Psychophysiology, 38 (2001), 99–106. Cambridge University Press. Printed in the USA.

Regional brain activation as a biological marker of affective responsivity to acute exercise: Influence of fitness

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Abstract

Previous research has shown that regional brain activation, assessed via frontal electroencephalographic (EEG) asymmetry, predicts affective responsivity to aerobic exercise. To replicate and extend this work, in the present study we examined whether resting brain activation was associated with affective responses to an acute bout of aerobic exercise and the extent to which aerobic fitness mediated this relationship. Participants (high-fit, $n = 22$; low/moderate-fit, $n = 45$) ran on a treadmill for 30 min at 75% VO_2max. EEG and affect were assessed pre- and 0-, 10-, 20-, and 30-min postexercise. Resting EEG asymmetry predicted positive affect (as measured by the energetic arousal subscale of the Activation Deactivation Adjective Check List) postexercise. Furthermore, resting frontal EEG asymmetry predicted affect only in the high-fit group, suggesting the effect might be mediated by some factor related to fitness. It was also shown that subjects with relatively greater left frontal activation had significantly more energy (i.e., activated pleasant affect) following exercise than subjects with relatively greater right frontal activation. In conclusion, aerobic fitness influenced the relationship between resting frontal asymmetry and exercise-related affective responsivity.

Descriptors: Brain activation, Aerobic exercise, Affect, Fitness

Exercise has been related to improved mood and psychological well-being (McAuley, 1994; Plante & Rodin, 1990; Raglin, 1990), decreased anxiety (Landers & Petruzzello, 1994; Petruzzello, Landers, Hatfield, Kubitz, & Salazar, 1991), and decreased depression (Martinsen, 1990; North, McCullagh, & Tran, 1990). However, the mechanisms by which these changes occur are not well known.

Recent studies have shown that resting frontal electroencephalographic (EEG) asymmetry may act as a biological marker of affective style (for reviews, see Davidson, 1992, 1993a, 1993b, 1994, 1998). Specifically, Davidson (1992) proposed that anterior brain asymmetries reflect a basic neuroanatomical asymmetry implicated in the control of approach and withdrawal-related behaviors. To approach or withdraw from a situation is a fundamental adaptive response, with approach behavior being associated with positive affect and withdrawal behavior being related to negative affect (Davidson, 1993b). In this framework, greater left frontal activation relative to right is associated with the approach systemand positive affect and greater right frontal activation relative to left is associated with the withdrawal system and negative affect.

In this framework, baseline measures of asymmetric anterior activation are associated with a propensity to experience positive or negative emotions, given the requisite environmental elicitors (Davidson, 1993b). Frontal EEG asymmetry is theorized to reflect a diathesis that, in conjunction with an emotion-eliciting stimulus of sufficient intensity, will result in a change in positive or negative affect appropriate with the emotion-eliciting stimulus. For example, individuals who show greater right relative to left frontal activation may currently be nondepressed, but may be more vulnerable to depression and may display more intense negative affect in response to negative affective elicitors (e.g., death of a loved one, watching a sad movie).

Tomarken, Davidson, and Henriques (1990) demonstrated that resting frontal EEG asymmetry significantly predicted negative affective responses to film clips and global affective valence (positive affect minus negative affect). Additionally, there was a strong relationship between frontal asymmetry and fear responses to films. With these findings, the authors proposed that resting anterior asymmetry might be a state-independent index of an individual's predisposition to respond affectively. Similar results were found by Wheeler, Davidson, and Tomarken (1993), who showed that greater left frontal activation was associated with reports of more intense positive affect in responses to positive film clips and greater right frontal activation was associated with more intense reports of negative affect in response to the negative film clips.

This psychophysiological framework has also been applied successfully to exercise (Petruzzello & Landers, 1994; Petruzzello & Tate, 1997). Using exercise as an emotion-eliciting stimulus, Petruzzello and Landers (1994) found resting EEG asymmetry to significantly predict state anxiety following a 30-min treadmill run at 75%VO_2max. After controlling for pre-exercise state anxiety, rest-

This research was supported by a grant from the National Institute of Mental Health (MH55513) to S.J. Petruzzello.

