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Running title: Emotional exposure after exercise

Abstract

Purpose: Despite the well-known anxiolytic effect of acute exercise, it is unknown if anxiety reductions after acute exercise conditions survive in the face of a subsequently experienced arousing emotional exposure. The purpose of this study was to compare the effects of moderate intensity cycle ergometer exercise to a seated rest control condition on state anxiety symptoms after exposure to a variety of highly arousing pleasant and unpleasant stimuli. **Method:** Thirty-seven healthy and normally physically active young adults completed two conditions on separate days: 1) 30-minutes of seated rest, and; 2) 30-minutes of moderate intensity cycle ergometer exercise (RPE = 13; 'somewhat hard'). After each condition, participants viewed 90 arousing pleasant and unpleasant and neutral pictures from the International Affective Picture System (IAPS) for 30 minutes. State anxiety was measured before and 15 minutes after each condition, and again after exposure to the affective pictures. **Results:** State anxiety significantly decreased from baseline to after the exercise and seated rest conditions ($p = .003$). After the emotional picture viewing period, state anxiety significantly increased to baseline values after the seated rest condition ($p = .001$) but remained reduced after the exercise condition. **Conclusion:** These findings suggest the anxiolytic effects of acute exercise may be resistant to the potentially detrimental effects on mood after exposure to arousing emotional stimuli.

KEY WORDS: Affect; Emotion; IAPS; Mood; Physical Activity; Quiet Rest

Introduction

Paragraph Number 1 The effect of a single session of exercise to improve mood and reduce subjective symptoms of anxiety in healthy non-anxious adults has been well established . However, in many investigations, anxiety reductions after acute exercise have been shown to be similar to the effect of a ‘quiet rest’ or similar control condition . While the anxiolytic effects of acute exercise have been shown to persist longer compared to quiet rest conditions , this difference has not been observed consistently .

Paragraph Number 2 The efficacy of quiet rest conditions to improve mood suggests there may be a common anxiety-reducing factor present during exercise and rest conditions, such as a time-out from stressors or other worries . Other studies have modified the exercise and rest conditions through manipulations of body temperature or caffeine ingestion and have shown that the anxiolytic effects of exercise survive these manipulations whereas quiet rest conditions do not. This suggests a specific yet undefined effect of acute exercise, not evoked during quiet rest, that promotes durability of its anxiolytic effect. While adaptations to repeated bouts of exercise stress have been purported to provide protection against other non-exercise stressors (i.e., the cross-stressor adaptation hypothesis;), these effects have been shown to be quite heterogeneous and dependent on the type of laboratory stressor used, among other factors . This literature has focused on the effects of exercise training or cross-sectional differences in fitness, not acute exercise, in response to laboratory stress tasks (e.g., mental arithmetic, cold-water immersion, Stroop color-word conflict task) that lack face validity for the types of emotional stressors encountered in daily life. A key unanswered question is whether acute exercise confers short-term protection, after its cessation, against typically experienced psychological stressors or emotional provocation.

Paragraph Number 3a As described by Lang and his colleagues, emotions can be defined as ‘action dispositions’ . As such, the physiological and neural systems that govern emotional responsiveness overlap considerably with the physiological and neural systems that govern muscular activation and motor behavior. Exposure to a variety of affective picture stimuli has been shown to evoke changes in autonomic nervous system activation, including sympathetic activation and cardiac-vagal withdrawal , that also occur during acute exercise. Furthermore, Smith and colleagues have reported that reactivity during repeated exposure to emotional stimuli is sensitive to self-reported state anxiety. This suggests that anxiety reducing treatments, such as acute exercise or quiet rest, may modify the cumulative effects of exposure to emotionally arousing stimuli .

Paragraph Number 3b Very little is known, however, regarding whether acute exercise provides subsequent protection against the potentially stressful effects related to exposure to arousing emotional stimuli. Smith and colleagues reported that acute exercise did not alter emotional reactivity during the viewing of pleasant, neutral, and unpleasant pictures. In that study, state anxiety was assessed after the exercise and rest conditions prior to exposure to the emotional pictures, but not after picture viewing. Thus, it is not clear if state anxiety after exercise remains reduced when exposed to arousing emotional stimuli. The aim of this study was to compare the effects of moderate intensity exercise to a seated rest control condition on state anxiety symptoms after exposure to a variety of highly arousing pleasant and unpleasant stimuli. It was hypothesized that state anxiety would be reduced after both exercise and seated rest. Because acute exercise actively engages the physiological systems involved in emotional responsiveness, it was further hypothesized that anxiety reductions would persist after exposure to emotional stimuli for the exercise but not the seated rest condition.

