Acute Exercise Prevents Angry Mood Induction but Does Not Change Angry Emotions

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ABSTRACT

THOM, N. J., P. J. O'CONNOR, B. A. CLEMENTZ, and R. K. DISHMAN. Acute Exercise Prevents Angry Mood Induction but Does Not Change Angry Emotions. *Med. Sci. Sports Exerc.*, Vol. 51, No. 7, pp. 1451–1459, 2019. **Introduction:** Exercise is well known to enhance a variety of mood states, but few studies have been specifically designed to investigate whether acute aerobic exercise alters feelings of anger. The goal of this study was to determine the magnitude of the effects of acute exercise on both angry mood and angry emotions. **Methods:** Angry mood and angry emotions were assessed in 16 men with elevated trait anger who viewed a variety of emotionally evocative scenic pictures before and after 30 min of moderate- to vigorous-intensity aerobic exercise. Angry mood, captured by self-reports of state anger, angry emotions, as indexed by event-related brain activity (e.g., early posterior negativity and late positive potential), and self-reports of anger intensity were measured. **Results:** The results indicate that acute exercise both 1) reduces angry mood and 2) mitigates angry mood induction but does not change the intensity of angry emotions or the associated event-related potential responses to anger-inducing pictures in college-age men who have elevated trait anger. **Conclusion:** Future studies should explore the mechanisms underlying the effect of exercise on preventing angry mood induction, consider alternative anger induction methods that might induce higher levels of angry emotions, and test the effects of chronic exercise training on anger and its expression. **Key Words:** ANGER EXPRESSION, ELECTROENCEPHALOGRAPHY, EMOTION, ERP, MOOD

Extensive evidence suggests that exercise enhances pleasant affect and ameliorates negative moods, including tension, anxiety, and depression, and people report that exercise is one of the most common approaches they take to manage their mood. By contrast, very few studies have tested whether acute exercise alters emotional processing, a mood-related construct. Moods tend to be longer-lasting cognitive states with no antecedent event nor any neurophysiological correlates, whereas emotions tend to be of shorter duration with a specific causal triggering event and measurable neurophysiology (1). Although there are a few studies that have evaluated the effects of acute exercise on general emotional processing (2–4), we are unaware of any studies that have evaluated both angry mood and emotions in men with high levels of trait anger, despite the considerable burden of anger on public health and welfare (5). For example, anger is associated with acts of violence and aggression (6) as well as elevated odds of hypertension (7), cardiovascular disease (8), and cardiovascular events (9). Angry mood and emotions are regulated by limbic and frontal brain regions that can be altered by acute exercise (10). Therefore, it is plausible that acute exercise could reduce anger by altering activity in neural circuits that control mood and emotion. The purpose of this study was to investigate the effects of acute moderate-intensity aerobic exercise on angry mood, and brain and behavioral correlates of angry emotional responses in a sample of high trait anger, college-age men.

Different types of studies suggest that exercise could reduce angry mood. Cross-sectional studies found an inverse relation between angry mood and exercise session duration, especially in men (11), and those individuals who exercise more than twice a week experience less anger (12). A review of experimental and quasi-experimental studies on the effects of acute exercise on mood found that a bout of exercise is accompanied by a moderate reduction in state anger (Thom, unpublished observations, August 2009). Most of those studies were not conducted for the purpose of evaluating anger outcomes of acute exercise; therefore, most study participants had low levels of trait or state anger before exercise. However, it is likely that reductions in anger after acute exercise would be more pronounced after evoking anger, or in high trait anger individuals, as is the case with anxiety (13). Also, most of the studies evaluated did not attempt to manipulate anger, which precludes causal inferences about reductions in anger after exercise. One study that did manipulate anger used guided imagery to induce an upset/angry mood and reported a reduction in state anger after a bout of resistance exercise (14). The implications of those results are limited, however, because the reduction in anger after exercise was of the same magnitude as in the control

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group. Furthermore, many of the studies used the anger–hostility scale of the Profile of Mood States to measure angry mood, but that scale was designed to measure the intensity of the mood of anger and does not differentiate between the experience and the expression of anger. By contrast, the State-Trait Anger Expression Inventory 2 (STAXI-2) was designed to separate anger from hostility and aggression as well as measure the experience and expression of anger (15). Another methodological limitation of a majority of the studies was the sole use of self-report outcomes, which are vulnerable to experimenter and subject expectancy effects. An alternative, and potentially stronger, methodology would include measuring a physiological index of anger to provide objective complementary or convergent evidence for self-reports. Although moods do not produce marked physiological changes, emotions do. Therefore, it would be possible to measure a physiological index of anger by evoking angry emotions. Because angry emotions are regulated by several limbic system structures and the prefrontal cortex, studies designed to test the effects of exercise on angry emotions could benefit from concurrently measuring changes in relevant brain activity.

