (2011). The Godin-Shephard Leisure-Time Physical Activity Questionnaire. *The Health & Fitness Journal of Canada*, 18-22 Pages. https://doi.org/10.14288/HFJC.V4I1.82

Gomez-Pinilla, F., & Hillman, C. (2013). The Influence of Exercise on Cognitive Abilities. In Y. S. Prakash (Ed.), *Comprehensive Physiology* (1st ed., pp. 403–428). Wiley. https://doi.org/10.1002/cphy.c110063

Goodwin, R. D., Weinberger, A. H., Kim, J. H., Wu, M., & Galea, S. (2020). Trends in anxiety among adults in the United States, 2008–2018: Rapid increases among young adults. *Journal of Psychiatric Research*, *130*, 441–446. https://doi.org/10.1016/j.jpsychires.2020.08.014

Gramfort, A. (2013). MEG and EEG data analysis with MNE-Python. *Frontiers in Neuroscience*, *7*. https://doi.org/10.3389/fnins.2013.00267

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology*, *85*(2), 348–362. https://doi.org/10.1037/0022-3514.85.2.348

Hajcak, G., & Foti, D. (2020). Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review. *Psychophysiology*, *57*(7), e13570. https://doi.org/10.1111/psyp.13570

Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-Related Potentials, Emotion, and Emotion Regulation: An Integrative Review. *Developmental Neuropsychology*, *35*(2), 129–155. https://doi.org/10.1080/87565640903526504

Harrison, N. R., & Chassy, P. (2019). Habitual Use of Cognitive Reappraisal Is Associated With Decreased Amplitude of the Late Positive Potential (LPP) Elicited by Threatening Pictures. *Journal of Psychophysiology*, *33*(1), 22–31. https://doi.org/10.1027/0269-8803/a000202

Hilchey, C. A., & Clark, D. A. (2014). Context in Anxiety Sensitivity: The Role of Expectancy, Catastrophic Misinterpretations and Diminished Reappraisal in Response to Hypothetical Physical Arousal Scenarios. *Cognitive Therapy and Research*, *38*(3), 343–348. https://doi.org/10.1007/s10608-013-9594-4

IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp

Jardin, C., Paulus, D. J., Garey, L., Kauffman, B., Bakhshaie, J., Manning, K., Mayorga, N. A., & Zvolensky, M. J. (2018). Towards a greater understanding of anxiety sensitivity across groups: The construct validity of the Anxiety Sensitivity Index-3. *Psychiatry research*, *268*, 72–81. https://doi.org/10.1016/j.psychres.2018.07.007

Kashdan, T. B., Zvolensky, M. J., & McLeish, A. C. (2008). Anxiety sensitivity and affect regulatory strategies: Individual and interactive risk factors for anxiety-related symptoms. *Journal of Anxiety Disorders*, *22*(3), 429–440. https://doi.org/10.1016/j.janxdis.2007.03.011

Kemper, C. J., Lutz, J., Bähr, T., Rüddel, H., & Hock, M. (2012). Construct validity of the Anxiety Sensitivity Index-3 in clinical samples. *Assessment*, *19*(1), 89–100. https://doi.org/10.1177/1073191111429389

Keum, B. T., Miller, M. J., & Inkelas, K. K. (2018). Testing the factor structure and measurement invariance of the PHQ-9 across racially diverse U.S. college students. *Psychological Assessment*, *30*(8), 1096–1106. https://doi.org/10.1037/pas0000550

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2001). The PHQ-9: Validity of a brief depression severity measure. *Journal of General Internal Medicine*, *16*(9), 606–613. https://doi.org/10.1046/j.1525-1497.2001.016009606.x

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). **lmerTest** Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13). https://doi.org/10.18637/jss.v082.i13

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

Leutgeb, V., Schäfer, A., Köchel, A., & Schienle, A. (2012). Exposure therapy leads to enhanced late frontal positivity in 8- to 13-year-old spider phobic girls. *Biological Psychology*, *90*(1), 97–104. https://doi.org/10.1016/j.biopsycho.2012.02.008

Leutgeb, V., Schäfer, A., & Schienle, A. (2009). An event-related potential study on exposure therapy for patients suffering from spider phobia. *Biological Psychology*, *82*(3), 293–300. https://doi.org/10.1016/j.biopsycho.2009.09.003

LeBouthillier, D. M., & Asmundson, G. J. G. (2015). A Single Bout of Aerobic Exercise Reduces Anxiety Sensitivity But Not Intolerance of Uncertainty or Distress Tolerance: A Randomized Controlled Trial. *Cognitive Behaviour Therapy*, *44*(4), 252–263. https://doi.org/10.1080/16506073.2015.1028094