Method

Paragraph Number 4 Participants. Thirty-seven healthy college students (22 men, 15 women) volunteered to complete the study. One male participant was excluded from the analysis due to missing data. The Institutional Review Board approved the study and written informed consent was obtained from each participant. Participants were recruited from undergraduate courses but were not offered extra course credit or payment for participation. The exclusion criteria included left-handedness, current use of antidepressant or anti-anxiety medication, or contraindications to exercise (e.g., heart disease, high blood pressure, high cholesterol). No participants were excluded based on these exclusion criteria. The participants were within the normal range on trait anxiety, which measures the proneness to experience anxiety symptoms (mean (SD) score 45.7 (3.4), range 38-54), and reported normal (minimal to mild) levels of depression symptoms (mean (SD) 4.4 (4.7), range 0-18).

Paragraph Number 5 Design. A within-subjects experimental design was employed. Each participant completed two conditions, seated quiet rest and moderate intensity cycle ergometer exercise, and afterward viewed emotional pictures from the International Affective Picture System (IAPS). The primary dependent variable was state anxiety score, measured before and after each condition and after affective picture viewing. Testing occurred on two different days within a seven-day period. The order of condition was counterbalanced across subjects and two different picture orders were counterbalanced across testing day and condition. A power analysis based on an expected moderate correlation between repeated measures ($r = 0.6$) and a small effect ($d = .25$) for the interaction between condition (exercise vs. seated rest) and time (pre-, post-, post-picture viewing) detected at alpha of 0.05 indicated a sample size of 36 provides statistical power of 0.95.

Paragraph Number 6 Procedures. Participants were instructed to arrive each day prepared to exercise. On the first day participants completed written informed consent, a health history questionnaire, the Beck Depression Inventory-II , and the State-Trait Anxiety Inventory (STAI) in a sound-attenuated and temperature controlled room (approximately 24 ± 1 degree Celsius). Then participants were taken to a different nearby room where they were informed of the experimental condition that would be performed. For the exercise condition participants pedaled an electronically braked cycle ergometer (Corival, Lode B.V., Groningen, Nederland). After the seat height was adjusted, standardized instructions were provided regarding the use of the rating of perceived exertion (RPE) scale . A 5-minute warm-up and cool-down was completed at 50 Watts. During the exercise condition the participant pedaled for 30 minutes at an intensity that corresponded with a RPE of 13 (associated with the verbal anchor ‘somewhat hard’). The participant was free to adjust the resistance to match the perception of ‘somewhat hard’ throughout the 30-minute session. Pedal cadence was maintained between 70-90 rpm. Heart rate (Polar), RPE, and work rate were recorded every 5 minutes. During the seated rest condition the same procedures were followed but the participant sat on the bike for 40 minutes and did not pedal.

Paragraph Number 7 After the exercise or rest condition the participant was provided water ad libitum and returned to the sound attenuated room. Fifteen minutes after the completion of the exercise or rest condition, participants completed form Y1 (state anxiety) of the STAI. The STAI-Y1 instrument is widely regarded as a reliable (internal consistency $\alpha = .92$; test-retest $r = .88$) and valid measure of state anxiety defined as “a temporal cross-section in the emotional stream-of-life of a person, consisting of subjective feelings of tension, apprehension, nervousness, and worry, and activation or arousal of the autonomic nervous system” . The STAI

has been used in many different disciplines (over 3000 publications, translated to 30 languages;) and is the most cited anxiety instrument in the context of exercise . Participants then viewed 90 pictures from the IAPS on a 14-inch color monitor located approximately 1 meter away. The IAPS has been used world wide as a set of visual stimuli to induce emotion in a laboratory setting. Repeated exposure to unpleasant IAPS pictures has been shown to induce a shift in mood and to be sensitive to baseline state anxiety . Among the 90 pictures used, 30 were pleasant (15 erotica, 15 babies, families and cute animals), 30 were neutral (15 neutral people, 15 neutral objects and scenes), and 30 were unpleasant (15 threat, 15 mutilation) based on normative ratings of valence (see Table 1 for normative ratings and Supplemental Digital Content 1. Appendix (International Affective Picture System (IAPS) stimuli) for IAPS numbers). The 90 pictures were arranged in three blocks of 30; each block contained 10 pictures from each valence category. The order within each block was pseudo-random in that no more than two pictures from the same category could appear consecutively. Two different picture orders were constructed and counterbalanced across testing day and experimental condition. Each picture was shown for four seconds and was followed by a 12-, 14-, or 16-s inter-picture interval (mean 14 s) that consisted of a centrally located fixation cross. The total picture viewing time, including brief breaks between each picture block, was approximately 30 minutes. Participants were instructed to look at each picture the entire time it was on the monitor and to subjectively categorize each picture as pleasant, neutral, or unpleasant using (with their right hand) a 3-button response pad resting on their lap. The purpose of the picture categorization task was to promote visual attention to the pictures. Immediately after the picture viewing task (approximately 50 minutes after the cessation of the exercise and rest conditions) participants completed form Y1 of

the STAI. Upon completion of the study procedures on Day 2, participants rated each of the 90 pictures (hard copy, one picture per page in a standard order, self-paced) using the SAM.

