Emotional responsiveness after low- and moderate-intensity exercise and seated rest

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ABSTRACT

SMITH, J. C., P. J. O'CONNOR, J. B. CRABBE, and R. K. DISHMAN. Emotional responsiveness after low- and moderate-intensity exercise and seated rest. *Med. Sci. Sports Exerc.*, Vol. 34, No. 7, pp. 1158–1167, 2002. **Purpose:** Few experiments have been conducted regarding the effects of exercise on emotional responsiveness. The aim of this experiment was to determine whether anxiety-reducing conditions of low- and moderate-intensity cycling exercise lead to changes in emotional responsiveness to pictures designed to elicit pleasant, neutral, and unpleasant emotions. **Methods:** 24 healthy college women completed counterbalanced conditions of 25 min of low- and moderate-intensity cycling exercise and seated rest. Indices of emotional responsiveness, including the acoustic startle eyeblink and corrugator supercilii responses, as well as baseline corrugator supercilii electromyographic (EMG) activity, were measured immediately before and 20 min after each condition while participants viewed pleasant, neutral, and unpleasant pictures from the International Affective Picture System. **Results:** State anxiety was significantly reduced 20 min after each condition. Startle response magnitude was modulated by the affective content of the pictures and was reduced after each condition in response to each type of picture. Baseline corrugator EMG activity did not change after seated rest but decreased in an exercise intensity–dependent fashion after cycling. Corrugator EMG responses during the pictures were not different between conditions or from pre- to post-conditions. **Conclusion:** The findings suggest that cycling exercise results in decreased baseline activity of facial muscles involved in the expression of emotion but does not lead to changes in appetitive or defensive responses to emotional stimuli. Furthermore, anxiolytic conditions of low- and moderate-intensity cycling exercise and seated rest are related to decreased startle magnitude in healthy college women. **Key Words:** ANXIETY, CORRUGATOR, CYCLING, EMG, IAPS, STARTLE

Researchers have reported consistently that mood states, such as state anxiety, are improved after an acute bout of physical activity (8,24). Much less attention has been paid to whether emotions are influenced by exercise. Dysfunctional emotional responsiveness is an underlying feature of all anxiety disorders, so it should be useful to learn whether exercise influences emotion (12).

The primary aim of this experiment was to examine whether a change in mood after exercise, namely decreased state anxiety, resulted in a change in emotional responsiveness to pleasant and unpleasant pictures. In this experiment, mood and emotion were considered to be distinct constructs. An emotion is a brief response, typically lasting milliseconds to minutes, to a sudden antecedent event. Emotional responses occur in the context of ongoing mood states, which are longer lasting (16). Mood was assessed subjectively through self-report, and emotional responsiveness was measured objectively using facial electromyography (EMG) during the viewing of standardized affective pictures. Two facial EMG responses, the acoustic startle eyeblink response (a defensive reflex to a sudden burst of noise, recorded from the orbicularis oculi muscle, that is known to be modulated by both pleasant and unpleasant affective states) and corrugator supercilii muscle responses (the "frown" muscle, known to increase during various unpleasant affective states (18)), were measured during the presentation of standardized affective pictures before and after anxiety-reducing conditions of low- and moderate-intensity exercise and seated rest. It was hypothesized that postcondition anxiety reductions would correspond to changes in startle and corrugator responses during picture viewing. Although anxiety reduction occurs after both low- and moderate-intensity exercise (27), the effect of different exercise intensities on emotional responsiveness has not been examined and so was explored in this investigation (17).

Contemporary emotion researchers and theorists have characterized human emotions as being organized along two orthogonal dimensions, one representing affective valence (i.e., pleasantness) and the other representing affective arousal. The two primary motivational systems along the valence dimension are the appetitive system, governing approach toward pleasant stimuli, and the defensive system, governing defensive withdrawal from noxious stimuli (22). It has been hypothesized that responses from both the appetitive and defensive systems are augmented by increased arousal within each system.

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The acoustic startle and corrugator responses have been employed as valid psychophysiological indices of human emotion during the presentation of affective pictures (22). When an individual is processing an unpleasant stimulus, motor programs linked to the defensive system have a higher probability of access, and an increased potential for an augmented response, than information linked to the appetitive system (22). This type of emotional priming is evidenced by the often replicated finding that the magnitude of the acoustic startle eyeblink response is potentiated when processing unpleasant stimuli and is inhibited when processing pleasant stimuli (7,22,35). Thus, the startle response is a useful tool to assess the relative engagement of the appetitive system or defensive system, but it does not assess specific emotions. Similarly, the corrugator supercilii muscle does not characterize a specific emotion but is active in response various unpleasant stimuli (18).

In addition to being modulated by affective foreground stimuli, such as pictures, the acoustic startle eyeblink response also may be influenced by anxiety. Individuals diagnosed with anxiety disorders exhibit larger startle eyeblink responses than healthy individuals (20). Also, experimental presentations of threatening situations (e.g., shock) and administrations of anxiety-reducing drugs (e.g., diazepam) to healthy individuals and animals result in increases and decreases in startle response magnitude, respectively (13,19,25,29). Furthermore, the administration of anxiety-reducing drugs leads to greater reductions in startle magnitude during unpleasant (25) or threatening stimuli (4). Research has shown that startle magnitude is not reduced after exercise in the absence of anxiety reduction (33,34). Thus, it was hypothesized that startle response magnitude during affective picture viewing would be attenuated 20 min after exercise conditions that resulted in reduced state anxiety and that decreased state anxiety would be positively associated with decreased startle magnitude. In addition, we also tested the hypothesis that greater postexercise reductions in startle magnitude would occur to the unpleasant pictures.

