

Emotion

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Attentional Bias to Emotional Stimuli Is Altered During Moderate- but Not High-Intensity Exercise

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Little is known regarding how attention to emotional stimuli is affected during simultaneously performed exercise. Attentional biases to emotional face stimuli were assessed in 34 college students (17 women) using the dot-probe task during counterbalanced conditions of moderate- (heart rate at 45% peak oxygen consumption) and high-intensity exercise (heart rate at 80% peak oxygen consumption) compared with seated rest. The dot-probe task consisted of 1 emotional face (pleasant or unpleasant) paired with a neutral face for 1,000 ms; 256 trials (128 trials for each valence) were presented during each condition. Each condition lasted approximately 10 min. Participants were instructed to perform each trial of the dot-probe task as quickly and accurately as possible during the exercise and rest conditions. During moderate-intensity exercise, participants exhibited significantly greater attentional bias scores to pleasant compared with unpleasant faces ($p < .01$), whereas attentional bias scores to emotional faces did not differ at rest or during high-intensity exercise ($p > .05$). In addition, the attentional bias to unpleasant faces was significantly reduced during moderate-intensity exercise compared with that during rest ($p < .05$). These results provide behavioral evidence that during exercise at a moderate intensity, there is a shift in attention allocation toward pleasant emotional stimuli and away from unpleasant emotional stimuli. Future work is needed to determine whether acute exercise may be an effective treatment approach to reduce negative bias or enhance positive bias in individuals diagnosed with mood or anxiety disorders, or whether attentional bias during exercise predicts adherence to exercise.

Keywords: acute exercise, affect, dot-probe, dual-task, emotional faces

The effects of acute and chronic exercise to reduced symptoms of anxiety and depression in healthy adults and in patients diagnosed with major depression and some anxiety disorders have been well documented (Blumenthal et al., 1999; Herring, O'Connor, & Dishman, 2010; Morgan, 1985; North, McCullagh, & Tran, 1990; Strohle et al., 2009). Experiments in humans have largely focused on self-reported measures of anxiety or depression symptoms or clinical rating scales to assess the effects of exercise after a single session, in response to a period of exercise training, or affective responses during exercise (Ekkkekakis & Lind, 2006; Smith & O'Connor, 2003; Smith, O'Connor, Crabbe, & Dishman, 2002; Williams et al., 2008). Although these investigations have provided valuable insight regarding the short- and long-term benefits of exercise on mood and the affective experience during exercise,

the effects of exercise on the processing of emotional stimuli at the time that the exercise is being performed are less well understood. Because affective and anxiety disorders are considered disorders of emotion processing, it is important to understand how exercise may affect emotion. Attentional bias to unpleasant emotional stimuli has been demonstrated in major depression and anxiety disorders (B. P. Bradley, Mogg, White, Groom, & de Bono, 1999; Joormann & Gotlib, 2007), and recent work has suggested that attentional retraining may have beneficial effects on clinical outcomes (Koster, Baert, Bockstaele, & De Raedt, 2010). Currently, there is a lack of objective evidence regarding the behavioral effects of exercise on attention to emotion that may drive the affective experience during and after exercise. To address this gap in the literature, we examined whether shifts in attention toward or away from pleasant and unpleasant face stimuli were altered during moderate- and high-intensity exercise compared with a resting control condition.

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Attention and Emotion

Accumulating evidence over the past several decades suggests that information processing is limited in the human visual system when individuals are faced with the task of attending to multiple objects at the same time (Kastner & Ungerleider, 2000). Studies have shown that multiple stimuli can either integrate or compete when they are displayed in the same visual field at a given time (Blum & Barbour, 1979; Fox, 1993; Locascio & Snyder, 1975). Some stimuli are preferentially processed because the brain presumably has been designed to process salient stimuli more so than

nonsalient stimuli. Experimental studies have generally confirmed that relevant or salient visual stimuli produce deeper or more effective cognitive processing than other irrelevant stimuli (Behrmann, Black, & Murji, 1995; Danckert et al., 2000; Egeth & Yantis, 1997; Fuster, 1990; Yantis & Jonides, 1984). Emotional stimuli, in particular, have been shown to naturally engage the visual attention system (Keil, Moratti, Sabatinelli, Bradley, & Lang, 2005).

Numerous studies investigating selective attention to emotional stimuli have demonstrated that people are faster to shift their attention toward emotional contents than neutral contents (Allegrì, 2000; Berman & Colby, 2009; Garcia-Ogueta, 2001; Rees, 2001). Furthermore, the emotional cues were shown to modulate spatial shifts of attention (Ohman, Flykt, & Esteves, 2001; Stormark & Hugdahl, 1996, 1997). Engagement of the brain's fear system serves an adaptive function, allowing individuals to detect threat quickly in the environment and react appropriately (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Ohman, 2005). However, a heightened tendency to direct attention to threatening stimuli, or the failure to disengage attention to threat, has been associated with affective and anxiety disorders (B. P. Bradley et al., 1999).