Paragraph Number 8 Data Analysis. State anxiety scores were analyzed using a 2 (Condition: exercise, seated rest) by 3 (Time: pre-exercise, post-exercise, post-picture viewing) repeated measures ANOVA. Follow-up contrasts were computed using a general linear model and paired samples t-tests. There were no violations of the sphericity assumption as indicated by the Mauchly's test of sphericity (all $p > 0.2$). Preliminary analysis indicated no significant effects of sex, so sex was not included as a factor in the analysis.

Results

Paragraph Number 9 Characteristics of the sample and subjective valence and arousal ratings of the pictures are shown in Table 1. Physiologic and subjective responses associated with each condition across the different measurement periods are shown in Table 2. As expected, heart rate was significantly greater during and 15-min after the exercise compared to the rest condition. In addition, ratings of perceived exertion, leg muscle pain, and affective arousal were greater during exercise compared to during seated rest. Subjective ratings of pleasantness were greater before and 15-min after exercise compared to seated rest (see Table 2).

Paragraph Number 10 There were no differences in state anxiety scores before each condition, $F(1,35) = 0.266$, $p = .609$, $\eta^2_p = .008$). There was a Condition x Time interaction, $F(2, 70) = 3.029$, $p = .055$, $\eta^2_p = .080$, and a main effect for Time, $F(2,70) = 4.170$, $p = .019$, $\eta^2_p = .106$. Follow-up contrasts indicated state anxiety significantly decreased from before to 15-minutes after both conditions, $F(1,35) = 10.003$, $p = .003$, $\eta^2_p = .222$. However, in comparison to the 15-minute post-condition measurement (before exposure to emotion) state anxiety remained decreased after emotional exposure for the exercise condition ($p = .842$) and significantly

increased after emotional exposure for the seated rest condition ($p = .001$) (see Figure 1).

Furthermore, the only significant difference in state anxiety between the exercise and seated rest conditions occurred after exposure to emotional pictures when state anxiety was significantly lower after exercise compared to seated rest, $F(1,35) = 9.472$, $p = .004$, $\eta^2_p = .213$.

Discussion

Paragraph Number 11 There have been few investigations regarding how acute exercise may affect responses to a subsequent exposure to emotional stimuli. The novel finding of the current study was that state anxiety was reduced after 30 minutes of moderate intensity exercise and remained reduced after the viewing of arousing emotional pictures. In contrast, the anxiolytic effect of quiet rest did not persist, but rather, returned to baseline after emotional picture viewing.

Paragraph Number 12 This work extends the findings reported by Smith et al. in which they found that neither low intensity nor moderate intensity acute exercise modified facial EMG responses during affective picture viewing. Electroencephalographic (EEG) responses during affective picture viewing were also reported to be unaffected by acute exercise or seated rest. While state anxiety was reduced after both the exercise and seated rest conditions in the Smith et al. study, they did not measure state anxiety after exposure to the emotional stimuli. In the study by Crabbe et al., ratings of picture pleasantness were unaffected by acute exercise, however ratings of arousal during the viewing of unpleasant pictures were lower after exercise compared to rest, suggesting that acute exercise may have affected subjective responses specific to unpleasant pictures. In the current study, subjective ratings of the picture stimuli occurred only once at the end of the study after the pictures had been viewed twice previously. Thus, it was not possible, in a novel context, to determine if there were differences between exercise and rest on

arousal or pleasantness ratings of the pictures. Another recent study reported that attentional bias toward pleasant and unpleasant IAPS pictures was not changed after acute exercise, suggesting that subjective appraisal of specific single instances of emotional stimuli is unaltered after the exercise has ended. The failure of acute exercise to alter psychophysiological responsiveness during the actual viewing of an arousing pleasant or unpleasant stimulus suggests that the neural systems that process and respond to specific instances of emotion remain undisturbed. Despite intact emotional responsiveness to briefly presented visual stimuli, the current study suggests that acute exercise may protect one from the *cumulative* effects of exposure to a variety of arousing emotional stimuli.

Paragraph Number 13 It is not yet clear, however, how the neural systems that process emotional stimuli are affected *during* moderate intensity acute exercise. Low intensity exercise (40% of maximal capacity) did not alter emotional responsiveness to IAPS pictures. However, it has been recently reported that visual attentional bias was altered during moderate intensity exercise. Using the dot-probe task it was shown that attentional bias shifted (from a neutral bias at rest) toward pleasant faces and away from unpleasant faces during moderate intensity exercise similar to that used in the current study. This suggests that engagement of the appetitive motivational system may be enhanced, and engagement of the aversive motivational system may be inhibited, during moderate intensity exercise. However, it is not clear if these effects on the visual attention system may persist into the post-exercise period or if acute exercise modifies attentional bias among people diagnosed with affective or anxiety disorders.