In addition to startle eyeblink EMG magnitude, we sought to examine the influence of exercise on EMG activity of the corrugator supercilii at baseline and in response to the emotion-eliciting pictures. It has been shown that basal EMG activity is reduced after exercise, and it has been suggested that this effect reflects a change in emotional responsiveness (9). Most of these studies, however, have assessed tension in skeletal muscles, such as the biceps brachii and quadriceps femoris, that are not directly involved in the expression of emotion (14). It is not clear from previous research whether the effect of reduced muscular tension after exercise is solely a peripheral response or if it also reflects changes in brain systems that govern emotional responsiveness. The examination of baseline corrugator EMG in the absence of an emotion-eliciting stimulus and corrugator EMG responses during the presentation of standardized emotion-eliciting pictures permits a preliminary examination of the hypothesis that reduced muscular tension after exercise reflects a change in emotion. We hypothesized that baseline (i.e., before each picture was presented) corrugator supercilii EMG activity would be reduced after both exercise conditions compared with rest and that the effect for exercise would be intensity dependent. We also tested the hypothesis that anxiolytic exercise conditions would lead to reductions in preexercise corrugator EMG responses to unpleasant pictures.

METHODS

Participants.

Twenty-six women volunteered from Exercise Science courses at the University of Georgia and received extra course credit for participation. All participants signed an informed consent form approved by the Institutional Review Board. One participant withdrew from the experiment because of the perceived aversiveness of the noise stimulus. A second potential participant was excluded because she reported using antidepressant medication. All remaining participants were medication free, except nine who reported using oral contraceptives. Based on an expected moderate effect size (Cohen's $d = 0.5$) for the condition by valence by time interaction for startle magnitude, moderate correlations ($R = 0.4$) between repeated measures of startle magnitude across conditions and time, and large correlations ($R = 0.8$) between repeated measures of startle magnitude for valence, 24 participants tested at an alpha of 0.05 provided *a priori* powers of 0.94 to detect a significant condition main effect, 1.00 to detect a significant valence main effect, 0.97 to detect a significant time main effect, and 0.56 to detect a significant 3 (condition) by 3 (valence) by 2 (time) interaction (26). Descriptive statistics for the sample ($N = 24$) are shown in Table 1 for age, height, weight, peak oxygen consumption ($\dot{V}O_{2peak}$), 7-d physical activity history (5), trait anxiety (31), and depression scores (3). Scores for trait anxiety and depression were not employed as dependent measures but were obtained only on the first day of testing and describe psychological characteristics of the participants.

Overview of Design and Procedures

A within-subjects repeated measures design was employed. After a first day of testing to determine $\dot{V}O_{2peak}$ and

TABLE 1. Characteristics of the participants ($N = 24$).

Characteristic	Mean (±SD)	Minimum	Maximum	Comparative Data
Age (yr)	22 (2)	19	27	
Height (cm)	167 (7)	157	178	
Weight (kg)	61.5 (7.9)	46	82	
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	39.2 (7.3)	25	54	35.2[a]
7-Day Physical Activity Recall (kJ·kg^{-1}·d^{-1})	114 (14)	100	163	150.4 (14.4)[b]
Trait Anxiety (STAI-Y2)	33.7 (8.7)	21.0	61.0	40.4 (10.2)[c]
Beck Depression Inventory	4.3 (3.5)	0.0	13.0	10.9 (8.1)[d]

[a] Value is the 50th percentile for women aged 20–29 ($N = 764$) (1).
[b] Data from 158 college-aged women (study 1) (15).
[c] Based on 531 college-aged women (31).
[d] Based on 115 men and women rated by a psychiatrist as being not clinically depressed (3).

to obtain subjective ratings of the affective pictures, each participant completed three conditions in a counterbalanced order on separate days: cycling exercise at 40% and 70% of $\dot{V}O_{2peak}$ and seated rest. State anxiety was measured using a 10-item scale before preparation for physiological recording each day, and immediately before and 20 min after each condition. After the pre- and post-condition assessments of state anxiety, recordings of the acoustic startle eyeblink and corrugator supercilii EMG responses were obtained during the viewing of pleasant, neutral, and unpleasant pictures.

Materials

Seven different slide shows were constructed from 147 color pictures chosen from the International Affective Picture System (IAPS) (10). One slide show was viewed on the first day of testing during a "free viewing" session. The remaining six slide shows were viewed across three subsequent days of testing: one slide show before and a different slide show after each of three conditions. During the free viewing session on day 1, viewing time was recorded and subjective ratings to each slide were made using the Self-Assessment Manikin (SAM) (21). The SAM is a nonverbal pictorial method for obtaining affective ratings of valence, arousal, and dominance (dominance defined as feelings of being in control, important, dominant, versus feelings of being controlled, submissive, guided). The participants placed an "X" on one of five figures, or between two of the figures, to indicate their feelings on each of the three dimensions (resulting in a 9-point scale for each). The purpose of the free viewing session was to check the manipulation of the intended affective content of the pictures. The recording of free viewing time served as a behavioral measure of interest and confirmed that the participants were interested equally in the pleasant and unpleasant pictures (35).

Each slide show contained 21 pictures, 7 from each of three valence categories (pleasant, neutral, and unpleasant). Pleasant and unpleasant pictures with the highest arousal ratings were chosen from the IAPS (the Appendix lists the pictures employed in each slide show). All seven slide shows were designed to evoke similar mean valence ratings based on SAM norms (23). There were very small differences among the slide shows. The largest mean difference among the seven slide shows in normative ratings of affective valence for pleasant, neutral, and unpleasant pictures was 0.14, 0.27, and 0.44 SAM raw score units, respectively.

The 21 pictures in each slide show were arranged into three blocks of seven slides. The order of the slides in each block was determined pseudo-randomly by shuffling the slides by hand. Each block of seven slides contained six pictures that were presented with the acoustic stimulus (two pleasant, two neutral, and two unpleasant pictures) and one slide from one of the three valence categories that was presented with no acoustic stimulus. The nonprobed slide was included to maintain an unpredictability about whether the noise stimulus would be presented.