Measures of "attentional bias" to emotion have been used as behavioral manifestations of affective and anxiety disorders. The dot-probe task is an often-used paradigm to investigate visual attention to emotional stimuli, in particular, threat-relevant stimuli (Cooper & Langton, 2006; Koster, Crombez, Verschuere, & De Houwer, 2004; Lee & Knight, 2009; Lipp & Derakshan, 2005; Mogg, Bradley, de Bono, & Painter, 1997; Waters, Lipp, & Spence, 2004). The dot-probe task indexes visual attention to simultaneously presented emotional and neutral valence stimuli through the measurement of reaction time to identify a probe presented in the former location of either the emotional or neutral stimulus, and it provides behavioral evidence of selective attention. Several studies have shown that there is an attentional bias toward threatening stimuli in people with high anxiety scores or those diagnosed with anxiety disorders (M. M. Bradley, 2009; Derryberry & Reed, 2002; Frewen, Dozois, Joannisse, & Neufeld, 2008; Koster et al., 2004; Lindstrom et al., 2009; MacLeod, Mathews, & Tata, 1986; Mogg et al., 1997; Mueller et al., 2009).

Despite the well-documented mood-enhancing, antidepressant, and anxiolytic effects of exercise, it has not yet been demonstrated that acute exercise may be useful to shift attentional bias away from threatening stimuli. One study has investigated the effects of acute exercise on attentional bias using a modified dot-probe task and found that *prior* exercise had no effect on visual attention to emotion (Barnes, Coombes, Armstrong, Higgins, & Janelle, 2010). It is not known, however, if attention to emotion is altered *during* exercise.

Attention to Emotion During Exercise

Visual attention during physical exercise has been examined in both athletes and nonathletes (Ando, Kokubu, Kimura, Moritani, & Araki, 2008). Notably, most visual attention tasks previously used during exercise have not included emotional targets. This is important as emotional information processing conveys significant information in directing both attention and action (Lang & Bradley, 2010). We have previously reported that facial muscle reac-

tions to emotional picture stimuli were not altered when viewed simultaneously during low-intensity cycling exercise (40% of maximal capacity) compared with those during rest (Smith & O'Connor, 2003). Recently, we also reported that accuracy and response time to detect both threat and nonthreat relevant targets were enhanced during moderate- (60% of maximal capacity) and high-intensity (85% of maximal capacity) exercise compared with those during seated rest (Shields, Larson, Swartz, & Smith, in press). These findings indicate that emotion-processing networks are activated and responsive to external stimuli, even during high-intensity exercise, and do not support the hypothesis that emotion circuits are inhibited during exercise (Dietrich & Audiffren, 2011). We also found that accuracy to detect neutral targets was greater during moderate- compared with high-intensity exercise (Shields et al., in press). However, because previous studies have not included pleasant targets, it is not clear whether exercise affects attention to any visual target, or whether moderate- and high-intensity exercise may differentially prime the appetitive or defensive motivational systems.

The purpose of this study was to address this gap in the literature. We aimed to determine whether attentional bias to pleasant and unpleasant face stimuli, as assessed by the dot-probe task, would be affected during moderate- and high-intensity exercise compared with rest. Based on the expected report of increased positive affect during moderate-intensity exercise and our previous report (Shields et al., in press), we hypothesized that participants would show enhanced attentional bias toward pleasant stimuli and reduced attentional bias toward unpleasant stimuli during moderate-intensity exercise compared with rest and high-intensity exercise conditions. Because high-intensity exercise is typically subjectively perceived as more unpleasant compared with rest and moderate-intensity exercise, we hypothesized that attentional bias toward pleasant stimuli would be diminished and attentional bias toward unpleasant stimuli would be augmented during high-intensity exercise compared with the rest and moderate-intensity exercise conditions.

Method

Participants

Thirty-four healthy college students (17 women) who were regularly physically active participated in this study at the University of Wisconsin–Milwaukee. The recruitment was through course announcements in the Department of Human Movement Sciences and via flyers posted on campus and in the surrounding community. Healthy adults who were regularly physically active as defined by self-reported 3 days per week of moderate to strenuous physical activity for at least 15 min using the Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1997), in the age range of 18 to 35 years old, and right-handed, were included in this experiment. Criteria for exclusion from this study included current or previous heart disease, stroke, cancer, or psychiatric condition, or the present symptoms of chest pain/discomfort, shortness of breath, and dizzy spells on the health history and demographic questionnaire. In addition, participants with a self-reported mental disorder or who took antidepressant, anti-anxiety, or psychoactive medications within the past 2 years were excluded.

Procedure

The experiment took place on 2 days of testing within 8 days. On Day 1, participants read and signed an informed consent form that was approved by the Institutional Review Board and completed the health history and demographic questionnaire, the Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1997), Edinburgh Handedness Inventory (Oldfield, 1971), and State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants were then given instructions about the dot-probe task. A total of 256 paired facial expressions were selected as the stimuli of the dot-probe task from the MacArthur Network Face Stimuli Set (Tottenham et al., 2009). Half of the trials (128 trials) contained a neutral expression paired with a pleasant expression, and the other half (128 trials) contained a neutral expression paired with an unpleasant expression. Each pair of neutral and emotional faces depicted the same person. The dot-probe task started with a fixation in the central screen for 500 ms. A pair of facial expressions, one on the left and on the right, was then presented for 1,000 ms. The face stimuli were simultaneously removed and the letter *E* or *F* was immediately presented at the center of the location of either the emotional face or neutral face. The letter remained on the screen until the participant pressed the button to indicate the identity of the letter probe (right index finger press for *E*, right middle finger press for *F*). Participants were instructed to respond as accurately and as quickly as possible. The location of emotional stimulus as well as the location of the letter character were counterbalanced throughout the task. There was a short break (approximately 1 min) after 128 trials during which the participant continued to perform the pedaling or rest condition. The 256 dot-probe trials lasted approximately 10 min. All participants practiced the entire task (256 trials) on Day 1 to minimize the effect of practice on reaction times during each experimental condition. After the practice session, all participants completed a maximal exercise test on a cycle ergometer to determine their physical fitness levels (see description below).