Paragraph Number 14 There is evidence to support the hypothesis that exercise may promote a persistence of post-exercise anxiety reduction and a resiliency to perturbation by emotional stressors. For example, when the time-out during exercise was blocked by having

high-anxious women study academic material while they exercised, their anxiety scores still decreased by a greater magnitude after exercise compared to when they studied during a quiet rest condition . It has also been shown that that exercise performed after caffeine ingestion (which leads to increased state anxiety) results in anxiety reduction; an effect not observed after quiet rest conditions .

Paragraph Number 15 There are several studies that have examined the effect of acute exercise on anxiety and panic-like symptoms in response to interoceptive sensations induced during a biological challenge. In two studies, a 35% CO₂ mixture with oxygen was inhaled after acute exercise compared to after a control condition in healthy adults . Panic-like symptoms after the CO₂ inhalation were attenuated after exercise compared to after rest , and these effects were also shown to be independent of anxiety sensitivity, negative affectivity, and cardiorespiratory fitness . Similar results were reported by Ströhle and colleagues in which panic-like symptoms were reduced when cholecystokinin tetrapeptide (CCK₄) was administered to healthy adults after acute exercise compared to after a rest control condition. It has also been shown that the anxiogenic effects of a 35% CO₂ challenge are reduced after acute exercise in patients diagnosed with panic disorder . There are two important distinctions between this previous work and the current study. First, state anxiety scores have not been reported after exercise or the physiological challenge; rather, panic-like symptoms or fear have been assessed, which are considered to be different from anxiety . Second, air enriched with CO₂ (or injection of CCK₄) is a strong anxiogenic stimulus and when inhaled is a substantial threat to homeostasis. Prior acute exercise did not prevent fear or panic-like symptoms during a CO₂ challenge, but it did lessen its impact. While highly arousing affective pictures do not induce the large-scale interoceptive sensations and biological challenge that occur while breathing 35% CO₂, emotional

picture viewing has been shown to affect peripheral psychophysiological systems and neural indices of both defensive *and appetitive* activation . An emotional picture-viewing paradigm may be more representative of the breadth of repeated emotional challenges people face on a daily basis.

Paragraph Number 16a The timing of the anxiety measurements post-exercise was based on two factors: 1) the largest effects of anxiety reductions after acute exercise have been observed 15-20 minutes after the cessation of exercise, not immediately after exercise ; and 2) since physiological arousal is theorized to affect reactions to emotional stimuli , the 15 minute delay also served to equate subjective arousal between the exercise and control conditions (as shown in Table 2). The study was designed to provide exposure to emotion at a time when anxiety had been reduced and when arousal was equivalent between conditions. In this regard, any subsequent change in anxiety (or lack thereof) could not be attributable to differences in physiological arousal during emotion exposure, but only to the method by which the anxiety reduction had been realized. The similarity between the exercise and rest condition in this 15-minute break preserved the internal validity of the acute exercise manipulation. If the anxiolytic effects of exercise provide a buffer against emotion provocation, as suggested here, and are to be considered useful for the management of anxiety symptoms in the face of ongoing exposure to emotional events in our environment, then one might expect these effects would persist after the exercise has ended. In this case the anxiety reduction was maintained approximately one-hour after exercise, which is consistent with previous reports and reviews . It will be important for future studies to examine when these effects may dissipate and if these effects are observed in those diagnosed with anxiety disorders.

Paragraph 16b The STAI form Y1 was used as the measure of the multidimensional and multisystem construct ‘state anxiety’ because this instrument has been shown repeatedly to demonstrate good reliability, a stable factor structure, and exceptional construct validity evidenced by numerous experimental manipulations and cross-sectional comparisons of clinically diagnosed patient groups . The recent work by Vautier and Pohl confirmed the original four-factor structure of the STAI (state anxiety present; state anxiety absent; trait anxiety present; and trait anxiety absent). Furthermore, they confirmed that both the state and trait anxiety forms (Y1 and Y2, respectively) measure unified bipolar constructs, not separate constructs such as anxiety and serenity or somatic and cognitive anxiety. This is consistent with the criteria for diagnosis of anxiety disorders, which describes anxiety as an amalgamated multidimensional construct affecting both mind and body . Due to the large inter-individual variability in state anxiety scores across time, the use of form Y1 to measure state anxiety change were shown by Vautier and Pohl to be highly reliable . Thus, investigators and clinicians should be encouraged to continue use of the STAI to measure changes in state anxiety in the contexts of exercise and physical activity .