Electroencephalography (EEG) has been widely used to measure brain activity during emotion, and oscillatory and event-related brain dynamics can be measured as correlates of emotional processing. Event-related potentials (ERP) are linked to functional hemodynamics during emotional processing and are therefore a precise measure of brain activity during emotion processing (16). Numerous studies have measured ERP during emotion and have found that the amplitude of several components (e.g., early posterior negativity [EPN] and late positive potential [LPP]) is altered while participants view arousing emotional stimuli (for a review, see Schupp et al. (17)). In short, middle-latency components like the EPN are altered by the emotional content of scenic pictures, such that highly arousing pleasant and unpleasant pictures result in greater EPN amplitude, indexing selective attention (18). In addition, the LPP has been linked to the process of encoding relevant stimuli into working memory (19) and is also altered by the emotional valence and arousal level of evocative pictures (20). EPN and LPP are the most widely studied ERP indices of emotional processing. To our knowledge, no studies have measured ERP correlates of angry emotions after exercise, but one study did show reduced self-reported arousal to unpleasant pictures after acute aerobic exercise (2), suggesting that unpleasant emotional stimuli are processed differently by the brain after a single bout of aerobic exercise.

In this study, we assessed angry mood and emotions in men with elevated trait anger before and after 30 min of quiet rest or moderate-intensity aerobic cycling exercise. The goal of this study was to determine the magnitude of the effects of acute exercise on angry mood and on anger-associated brain and behavioral responses to emotionally evocative stimuli. The main hypotheses were that an acute bout of exercise would 1) reduce postexercise anger mood state and 2) reduce the intensity of angry emotions and the associated EPN and LPP amplitude during the viewing of anger-evoking pictures.

MATERIALS AND METHODS

Participants

Male students in psychology classes at the University of Georgia were recruited and were given course credit for participation. To recruit men with elevated trait anger, 430 potential participants filled out the trait portion of the anger scale, along with several other questionnaires to mask the intent of the study. Inclusion criteria required trait anger scores 1 SD above the normative mean. Exclusion criteria included 1) any contraindications to maximal aerobic training based on the American College of Sports Medicine guidelines, 2) any use of psychoactive drug, 3) physician-diagnosed mood disorder, and 4) seizure disorder or history of migraines. Sixteen eligible Caucasian men volunteered. All participants read and signed an informed consent form that was approved by the University of Georgia Institutional Review Board. Table 1 provides selected characteristics of the sample.

Power Calculation

An acute bout of exercise can alter P300 by 0.5 SD during a cognitive task (21). Therefore, it was estimated that 16 participants were needed to detect a moderate condition–time effects (0.5 SD, $\beta = 0.80$, $\alpha = 0.01$, correlation between repeated measures = 0.80, nonsphercity correction = 0.70) of exercise on state anger and the amplitude of the ERP waveforms of interest (17).

Measures

STAXI-2. Spielberger's STAXI-2 was used to measure anger characteristics of the participants (22). The STAXI-2 is a 57-item self-report measure consisting of six scales, five subscales, and an anger expression index of the expression and control of anger. The six scales consist of the following: state anger, trait anger, anger expression—out, anger expression—in, anger control—out, and anger control—in. The state anger scale consists of three subscales with five items each that measure general feelings of anger, feeling about expressing anger verbally, and feeling about expressing anger physically. For trait anger, the STAXI-2 has two subscales with four items each that measure angry temperament and angry reaction. The anger expression and anger control scales are trait measures that describe the way an individual tends to express and control their anger.

Self-assessment manikin. The self-assessment manikin (SAM) scales allow the separate measurement of valence (pleasantness/unpleasantness) and arousal. The valence scale

TABLE 1. Selected participant characteristics with normative data for comparison.

	This Sample (n = 16)	Norms[a]
Age (yr)	20.1 ± 2.6	
Height (cm)	182.4 ± 6.6	
Weight (kg)	87.0 ± 20.0	160 ± 22
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	36.8 ± 7.6	42 ± 10
Physical activity (kcal·kg^{-1}·d^{-1})	52.6 ± 5.2	37.2 ± 3.3
Trait anger (STAXI-2)	26.13 ± 5.92	18.4 ± 5.4

Data are presented as mean ± SD.
[a]Norms: weight and $\dot{V}O_{2peak}$ (42); physical activity (43); trait anger (33).

consists of a graphic figure representing a smiling happy figure to a frowning unhappy figure, whereas the arousal scale consists of a similar figure ranging from an excited, wide-eyed figure to a relaxed, sleepy figure. Participants rate their feelings on a 1–9 scale by selecting the number associated with each SAM figure. A score of 9 is a high score on each scale, such that scores of 9 indicate highly arousing or highly pleasant pictures. Substantial evidence suggests the SAM is a highly reliable and valid measure of arousal and valence.

Ordered categorical anger intensity scale. Anger intensity in response to picture viewing was measured by an ordered categorical scale. The scale ranged from 0 to 9 and was anchored on the zero-end by the phrase "I am not angry" and the nine-end by the phrase "I could not be angrier." A standard set of instructions was read to each participant before providing self-reports of anger intensity that directed participants to provide a rating that represented how they felt while watching the picture.