On Day 2, participants completed three conditions, rest, moderate-intensity cycling (heart rate [HR] at 45% $\text{VO}_{2\text{peak}}$ [peak oxygen consumption]), and high-intensity cycling (HR at 80% $\text{VO}_{2\text{peak}}$) on a Monark cycle ergometer (Varberg, Sweden), in a counterbalanced order (four orders were completed by six participants, and the remaining two orders were completed by five participants) while performing the dot-probe task. The exercise intensity was determined by the HR during the maximal exercise test on Day 1 that corresponded to 45% and 80% $\text{VO}_{2\text{peak}}$, respectively. The experimental session occurred in a closed sound-attenuated room that was maintained at 21 °C. A 19-in. color monitor was placed on a height-adjustable table at the level of the ergometer handlebars, and the top of the monitor was centered and located approximately 1 m in front of the participant's nasion. A button response pad was located immediately in front of the participant's right hand at the level of the handlebar such that the buttons could be pressed with the right index and middle fingers while keeping the proximal pad of the hand on the handlebar. During the exercise conditions, the participants were instructed to continuously pedal at their preferred cadence and to complete each trial of the dot-probe task as accurately and as quickly as possible. The experimenter was in the exam room to continuously monitor the participant's HR and adjusted the resistance, if needed, to

maintain the exercise intensity within the estimated HR zone for each individual.

State anxiety level was measured immediately before each condition using the State-Trait Anxiety Inventory (Spielberger et al., 1983). Both the moderate- and high-intensity exercise conditions started with warm-up at 20 W and also ended with cool-down at 20 W, both in the absence of the task (approximately 1–2 min). Participants began the dot-probe task once their HR reached the target intensity level. During the short break, arousal and pleasantness levels were assessed using the Self-Assessment Manikin (SAM; Lang, 1980) while participants remained seated or pedaled on the cycle ergometer. HR, ratings of perceived exertion (RPE; Borg, 1998), and ratings of leg muscle pain intensity (Cook, O'Connor, Eubanks, Smith, & Lee, 1997) were also obtained during the short break as manipulation checks. HR was recorded using a Polar HR monitor (Oulu, Finland). The 9-point SAM ratings were employed to assess arousal and pleasantness before, during, and after each condition, also as manipulation checks. SAM is a picture scale that assesses subjective valence (pleasant to unpleasant) and arousal (excited to calm; Lang, 1980). Ten minutes of recovery time was provided between each experimental condition during which time HR was continuously measured and SAM ratings were obtained. All conditions, including the maximal exercise test, rest, moderate-intensity exercise, and high-intensity exercise, were performed during the same time period of the day for each participant (e.g., mornings, afternoons, or evenings) to minimize potential intraindividual circadian effects.

Data Reduction

A total of 256 trials were shown in the dot-probe task during each condition. Consistent with previous research, we analyzed only trials with correct responses (Joormann & Gotlib, 2007). Error rates were extremely low (the means for all three conditions were less than 3%). To further minimize the effect of outliers, we excluded response times that were less than 100 ms and more than 1,000 ms (Joormann & Gotlib, 2007). The exclusion of these extreme types of responses accounted for less than 2% of the overall trials for all three conditions. The attentional bias scores were computed from the standardized equation for each emotional valence (pleasant and unpleasant) based on the mean reaction time to each of four types of trials (Mogg, Bradley, & Williams, 1995): Attentional bias score = $1/2 [(RpLe - RpRe) + (LpRe - LpLe)]$, where R = right position, L = left position, p = probe/character, and e = emotional face. For instance, RpLe represents the trial in which the letter probe (p) was located on the right (R) and the emotional face (e) was on the left (L), and so on. Positive bias scores indicate attention is toward the location of emotional faces relative to the paired neutral faces, and negative bias scores indicate that attention is away from the spatial location of emotional faces relative to paired neutral faces.

Internal Consistency Reliability

To examine the reliability of the attentional bias scored calculated from the dot-probe task, we determined the internal consistency reliability for the mean reaction time during the four types of trials used to compute the bias scores using Cronbach's alpha (two-way random effects model). Only correct trials with an equal

minimal number across trial types, trial valence, and conditions for all participants (24 trials) were selected for internal consistency analyses. Cronbach's alpha was consistently high, with all the values above .90.

Determination of $\text{VO}_{2\text{peak}}$

After the completion of the dot-probe task practice session on Day 1, participants each performed a maximal exercise test on a Lode cycle ergometer (Corival, Groningen, the Netherlands) to determine the peak rate of oxygen uptake. A ParvoMedics TrueOne metabolic cart (Sandy, UT) continuously measured ventilation (VE), oxygen consumption (VO_2), carbon dioxide production (VCO_2), and the respiratory exchange ratio (RER; i.e., VCO_2/VO_2), with average values displayed every 30 s throughout the test. HR was measured using a Polar HR monitor throughout the test.