Paragraph Number 16c There are several limitations of the current study. An intermixed presentation of pleasant, neutral, and unpleasant pictures was used, so it is not clear which emotional content could be more important to the effects observed. The study by Crabbe et al. suggests subjective arousal during unpleasant picture viewing may be reduced after exercise. The work by Tian & Smith , however, suggests visual attention toward pleasant and away from unpleasant pictures may occur *during* exercise. Future studies should confirm these findings and further examine distinctions between emotion processing during and after exercise, as well as effects of acute exercise on anxiety following a sustained presentation of specific

affective content . Second, unlike previous studies that have used a “lazy boy” chair, the seated rest condition was conducted on the bike, which provided a control condition that differed from the experimental condition *only* in the volitional exertion required to pedal at a moderate intensity. As noted in Table 2, other than expected differences in leg muscle pain and affective arousal between the conditions attributable to the manipulation , the affective experience was very similar between the exercise and seated rest conditions. Consistent with the affective picture viewing literature, subjects sat in a comfortable padded chair during picture viewing after both conditions. Thus, it is unlikely that postural or affective differences between the conditions influenced the results. Finally, the sample consisted of healthy young adults in the normal range for trait and state anxiety. This study was focused on the issue of the *quality*, not quantity, of the anxiety reduction after experimental exercise and rest conditions. The innovation of this work in comparison to the corpus of literature is a manipulation of exposure to a variety of typical ‘real-world’ emotional stimuli after the anxiolytic effects occurred. This study demonstrated that the anxiolytic effects of acute exercise survive subsequent exposure to emotional stimuli, whereas the anxiolytic effects of quiet rest do not. The demonstration of this effect in normal healthy adults is important and has broad implications for public health, mental health, and the prevention of emotion-related mental disorders in the healthy adult population. However, it is not known if these effects generalize to people diagnosed with anxiety or affective disorders, to less healthy or less physically active individuals, or to older adults.

Paragraph Number 17 In summary, both acute moderate intensity exercise and seated rest were shown to reduce state anxiety scores. However, when faced with a 30-minute exposure to a variety of emotional stimuli, state anxiety remained reduced after exercise but increased

back to baseline after the seated rest condition. This suggests acute exercise may enhance resilience to the cumulative effects of exposure to arousing emotional stimuli.

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References

1. Bahrke, M.S., and W.P. Morgan. Anxiety reduction following exercise and meditation. *Cognitive Therapy and Research*. 1978; 2:322-333.
2. Barnes, L.L.B., D. Harp, and W.S. Jung. Reliability generalization of scores on the Spielberger State-Trait Anxiety Inventory. *Educational and Psychological Measurement*. 2002; 17:256-266.
3. Barnes, R.T., et al. Evaluating attentional and affective changes following an acute exercise bout using a modified dot-probe protocol. *J Sports Sci*. 2010; 28:1065-76.
4. Beck, A.T., R.A. Steer, and G.K. Brown. *Manual for the Beck Depression Inventory-II*. San Antonio, TX: Psychological Corporation, 1996, pp. 35.
5. Borg, G. *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics, 1998, pp. 1-104.
6. Breus, M.J., and P.J. O'Connor. Exercise-induced anxiolysis: a test of the "time out" hypothesis in high anxious females. *Med Sci Sports Exerc*. 1998; 30:1107-12.
7. Cook, D.B., et al. Naturally occurring muscle pain during exercise: assessment and experimental evidence. *Med Sci Sports Exerc*. 1997; 29:999-1012.
8. Cox, R.H., et al. Effects of acute 60 and 80% VO₂max bouts of aerobic exercise on state anxiety of women of different age groups across time. *Res Q Exerc Sport*. 2004; 75:165-75.
9. Crabbe, J.B., and R.K. Dishman. Brain electrocortical activity during and after exercise: a quantitative synthesis. *Psychophysiology*. 2004; 41:563-74.
10. Crabbe, J.B., J.C. Smith, and R.K. Dishman. Emotional & electroencephalographic responses during affective picture viewing after exercise. *Physiol Behav*. 2007; 90:394-404.