$\dot{V}O_{2peak}$ testing. Peak oxygen consumption ($\dot{V}O_{2peak}$) was measured via open-circuit spirometry (Parvo Medics TrueOne 2400) on an electronically braked, computer-driven cycle ergometer (Lode BC, Groningen, The Netherlands). The purpose of determining $\dot{V}O_{2peak}$ was to standardize the subsequent exercise bouts to the same relative percentage across individuals. Initially, each participant was outfitted with a Polar S120 heart rate monitor (Polar Electro Oy, Kempele, Finland) to allow continuous measurement of heart rate and fitted to the cycle ergometer. At the outset of the test, participants cycled at 50 W for 3 min as a warm-up and to allow familiarization with the testing equipment. Participants were instructed to keep pedal cadence between 60 and 90 rpm. After the warm-up period, the work rate increased continuously at a rate of 24 $W \cdot min^{-1}$ until volitional exhaustion. Respiratory and metabolic variables were collected over 15-s intervals; heart rate and Borg's RPE were collected during the last 10 s of every minute and immediately after the participant reached volitional exhaustion. The RPE scale ranges from 6 to 20 and is anchored by "very, very light" (7) and "very, very hard" (19). $\dot{V}O_{2peak}$ was defined as the highest $\dot{V}O_2$ value when two of the three following criteria were satisfied: 1) HR within 10 bpm of age-predicted max, RER > 1.10, or RPE ≥ 18. All criteria were met: mean HR = 202.75 ± 3.47, RER = 1.37 ± 0.02, and RPE = 19.06 ± 0.14. In addition, ventilatory threshold (VT) was estimated based on plots of $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ as a function of time and was on average 60.3% ± 1.3% of $\dot{V}O_{2peak}$.

EEG. Vertex-referenced EEG data were recorded using a 256-sensor Geodesic Sensor Net and NetAmps 200 amplifiers (Electrical Geodesics; EGI, Eugene, OR). The sensor net was adjusted until all pedestals were properly seated on the scalp (i.e., not sitting on mats of hair that could result in bridging between sensors). Individual sensor impedances were adjusted until they were below 50 kΩ. In addition, an electrolyte bridge test was conducted between all pairs of sensors before recording, and if there was evidence of bridging, sensors were adjusted until bridging was no longer evident (this was rarely required). Data were sampled at 250 Hz with an analog band-pass filter of 0.1–200 Hz.

EEG data reduction and analysis. Data were preprocessed following recommendations (with minimal modification) made by Junghöfer et al. (23). Raw data were visually inspected offline for bad sensor recordings. Bad sensors were interpolated (no more than 5% of sensors for any subject) using a spherical spline interpolation as implemented in BESA 5.2 (MEGIS Software, Gräfelfing, Germany). Data were transformed to an average reference and digitally filtered from 0.5 to 58 Hz (12 dB per octave roll-off, zero-phase) and notch filtered at 60 Hz (4 Hz width). Eye blink and cardiac artifact correction was achieved by using the independent component analysis toolbox in EEGLAB 14 under Matlab (version 7.0; MathWorks, Natick, MA). Independent component analysis allows artifact removal without spatially distorting the data by using higher-order statistics to produce temporally independent signals in the data. Independent components representing saccades, blinks, and heart rate artifact were removed.

To evaluate the ERP waveform, epochs of 1200 ms (200 ms prestimulus and 1000 ms poststimulus) were obtained for each picture from the continuously recorded EEG. To account for baseline electrocortical activity, the mean power in the first 200 ms (before stimulus onset) was subtracted from the remaining ERP. To assess ERP peaks and their time course, the global power of the ERP was computed. Global power is computed as the mean square of the averaged signal across electrodes for each emotional content category (e.g., fear, anger, etc.), weighted by the SD of the voltage across trials at each electrode and time point. The maximum amplitude of the global field plot for the most pronounced peak between 260 and 280 ms and between 600 and 800 ms was operationalized as EPN and LPP, respectively. For each participant and each component, top–down meridian plots were constructed in BESA to confirm the appropriateness of spatial distribution of the component. Cluster thresholding was used to determine which scalp regions showed differential activity based on the picture content. This technique was used to allow for multiple comparisons among numerous sites of activity without using Bonferroni correction for multiple comparisons, which tends to be too conservative for brain data. To maintain a family-wise alpha lower than 0.01, two conditions were necessary. First, the P value associated with the statistical test for each sensor must be less than 0.035, and that sensor must be adjacent to at least six sensors with P values less than 0.035. These estimates were derived from the baseline level of noise in the data and Monte Carlo simulations using AlphaSim in AFNI. These conditions are also based on the assumption that relevant brain activity at the sensor level will likely be highly correlated with adjacent sensors. After determining which scalp regions were of interest, intraclass correlations were calculated across sensors in each region and if appropriate (if the intraclass correlation-2 was high) averages across the clusters were calculated and used for statistical analysis.