Lenth, R., Love, J., & Hervé, M. (2017). Package 'emmeans'. *The American Statistician* 34: 216–21

Ligeza, T. S., Kałamała, P., Tarnawczyk, O., Maciejczyk, M., & Wyczesany, M. (2019). Frequent physical exercise is associated with better ability to regulate negative emotions in adult women: The electrophysiological evidence. *Mental Health and Physical Activity*, *17*, 100294. https://doi.org/10.1016/j.mhpa.2019.100294

MacNamara, A., Joyner, K., & Klawohn, J. (2022). Event-related potential studies of emotion regulation: A review of recent progress and future directions. *International Journal of Psychophysiology*, *176*, 73–88. https://doi.org/10.1016/j.ijpsycho.2022.03.008

Mason, J. E., & Asmundson, G. J. G. (2018). A single bout of either sprint interval training or moderate intensity continuous training reduces anxiety sensitivity: A randomized controlled trial. *Mental Health and Physical Activity*, *14*, 103–112. https://doi.org/10.1016/j.mhpa.2018.02.006

Metzger, R. L. (1976). A reliability and validity study of the State-Trait Anxiety Inventory. *Journal of Clinical Psychology*, *32*(2), 276–278. https://doi.org/10.1002/1097-4679(197604)32:2<276::AID-JCLP2270320215>3.0.CO;2-G

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the penn state worry questionnaire. *Behaviour Research and Therapy*, *28*(6), 487–495. https://doi.org/10.1016/0005-7967(90)90135-6

Moser, J. S., Hartwig, R., Moran, T. P., Jendrusina, A. A., & Kross, E. (2014). Neural markers of positive reappraisal and their associations with trait reappraisal and worry. *Journal of Abnormal Psychology*, *123*(1), 91–105. https://doi.org/10.1037/a0035817

Moser, J. S., Przeworski, A., Schroder, H. S., & Dunbeck, K. M. (2014). Multimethod Assessment of Anxiety: Integrating Data from Subjective Experience, Cognitive Performance, and Neurophysiological Measures. In Hopwood, C. J., & Bornstein, R. F. (Eds.), *Multimethod clinical assessment*. The Guilford Press.

Moser, J. S., Krompinger, J. W., Dietz, J., & Simons, R. F. (2009). Electrophysiological correlates of decreasing and increasing emotional responses to unpleasant pictures. *Psychophysiology*, *46*(1), 17–27. https://doi.org/10.1111/j.1469-8986.2008.00721.x

National Alliance on Mental Illness. (n.d.). *Anxiety disorders*. https://www.nami.org/About-Mental-Illness/Mental-Health-Conditions/Anxiety-Disorders

Ojalehto, H. J., Abramowitz, J. S., Hellberg, S. N., Butcher, M. W., & Buchholz, J. L. (2021). Predicting COVID-19-related anxiety: The role of obsessive-compulsive symptom dimensions, anxiety sensitivity, and body vigilance. *Journal of Anxiety Disorders*, *83*, 102460. https://doi.org/10.1016/j.janxdis.2021.102460

O'Neill, C., & Dogra, S. (2020). Reducing Anxiety and Anxiety Sensitivity With High-Intensity Interval Training in Adults With Asthma. *Journal of Physical Activity and Health*, *17*(8), 835–839. https://doi.org/10.1123/jpah.2019-0521

Plag, J., Ergec, D.-L., Fydrich, T., & Ströhle, A. (2019). High-Intensity Interval Training in Panic Disorder Patients: A Pilot Study. *Journal of Nervous & Mental Disease*, *207*(3), 184–187. https://doi.org/10.1097/NMD.0000000000000944

Pontifex, M. B. (2024). Rmimic

Pontifex, M. B., Parks, A. C., Delli Paoli, A. G., Schroder, H. S., & Moser, J. S. (2021). The effect of acute exercise for reducing cognitive alterations associated with individuals high in anxiety. *International Journal of Psychophysiology*, *167*, 47–56. https://doi.org/10.1016/j.ijpsycho.2021.06.008

Pontifex, M. B., McGowan, A. L., Chandler, M. C., Gwizdala, K. L., Parks, A. C., Fenn, K., & Kamijo, K. (2019). A primer on investigating the after effects of acute bouts of physical activity on cognition. *Psychology of Sport and Exercise*, *40*, 1–22. https://doi.org/10.1016/j.psychsport.2018.08.015