11. Davis, M. Are different parts of the extended amygdala involved in fear versus anxiety? *Biol Psychiatry*. 1998; 44:1239-47.
12. Dozois, D.J., K.S. Dobson, and J.L. Ahnberg. A psychometric evaluation of the Beck Depression Inventory-II. *Psychological Assessment*. 1998; 10:83-89.
13. DSM-IV-TR. *Diagnostic and statistical manual of mental disorders*. Arlington, VA: American Psychiatric Association, 2000, pp. 429-484.
14. Esquivel, G., et al. Acute exercise reduces the effects of a 35% CO₂ challenge in patients with panic disorder. *J Affect Disord*. 2008; 107:217-20.
15. Esquivel, G., et al. The effects of acute exercise and high lactate levels on 35% CO₂ challenge in healthy volunteers. *Acta Psychiatr Scand*. 2002; 106:394-7.
16. Faul, F., et al. G*Power Software. Version 3.1.3. <http://www.psych.uni-duesseldorf.de/aap/projects/gpower/>
17. Garvin, A.W., K.F. Koltyn, and W.P. Morgan. Influence of acute physical activity and relaxation on state anxiety and blood lactate in untrained college males. *Int J Sports Med*. 1997; 18:470-6.
18. Godin, G., and R.J. Shephard. A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci*. 1985; 10:141-6.
19. Jackson, E.M., and R.K. Dishman. Cardiorespiratory fitness and laboratory stress: a meta-regression analysis. *Psychophysiology*. 2006; 43:57-72.
20. Lang, P.J. Behavioral treatment and bio-behavioral assessment: computer applications. In: *Technology in Mental Health Care Delivery Systems*. J.B. Sidowski, J.H. Johnson, and T.A. Williams (Eds.) Norwood, NJ: Albex, 1980, pp. 119-137.

21. Lang, P.J., and M.M. Bradley. Emotion and the motivational brain. *Biol Psychol.* 2010; 84:437-450.
22. Lang, P.J., Bradley, M.M., & Cuthbert, B.N. International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8. Gainesville, FL, 2008, pp. 1-61.
23. Morgan, W.P. Affective beneficence of vigorous physical activity. *Med Sci Sports Exerc.* 1985; 17:94-100.
24. Morgan, W.P., J.A. Roberts, and A.D. Feinerman. Psychologic effect of acute physical activity. *Arch Phys Med Rehabil.* 1971; 52:422-5 passim.
25. Motl, R.W., and R.K. Dishman. Effects of acute exercise on the soleus H-reflex and self-reported anxiety after caffeine ingestion. *Physiol Behav.* 2004; 80:577-85.
26. Petruzzello, S.J., et al. A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. Outcomes and mechanisms. *Sports Med.* 1991; 11:143-82.
27. Petruzzello, S.J., et al. Anxiety and mood changes associated with acute cycling in persons with multiple sclerosis. *Anxiety Stress Coping.* 2009; 22:297-307.
28. Raglin, J.S. Exercise and mental health. Beneficial and detrimental effects. *Sports Med.* 1990; 9:323-9.
29. Raglin, J.S. Anxiety and sport performance. *Exerc Sport Sci Rev.* 1992; 20:243-74.
30. Raglin, J.S., and W.P. Morgan. Influence of exercise and quiet rest on state anxiety and blood pressure. *Med Sci Sports Exerc.* 1987; 19:456-63.
31. Raglin, J.S., P.E. Turner, and F. Eksten. State anxiety and blood pressure following 30 min of leg ergometry or weight training. *Med Sci Sports Exerc.* 1993; 25:1044-8.

32. Smith, J.C., M.M. Bradley, and P.J. Lang. State anxiety and affective physiology: effects of sustained exposure to affective pictures. *Biol Psychol.* 2005; 69:247-60.
33. Smith, J.C., and P.J. O'Connor. Physical activity does not disturb the measurement of startle and corrugator responses during affective picture viewing. *Biol Psychol.* 2003; 63:293-310.
34. Smith, J.C., et al. Emotional responsiveness after low- and moderate-intensity exercise and seated rest. *Med Sci Sports Exerc.* 2002; 34:1158-67.
35. Smits, J.A., et al. The effects of acute exercise on CO(2) challenge reactivity. *J Psychiatr Res.* 2009; 43:446-54.
36. Sothmann, M.S., et al. Exercise training and the cross-stressor adaptation hypothesis. *Exerc Sport Sci Rev.* 1996; 24:267-87.
37. Spielberger, C.D. Assessment of state and trait anxiety: Conceptual and methodological issues. *The Southern Psychologist.* 1985; 2:6-16.
38. Spielberger, C.D. *State-Trait Anxiety Inventory: A comprehensive bibliography.* Palo Alto, CA: Consulting Psychologists Press, 1989.
39. Spielberger, C.D., et al. *Manual for the State-Trait Anxiety Inventory.* Palo Alto, CA: Consulting Psychologists Press, Inc., 1983, pp. 5.
40. Strohle, A., et al. The acute antipanic activity of aerobic exercise. *Am J Psychiatry.* 2005; 162:2376-8.
41. Tian, Q., and J.C. Smith. Attentional bias to emotional stimuli is altered during moderate-but not high-intensity exercise. *Emotion.* 2011; 11:1415-24.
42. Vautier, S., and S. Pohl. Do balanced scales assess bipolar constructs? The case of the STAI scales. *Psychol Assess.* 2009; 21:187-93.