Procedures

All testing was performed at the Bio-Imaging Research Center at the University of Georgia. Each participant underwent

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3 d of testing that lasted approximately 2 h and conducted at about the same time each day within subjects. Each session was separated by 24–72 h, and all sessions were completed within 7 d. During the first day, participants filled out the informed consent and a self-administered medical history questionnaire, and they underwent the 7-Day Physical Activity Recall Interview (24). If no contraindications to exercise were present, each participant underwent $\dot{V}O_{2peak}$ testing.

During the two subsequent intervention days, before any physical activity, participants completed the state anger portion of the STAXI-2 before (baseline) and after (precondition) viewing pictures that were neutral or shown to elicit emotions of anger, fear, and pleasantness based on our (25) and other's work using the International Affective Picture System and other pictures of natural scenes to elicit these emotions (26). EEG activity was collected during picture viewing, and self-reports of arousal and valence (pleasantness) in response to each picture were collected using the SAM. Anger intensity was also measured during each slide using an ordered categorical scale. In a counterbalanced fashion, the participant either rested quietly for 30 min or performed an acute bout of cycling exercise at an intensity that approximated 65% of $\dot{V}O_{2peak}$. We chose to use a moderate to vigorous intensity because we have previously shown that college-age men prefer cycling exercise at an intensity approximating or slightly exceeding 60% of their $\dot{V}O_{2peak}$. Perceptual responses to the exercise were confirmed using RPE and leg muscle pain intensity ratings. Expired gases were measured using open-circuit spirometry at 10 and 20 min to document changes in $\dot{V}O_2$. After the intervention, participants again completed the state anger portion of the STAXI-2 before (postcondition, pre–slide show) and after (postcondition, post–slide show) viewing the same pictures in a different order while self-report and EEG responses were measured.

Picture presentation. Participants first viewed a set of six pictures that were not used during data collection to gain experience using the keyboard to provide self-report responses during picture viewing. This initial exposure to the procedures was also used to train the participant how to remain fixated on the center of the screen during picture viewing. This was verified during data collection by watching EOG channels. No participants had excessive saccades during picture viewing. Subsequently, participants were outfitted with the high-density electrode array as described below. During data collection, participants viewed a selection of scenic pictures that have been previously shown to induce anger (26), fear, pleasantness, and no emotion. In a random fashion, 12 pictures from each content area were presented twice for total of 96 pictures. Participants first viewed a fixation cross for 750 ms, followed by a picture for 3000 ms, a black screen for 1000 ms, each rating scale (anger intensity, arousal, and valence), and finally a black screen for 1000 ms. Each picture was presented twice to increase the signal-to-noise ratio within each content area. Interstimulus interval varied between subjects, commonly 5–10 s, resulting in a picture-viewing paradigm of 30–45 min.

Data analysis. Baseline scores on the STAXI-2 were computed and are presented in Table 2. To determine the effects of exercise on measures of state anger (STAXI-2), a 2 × 4 condition (exercise vs quiet rest)–time (baseline vs precondition, postviewing vs postcondition vs postcondition, postviewing) repeated-measures (RM) ANOVA was computed with condition and time repeated. Significant effects were decomposed by follow-up RM ANOVA within condition and simple contrasts. Partial eta square was computed to evaluate the magnitude of significant contrasts. For anger intensity, arousal, valence, and ERP amplitudes, a separate 2 × 2 × 4 condition (exercise vs quiet rest)–time (pre- vs postsession)–content (anger vs fear vs pleasant vs neutral) RM ANOVA was computed with condition, time, and content repeated. The effect of picture viewing on state anger was analyzed by a 2 × 2 condition (exercise vs quiet rest)–time (baseline vs precondition) RM ANOVA. Tests were corrected for violations of the assumption of sphericity by Huynh–Feldt ε when appropriate. Data are presented as mean ± SD except when noted otherwise (e.g., in the figures).

RESULTS

Effects of Exercise

The exercise manipulation was successful at eliciting a moderately vigorous response. As evidence, the mean percentage of $\dot{V}O_{2peak}$ achieved during the exercise session was 65.11% ± 6.7% with a mean RPE of 13.39 ± 1.3 ("somewhat hard") and a mean leg muscle pain intensity rating of 3.96 ± 1.03 ("somewhat strong pain"). All participants exercised at an intensity approximating or slightly above VT (VT plus 5.4% ± 8.8%).

Angry mood. Exercise resulted in two important findings related to angry mood: 1) it reduced angry mood (see Fig. 1), and 2) it mitigated the induction of an angry mood that resulted from the emotionally evocative picture-viewing session (see Fig. 2). Condition–time effects were significant for general feelings of anger ($F_{3,\ 45}$ = 7.136, ε = 0.818, P = 0.001, η^2 = 0.322), and for expressing anger verbally ($F_{3,\ 45}$ = 3.627, ε = 1.000, P = 0.020, η^2 = 0.195) but not physically ($F_{3,\ 45}$ = 1.455, ε = 0.704, P = 0.248, η^2 = 0.088).