Pontifex, M. B., Miskovic, V., & Laszlo, S. (2017). Evaluating the efficacy of fully automated approaches for the selection of eyeblink ICA components. *Psychophysiology*, *54*(5), 780–791. https://doi.org/10.1111/psyp.12827

Pontifex, M. B., Gwizdala, K. L., Parks, A. C., Billinger, M., & Brunner, C. (2017). Variability of ICA decomposition may impact EEG signals when used to remove eyeblink artifacts. *Psychophysiology*, *54*(3), 386–398. https://doi.org/10.1111/psyp.12804

Pontifex, M. B., Hillman, C. H., Fernhall, B., Thompson, K. M., & Valentini, T. A. (2009). The Effect of Acute Aerobic and Resistance Exercise on Working Memory. *Medicine & Science in Sports & Exercise*, *41*(4), 927–934. https://doi.org/10.1249/MSS.0b013e3181907d69

Preece, D. A., Becerra, R., Hasking, P., McEvoy, P. M., Boyes, M., Sauer-Zavala, S., Chen, W., & Gross, J. J. (2021). The Emotion Regulation Questionnaire: Psychometric Properties and Relations with Affective Symptoms in a United States General Community Sample. *Journal of Affective Disorders*, *284*, 27–30. https://doi.org/10.1016/j.jad.2021.01.071

Qi, S., Li, Y., Tang, X., Zeng, Q., Diao, L., Li, X., Li, H., & Hu, W. (2017). The temporal dynamics of detached versus positive reappraisal: An ERP study. *Cognitive, Affective, & Behavioral Neuroscience*, *17*(3), 516–527. https://doi.org/10.3758/s13415-016-0494-4

Quelhas Martins, A., Kavussanu, M., Willoughby, A., & Ring, C. (2013). Moderate intensity exercise facilitates working memory. *Psychology of Sport and Exercise*, *14*(3), 323–328. https://doi.org/10.1016/j.psychsport.2012.11.010

R Core Team (2019) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Reiss, S., Peterson, R. A., Gursky, D. M., & McNally, R. J. (1986). Anxiety sensitivity, anxiety frequency and the prediction of fearfulness. *Behaviour Research and Therapy*, *24*(1), 1–8. https://doi.org/10.1016/0005-7967(86)90143-9

Robertson, R. J., Goss, F. L., Boer, N. F., Peoples, J. A., Foreman, A. J., Dabayebeh, I. M., Millich, N. B., Balasekaran, G., Riechman, S. E., Gallagher, J. D., & Thompkins, T. (2000). Children???s OMNI Scale of Perceived Exertion: Mixed gender and race validation: *Medicine & Science in Sports & Exercise*, *32*(2), 452. https://doi.org/10.1097/00005768-200002000-00029

Sabourin, B. C., Watt, M. C., Krigolson, O. E., & Stewart, S. H. (2016). Two Interventions Decrease Anxiety Sensitivity Among High Anxiety Sensitive Women: Could Physical Exercise Be the Key? *Journal of Cognitive Psychotherapy*, *30*(2), 131–146. https://doi.org/10.1891/0889-8391.30.2.131

Sabourin, B. C., Stewart, S. H., Watt, M. C., & Krigolson, O. E. (2015). Running as Interoceptive Exposure for Decreasing Anxiety Sensitivity: Replication and Extension. *Cognitive Behaviour Therapy*, *44*(4), 264–274. https://doi.org/10.1080/16506073.2015.1015163

Schmidt, N. B., Keough, M. E., Mitchell, M. A., Reynolds, E. K., MacPherson, L., Zvolensky, M. J., & Lejuez, C. W. (2010). Anxiety sensitivity: Prospective prediction of anxiety among early adolescents. *Journal of Anxiety Disorders*, *24*(5), 503–508. https://doi.org/10.1016/j.janxdis.2010.03.007

Schwarzer, R., & Jerusalem, M. (1995). Generalized Self-Efficacy scale. In J. Weinman, S. Wright, & M. Johnston, *Measures in health psychology: A user's portfolio. Causal and control beliefs* (pp. 35-37). Windsor, UK: NFER-NELSON.