Physiological Recordings

Participants were prepared for EMG recordings of orbicularis oculi eyeblink responses and corrugator supercilii activity according to the recommendations by Fridlund and Cacioppo (18). The skin surface was abraded lightly with fine-grained sandpaper (220 grains·in.$^{-2}$) and alcohol swabs. Four miniature Med-Associates (Georgia, VT) Ag-AgCl biopotential surface electrodes were filled with EC2 electrode cream and attached near the left eye. For recordings of orbicularis oculi activity, one electrode was placed 5 mm lateral from the exocanthion and a second electrode was placed 10 mm medial and 5 mm inferior to the first electrode. For recordings of corrugator supercilii activity, one electrode was placed directly above the brow along a line that traversed the endocanthion and a second electrode was positioned 1 cm lateral and superior to the first electrode. A fifth pregelled Ag-AgCl electrode (Eaton Electrode Co., Ann Arbor, MI) was placed medially on the forehead just below the hairline and served as the common reference. Electrode impedance was verified at each electrode site as less than 5 kohm with a Grass Electrode Impedance Meter (Model EZM 4; Astro-Med, Inc., West Warwick, RI).

Raw EMG signals were amplified 5000 times using Grass P511 amplifiers with half-amplitude settings of 1 and 1000 Hz. Raw EMG signals were then routed to a 16-bit A/D board interfaced with an IBM-PC and were digitized at 800 Hz, then displayed digitally using PolyVIEW version 2.0 software (Astro-Med, Inc.). Corrugator supercilii and orbicularis oculi EMG activity were integrated using time constants of 600 ms and 100 ms, respectively. The Grass P511 amplifiers were calibrated before each experimental session. A steep-rise impulse of 1 mV for a duration of a 500 ms was applied from an internal calibration source, and the output of the calibration signal from the P511 amplifier was measured on an oscilloscope.

Acoustic Stimulus

The acoustic stimulus, employed to evoke blink responses measured from the orbicularis oculi, was a 50 ms, 110-dB burst of white noise produced by a Grason-Stadler 455C noise generator (West Concord, MA) and passed through a Massey Dickinson amplifier (Saxonville, MA) with a <1 ms rise/fall time. The acoustic stimulus was delivered binaurally through Sony Dynamic Stereo Headphones (Model MDR-V200). Before each experimental session, the intensity of the acoustic stimulus was calibrated at the surface of the headphone using a General Radio 1551-C decibel meter (General Radio Co., Concord, MA).

Dependent Measures

Corrugator baseline activity was defined as the mean integrated EMG (IEMG) activity in microvolts during the 1 s before slide onset. Corrugator responses were defined as the difference in microvolts between baseline IEMG activity and the mean IEMG activity during the 6-s slide interval. For orbicularis oculi eyeblink responses, the magnitude of the highest peak within 150 ms after the onset of the noise stimulus was determined according to the scoring criteria described by Balaban et al. (2). The only exception was that the criteria for a stable baseline integrated EMG was set more stringently at 10 A/D units rather than 20 A/D units. Of a possible 3024 eyeblinks (24 participants × 6 slide shows/participant × 21 blinks/slide show), 353 (11.7%) were excluded due to unstable baselines. Previous studies have reported unstable baseline EMG for the orbicularis oculi on 5.8% of trials using the criteria of 20 A/D units (35). Measures of startle magnitude were standardized within each participant and each test day using Z-scores. A subset of 299 blinks from 3 participants was scored by two trained individuals. The percentage agreement between the two raters as to when an eyeblink occurred was high (96.3%), as was the intra-class coefficient (one-way random effects model) for startle magnitude (R = 0.86).

Determination of $\dot{V}O_{2peak}$

Each participant completed a maximal cycle ergometer test on day 1. The electronically braked cycle ergometer (Mijnhardt, Bunnik, The Netherlands) continuously increased resistance at a rate of 20 $W \cdot min^{-1}$. Before each exercise session, a SensorMedics metabolic cart (Model 2900, Yorba Linda, CA) was calibrated with concentrations of known gas samples (30). The metabolic cart obtained measures of ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and respiratory exchange ratio (i.e.,$\dot{V}CO_2/\dot{V}O_2$) every 20 s throughout the exercise test. Heart rate (HR) was continuously displayed only to the experimenter with a UNIQ heart rate monitor. Ratings of perceived exertion (RPE) using a validated 6–20 scale were obtained every 2 min during exercise until volitional exhaustion (6). Before exercise, explicit instructions for scale use were provided orally (11). Demonstration of peak oxygen consumption included meeting at least two of the following criteria: 1) a respiratory exchange ratio above 1.10; 2) a rating of perceived exertion of at least 18; and 3) a heart rate at least 90% of age predicted maximal heart rate (220 minus age).

Procedure

Testing occurred on 4 d during a 1-wk period. To minimize the potential effects of menstrual phase, participants were scheduled to be tested in their early follicular phase (i.e., during the week after the end of menses). Menstrual phase was confirmed by oral and written self-report.

Each slide show lasted 865 s (14.4 min). Each slide was shown for 6 s and was followed by a 35-s intertrial interval. Twenty-one acoustic stimuli were delivered during each slide viewing session, seven in each block of seven slides (during 2 pleasant, 2 neutral, and 2 unpleasant slides and 1 during an intertrial interval). Acoustic stimuli were delivered randomly from 2 to 6 s after picture onset. Three acoustic stimuli were delivered randomly during intertrial intervals of each slide show, 1 during each block of 7 slides. These responses were not scored but served to maintain a degree of unpredictability regarding the delivery of the noise stimulus.

Participants viewed each slide show while seated comfortably in a reclining chair in a 2.1 × 2.7 m sound attenuated, environmentally controlled (23 ± 1°C, 40 ± 3% relative humidity, 50 ± 2 lux illumination when the slide projector was off) chamber. The slides were projected from a Kodak Carousel 4600 Projector located outside the chamber onto a white wall approximately 2.2 m in front of the participant. Each participant was instructed to "attend to each slide the entire time" it was shown and to "ignore the occasional sounds from the headphones."