Air flow and gas (O_2 and CO_2) analyzers were calibrated prior to every test. The current relative humidity, temperature, and barometric pressure were entered into the metabolic cart system to convert expired minute volume values to standard temperature and dry gas at standard barometric pressure. When the test began, the electronically braked cycle ergometer continuously increased workload at a rate of $25 \text{ W} \cdot \text{min}^{-1}$ for women and $30 \text{ W} \cdot \text{min}^{-1}$ for men, with an initial workload of 50 W. Participants were verbally instructed and encouraged to give a maximal effort and to exercise as long as possible to volitional exhaustion throughout the test. The test ended when the participant indicated she/he was not able to continue (e.g., muscle fatigue, etc.) using predetermined hand gestures. Ratings of perceived exertion were obtained every 2 min and immediately after the test ended. The maximal exercise test lasted between 8 and 12 min. The criteria for the determination in reaching a peak oxygen consumption were meeting two of the following three criteria: (1) maximal RER > 1.1 , (2) at least 90% of the age-predicted maximal HR ($220 - \text{age}$), and (3) a rated perception of effort of at least 17 on Borg's 6–20 RPE scale (Borg, 1998). The purpose of this maximal exercise test was to determine physical fitness level and to set the relative exercise intensity on Day 2.

Data Analysis

Statistical analyses were performed using SPSS 13.0 for Windows (SPSS, Inc. Chicago). This study employed a repeated measures analysis of variance (ANOVA) and a priori level of significance of .05 was used. A preliminary analysis showed that there were no effects of order of condition and no interactions between condition and sex on attentional bias scores. The effect of exercise on attentional bias scores was analyzed using a 3 (condition) \times 2 (trial valence) ANOVA. SAM ratings of valence and arousal to each condition were analyzed using a 3 (condition) \times 3 (time) ANOVA. The manipulation checks, including HR, RPE, leg pain intensity, and state anxiety, were compared across the three conditions by performing one-way repeated measures ANOVAs. For repeated measures of ANOVAs with more than two levels, we used the Huynh–Feldt correction factor to adjust the degrees of freedom when Mauchly's test of sphericity was significant at $p < .05$. Corrected p values are reported with original the degrees of freedom and Huynh–Feldt epsilon in these cases. When significant

main effects and interactions were detected, pairwise comparisons were then performed via paired-samples t tests. Effect sizes were also calculated.

Results

Participant Characteristics

Demographic characteristics of 34 participants by sex are presented in Table 1. The values are shown as means and standard deviations. Participants were normal weight and had average cardiorespiratory fitness (American College of Sports Medicine, 2006). By performing the independent sample two-tailed t tests, there were sex differences for $\text{VO}_{2\text{peak}}$, $t(17) = 4.115$, $p < .001$; height, $t(17) = 5.644$, $p < .001$; weight, $t(17) = 4.991$, $p < .001$; and body mass index, $t(17) = 2.195$, $p < .05$.

Attentional Bias Scores

It was anticipated that participants performing moderate-intensity exercise would exhibit increased attentional bias toward pleasant faces and decreased attentional bias toward unpleasant faces compared with rest and high-intensity exercise. In addition, we hypothesized that high-intensity exercise would be subjectively perceived the most unpleasant among these three conditions (Smith et al., 2002); therefore, participants would show the lowest bias scores to pleasant faces and the highest bias scores to unpleasant faces. To test our hypotheses, we used a 3 (condition) \times 2 (trial valence) \times 2 (sex) repeated measures ANOVA to examine the effect of condition and sex on attentional bias scores to pleasant and unpleasant stimuli. There was a significant interaction of condition and trial valence, $F(2, 66) = 3.704$, $p = .030$, $\eta_p^2 = .101$. This interaction is illustrated in Figure 1. As expected, during moderate-intensity exercise, participants exhibited significantly greater attentional bias scores to pleasant stimuli than to unpleasant stimuli, $F(1, 33) = 9.248$, $p = .005$, $\eta_p^2 = .219$. The attentional bias to unpleasant stimuli was significantly lower during moderate-intensity exercise compared with that during rest ($p = .025$). However, the second hypothesis that high-intensity exercise would lead to the lowest bias scores toward pleasant stimuli and the highest bias scores toward unpleasant stimuli was not sup-

Table 1
Demographic and Exercise Variables by Sex (Mean \pm SD)

Variable	All ($N = 34$)	Men ($n = 17$)	Women ($n = 17$)
Age (years)	22.2 \pm 4.2	23.1 \pm 4.3	21.3 \pm 3.9
Height (m)*	1.7 \pm 0.1	1.8 \pm 0.1	1.7 \pm 0.1
Weight (kg)*	69.4 \pm 12.6	77.6 \pm 11.7	61.2 \pm 6.9
BMI (kg/m^2)*	23.0 \pm 2.9	24.1 \pm 2.9	21.9 \pm 2.7
Trait anxiety (STAI-Y2)	30.4 \pm 8.1	28.7 \pm 6.2	32.2 \pm 9.6
$\text{VO}_{2\text{peak}}$ (ml/kg/min)*	38.9 \pm 5.3	42.0 \pm 4.8	35.9 \pm 3.8
Total leisure activity score	59.6 \pm 20.3	63.4 \pm 17.4	55.9 \pm 22.8

Note. BMI = body mass index; STAI-Y2 = trait anxiety questionnaire (Spielberger et al., 1983); $\text{VO}_{2\text{peak}}$ = peak rate of oxygen uptake; Total leisure activity scores = Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1997).

* Significant difference between men and women ($p < .05$).