Smits, J. A. J., Berry, A. C., Rosenfield, D., Powers, M. B., Behar, E., & Otto, M. W. (2008). Reducing anxiety sensitivity with exercise. *Depression and Anxiety*, *25*(8), 689–699. https://doi.org/10.1002/da.20411

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Spitzer, R. L., Kroenke, K., Williams, J. B. W., & Löwe, B. (2006). A Brief Measure for Assessing Generalized Anxiety Disorder: The GAD-7. *Archives of Internal Medicine*, *166*(10), 1092. https://doi.org/10.1001/archinte.166.10.1092

Sriken, J., Johnsen, S. T., Smith, H., Sherman, M. F., & Erford, B. T. (2022). Testing the Factorial Validity and Measurement Invariance of College Student Scores on the Generalized Anxiety Disorder (GAD-7) Scale Across Gender and Race. *Measurement and Evaluation in Counseling and Development*, *55*(1), 1–16. https://doi.org/10.1080/07481756.2021.1902239

Stathopoulou, G., Powers, M. B., Berry, A. C., Smits, J. A. J., & Otto, M. W. (2006). Exercise Interventions for Mental Health: A Quantitative and Qualitative Review. *Clinical Psychology: Science and Practice*, *13*(2), 179–193. https://doi.org/10.1111/j.1468-2850.2006.00021.x

Strickland, J. C., & Smith, M. A. (2014). The anxiolytic effects of resistance exercise. *Frontiers in Psychology*, *5*, 753. https://doi.org/10.3389/fpsyg.2014.00753

Tartar, J., Salzmann, S., Pierreulus, R., & Antonio, J. (2018). Acute Aerobic Exercise Decreases a Neurophysiological Response to Emotionally Negative Stimuli. *Journal of Exercise and Nutrition*, *1*(5). https://journalofexerciseandnutrition.com/index.php/JEN/article/view/30

Taylor, S. (2019). Treating anxiety sensitivity in adults with anxiety and related disorders. In *The Clinician's Guide to Anxiety Sensitivity Treatment and Assessment* (pp. 55–75). Elsevier. https://doi.org/10.1016/B978-0-12-813495-5.00004-8

Taylor, S., Zvolensky, M. J., Cox, B. J., Deacon, B., Heimberg, R. G., Ledley, D. R., Abramowitz, J. S., Holaway, R. M., Sandin, B., Stewart, S. H., Coles, M., Eng, W., Daly, E. S., Arrindell, W. A., Bouvard, M., & Cardenas, S. J. (2007). Robust dimensions of anxiety sensitivity: development and initial validation of the Anxiety Sensitivity Index-3. *Psychological assessment*, *19*(2), 176–188. https://doi.org/10.1037/1040-3590.19.2.176

Thomas, S., Reading, J., & Shephard, R. J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Canadian Journal of Sport Sciences = Journal Canadien Des Sciences Du Sport*, *17*(4), 338–345.

Tingley, D., Yamamoto, T., Hirose, K., Keele, L., & Imai, K. (2014). **mediation**: *R* Package for Causal Mediation Analysis. *Journal of Statistical Software*, *59*(5). https://doi.org/10.18637/jss.v059.i05

Warren, A. M., Zolfaghari, K., Fresnedo, M., Bennett, M., Pogue, J., Waddimba, A., Zvolensky, M., Carlbring, P., & Powers, M. B. (2021). Anxiety sensitivity, COVID-19 fear, and mental health: Results from a United States population sample. *Cognitive Behaviour Therapy*, *50*(3), 204–216. https://doi.org/10.1080/16506073.2021.1874505

Watson, D., Weber, K., Assenheimer, J. S., Clark, L. A., Strauss, M. E., & McCormick, R. A. (1995a). Testing a tripartite model: I. Evaluating the convergent and discriminant validity of anxiety and depression symptom scales. *Journal of Abnormal Psychology*, *104*(1), 3–14. https://doi.org/10.1037/0021-843X.104.1.3

Watson, D., Clark, L. A., Weber, K., Assenheimer, J. S., Strauss, M. E., & McCormick, R. A. (1995b). Testing a tripartite model: II. Exploring the symptom structure of anxiety and depression in student, adult, and patient samples. *Journal of Abnormal Psychology*, *104*(1), 15–25. https://doi.org/10.1037/0021-843X.104.1.15

APPENDIX A: REAPPRAISAL INSTRUCTIONS

View and Reappraisal Instructions

EEG Task Instructions:

"First I will provide you with instructions on how to look at these images."

View Instructions:

"In this experiment, some images will be preceded by the phrase 'View Neutral' or 'View Negative'. This indicates you should let yourself respond naturally to the image. Do not change your natural emotional response; just respond to the image as you naturally would.

For example, if the image made you feel anxious, you would simply view the image and allow yourself to experience the anxiety. Do you have any questions so far?