Testing day 1. After completing the informed consent, form Y2 of the State-Trait Anxiety Inventory, and the Beck Depression Inventory, the participant was prepared for physiological recordings. Then each participant sat in the environmental chamber and listened to recorded instructions regarding the use of the SAM and the procedures during the free viewing session. During the free viewing session, participants advanced the slides at their own pace by pressing a key on a keyboard. Immediately after each picture was viewed, the participants were visually prompted to rate their emotional response to each picture using the SAM. Mean SAM ratings to pleasant, neutral, and unpleasant pictures during the free viewing session on day 1 were consistent with the published normative values for college women (Table 2). The time each slide was viewed was recorded to the nearest second by a computer. The mean (±SD) free viewing time for pleasant, neutral, and unpleasant pictures was 9.5 (2.8), 8.9 (2.8), and 10.2 (3.8) s, respectively. A one-way repeated measures ANOVA was conducted for free viewing time. Free viewing time did not differ between pleasant, neutral, or unpleasant pictures [$F(2,22) = 2.05$, $P = 0.146$, $\epsilon = 0.903$]. Lastly, on day 1, participants completed the test of peak oxygen consumption.

Testing days 2, 3, and 4. State anxiety was measured immediately upon entry into the laboratory each day. Next, the participant was prepared for EMG recordings of orbicularis oculi and corrugator supercilii muscle activity. This procedure lasted approximately 10 min. Each participant then viewed one of seven slide shows within the chamber while eyeblinks were evoked and EMG activity was recorded. After the precondition slide show, participants completed the precondition state anxiety inventory and then either 25 min of cycling at 40% $\dot{V}O_{2peak}$ or 70% $\dot{V}O_{2peak}$, or 25 min of no physical activity that

TABLE 2. Mean (±SD) SAM ratings to pleasant, neutral, and unpleasant slides (averaged across all seven slides shows) for the present sample (N = 24), including summarized normative data for the IAPS slides employed (23).

	Slide Content		
	Pleasant	Neutral	Unpleasant
Valence rating			
Sample	7.13 (0.92)	4.76 (0.54)	2.48 (1.20)
Normative	7.38 (0.61)	5.01 (0.31)	1.80 (0.40)
Arousal rating			
Sample	5.59 (1.42)	4.01 (1.35)	6.31 (1.33)
Normative	5.90 (0.55)	3.48 (0.98)	6.77 (0.59)
Dominance rating			
Sample	5.90 (1.30)	4.91 (0.75)	3.68 (1.31)
Normative	5.77 (0.93)	5.50 (0.94)	3.41 (1.02)

involved sitting quietly (seated rest) on the cycle ergometer in the same room that the exercise was performed. One of the six possible orders for completing the three conditions was assigned to four participants (i.e., 4 participants per order × 6 orders = 24 participants). All participants completed all three experimental conditions. A 5-min warm up at 50 W was provided before each 25 min of cycling. RPE was assessed during exercise, and subjective affective responses to the exercise and rest conditions were assessed by SAM ratings, at the 15- and 25-min marks during the conditions. Participants were reminded of the instructions for RPE and for the SAM and were asked to "please rate how the exercise (or sitting here) makes you feel right now" (instructions modified from the IAPS technical manual). After all conditions, 20 min of quiet semirecumbent recovery was provided inside the environmental chamber. Participants completed the SAM and the state anxiety questionnaire beginning at 20 min postcondition. After this, postcondition recordings of startle eyeblink and facial EMG during an IAPS slide show were obtained.

Data Analysis

Raw data were entered into SPSS (SPSS, Inc., Chicago, IL) and the accuracy of data entry verified. Based on a regression equation computed from raw calibration pulses that were integrated and rectified using PolyVIEW 2.0, blink magnitude was linearly transformed from units of mV·s back to microvolts and then expressed as a Z-score within each participant for each day of testing. The distribution of the data was examined for skewness, kurtosis, and the presence of outliers. Further transformation of data was not required and outliers were not observed. The first blink of each slide show was not included in the analyses. Those who were taking oral contraceptives ($N = 9$) and those who were not ($N = 15$) did not differ statistically in startle magnitude or state anxiety scores.

Measurements of startle magnitude and corrugator supercilii activity (baseline and responses to pictures) were analyzed with 3 (condition) by 3 (valence) by 2 (time) repeated measures ANOVAs. A 3 (condition) by 3 (time) repeated measures ANOVA was conducted for state anxiety scores and SAM ratings during the conditions. The Greenhouse-Geisser epsilon (ϵ) was employed to adjust the degrees of freedom when Mauchly's test of sphericity was significant at $P < 0.05$ (the ϵ and adjusted P-values are reported). The family-wise error rate was controlled using the Bonferroni adjustment when tests for simple effects and contrasts were conducted. Effect sizes associated with F-statistics were expressed as eta-squared (η^2). Effect sizes based on mean differences were expressed as Cohen's d. The relationship between change in startle magnitude and change in state anxiety was examined using Pearson's r.

RESULTS

Eyeblink magnitude. Mean startle eyeblink magnitude for pleasant, neutral, and unpleasant pictures before and after conditions of seated rest, cycling at 40% $\dot{V}O_{2peak}$, and cycling at 70% $\dot{V}O_{2peak}$ are shown in Figure 1. A significant main effect for valence [$F(2,46) = 16.19$, $P < 0.001$, $\eta^2 = 0.413$] was observed for orbicularis oculi eyeblink magnitude. Startle magnitude was greatest during unpleasant compared with pleasant ($P < 0.001$) and neutral ($P = 0.027$) pictures. In addition, startle magnitude was greater during neutral compared with during pleasant pictures ($P = 0.018$). The estimates for the mean (± SE) magnitude (z-score) associated with the valence main effect for pleasant, neutral, and unpleasant pictures were −0.148 (0.029), −0.010 (0.034), and 0.166 (0.040), respectively. A significant main effect for time was also observed [$F(1,23) = 34.32$, $P < 0.001$, $\eta^2 = 0.599$]. Startle magnitude was reduced after all conditions, independent of the emotional content of the slide