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ing brain asymmetry explained 30% of the unique, additional variance in postexercise state anxiety such that greater left anterior activation, relative to right, predicted anxiety reduction following treadmill running. Petruzzello and Tate (1997), seeking to replicate and extend this work, examined resting EEG asymmetry in three conditions: (1) control (sitting on a bicycle ergometer for 30 min); (2) bicycling for 30 min at 55% VO_2 max; and (3) bicycling for 30 min at 70% VO_2 max. At 70% VO_2 max, resting EEG explained 23% of unique variance in energetic arousal (an activated, pleasant affective state; Thayer, 1986) immediately following exercise (after controlling for pre-exercise energetic arousal), 23% of unique variance in state anxiety 5-min postexercise (after controlling for pre-exercise state anxiety), and 19% of unique variance in state anxiety 10-min postexercise (again controlling for pre-exercise state anxiety). Resting EEG asymmetry did not significantly predict any of the unique variance following the 55% VO_2max or control conditions. Both of these studies examined the brain asymmetry-exercise-affect relationship predominantly in men and relatively high-fit and high-active subjects.

Petruzzello and Tate also found some tentative evidence consistent with Tomarken and Davidson's (1994) speculation that relative activation in the left frontal region may be linked to dampened responses to negatively valenced stimuli. Using postexercise asymmetry scores as the basis for selection, participants with extreme left-sided activation had significantly greater positive affect and had lower perceptions of effort *during* exercise as reflected in ratings of perceived exertion. Individuals with extreme right-sided activation had *increased* state anxiety and perceived the exercise stimulus as more demanding, even though it was physiologically equivalent (i.e., relative intensity) for all individuals.

Given the preceding considerations, the present study had a number of objectives. In an effort to replicate and extend previous work, in this study we examined whether resting brain activation was associated with affective responses to an acute bout of aerobic exercise and the extent to which aerobic fitness mediated this effect. It was hypothesized that those participants with greater resting activation of the left anterior hemisphere, relative to the right, would respond with more positive/less negative affect postexercise and that fitness would mediate this relationship. Specifically, more fit individuals were hypothesized to have both greater relative left-sided activation and more positive/less negative affective responses to exercise. An additional purpose was to replicate previous work by determining whether subjects with stronger right- or left-sided asymmetry scores, independent of fitness, would respond differently to an acute bout of aerobic exercise. It was hypothesized that participants with greater resting left-sided activation would respond more favorably (i.e., with increased positive/decreased negative affect) to an acute bout of aerobic exercise than individuals with greater resting right-sided activation patterns. A final purpose was to determine the extent to which the relationship between differential brain activation and affect is specific to the anterior portions of the brain as opposed to a more generalized effect occurring in both anterior and posterior regions. Based on prior work (Petruzzello & Tate, 1997), it was hypothesized that any effects of brain activation on affect would be localized to the anterior brain regions.

Methods

Participants

Sixty-nine college-aged students (38 men, 31 women, *M* age = 21.4 ± 2.91 years, *M* male VO_2max = 49.92 ± 7.28 ml·kg^{-1}·min^{-1}, *M* female VO_2max = 45.25 ± 6.19 ml·kg^{-1}·min^{-1}) completed a statement of informed consent and were paid $10.00 for their participation in the study. Technical problems prevented the determination of VO_2max values for 1 man and 1 woman, thus analyses of fitness were conducted on a sample of 67 individuals.