43. Wipfli, B.M., C.D. Rethorst, and D.M. Landers. The anxiolytic effects of exercise: a meta-analysis of randomized trials and dose-response analysis. *J Sport Exerc Psychol.* 2008; 30:392-410.
44. Youngstedt, S.D., et al. Does body temperature mediate anxiolytic effects of acute exercise? *J Appl Physiol.* 1993; 74:825-31.
45. Youngstedt, S.D., et al. Acute exercise reduces caffeine-induced anxiogenesis. *Med Sci Sports Exerc.* 1998; 30:740-5.

Supplemental Digital Content

Appendix. International Affective Picture System (IAPS) stimuli.

Figure Caption

Figure 1. State anxiety scores before (Pre-) and after (Post-) the exercise and seated rest conditions, and after the picture viewing session (After Pictures). The mean (\pm SD) state anxiety scores were: Pre-Exercise 31.7 (10.2); Pre-Rest 30.7 (10.6); Post-Exercise 28.8 (6.3); Post-Rest 28.4 (8.4); After Pictures-Exercise 28.5 (9.7); After Pictures-Rest 31.8 (10.2). Error bars = SEM.

* significant difference between the exercise and seated rest condition ($p = .004$).

Figure 1

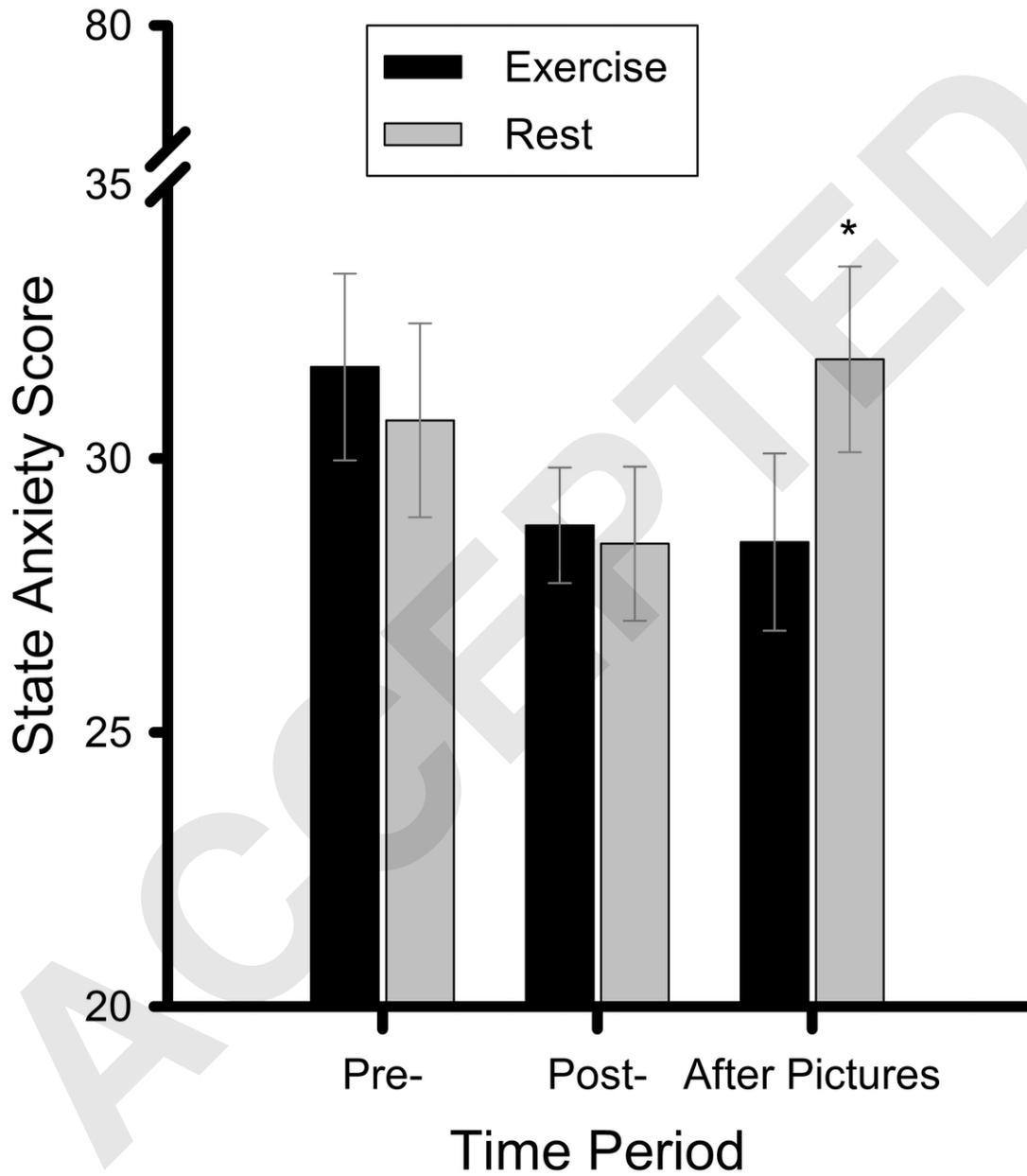


Table 1. Participant characteristics and affective ratings of picture stimuli (N = 36)^a.