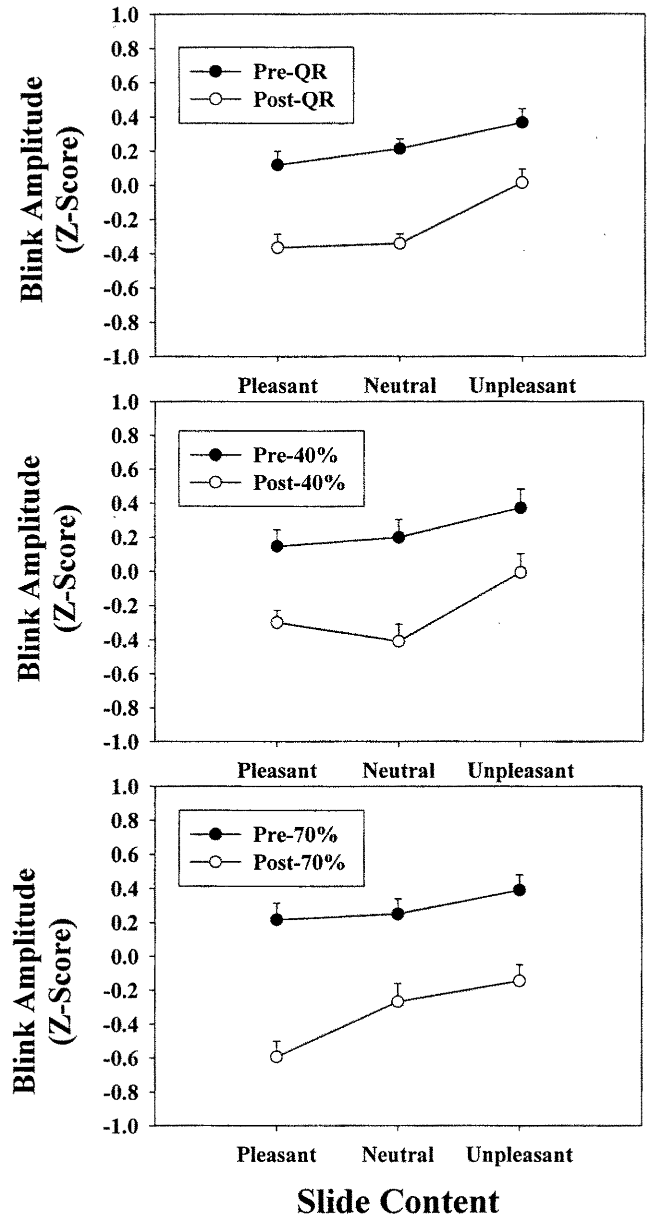

FIGURE 1—Acoustic startle eyeblink magnitude (Z-score) as a function of slide content before and 20 min after 25 min of seated rest (top) and low- (middle) and moderate- (bottom) intensity cycling exercise. Data are expressed as mean (±SEM).

(mean Cohen's $d = -1.21 \pm 0.42$). The estimates for the mean (± SE) magnitude (Z-score) associated with the Time main effect for pre- and post-conditions were 0.254 (0.047) and −0.249 (0.043), respectively. The condition main effect, as well as the condition by time, the condition by valence, the valence by time, and the condition by valence by time interactions were not significant (all $Fs < 1$). The correlation between change in startle magnitude (averaged across picture types and conditions) and change in state anxiety scores from pre- to post-condition (averaged across conditions) was $r = 0.47$ ($P < 0.05$).

Baseline corrugator supercilii. Baseline corrugator supercilii EMG data before and after conditions of seated rest, cycling at 40% $\dot{V}O_{2peak}$, and cycling at 70% $\dot{V}O_{2peak}$ are shown in Figure 2. A significant condition by time interaction was observed for baseline corrugator supercilii activity [$F(2,46) = 4.88$, $P = 0.020$, $\epsilon = 0.783$, $\eta^2 = 0.175$] as well as a main effect for time [$F(1,23) = 11.27$, $P = 0.003$, $\eta^2 = 0.329$]. A test for simple effects showed that baseline corrugator supercilii activity did not change from pre- to post-seated rest, decreased from pre- to post-40% $\dot{V}O_{2peak}$ ($P = 0.11$, $d = -0.21$), and decreased significantly from pre- to post-70% $\dot{V}O_{2peak}$ ($P = 0.01$, $d = -0.51$). The estimates for the mean (± SE) IEMG (μV) associated with the condition by time interaction before and after seated rest, cycling at 40% $\dot{V}O_{2peak}$, and cycling at 70% $\dot{V}O_{2peak}$ are 112.9 (11.9) and 113.0 (11.4), 111.2 (9.2) and 102.0 (9.1), and 120.9 (12.5) and 94.5 (8.7), respectively. There were no significant effects for condition ($P = 0.573$) or valence ($P = 0.797$). Also, there were no differences among conditions in baseline corrugator supercilii activity measured before treatment.

Corrugator supercilii response. Mean corrugator supercilii EMG responses (change from baseline scores) during pleasant, neutral, and unpleasant pictures before and after conditions of seated rest, cycling at 40% $\dot{V}O_{2peak}$, and cycling at 70% $\dot{V}O_{2peak}$ are shown in Figure 3. There was a significant main effect for valence [$F(2,46) = 21.63$, $P < 0.001$, $\epsilon = 0.774$, $\eta^2 = 0.485$] for the corrugator supercilii response. Corrugator supercilii activity increased from baseline to a greater extent during unpleasant compared with pleasant and neutral pictures. No significant interactions [condition × time $F(2,46) = 1.34$, $P = 0.269$, $\epsilon = 0.724$, $\eta^2 = 0.055$], condition, or time effects were observed.

Manipulation checks. SAM ratings of valence, arousal, and dominance during picture viewing are shown in Table 2. SAM ratings during and 20 min after the exercise and seated rest conditions are shown in Table 3. For SAM ratings during and after exercise and seated rest, there were significant condition by time interactions for valence [$F(4,92) = 4.635$, $P = 0.004$, $\epsilon = 0.809$, $\eta^2 = 0.168$] and arousal [$F(4,92) = 24.633$, $P < 0.001$, $\epsilon = 0.597$, $\eta^2 = 0.517$], and a significant main effect of condition for dominance [$F(2,46) = 6.692$, $P = 0.003$, $\epsilon = 0.606$, $\eta^2 = 0.225$]. An *a priori* contrast showed that there were no differences between conditions for SAM ratings of valence, arousal, or dominance 20 min after each condition, before the postcondition slide show. However, during the conditions: 1) valence ratings were significantly higher in the 40% condition, reflecting more pleasantness, compared with during the seated rest and 70% condition; 2) arousal ratings significantly increased with exercise intensity; and 3) dominance ratings were significantly lower during the 70% compared with the 40% condition.