Measures

Self-reported affect. Affect was assessed with the Activation Deactivation Adjective Check List (AD ACL; see Thayer, 1989, Appendix A, pp. 178–180) and the short form of the State Anxiety Inventory (SAI, Form Y-1; Spielberger, 1983). The AD ACL is a 20-item self-report measure that assesses two arousal dimensions: energetic arousal (EA) and tense arousal (TA). EA and TA are each composed of two 5-item subscales. EA is a combination of energy (active, energetic, vigorous, lively, full-of-pep), which reflects an activated pleasant affective state, and tiredness (sleepy, tired, drowsy, wide-awake, wakeful), that reflects an unactivated unpleasant state. TA is composed of tension (jittery, intense, fearful, clutched-up, tense), reflective of an activated unpleasant state, and calmness (placid, calm, at-rest, still, quiet), an index of an unactivated pleasant state. From a theoretical standpoint, the dimensions of EA and TA in Thayer's model and the dimensions of positive activation (formerly positive affect) and negative activation (formerly negative affect) in Watson, Wiese, Vaidya, and Tellegen's (1999) model are compatible (Thayer, 1989; Watson et al., 1999). The AD ACL was chosen over other measures of affect because it gives a more comprehensive representation of the global affective space (i.e., incorporating both valence and activation dimensions), is theoretically based on an activation model that is relevant in the exercise context, and has been used successfully in the exercise domain. The reliability and construct validity of the AD ACL are well established (Thayer, 1986). The short form of the SAI, which consists of 10 items from the full 20-item scale, was used to measure state anxiety. This briefer version has been shown to be a valid and reliable measure of state anxiety.

Brain activation. Resting brain activity (i.e., EEG) was recorded from nine scalp locations. These included left, right, and midline recordings from the midfrontal, central, and parietal regions. Raw EEG data were subjected to spectral analysis to decompose the complex EEG waveform into its component sine wave frequencies (see Data Reduction & Analysis section below). Because of its extensive use in the brain activation-affect literature, activity in the alpha frequency band (8–13 Hz) was of primary interest. Activity in this bandwidth is thought to reflect activation of the underlying cortex, such that greater alpha activity is related to less activation, whereas less alpha activity is associated with greater activation (Davidson, 1988). Resting EEG has been shown to be a reliable index of regional brain activation (Tomarken, Davidson, Wheeler, & Kinney, 1992).

EEG Recording

A stretchable Lycra electrode cap (Electro-Cap, Inc.) was fitted on the participant's head for electrode application and assessment of regional brain activation (i.e., EEG). Placement of the cap utilized anatomical landmarks (i.e., the inion and nasion) on the subject's head to ensure proper location. Using this procedure, electrode placements have been shown to deviate negligibly from the International 10-20 System locations (Blom & Anneveldt, 1982). EEG activity was recorded from the left, right, and midline of the midfrontal (F3, F4, Fz), central (C3, C4, Cz), and parietal (P3, P4, Pz) regions (only data from F3, F4, P3, P4 were used for this study).

All leads were referenced to linked earlobes and all electrode impedances were below 5 kΩ. Impedances for homologous (e.g., F3, F4) sites were within 500 Ω of each other. Ocular artifact (e.g., eye movements, eyeblinks) was assessed by electrooculogram (EOG) recording from electrodes placed laterally to both eyes as well as above and below one eye.

EEG data were acquired using a Grass Model 12 Neurodata acquisition system equipped with Model 12A5 amplifiers. All bioelectric signals were amplified 20,000×, and high- and low-pass filters were set at 1 and 100 Hz, respectively (roll-off = 6 dB/octave; 60-Hz notch filter in). The amplified and filtered signal was digitized at 256 samples per second and stored on a Gateway 486/DX2 computer for later analysis using EEGSYS software (Version 5.5, Friends Medical Science Research Center, Baltimore, MD).

Procedures

Participants visited the laboratory two times, separated by approximately 3 weeks (18.5 days). For the first visit, participants performed a graded exercise test to determine maximal aerobic capacity (VO_2max). VO_2max was determined by direct measurement and analysis of expired air samples taken during exercise on a motorized treadmill. Termination of the test was based on satisfying one of the following criteria: (a) reaching a peak or plateau in oxygen consumption rate (changes of ± 2 ml·kg^{-1}·min^{-1} or less) followed immediately by a decrease in consumption with increasing workloads; (b) a respiratory exchange ratio of 1.10 or higher; or (c) exceeding age-predicted maximal heart rate (i.e., 220 − age). Heart rate was assessed with a Polar Vantage Model XL heart rate monitor.

Submaximal exercise workloads were derived by calculating 75% of the participant's maximal oxygen consumption value. These values were then matched with the accompanying workload assessed during the VO_2max session and the corresponding heart rates were used to match the submaximal workload.