As depicted in Figure 1, there was a significant reduction in angry mood after exercise (P = 0.028), but no reduction in angry

TABLE 2. STAXI-2 scores and normative data (22).

	This Sample	Norms
Total trait anger	26.13 ± 5.92	18.37 ± 4.83
Angry temperament	9.25 ± 2.26	6.36 ± 2.4
Angry reaction	12.06 ± 2.65	8.76 ± 2.47
Anger expression		
Expression—in	18.88 ± 4.50	16.64 ± 3.96
Expression—out	21.75 ± 4.04	15.00 ± 3.50
Control—in	19.50 ± 5.61	23.05 ± 5.64
Control—out	19.37 ± 4.50	23.62 ± 4.76
Total state anger	22.04 ± 8.73	18.95 ± 6.63
Feeling	9.23 ± 3.42	6.94 ± 2.67
Verbal	6.58 ± 2.51	6.32 ± 2.65
Physical	6.23 ± 2.79	5.71 ± 1.99

Data are presented as mean ± SD.

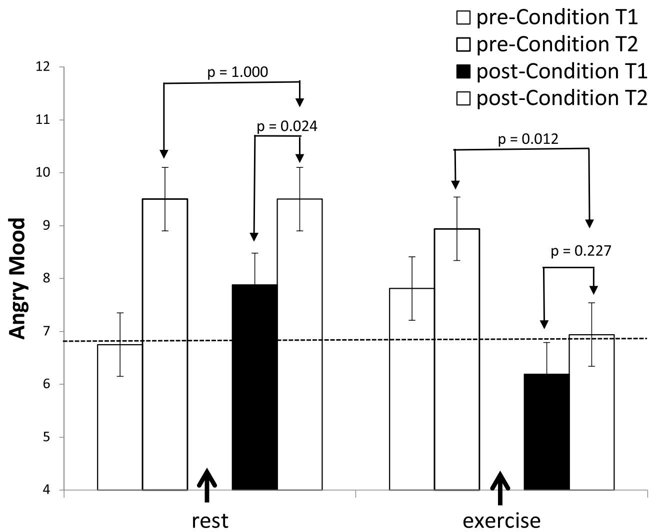

FIGURE 1—STAXI-2 scores for general feelings of anger (i.e., mood) from before and after quiet rest or exercise. Acute aerobic exercise resulted in a large reduction in angry mood. Dashed line represents normative mean (see Table 2). Data are presented as mean ± SEM.

mood after quiet rest (P = 0.201). As depicted in Figure 2, angry mood was increased after the second picture viewing (P = 0.024) to the level observed after the first viewing (P = 1.0) in the quiet rest condition. By contrast, angry mood was not significantly increased by picture viewing after exercise (P = 0.227) and was lower than after the first viewing before exercise (P = 0.012). The mitigation of anger by exercise after slide viewing was a large effect (about 2/3 of an SD).

There were no significant effects of exercise on verbal anger expression (P = 0.288). Verbal anger expression was increased above baseline by picture viewing before quiet rest (P = 0.036), unchanged after quiet rest (P = 0.110), and increased above baseline by picture viewing after quiet rest (P = 0.043).

Emotions during picture viewing. The pictures successfully evoked emotional responses by eliciting anger intensity, arousal, and pleasantness that were in line with numerous previous reports that are cited in the Procedures section. However, exercise had no effect on emotions (i.e., anger intensity, arousal, or pleasantness).

Anger intensity during picture viewing was reduced after both exercise and quiet rest. There were main effects of time ($F_{1,\ 15}$ = 8.418, P = 0.011, η^2 = 0.359) and content ($F_{3,\ 45}$ = 33.692, ε = 0.483, P < 0.001, η^2 = 0.692), but no other main or interaction effects ($\eta^2 \leq 0.157$, $P \geq 0.085$). The main effect of time was not explained by any linear trend associated with repeated viewing of anger-inducing pictures ($F_{23,\ 345}$ = 1.713, P = 0.164, η^2 = 0.102).

Arousal during picture viewing was not affected by exercise for any of the content categories. Consistent with previous literature (20), there was a main effect of content ($F_{3,\ 45}$ = 31.981, ε = 0.580, P < 0.001, η^2 = 0.68). There was no main effect of time or interaction effects ($\eta^2 \leq 0.062$, P values $\geq$ 0.380).

Pleasantness during picture viewing was not affected by exercise for any of the content categories. Consistent with previous literature, there was a main effect of content ($F_{3,\ 45}$ = 67.608, ε = 0.516, P < 0.001, η^2 = 0.82). There were no other main or interaction effects ($\eta^2 \leq 0.22$, P values $\geq$ 0.06).