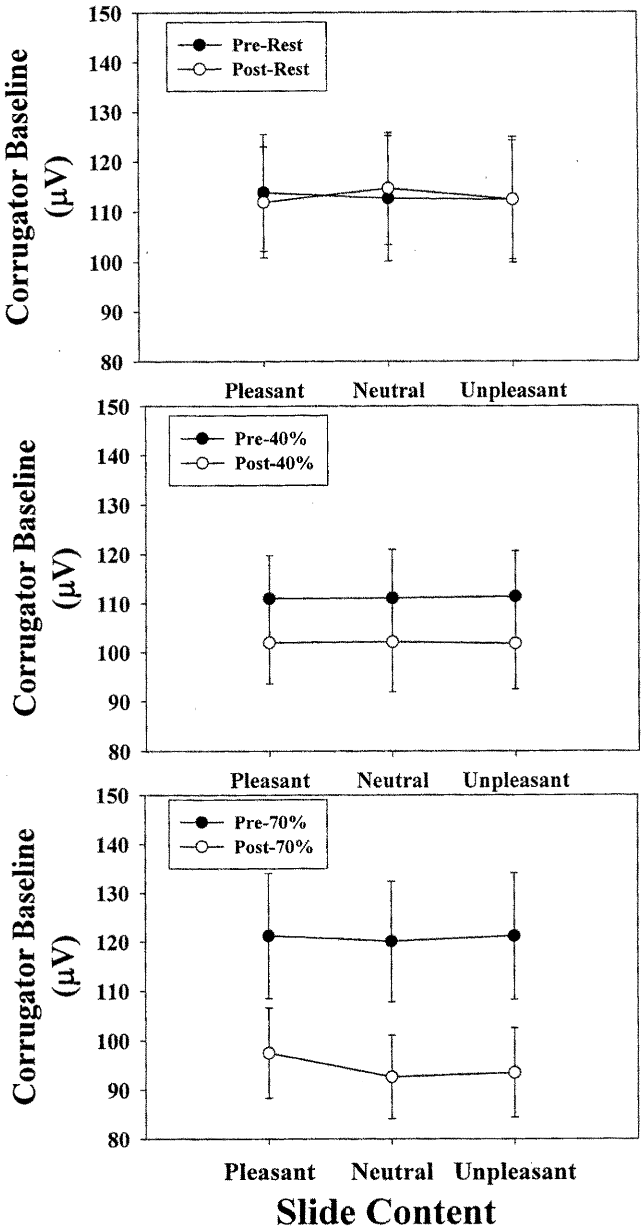

FIGURE 2—Baseline corrugator supercilii EMG (μV) (defined as the mean activity during the 1 s before slide onset) as a function of slide content before and 20 min after 25 min of seated rest (top) and low- (middle) and moderate- (bottom) intensity cycling exercise. Data are expressed as mean (±SEM).

The mean (± SD) rates of oxygen consumption (%$\dot{V}O_{2peak}$) at the 15- and 25-min marks were 9.6 (3.3%) and 9.0 (2.7%), 40.8 (3.3%) and 40.7 (2.5%), and 68.5 (5.6%) and 70.2 (4.0%) for the seated rest, 40%, and 70% $\dot{V}O_{2peak}$ conditions, respectively. The mean (± SD) perceived exertion ratings during the 40% and 70% $\dot{V}O_{2peak}$ conditions at 15 and 25 min were 11.2 (1.5) and 11.5 (1.4), and 14.8 (1.5) and 15.5 (1.7), respectively.

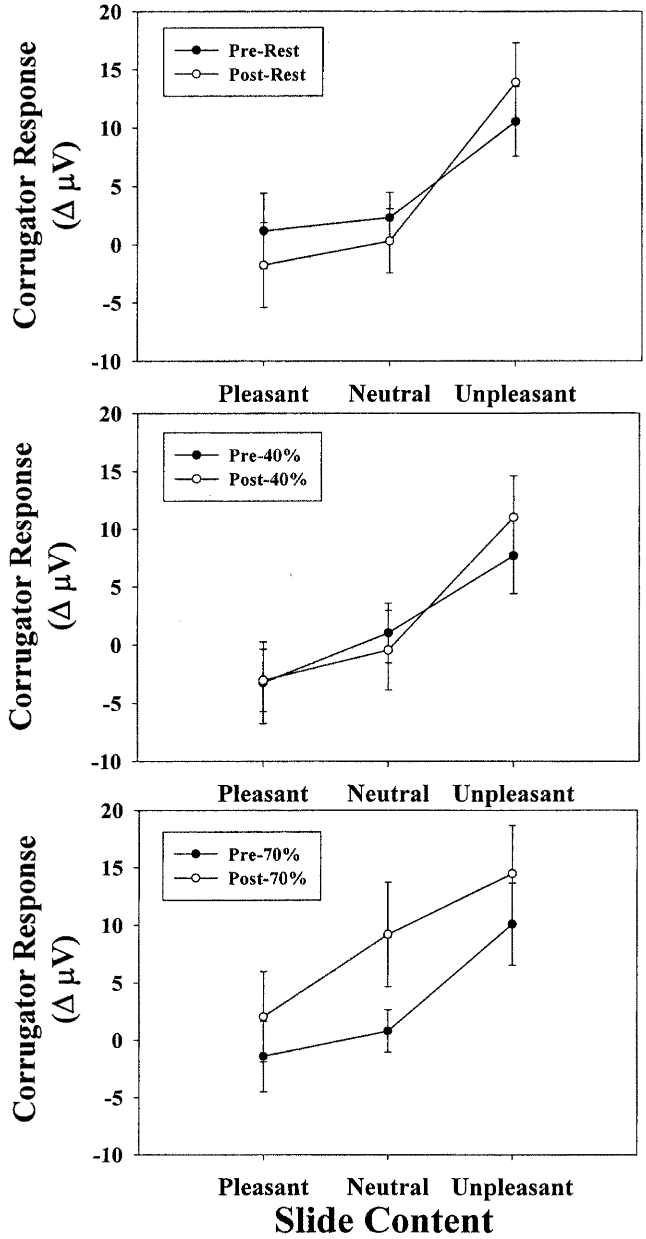

FIGURE 3—Corrugator supercilii responses (change from baseline in μV) as a function of slide content before and 20 min after 25 min of seated rest (top) and low- (middle) and moderate (bottom) intensity cycling exercise. Data are expressed as mean (±SEM).