Prior to the submaximal exercise, participants were prepped for EEG recording while seated in a comfortable chair. After signal integrity had been confirmed and recorded via impedance checks, subjects were asked to sit quietly while baseline measures of EEG were collected. Resting EEG measures were obtained for eight, 60-s baseline periods during which subjects had their eyes closed. During the recording of these baselines, participants were instructed to be as "restful" as possible. After completion of EEG recording, the self-report measures of affect (i.e., SAI, AD ACL) were completed. Participants then ran on a motorized treadmill at a workload equal to 75% of VO_2max for 30 min. EEG (60-s) and affect were assessed immediately and again at 10-, 20-, and 30-min postexercise.

Data Reduction and Analysis

Offline, EEG waveforms were visually inspected for artifact by comparing activity at the scalp leads with the EOG. EEG containing artifact was marked and excluded from each EEG trial prior to further analysis of the data. All artifact-free data that were at least 2.0 s in duration were subjected to a fast Fourier transform (FFT) with a Hanning window to avoid error due to discontinuities at the beginning and end of each epoch (the Hanning windowing filter used a cosine-bell function to taper the first and last 10% of the epoch to zero). The FFT produced estimates of absolute spectral power (in μV^2) for the alpha frequency band (8–13 Hz). Power density values (in μV^2/Hz) for each 60-s trial were computed by dividing by the number of Hz estimates within the band, providing an index of the mean power density within the alpha frequency range. A natural log transformation was applied to all power density values to normalize the distribution (Gasser, Bacher, & Mocks, 1982). All subjects had a minimum of 20 artifact-free epochs (or seconds) for each given baseline (Gasser, Bacher, & Steinberg, 1985; Mocks & Gasser, 1984).

An EEG asymmetry index was derived (Pivik et al., 1993) that reflects the log alpha power density difference in corresponding regions of the two hemispheres (i.e., log R − log L alpha power). Thus, higher asymmetry scores represent lower amounts of alpha activity and relatively greater activation in the left hemisphere for a particular region. This asymmetry score has been demonstrated to have acceptable psychometric properties (Tomarken et al., 1992).

Regression analyses were used to examine the predictive power of EEG asymmetry scores on postexercise affect (i.e., state anxiety, EA, TA) after partitioning out pre-exercise affect. The influence of fitness was also of interest. Therefore, regression analyses were done using fitness group as a categorical variable to determine if there was an interaction between frontal (or parietal) alpha asymmetry and fitness group. Similar to the whole group regression equations, pre-exercise affect was partitioned out in a first step and frontal (or parietal) asymmetry was entered as a second step. Fitness group was then effect coded (see Pedhazur, 1997, for an extended discussion of the procedures involved in effect coding) and entered in as the third step. For the fourth step, the interaction between frontal (or parietal) asymmetry and fitness group (Frontal Asymmetry × Fitness Group) was entered. If the R^2 for the interaction term was significant, then separate regression equations were calculated for each fitness group (Pedhazur, 1997).

Results

Because both men and women were included in this study, gender effects were examined for all variables. Preliminary analyses including gender as an independent variable (both within multivariate analysis of variance [MANOVA] and regression analyses) indicated a similar effect on all variables for males and females, thus gender was not examined further. To examine the influence of fitness, the total group was split into what will be called a high-fit and low/moderate-fit group. This split was achieved by first performing a tertiary split on VO_2max by sex and then combining the groups (i.e., males, females) based on high (upper 30%) or low/moderate (lower 70%) fitness.[1] The low/moderate-fit group (n = 45) included 20 women (M VO_2max = 41.65 ± 3.56 ml·kg^{-1}·min^{-1}) and 25 men (M VO_2max = 46.00 ± 4.26 ml·kg^{-1}·min^{-1}), whereas the high-fit group (n = 22) was com-