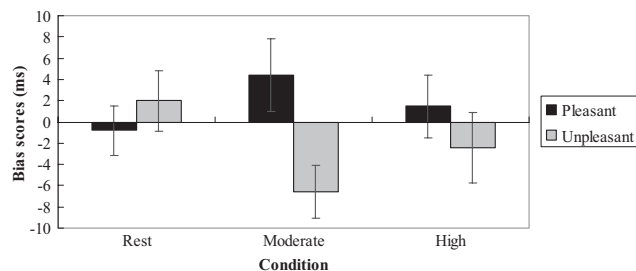


Figure 1. Attentional bias scores for pleasant and unpleasant faces relative to neutral faces during the conditions of rest, moderate-intensity exercise, and high-intensity exercise across all participants ($N = 34$). Error bars represent 1 standard error of the mean.

ported. In fact, participants at rest exhibited the greatest bias toward unpleasant faces and the lowest bias toward pleasant faces compared with during exercise.

Manipulation Checks

SAM ratings. SAM ratings of valence and arousal were collected before, during, and after each condition. The mean values across all participants are shown in Table 2. A 3 (condition) \times 3 (time) repeated measures ANOVA was used to test SAM ratings of valence and arousal to each condition. For SAM ratings of valence, the interaction of condition and time was statistically significant, $F(4, 132) = 8.221, p < .001, \eta_p^2 = .199$. The main effect of condition, $F(2, 66) = 7.150, p = .002, \eta_p^2 = .178, \epsilon = 0.846$, and the main effect of time, $F(2, 66) = 21.098, p < .001, \eta_p^2 = .390$, were also significant. The condition main effect showed that SAM ratings of valence during rest, moderate-intensity exercise, and high-intensity exercise conditions were significantly different from each other ($p < .001$). Participants at rest showed the highest SAM ratings of valence, whereas high-intensity exercise caused the lowest SAM ratings of valence among three conditions. SAM ratings of valence at premoderate-intensity exercise were significantly higher than during moderate-intensity exercise ($p = .014$). For the high-intensity exercise condition, SAM ratings of valence at three time points were significantly different from each other ($p < .001, p < .001, \text{ and } p = .020$, respectively). SAM ratings of valence at prehigh-intensity exercise were highest among the three time points and lowest during high-intensity exercise. For the rest condition, no significant differences were found ($p > .05$). For SAM ratings of arousal, there was a significant interaction of condition and time, $F(4, 132) = 29.869, p < .001, \eta_p^2 = .475, \epsilon = 0.764$. There were also significant main effects of condition, $F(2, 66) = 48.978, p < .001, \eta_p^2 = .597, \epsilon = 0.829$, and time, $F(2, 66) = 32.207, p < .001, \eta_p^2 = .494$. SAM ratings of arousal during the three conditions were significantly different from each other ($p < .001$). Participants showed the highest SAM ratings of arousal during high-intensity exercise and the lowest value at rest. Similarly, there were significant differences among SAM ratings of arousal right after the three conditions ($p < .001$). SAM ratings of arousal were highest right after high-intensity exercise and lowest after the rest condition. SAM ratings of arousal at postrest were significantly lower than at pretest ($p = .023$). SAM ratings of arousal were significantly lower at premoderate-intensity exer-

cise than during moderate-intensity exercise and postmoderate-intensity exercise ($p = .002, p = .001, \text{ and } p = .002$, respectively). Similar results were found in high-intensity exercise. SAM ratings of arousal at prehigh-intensity exercise were significantly lower than during and after high-intensity exercise ($p < .001$). The effects of order and sex on arousal ratings were examined, but no significant differences were found ($p > .05$).

HR. To verify the exercise intensity, we conducted several manipulation checks during each condition. Individual HR at the estimated percentage of $\text{VO}_{2\text{peak}}$ was measured. A one-way repeated measures ANOVA showed a large and significant difference in HR across the three conditions, $F(2, 66) = 760.495, p < .001, \eta_p^2 = .958, \epsilon = 0.846$. The HRs during rest, moderate-intensity, and high-intensity exercise conditions are shown in Table 2 and were significantly different from each other ($p < .001$). HR was highest during high-intensity exercise and lowest at rest. No sex difference was detected ($p > .05$). There was a significant interaction with order of experimental condition such that HR during the rest condition was significantly higher in the two orders when rest was the third condition performed (moderate-high-rest: 91.5 ± 7.4 beats per minute [bpm]; high-moderate-rest: 91.6 ± 9.5 bpm) compared with when rest was the first condition performed in the order rest-high-moderate (75.7 ± 8.2 bpm, $ps < .05$). Despite these small differences, HR during the rest condition was always markedly and significantly lower compared with that in the moderate- and high-intensity conditions for all six orders of the conditions ($p < .001$; see Table 2).

RPE. Subjectively measured RPE were measured using the Borg 6–20 RPE scale (Borg, 1998). Following a one-way repeated measures of ANOVA, there was a significant difference in RPE across the three conditions, $F(2, 66) = 249.270, p < .001, \eta_p^2 = .883$ (see Table 2). The RPE during the three conditions were significantly different from each other ($p < .001$). Participants exhibited highest RPE during high-intensity exercise and lowest RPE at rest. No sex or order effects were found ($p > .05$).