Descriptive state anxiety data are presented in Table 4. Before being prepped, the participants' state anxiety scores were ~0.5 to 0.75 SD units lower than college female normative values. Immediately before the start of each condition, the average state anxiety score was increased by a small, nonsignificant amount. Statistical analysis revealed nonsignificant effects for the condition and the condition by time factors but a significant time main effect [$F(2,42) = 5.947$, $P = 0.011$, $\epsilon = 0.763$, $\eta^2 = 0.221$]. State anxiety scores decreased after both exercise and the seated rest conditions compared with measures obtained preprep ($P = 0.049$) and precondition ($P = 0.016$).

TABLE 3. Mean (±SD) Self-Assessment Manikin ratings during (minute 15, minute 25), and 20 mins after, 25 mins of low- (40% $\dot{V}O_{2peak}$) and moderate- (70% $\dot{V}O_{2peak}$) intensity cycling exercise and seated rest.

	Minute 15	Minute 25	20 min Post
Valence			
Seated rest	5.54 (1.28)	5.71 (1.52)	5.54 (1.28)
40% $\dot{V}O_{2peak}$	6.33 (1.40)‡	5.83 (1.31)	5.88 (1.42)
70% $\dot{V}O_{2peak}$	4.96 (1.57)†	4.75 (1.59)†	6.04 (1.30)
Arousal			
Seated rest	2.00 (1.67)	1.96 (1.65)	1.92 (1.59)
40% $\dot{V}O_{2peak}$	4.17 (1.95)*	4.54 (2.00)*	1.92 (1.56)
70% $\dot{V}O_{2peak}$	5.92 (1.41)*†	5.92 (1.84)*†	2.33 (1.52)
Dominance			
Seated rest	5.83 (1.86)	5.83 (1.95)	5.54 (2.06)
40% $\dot{V}O_{2peak}$	6.42 (1.82)	6.50 (1.59)	6.21 (1.74)
70% $\dot{V}O_{2peak}$	5.00 (1.93)†	4.92 (1.89)†	5.67 (2.10)

‡ Significantly different from seated rest at $P < 0.05$.
* Significantly different from seated rest at $P < 0.001$.
† Significantly different from 40% at $P < 0.05$.

DISCUSSION

Based on these findings we conclude that anxiety-reducing conditions of cycling exercise or seated rest do not alter emotional responsiveness in healthy college women. Decreased state anxiety was related to decreased startle magnitude, but exercise or seated rest did not appear to affect the neural systems that mediate emotional responsiveness to pleasant or unpleasant pictures as measured by the startle response. Exercise intensity–related decreases in baseline corrugator activity were observed 20 min after exercise. Despite a reduction in baseline activity of the corrugator muscle after exercise, responsiveness of the corrugator muscle to unpleasant pictures did not change. This finding calls into question the interpretation of reduced muscular tension after exercise and suggests that this effect is not related to a change in emotional responsiveness or mood.

Eyeblink magnitude. Acoustic startle eyeblink response magnitude decreased uniformly across all valence categories after both exercise and the seated rest conditions. This finding confirmed our hypothesis because anxiety also decreased after all three conditions. This study replicated the finding of reduced state anxiety scores 20 min after both exercise conditions (24) and seated rest (28). Although not all seated rest conditions have resulted in anxiety reductions, our results are consistent with those that have (e.g., 28).

The expected affective responses to the pleasant, neutral, and unpleasant pictures were confirmed by subjective ratings of valence and arousal using the Self-Assessment Manikin (23). An additional replication was the finding that startle eyeblink response magnitude was significantly greater during unpleasant compared with pleasant pictures (35). We did not support the hypothesis that startle responses during unpleasant pictures would be reduced to a

TABLE 4. Mean (±SD) 10-item state anxiety scores immediately upon entry into the laboratory (preprep), before, and after each condition, including normative data for college women.

	Preprep	Precondition	Postcondition
Seated rest	15.9 (5.2)	16.7 (4.9)	13.7 (3.8)
40% $\dot{V}O_{2peak}$	15.2 (4.0)	15.8 (5.8)	13.1 (3.5)
70% $\dot{V}O_{2peak}$	14.1 (3.0)	16.2 (6.2)	14.0 (4.0)
College female norms[a]	19.1 (6.3)		

[a] Normative data based on 185 college-aged women (31).

greater degree after those conditions resulting in a decrease in anxiety compared with startle responses evoked during neutral or pleasant pictures. The failure to observe this effect should be viewed cautiously, however, due to the low statistical power to detect the three-way interaction ($1 - \beta = 0.56$).

The decrease in startle eyeblink response magnitude was moderately correlated with reductions in state anxiety after each condition (overall $r = 0.47$). This finding should be viewed cautiously, however, because anxiety and startle responses decreased after both the rest and exercise conditions. One plausible alternative interpretation of the startle response data is that the decrease observed from pre- to post-condition (~55 min elapsed time) reflects habituation to the noise stimulus. Though a lack of change in anxiety and startle magnitude from pre- to post-seated rest would have made interpretation of the results more straightforward, the present data are not inconsistent with those reported in experiments that examined startle responses in multiple sessions on the same day (29).

Patrick et al. (25) showed a greater reduction in startle magnitude during unpleasant pictures after a 15-mg dose of diazepam, but not a 10-mg dose, compared with a sugar placebo. The reduction in startle response magnitude during unpleasant pictures also corresponded to a reduction in negative affect in the 15-mg diazepam condition compared with the placebo treatment. The present findings are in contrast to the data reported by Patrick et al. (25). Rather, our findings for startle magnitude are similar to those reported by Stritzke et al. (32). Ethanol intoxication resulted in an overall attenuation of startle magnitude without affecting the relative difference in startle magnitude between the pleasant and unpleasant pictures. One interpretation of the present findings, and those by Stritzke et al., is that the attenuation of startle responses after each condition may reflect an overall decrease in emotional arousal without changing the appetitive or aversive appraisal of the pictures (32).