[1]The 70/30 split was used based on the distribution of the VO_2max values obtained. This split allowed examination of the upper end of the aerobic fitness continuum in this sample. Comparing our fitness data with norms, it was apparent that we had a sample of "moderately fit" individuals and a smaller group of "athletically fit" individuals. Examining their activity habits corroborated this assessment. Most of our subjects led generally active lives (participated in physical activity on a casual or semiregular basis) whereas others were more dedicated exercisers. In fact, a MANOVA with a median split on fitness (independent variable) and various indices of self-reported physical activity (frequency, duration, intensity, and years of training) as dependent variables was not significant, suggesting that a median split on fitness would not have been meaningful or informative. We opted to use the 70/30 split to obtain a meaningful contrast between those who were "generally active" (due more to their youth and good health rather than their regular exercise involvement) and those who were "athletically active" (and highly fit due to training). The 70/30 split led to a significant MANOVA on the physical activity indices and significant differences in all individual indices. Furthermore, using the 70/30 split, the average person from the bottom 70% does not satisfy the American College of Sports Medicine guidelines for improving or maintaining cardiorespiratory fitness, whereas the average person from the top 30% does.

prised of 10 women (M VO_2max = 52.44 ± 3.26 ml·kg^{-1}·min^{-1}) and 12 men (M VO_2max = 58.09 ± 5.11 ml·kg^{-1}·min^{-1}). The distinction using VO_2 max was further verified upon analysis of self-reported exercise frequency, intensity, duration, and length of regular exercise. The groups were significantly different on all four of these variables, Wilks' $\lambda = 0.703$, $F(4,60) = 6.33$, $p < .001$. The high-fit group reported ($M \pm SEM$) 3.6 ± 0.5 workouts·wk^{-1} for 50.4 ± 7.5 min at an rating of perceived exertion (RPE) of 4.9 ± 0.6 ("strong" or heavy on Borg's CR-10 scale; Borg, 1998).[2] They also reported being involved with regular exercise for 5.5 ± 1.0 years. By contrast, the low/moderate-fit group reported ($M \pm SEM$) 1.5 ± 0.3 workouts·wk^{-1} for 20.3 ± 4.7 min at an RPE of 2.4 ± 0.5 ("weak" to "moderate" or light on Borg's CR-10 scale). They also reported being involved with regular exercise for 1.2 ± 0.4 years.

A Group (2: low/moderate-fit, high-fit) × Time (5: pre, immediate-post, post-10, post-20, post-30) MANOVA was used to examine changes in self-reported affect (EA = energetic arousal; TA = tense arousal; SA = state anxiety). The main effect for time was significant, Wilks' $\lambda = 0.342$, $F(12,54) = 8.66$, $p < .001$. Univariate ANOVAs for each variable confirmed the significant time main effect, EA: $F(4,260) = 39.94$, $p < .001$, Greenhouse–Geisser $\epsilon = 0.67$; TA: $F(4,260) = 22.87$, $p < .001$, $\epsilon = 0.66$; SA: $F(4,260) = 4.45$, $p = .002$, $\epsilon = 0.65$. Fisher–Hayter tests (q_{FH}) for post hoc comparisons (alpha set at .01 for each comparison) revealed that all three variables increased immediately postexercise from pre-exercise levels and then showed varying degrees of returning to pre-exercise levels during recovery. SA and TA both returned to pre-exercise levels by 10-min postexercise, but EA remained significantly elevated throughout the 30-min postexercise recovery period.

Because the Group × Time interaction approached significance ($p = .080$), the individual univariate interactions for EA, TA, and SA were examined. Only the Group × Time interaction for EA was significant, $F(4,260) = 3.20$, $p < .025$; Greenhouse–Geisser $\epsilon = 0.68$. As shown in Figure 1, the interaction was due to greater levels of EA during recovery in the high-fit group relative to the low/moderate-fit group. That is, EA remained elevated significantly above pre-exercise levels at each postexercise timepoint up to 30 min postexercise in the high-fit group (effect sizes = 0.75, 0.54, and 0.59 at 10-, 20-, and 30-min postexercise, respectively; effect sizes at these same times in the low/moderate-fit group were 0.55, 0.19, and 0.12). Examination of the EA subscales (energy, tiredness) revealed that the increase in, and maintenance of, EA following exercise was due to a greater increase in energy (effect sizes = 1.54, 0.84, 0.73, and 0.71 at 0-, 10-, 20-, and 30-min postexercise vs. 1.27, 0.58, 0.19, and 0.18, respectively) and a greater decrease in tiredness (effect sizes = 1.48, 0.87, 0.99, and 0.78 at 0-, 10-, 20-, and 30-min postexercise vs. 0.93, 0.43, 0.18, and 0.23, respectively) in the high-fit group relative to the low/moderate-fit group.