Mean amplitudes for ERP. Exercise had no effect on the ERP. For the EPN, there were significant main effects of time and content ($F_{1,\ 12}$ = 9.952, P = 0.014, η^2 = 0.453; $F_{3,\ 36}$ = 15.647, ε = 0.736, P = 0.001, η^2 = 0.556), but no effect of condition (P = 0.994) and no interactions (all P values > 0.176). Simple effects revealed that EPN amplitude was larger after both interventions combined (P = 0.008) and that, consistent with extant previous literature (25), EPN amplitude was larger for arousing pictures (e.g., anger, fear, and pleasant) when compared with neutral pictures (all P values < 0.013) but that there were no differences between the evocative pictures (all P = 1.000). For the LPP (see Fig. 3), there was a main effect of content ($F_{3,\ 36}$ = 4.969, ε = 0.712, P = 0.014, η^2 = 0.293), consistent with extant previous literature (20). The LPP amplitude was larger for arousing pictures when compared with neutral pictures (all P values < 0.020), but there were no significant effects of condition, time, or any of the interactions (all P values > 0.150). The intraclass correlation-2 of the channels within the cluster was high for all components (all intraclass correlation-2 > 0.92).

DISCUSSION

The major novel findings of the study were that a bout of moderate-intensity aerobic exercise 1) reduced angry mood among men with elevated levels of trait anger, 2) mitigated the increase in angry mood that was induced by picture viewing, and 3) did not alter angry emotions in response to anger-evoking pictures or result in differences in the associated ERP components. As mentioned, moods are relatively long-lasting (e.g., typically hours or days) mental states that are not triggered

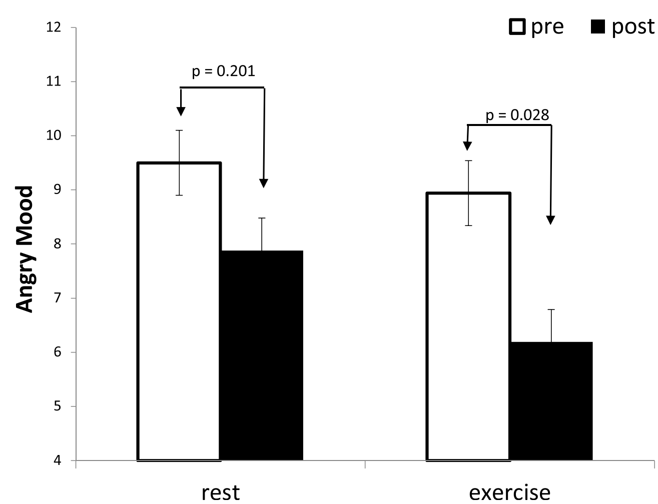

FIGURE 2—STAXI-2 scores for general feelings of anger (i.e., mood) from all four collection time points. Unexpectedly, the picture-viewing session evoked angry mood, but exercise mitigated this effect. That is, both before and after the control condition, the picture-viewing session evoked angry mood. However, after exercise, the picture-viewing session did not evoke an angry mood. Pre- or postcondition refers to before or after the acute bout of exercise or the quiet rest period, and T1 or T2 refers to before or after the picture-viewing session. Dashed line represents normative mean (see Table 2). Data are presented as mean ± SEM.

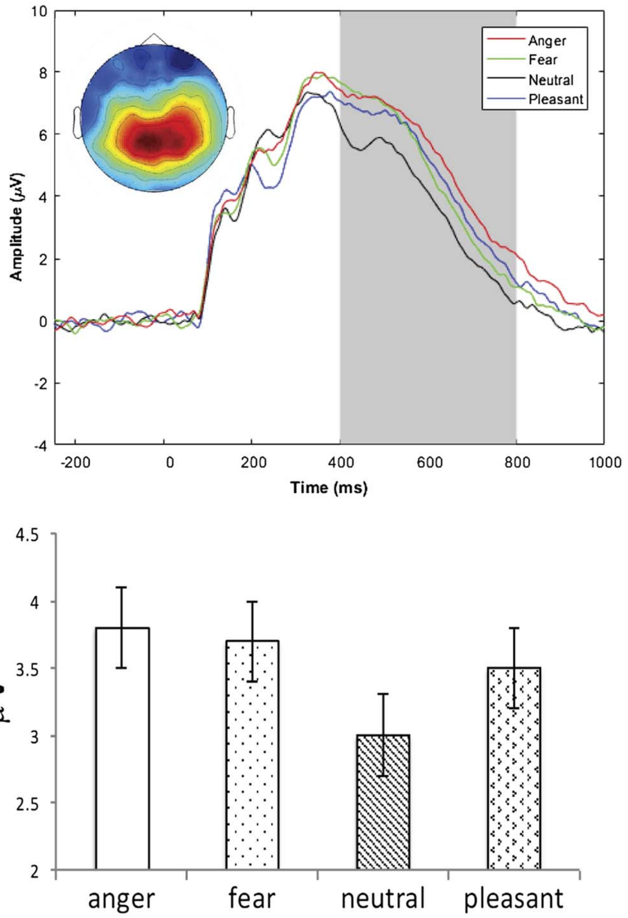

FIGURE 3—Depicted here are waveform plots and associated mean amplitudes for the LPP. At the top, the overall average waveforms and top–down meridian plots are presented for the main effect of content. The shaded region in the waveform plot represents the time window for the LPP, and the waveforms represent the average of the channels within the cluster that was revealed in the clusterwise analysis. The bar graphs represent mean amplitude across the LPP time frame (e.g., 400–800 ms) across all channels included in the LPP cluster.