The cue "View Neutral" or "View Negative" will appear prior to certain images to remind you to respond naturally and not to change your emotional response while viewing each image.

Remember, the instructions do not tell you what emotions to feel about each image; they only tell you to react naturally."

[Make sure subjects really understand that they are to simply look when given "View" prompts and not try to control their feelings.**]**

Reappraisal Instructions:

"Some images will be preceded by the phrase "Reappraise Negative." This indicates that you should view the image acknowledging that the reactions you are having will pass and that you will be alright.

For example, if the image made you feel anxious, you acknowledge that your anxiety will pass and that your feelings will not harm you. Do you have any questions so far?

The cue "Reappraise Negative" will appear prior to some images to remind you to acknowledge that your reactions will pass and that you will be alright as much as possible when focusing on what you are feeling in response to viewing each image.

Remember, the instructions do not tell you what emotions to feel about each image; they only tell you how to think about each image."

APPENDIX B: FIGURES

Figure 1.
Sequence of Session Elements

Figure 2.
Mediation Model

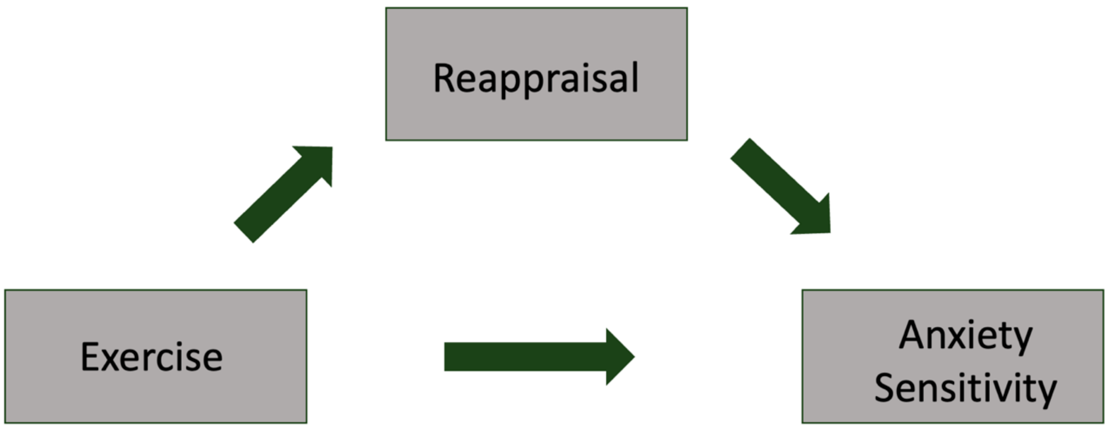


Figure 3.
Subtraction Grand Average Difference Waveforms (Posttest − Pretest) Waveforms