Variable	Current Sample		Comparative Data	
	Mean	SD	Mean	SD
Age	22.6	3.3	--	--
Trait anxiety (STAI-Y2)	45.7	3.4	39.6 ^b	9.8
Depression symptoms (BDI-II)	4.4	4.7	9.1 ^c	7.6
Leisure time physical activity (arbitrary units)	51.3	20.8	45.8 ^d	NR
Pleasant picture valence ratings (SAM)	6.73	0.94	7.15 ^e	1.68
Neutral picture valence ratings (SAM)	5.03	0.21	5.05 ^e	1.28
Unpleasant picture valence ratings (SAM)	2.07	0.96	2.27 ^e	1.55
Pleasant picture arousal ratings (SAM)	3.99	1.96	5.38 ^e	2.24
Neutral picture valence ratings (SAM)	2.33	1.43	3.14 ^e	1.93
Unpleasant picture valence ratings (SAM)	4.31	2.15	6.70 ^e	2.15

Notes: ^a Affective ratings of pictures were missing for two subjects; ^b Based on normative data from 855 college-aged students (531 female, 324 male) ; ^c Based on normative data from 1,022 college-aged students (531 female, 324 male) ; ^d Based on normative data from 306 healthy adults (163 men, 143 women, mean age 30.7 yrs) with a mean (SD) $\text{VO}_{2\text{max}}$ of 39.6 (6.0 ml kg⁻¹ min⁻¹); ^e Based on normative data from healthy college students . BDI-II = Beck Depression Inventory II; STAI-Y2 = State Trait Anxiety Inventory-Form Y2; NR = not reported; SAM = Self-Assessment Manikin, 1 to 9 scale .

Table 2. Physiologic and subjective responses before (Pre-), during, 15-min after (Post-), and after emotional picture viewing (After Pictures) for the exercise and rest conditions. P-value reflects the comparison between conditions within each variable (Bonferroni adjusted, $p < .0125$).

Variable	Exercise		Rest		Comparison p-value
	Mean	SD	Mean	SD	
Work (Watts)	83.4	29.1	--	--	--
Heart Rate (bpm)					
Pre-	86.8	18.8	86.9	18.0	ns
During	136.9	15.9	83.0	12.6	< 0.001
Post-	83.3	12.0	74.1	14.6	< 0.001
After Pictures	76.9	12.4	72.8	12.4	ns
RPE (6-20)					
Pre-	6.4	1.1	6.0	0.2	ns
During	13.0	0.5	6.1	0.2	< 0.001
Post-	6.2	0.9	6.0	0.2	ns
After Pictures	6.1	0.3	6.1	0.4	ns
Leg Pain (0-10)					
Pre-	0.1	0.3	0.0	0.1	ns
During	1.5	1.2	0.1	0.3	< 0.001
Post-	0.1	0.4	0.1	0.2	ns
After Pictures	0.1	0.4	0.0	0.1	ns
Pleasantness (1-9)					
Pre-	7.5	1.6	6.9	1.9	ns
During	7.3	1.4	7.1	1.5	ns
Post-	7.5	1.5	6.9	1.5	ns
After Pictures	6.6	2.0	6.4	1.7	ns
Arousal (1-9)					
Pre-	3.8	2.0	3.5	2.0	ns
During	5.3	1.7	3.4	1.9	< 0.001
Post-	3.9	2.2	3.4	1.9	ns
After Pictures	2.8	1.8	3.2	1.9	ns

Appendix. International Affective Picture System (IAPS) stimuli.

Pleasant: 1440, 1441, 1460, 1463, 1540, 1590, 1610, 1710, 1750, 1920, 1500, 1620, 1722, 1811, 1812, 4611, 4658, 4659, 4666, 4676, 4677, 4680, 4681, 4690, 4694, 4651, 4653, 4656, 4670, 4672. Neutral: 2191, 2214, 2215, 2372, 2383, 2393, 2394, 2480, 2595, 7550, 2381, 2485, 2495, 2499, 2570, 5740, 7036, 7041, 7050, 7100, 7130, 7161, 7224, 7234, 7500, 7140, 7150, 7235, 7205, 7217. Unpleasant: 1050, 1120, 1300, 1525, 1932, 3500, 3530, 6230, 6243, 6312, 6313, 6315, 6350, 6550, 6571, 3000, 3051, 3060, 3068, 3069, 3071, 3100, 3101, 3266, 3400, 3030, 3110, 3130, 3150, 3170

ACCEPTED