by a specific stimuli, do not have observable or measurable neurophysiological correlates, and are not controllable. By contrast, emotions are relatively short lived (e.g., lasting seconds or minutes), are triggered by a specific stimulus, are associated with measurable neurophysiological changes, and can be controlled (1). The results extend to angry mood a similar mitigation of anxious mood by exercise after emotional picture viewing (3), further suggesting that acute exercise can have a prophylactic effect in mitigating negative moods after emotional provocation.

To our knowledge, this is the first study to report positive effects of an acute bout of exercise on angry mood among high trait anger men using a validated measure of anger. The magnitude of this reduction (partial eta square = 0.33–40) is large and comparable with the effect of acute administration of gabapentin (Cohen's d = 0.79) (27) or tiagabine (Cohen's d = 0.60) (28) on aggression and on anger reduction after 8 wk of treatment for aggression with topirimate in men with borderline personality disorder (29). Changes in the desire to express anger verbally or physically followed a similar pattern as seen for general feelings of anger but were not altered by exercise in a statistically significant manner. The state anger questions developed for the STAXI-2 scale were designed to measure three components of anger, namely, general feelings of anger ranging from annoyed to furious, the desire to express anger by yelling at someone, or shouting out loud, and the desire to break things and hit or kick people. Therefore, the general feelings scale is more sensitive to lower levels of anger than the other two state anger subscales (22), which measure more overt expressions of anger. Even in a psychiatric samples, state anger scores for verbal and physical expression of anger are only minimally elevated (~2 points above the minimum score), whereas general angry feelings are substantially raised (greater than 4 points above minimum) (22). It is unlikely, therefore, that moderate-intensity exercise or sitting quietly would alter people's drives to verbally or physically express anger. Even when an angry mood was induced by picture viewing, the elevation was greatest for general angry feelings than for the desire to verbally or physically express anger, further demonstrating that the methodological manipulations used here would not be expected to alter verbal or physical expression of anger (although we mention several other methods to manipulate mood and emotion below that may elevate the desire to express anger verbally or physically). Nevertheless, the reduction in general feelings of anger after exercise is important because of the public health burden associated with elevated levels of anger.

Not only did exercise reduce state anger, but it also protected against the adventitious increase in angry mood that occurred after viewing evocative pictures. To our knowledge, only one other study has tested the effect of exercise on manipulated angry mood (14). Although that study found no benefit of exercise over quiet rest, the results presented here suggest that exercise may function in a prophylactic manner for preventing angry mood during anger-inducing events up to 30–45 min postexercise. Indeed, as shown in Figure 2, exercise led to the reduction and maintenance of anger levels below population norms, suggesting that exercise can powerfully reduce an evoked angry mood in a sample of individuals that tend to experience and express high levels of anger. Only one other study has investigated the effects of acute exercise on mood that was evoked by the viewing of emotional pictures (3). In that study, acute exercise prevented the rebound of anxiety to preexercise levels, an effect not seen in the quiet rest group. Here we extend this anxiolytic effect of exercise to an "angerlytic" effect of exercise.

It is unclear why viewing a series of randomly ordered evocative (i.e., anger, fear, and pleasant) and neutral pictorial stimuli would lead to an angry mood and subsequently be ameliorated by acute exercise. One plausible explanation is that the overall response to the pictures is influenced by the mood-congruent information biasing effects of anger, in this case, and anxiety, in Smith's study mentioned in the previous paragraph (3). That is, because the men in this study tend to experience and express higher than normal levels of anger, their perception of the evocative stimuli was biased toward the unpleasant, anger-evoking stimuli in a way that further elevated their angry mood. Then in turn, the mood-improving effects of exercise created an opposing pleasant mood that resulted in mood-congruent responses to the pleasant pictures thereby dampening responses to the unpleasant pictures, an effect demonstrated previously (2). These mood-congruent effects on emotion were not strong enough, however, to alter ratings of arousal and pleasantness to each picture individually, before or after exercise.

To further investigate this "angerlytic" effect, future studies should be designed to manipulate state anger using established mood manipulation paradigms. For example, narrative imagery has been successfully used to manipulate mood in the MRI environment (30), and others have used anger recall tasks to measure the cardiovascular effects of angry rumination (31). In addition, some film clips can provide replicable anger manipulation (32), whereas others suggest that anger is best manipulated by a combination of deception, using social psychology methods (e.g., insults by a confederate lab worker), and by recruiting participants that are easily angered by specific stimuli (33).