Leg pain intensity. The measurement of leg pain intensity on a 0–10 scale was measured as an index of the affective response during the exercise and rest conditions (Cook et al., 1997). A one-way repeated measures ANOVA revealed a significant differ-

Table 2
Average Self-Assessment Manikin Ratings of Valence (SAM-V) and Arousal (SAM-A), Heart Rate (HR), Ratings of Perceived Exertion (RPE), and Leg Pain Intensity During and State Anxiety Before Conditions of Rest, Moderate-Intensity, and High-Intensity Exercise (Mean \pm SD)

Condition	Exercise		
	Rest	Moderate intensity	High intensity
SAM-V	7.9 \pm 1.5 _a	7.4 \pm 1.8 _a	6.6 \pm 1.7 _a
SAM-A	1.3 \pm 0.6 _b	2.3 \pm 1.4 _b	4.2 \pm 1.8 _b
HR	85.1 \pm 10.0 _c	131.2 \pm 10.0 _c	164.9 \pm 9.1 _c
RPE	6.4 \pm 1.0 _d	9.9 \pm 2.2 _d	13.5 \pm 1.8 _d
Pain	0.1 \pm 0.2 _e	0.8 \pm 1.2 _e	2.7 \pm 2.0 _e
State anxiety	28.7 \pm 8.1 _f	30.0 \pm 8.7 _f	27.6 \pm 8.2

Note. Within each measure, values with common subscripts represent a significant difference between conditions ($p < .05$).

ence in leg pain intensity across the conditions, $F(2, 66) = 41.857$, $p < .001$, $\eta_p^2 = .559$, $\epsilon = 0.763$, and all conditions differed significantly from each other ($p < .001$; see Table 2). Women rated significantly higher leg pain intensity than men during moderate-intensity exercise ($p < .05$) but not during rest or high-intensity exercise. There was no order effect on leg pain intensity.

State anxiety. The state anxiety levels measured immediately prior to each condition are also shown in Table 2. The one-way repeated measures ANOVA yielded a significant difference in state anxiety scores, $F(2, 66) = 4.709$, $p = .012$, $\eta_p^2 = .125$. State anxiety scores premoderate-intensity exercise were significantly higher than prehigh-intensity exercise ($p = .014$). Despite this small difference, state anxiety levels were below the normative values for college students (Spielberger et al., 1983; Turner & Raglin, 1996). No effects of order or sex were found for state anxiety ($ps > .05$).

Discussion

Attention to Emotion During Exercise

The results of this study provide novel behavioral evidence regarding shifts in attention allocation toward pleasant emotional face stimuli and away from unpleasant emotional face stimuli *during* moderate-intensity exercise. Specifically, our findings showed that attentional bias scores to pleasant stimuli were significantly greater than bias scores to unpleasant stimuli during moderate-intensity exercise. This effect was not found at rest or during high-intensity exercise. Furthermore, bias scores to unpleasant stimuli during moderate-intensity exercise were significantly lower compared with those during rest.

Based on previous research regarding affective responses during exercise (Smith & O'Connor, 2003; Smith et al., 2002), we hypothesized that participants would exhibit the greatest bias scores toward pleasant stimuli and the lowest bias scores to unpleasant stimuli during relatively pleasant moderate-intensity exercise. The opposite pattern of results was hypothesized for high-intensity exercise, where the relatively less pleasant feelings (accompanied by leg muscle pain) were hypothesized to lead to reduced attentional bias toward pleasant stimuli and a greater attentional bias toward unpleasant stimuli. Our findings supported the hypothesis of a positive profile of attentional bias during moderate-intensity exercise. However, the hypothesized effect during high-intensity exercise was not supported. Furthermore, it is interesting to note that the participants at rest, rather than during high-intensity exercise, exhibited the lowest bias scores to pleasant faces and significantly higher bias scores to unpleasant faces compared with bias scores in the moderate-intensity exercise condition.

We expected that self-ratings of pleasantness would be related to attentional bias to emotion, but the results were inconsistent with subjectively measured affect during the exercise and rest conditions. Based on SAM ratings of valence, participants reported the highest ratings of pleasantness at rest and lowest ratings of pleasantness during high-intensity exercise. This is in contrast to the results from the dot-probe task, where moderate-intensity exercise resulted in the greatest bias scores toward pleasant stimuli and the lowest bias scores to unpleasant stimuli among the three conditions. The rest condition, on the other hand, led to the lowest bias scores to pleasant stimuli and the highest bias scores to

unpleasant stimuli. Thus, despite subjective feelings of pleasantness at rest, the behavioral evidence here indicates that the rest condition may have led to the most unpleasant affective state. This difference between subjectively measured ratings and attentional biases in the dot-probe task suggests that subjective measures of affect may not be sensitive enough to capture the propensity for attentional shifts toward or away from emotional face stimuli during exercise. The results during rest also underscore the difficulty of relying on purely subjective ratings of affect without consideration of behavior or a psychophysiological response to confirm the subjective rating (Lang & Bradley, 2010).

These data extend the results of two recent studies. Shields et al. (in press) found that the accuracy to detect a nonthreatening target among an array of threatening distractors was enhanced during moderate- compared with high-intensity exercise. One possible interpretation is that moderate-intensity exercise may prime the attentional system to promote accurate visual detection of non-threatening stimuli. The results of the current study extend these findings and suggest that moderate-intensity exercise may prime the appetitive motivational system linked to visual attention. The results also suggest that defensive motivational circuits linked to visual attention to faces may be inhibited during moderate-intensity exercise but not high-intensity exercise.

The effects we observed are in contrast to recent work that showed that acute exercise had no effect on attentional bias scores 5 min after the exercise in a sample with high trait anxiety scores (Barnes et al., 2010). Barnes et al. (2010) used a modified dot-probe task using International Affective Picture System (IAPS) pictures that included only 48 trials consisting of humans, animals, and scenes of nature. Their stimuli also varied in complexity (i.e., simple figure-ground vs. complex scene), and they did not include a high-intensity exercise condition. The current study included subjects who were within the norm on trait anxiety scores and used face stimuli that did not vary in physical complexity. Given the counterbalanced order of our brief bouts of exercise, which occurred during a single session with 10 min between each condition, we did not assess mood changes after exercise. It is possible, however, that the effectiveness of exercise to shift attentional bias toward pleasant stimuli and away from threatening stimuli is greatest while the exercise is being performed. It remains to be seen whether the effects we observed during exercise can be replicated in those with increased anxiety scores or those diagnosed with an anxiety disorder.