Corrugator supercilii. The findings of the present study for corrugator EMG activity suggest that exercise resulted in an intensity-dependent decrease in baseline EMG activity without affecting the emotional responsiveness of the corrugator muscle. This is an important finding, as previous studies that have documented an effect for exercise on muscular tension have assumed that decreased muscular tension reflects decreased emotional responsiveness (9). The results of this experiment suggest that reduced state anxiety scores do not necessarily correspond to reduced muscular tension in a muscle involved in the expression of unpleasant emotions. Furthermore, the responsiveness of the corrugator muscle to unpleasant stimuli remains intact despite reductions in self-reported state anxiety and baseline corrugator activity after exercise.

The current findings confirmed the hypothesis that baseline corrugator EMG would be decreased after exercise compared with seated rest and that this effect would be exercise-intensity related. The results from this experiment did not support the hypothesis that corrugator EMG responses to unpleasant pictures would be diminished along with reductions in state anxiety. The present findings support the interpretation that physiological arousal was reduced after exercise, but this did not affect the responsiveness of the corrugator muscle to aversive stimuli. A similar effect on physiological arousal can also be attributed to the results reported by deVries and Adams (14), in which biceps brachii activity decreased after treadmill walking, but walking did not affect increases in biceps brachii activity during mental arithmetic. In contrast, Fillingim et al. (17) did not report a change in baseline corrugator activity after exercise. In opposition to their hypothesis, a small effect for greater corrugator EMG responses after exercise was noted during sadness imagery compared with during anger imagery (our computation of Pearson's effect size $r = 0.29$ based on the F-value reported).

Subjective affect. Subjective ratings of affect during each condition were obtained using the Self-Assessment Manikin. One limitation to the interpretation of the effect of time for these data is that precondition SAM ratings were not obtained. Nevertheless, comparisons across conditions can be made at the time points in which data were obtained. Participants reported feeling less "pleasant" (based on valence ratings) and less "in control" (based on dominance ratings) during the 70% condition compared with during the 40% condition. During exercise compared with the control condition, intensity-dependent increases in rated arousal were obtained. These subjective ratings correspond to the objective measures of oxygen consumption during the conditions but do not influence the interpretation of the startle response and corrugator EMG data. The timing of the post-condition assessments was based on the desire to examine EMG responses at a time when state anxiety reductions known to occur after exercise had been realized and after arousal had returned to resting levels. The EMG responses were measured during slide shows that were presented 20 min after the cessation of exercise, and by that time subjective ratings of arousal had returned to resting levels and there were no differences between conditions for valence or dominance ratings. Thus, although individuals reported different affective states during the conditions, this did not appear to influence the EMG measures of emotional responsiveness during picture viewing that occurred 20 min later.

Conclusion. These findings suggest that anxiety reducing cycling exercise does not alter emotional responsiveness in healthy college women. Intensity-dependent decreases in baseline corrugator activity were observed 20 min after exercise; however, reduced baseline activity of the corrugator muscle did not alter emotional responsiveness to unpleasant stimuli. Decreases in state anxiety were not related to decreases in baseline corrugator EMG, and furthermore, neither decreases in state anxiety nor decreases in baseline corrugator EMG affected corrugator responses to unpleasant pictures. The effect of exercise on baseline muscular tension may be a more generalized peripheral nervous system effect unrelated to specific brain systems that govern emotional responsiveness and mood. However, without measures of EMG in emotion- and nonemotion-related muscles, along with indices of brain activation within the approach and avoidance systems, one cannot say with certainty that this is the case. Decreased state anxiety was related to decreased startle magnitude, although based on these findings, exercise or seated rest did not appear to affect the neural systems that mediate emotional responsiveness to aversive or appetitive stimuli.

APPENDIX

IAPS Pictures Employed. *Slide show 1:* pleasant, 8190, 4533, 5830, 8490, 8040, 4680, 5629*; neutral, 7006, 5533, 7050, 9210, 7560, 2720, 7170*; unpleasant, 3030, 9300, 6200, 9250, 3120, 9420, 6350.* *Slide show 2:* pleasant, 8034, 4660, 8180, 4532, 8470, 1710, 5626*; neutral, 7550, 7002, 5532, 2690, 7150, 7040, 9070*; unpleasant, 9530, 3170, 6260, 9810, 3080, 6540, 1120.* *Slide show 3:* pleasant, 4531, 4650, 8033, 5623, 8460, 2080, 8170*; neutral, 7035, 8260, 5531, 7000, 7140, 7500, 2410*; unpleasant, 9500, 6510, 3150, 3071, 9600, 6230, 2710.* *Slide show 4:* pleasant, 5621, 8031, 4640, 8400, 2070, 4520, 8161*; neutral, 5530, 7034, 7235, 2220, 6910, 8060, 7130*; unpleasant, 9040, 3110, 3010, 6313, 9800, 9050, 3530.* *Slide show 5:* pleasant, 4510, 8130, 8030, 8370, 4609, 2050, 5470*; neutral, 2210, 7233, 7830, 7030, 7100, 5520, 6150*; unpleasant, 6212, 3060, 9410, 6370, 9910, 3140, 9430.* *Slide show 6:* pleasant, 8300, 4608, 7502, 4490, 5460, 2040, 8090*; neutral, 7025, 2200, 7224, 5510, 7090, 5950, 7820*; unpleasant, 9560, 2730, 6560, 3100, 3400, 9921, 6300.* *Slide show 7:* pleasant, 7330, 4599, 4470, 8501, 5450, 8080, 8210*; neutral, 5500, 7201, 5920, 7710, 7080, 2190, 7217*; unpleasant, 3180, 3053, 6210, 6360, 3130, 9252, 9340.*

* Denotes pictures that were presented without a noise stimulus.

Note: Slide identification numbers for each slide show are grouped by valence and are not listed in the order in which they appeared during viewing.

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