In addition to measuring changes in angry mood after exercise, we evaluated changes in angry emotions in response to anger-inducing pictures. The intensity of evoked angry emotions was not reduced after exercise. One interpretation is that responses to pictures may be stable, traitlike characteristics that are not altered by acute exercise. This concept has been discussed in terms of general emotional responses to motivationally relevant stimuli (2), and our results suggest that angry emotions in response to affective picture viewing may be similarly resistant to change after exercise. Another possible explanation for these null findings is that only moderate levels of angry emotions were induced in this study (mean of 4.2 ± 2.6 SD out of 10) and were therefore not sufficiently elevated to be reduced by exercise. Other studies that used pictures of natural scenes to evoke anger found levels of anger intensity from 7% to 21% higher than those reported here (34,35). There are several plausible reasons why higher feelings of anger intensity were evoked during picture viewing in those studies. First, some of the anger-inducing images include attacks on women, and one of the studies included women participants (34) who may feel more anger while viewing these pictures. Second, the other studies used primarily images of racism and prejudice, recruited participants sensitive to the content of the pictures, and gave the participants the opportunity to act on their angry emotions (35), all of which would increase the emotional response. Perhaps if higher levels of angry emotions were elicited, exercise would have had a greater effect in the current study. As mentioned, one potential way to elicit higher levels of angry emotions would be to use social psychological methods that generate hyperrealistic and, therefore, more ecologically valid emotion manipulations. The challenge is that these methods typically require a complex experimental setup that involves deception (33).

Only a handful of relatively recent studies have evaluated the effect of acute exercise on general emotional responses, and they have found similar results ([2–4]; for a review, see Smith and Crabbe [36]), specifically that acute exercise had little effect on emotion. However, those studies focused on emotion in general. Our findings are perhaps more relevant in the context of early studies designed to evaluate the relationship between exercise and angry emotions. An initial study demonstrated that acute "exercise" (e.g., punching a target 10 times) did not lessen subsequent aggressive behavior directed toward an obnoxious confederate (37). Although our exercise prescription differs significantly from the one used in the Ryan study, and they measured aggressive actions (e.g., intensity/duration of shocks delivered to the confederate), not angry emotions, our results seem to be in line with this early finding given the relationship between emotions and behavioral output. Another series of early studies was designed to test the role that nonspecific arousal plays in emotional responses (38–41). In contrast to the Ryan study, and our findings, these studies demonstrated that acute exercise resulted in increased aggressive behavior (e.g., shock and loud noise) directed at a confederate. However, the short-duration (1.5 min), very high-intensity (245 W on a cycle erg) nature of the exercise stimulus may explain the increase in aggressive behavior. That is, the exercise stimulus was successfully used to generate a significant amount of nonspecific arousal, which in turn promoted aggressive behavior. In support of this interpretation is the finding that the most fit participants (who presumably would have been the least aroused by the intense exercise bout) showed the lowest levels of aggression. Therefore, our findings are likely contradictory to Zillman's work because of the nature of the exercise stimulus. Our exercise prescription was designed to improve mood and meet the American College of Sports Medicine recommendations for improving fitness, whereas their exercise prescription was designed to evoke high levels of arousal to test a particular model of emotion processing.

In addition to the self-report of emotion, EEG data were also collected during picture viewing. To our knowledge, this is the first study to evaluate ERP changes during emotional picture viewing after exercise. EPN and LPP were sensitive to picture content, showing increased amplitude for arousing pictures at sensors that were located in central posterior regions, as is common for EPN and LPP (20). However, neither EPN nor LPP amplitude was changed after exercise. This finding is consistent with previous results showing that acute exercise had no effect on startle magnitude (an alternative method for measuring emotional responses) while participants viewed emotionally evocative pictures (4). Moreover, this finding is not unexpected because feelings of arousal, pleasantness, and anger intensity were also unchanged after exercise. The ERP results, therefore, are consistent with the idea that EPN and LPP are only sensitive to changes in affective state, especially changes in arousal in response to emotionally evocative stimuli (17). Perhaps a single bout of acute moderate-intensity aerobic exercise is not sufficient to alter relatively stable neural dynamics that underlie emotional processing. It may take repeated bouts of exercise to elicit meaningful alterations to functional brain networks that process affective information to produce measurable and meaningful changes in evoked anger to the inducing stimuli.

In sum, this is the first study we know of to demonstrate that an acute bout of moderate-intensity cycling exercise reduces feelings of anger among men with elevated trait anger. Although exercise did not alter emotional responses during the viewing of pictures that evoke modest increases in anger, it mitigated the increase in angry mood evoked by picture viewing. Future studies should investigate participants with differing anger expression styles, which have been linked to disease outcomes. In addition, studies might further examine whether exercise has a prophylactic effect against more powerful methods of anger induction, both as an emotion and a mood.

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