Dual-Task Considerations

One might argue that the dual-task nature of the experimental protocol may have influenced the attentional bias score results (Wickens, 2008). It is important to note, however, that there was good separation between the tasks in their primary modalities and responses that were required (Wickens, 2008). The tasks were independently well practiced prior to the experimental session. In addition, the instructions to the participants to focus on the dot-probe task performance, paired with the relatively low attentional effort required to pedal a stationary bike in a well-controlled laboratory environment, allowed for a high degree of response accuracy while simultaneously pedaling and performing the dot-probe task. The experimenter took on the tasks of attending to the participants' HR, work rate, and pedal cadence. Thus, there was no

additional attentional effort required to perform the exercise. Unfortunately, we did not have the instrumentation to continuously record pedal cadence. The lack of a dual-task effect on task performance is best illustrated, however, by the fact that the exercise conditions did not adversely affect task performance. Error rates in all three conditions were within the published norms, ranging from a low of 2.2% in the moderate-intensity exercise condition to high of 3.3% in the high-intensity exercise condition. We excluded error trials, as well as trials with reaction times greater than 1,000 ms (less than 2% of all trials), in the calculation of bias scores. Thus, we removed any possible influence of dual-task-related decrements in task performance by including only correct trials in the analysis.

It has been recently hypothesized that the performance of exercise interferes with the ability to simultaneously perform implicit tasks that require activation of the prefrontal cortex, including the neural circuitry involved in emotion processing, thus leading to blunted affective responsiveness during exercise (Dietrich & Audiffren, 2011). There are several lines of evidence that refute the hypofrontality hypothesis. First, cerebral oxygenation has been shown to increase in the prefrontal cortex during moderate-intensity exercise (Rooks, Thom, McCully, & Dishman, 2010), and cerebral blood flow is increased and maintained up to 30 min after moderate-intensity exercise (Smith, Paulson, Cook, Verber, & Tian, 2010). The hypofrontality hypothesis fails to consider the extended cortical and subcortical network involved in modulation of both appetitive and defensive responsiveness (Fusar-Poli et al., 2009; Lang & Bradley, 2010). Inhibition of the prefrontal cortex during exercise would be hypothesized to strengthen activation of the amygdala in response to fear stimuli and exacerbate emotional distress (Foland-Ross et al., 2010; Hartley & Phelps, 2010; Sotres-Bayon & Quirk, 2010). Consistent with recent evidence that emotional reactions to affective picture stimuli are preserved during distraction (Hajcak, Dunning, & Foti, 2007; Wangelin, Low, McTeague, Bradley, & Lang, 2011), we previously reported that physiological reactions during pleasant and unpleasant picture viewing are undisturbed during exercise compared with rest (Smith & O'Connor, 2003). In addition, threat target detection was enhanced during both moderate- and high-intensity exercise (Shields et al., in press). Taken together, these findings suggest that emotion circuits may be primed during motor activation such as exercise and, based on the current findings, that moderate-intensity exercise in particular may promote the engagement of visual attention networks associated with pleasant face processing and concurrent inhibition of visual attention networks associated with unpleasant face processing. We found no evidence that emotional face processing is neglected during high-intensity exercise.

Affect During Exercise

SAM ratings of pleasantness were greater during moderate-intensity than during high-intensity exercise. However, the greatest ratings of pleasantness were recorded at rest. Others have also examined affective ratings during different intensities of exercise. Not surprisingly, high-intensity exercise is experienced as less affectively pleasant than lower intensity exercise and rest. For example, Bixby and Lochbaum (2006) reported that participants rated their affect as more positive during low-intensity cycling than during high-intensity cycling. Smith et al. (2002) found that

SAM ratings of pleasantness were higher during moderate-intensity exercise compared with those during rest and lowest during high-intensity exercise. Another study examined ratings of pleasantness at very low-intensity and moderate-intensity exercise and found that higher ratings of pleasantness were reported at the lower exercise intensity (Smith & O'Connor, 2003). It is important to note, however, that in comparison to normative ratings of valence and arousal to gruesome and threatening IAPS pictures, ratings of pleasantness are relatively moderate in normally physically active healthy adults during high-intensity exercise and even maximal-intensity exercise. These feelings of moderate pleasure during exercise occur despite very high ratings of emotional arousal and mild to moderate leg muscle pain (Smith & O'Connor, 2003; Smith et al., 2002). Some have suggested that unpleasant affective experience during exercise may promote nonadherence (Williams et al., 2008), and these effects may be related to prior experience with exercise and physical fitness (Ekkekakis & Lind, 2006). The current study was restricted to normally physically active healthy adults with average cardiorespiratory fitness, and subsequent adherence to physical activity was not assessed. However, the use of an objective measure of emotional bias during exercise, such as the dot-probe task, may be a useful behavioral marker for the prediction of adherence to physical activity and exercise training programs.