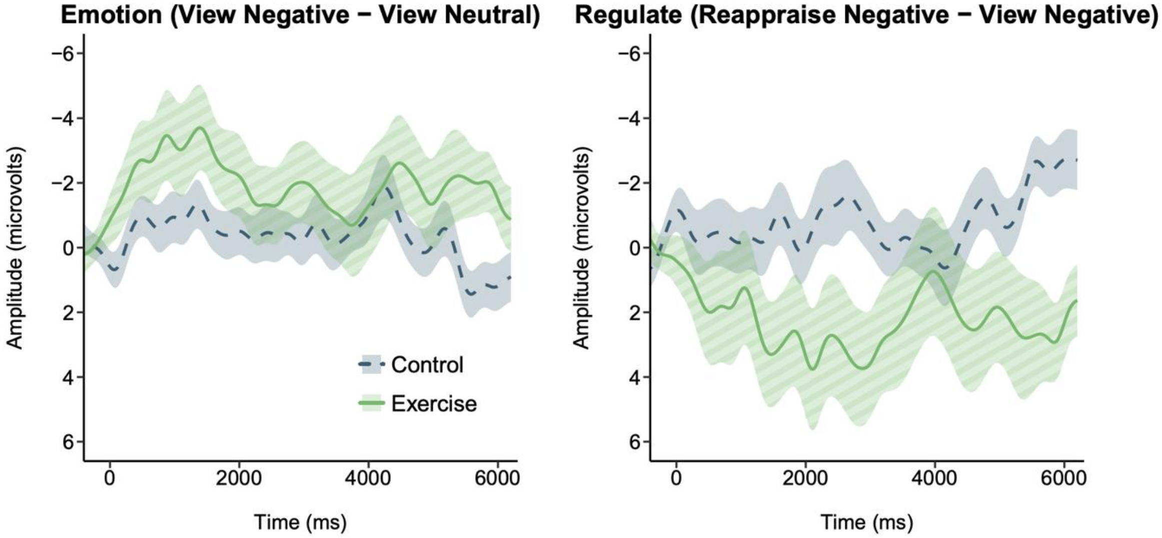
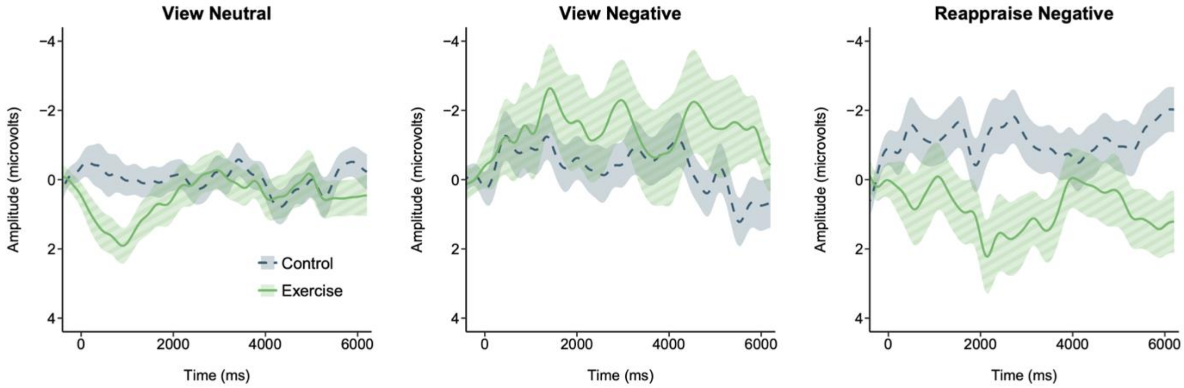


Figure 4.

Grand Average Difference Waveforms (Posttest − Pretest) by Trial Type



APPENDIX C: TABLES

Table 1.

Sociodemographic Characteristics

	M (SD)	Range	
Age	*19.59 (1.60)*	18-24	

		N	%
Sex			
	Female	27	100
	Male	0	0
	Intersex	0	0
	Prefer Not to Answer	0	0
	Not Listed (please specify in the box below)	0	0
Gender			
	Cisgender	26	96.30
	Transgender Man	0	0
	Transgender Woman	0	0
	Non-Binary	1	3.70
	Gender Fluid	0	0
	Gender Questioning	0	0
	Not Listed (please specify in the box below)	0	0
Sexuality			
	Asexual	1	3.70
	Bisexual	4	14.81
	Lesbian	4	14.81
	Heterosexual	14	51.86
	Queer	4	14.81
	Pansexual	0	0

Table 1 (cont'd)

Race & Ethnicity			
	African American or Black	1	3.70
	American Indian or Alaska Native	0	0
	Asian	1	3.70
	Hispanic or Latino (Non-White)	1	3.70
	Multiracial	1	3.70
	Native Hawaiian or Other Pacific Islander	0	0
Table 1 (cont'd)			
	White or Caucasian	23	85.2
	Prefer Not to Answer	0	0
	Not Listed (please specify in the box below)	0	0
Socioeconomic Status			
	Routinely unable to purchase sufficient food or other basic necessities	2	7.41
	Occasionally unable to purchase sufficient food or other basic necessities	1	3.70
	Have enough money for the necessities	7	25.93
	Have more than enough money for necessities and some luxuries	17	62.96

Table 2.
Descriptives of Repeated Measures Variables

	Exercise Pre M ± SD	Exercise Post M ± SD	Control Pre M ± SD	Control Post M ± SD
ASI-3	31.37 ± 12.728	29.71 ±12.234	31.63 ± 14.333	30.57 ± 13.843
STAI-S	42.35 ± 8.182	40.08 ± 8.838	40.33 ± 7.603	40.47 ± 8.037
ERQ - Reappraisal	27.29 ± 6.484	28.27 ± 8.346	28.20 ± 7.743	28.29 ± 7.877

Table 3.
Manipulation Checks

	Exercise **M ± SD**	**Control** **M ± SD**
Average Heart Rate	133.92 ± 10.703	79.08 ± 14.056
Average Ratings of Perceived Exertion	3.24 ± 1.267	1.08 ± 1.600
Average Self-Reported Affect	2.63 ± 1.073	2.55 ± 1.094