Limitations

There are a few potential limitations to our work. The sample of participants was selected from healthy, normally physically active college students without any history of mental disorders. We did not find elevated attentional bias scores during the rest condition (relative to zero), which is in contrast to some previous studies. The attentional bias literature in healthy individuals at rest is inconsistent, and the presence of an emotional bias may depend on the stimulus exposure duration used in the dot-probe task. For instance, a bias toward threatening faces and a bias away from happy faces were found when the stimulus duration was 500 ms, whereas participants exhibited the opposite pattern with a stimulus exposure of 100 ms (Cooper & Langton, 2006). A meta-analysis study also showed negative bias scores to threat stimuli when the stimulus durations were 200 ms and 500 ms in individuals with low anxiety scores (Frewen et al., 2008). When the duration was equal to or greater than 1,000 ms, positive bias scores toward threatening stimuli were shown. In comparison, our healthy participants, while at rest, showed slightly negative bias scores to pleasant stimuli and slightly positive bias scores to unpleasant stimuli, a finding that is consistent with other studies that have used longer exposure durations. It is also important to note that participants in the present study were tested on the cycle ergometer instead of a comfortable chair, as may have been typical in previous studies. Although seated at rest and not pedaling, the bike saddle may be considered less comfortable. It is plausible that discomfort associated with the saddle in the rest condition may have increased bias toward unpleasant faces and away from pleasant faces. Nevertheless, the pain intensity ratings were quite low during rest, and the SAM ratings indicated subjective feelings of pleasantness and low ratings of arousal (see Table 2). In addition, these findings may not generalize to sedentary individuals or those who are more physically active than the average healthy college

student. Finally, the dot-probe task is only one of a battery of detection tasks to examine emotion-related attentional performance. It would be helpful to use different types of tasks to assess emotion-related attention during exercise.

Implications for Anxiety and Depression

Recent work has indicated that attention deployment can be retrained using cognitive-behavioral therapy or manipulated using pharmacologic interventions (Bar-Haim et al., 2007; Browning, Holmes, & Harmer, 2010). The generally held view is that alterations in attentional biases toward a more positive profile will have a beneficial effect on anxious or depressive symptomatology (Schmidt, Richey, Buckner, & Timpano, 2009). Although acute and chronic exercise have been shown to have anxiolytic and antidepressive effects (Greer & Trivedi, 2009; Herring et al., 2010), we did not measure symptoms of anxiety or depression after exercise in our healthy subjects. However, as Browning et al. (2010) point out, it is important to demonstrate the effectiveness of treatments to affect attentional bias in a healthy population because these effects are not confounded by clinical status. In the future, it will be necessary to consider the effects of exercise during emotional attention allocation paradigms in patients diagnosed with mood and anxiety disorders.

Among treatment paradigms, it has been shown that serotonergic treatments affect the early stages of information processing, as reflected by changes in the subcortical pathways that include decreased amygdala activation (Del-Ben et al., 2005; Murphy, Norbury, O'Sullivan, Cowen, & Harmer, 2009), whereas cognitive-behavioral and cognitive bias modification treatments affect primarily the later stages of information processing (Koster et al., 2010) and may involve changes in activation of frontal cortical regions (Browning et al., 2010). We did not use stimulus exposure durations less than 1,000 ms, which would permit the examination of the earlier stages of information processing. Nevertheless, the fact that we observed a shift toward a more positive attentional bias profile suggests that acute exercise may be an effective method to alter anxious and depressive symptomatology in clinical populations (Browning et al., 2010; Herring et al., 2010). Further work is needed to examine the effects of acute exercise on functional brain activation during emotional tasks (Smith et al., 2010).

The mechanisms for the effects of exercise on attention to emotion observed here are difficult to ascertain in humans given the generalized effects of exercise to simultaneously increase activity in several neurotransmitter and hormonal systems. Manipulation of the serotonergic system, and to a lesser extent the noradrenergic system, has been shown to influence attention allocation to emotional stimuli (Browning, Reid, Cowen, Goodwin, & Harmer, 2007; Murphy et al., 2009). Exercise has been shown to increase brain serotonergic, noradrenergic, and dopaminergic function (Chaouloff, 1997; Dishman, 1997; Greenwood & Fleshner, 2008; Meeusen, 2005). Exercise also results in glucocorticoid release, and cortisol administration has also been shown to affect the processing of fearful faces (Putman, Hermans, Koppeschaar, van Schijndel, & van Honk, 2007). Exercise has also been shown to have strong neurogenic effects in the dentate gyrus (van Praag, Kempermann, & Gage, 1999), and it is possible that the neu-

rotrophic effects of exercise may impact brain systems that regulate attention and emotion.

Conclusion

In conclusion, the results of the present study provide behavioral evidence that during exercise at a moderate intensity, compared with seated rest, there is a shift in attention allocation toward pleasant and away from unpleasant emotional face stimuli. The same pattern shown during moderate-intensity exercise, although at a lesser magnitude, was observed during high-intensity exercise. This is contrary to the hypothesis that high-intensity exercise would lead to a more negative attentional bias profile. Although moderate-intensity exercise led to a greater attentional shift toward pleasant stimuli and away from unpleasant stimuli compared with during high-intensity exercise, the shifts in attentional bias during the exercise conditions did not differ statistically. These observations may help to inform follow-up studies about attentional biases *after* exercise. Our hypothesis is that moderate-intensity exercise, when compared with rest, may promote a shift in attentional bias that may help promote improved mood. Future studies should examine whether this same profile would be observed in clinical populations or individuals who vary in fitness or physical activity history, and whether attentional bias during exercise would help predict adherence to physical activity interventions or response to exercise as an adjunct treatment for affective and anxiety disorders.

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