Resting EEG Predicting Affect

No differences existed in resting EEG asymmetry between the high-fit group ($M \pm SEM$ asymmetry = 0.029 ± .012) and the low/moderate-fit group ($M \pm SEM$ asymmetry = 0.025 ± .009), as confirmed by a one-way ANOVA, $F(1,65) = 0.068$, $p = .796$. To assess the predictive power of resting frontal EEG asymmetry on affect (EA, TA, SA) after exercise, a set of hierarchical regression analyses were performed. Resting frontal EEG asymmetry accounted for 6.4% of the variance in EA 20 min after exercise, $F_{change}(2,66) = 6.40$, $p = .014$, after accounting for pre-exercise EA (See Table 1). This effect was further examined for the two EA subscales (energy, tiredness). Resting frontal EEG asymmetry accounted for 6.8% of the variance in energy 10 min after exercise, $F_{change}(2,66) = 7.91$, $p = .006$, after accounting for pre-exercise energy (See Table 1). Resting frontal EEG asymmetry also accounted for 11.5% of the variance in energy at 20 min, $F_{change}(2,66) = 13.25$, $p = .001$, and 6.7% of the variance at 30 min after exercise, $F_{change}(2,66) = 8.98$, $p = .004$. No significant results were found for tiredness.

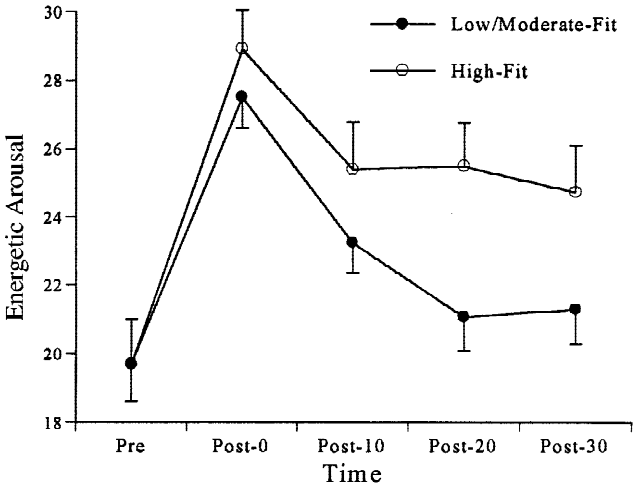

Figure 1. Changes in energetic arousal ($M \pm SEM$) from pre- to postexercise as a function of fitness group (high, low/moderate).

Hierarchical regression analyses were also conducted to determine the extent to which the predictive ability of the asymmetry metric was localized to anterior regions of the brain. After partitioning out the effects of pre-exercise affect (EA, TA, SA) on postexercise responses, resting parietal asymmetry failed to explain any significant additional variance in postexercise affect ($ps > .10$), pointing to the regional specificity of the effect.

To examine whether fitness influenced the ability of resting frontal asymmetry to predict postexercise affect, regression analyses were carried out to determine if there was a significant fitness group (high-fit vs. low/moderate-fit) by frontal asymmetry interaction (see Data Reduction and Analysis section above). A significant Fitness Group × Frontal Asymmetry interaction was found for EA at 10-min postexercise, $F_{change}(1,62) = 5.61$, $p = .021$. Therefore, separate regression analyses were performed for each fitness group. In the high-fit group, resting frontal asymmetry explained 11.7% of the variance in EA at 10 min, $F_{change}(1,19) = 5.98$, $p = .024$ (Table 2, top). Examination of the EA subscales revealed that this predictive ability was specific to the energy subscale. In the high-fit group, resting frontal asymmetry explained 24.4% of the variance in energy at 10 min, $F_{change}(1,19) = 16.84$, $p = .001$ (Table 2, bottom). No significant results were found in the low/moderate-fit group and again parietal asymmetry failed to explain any significant variation.

Further evidence of the fitness effect can be seen in lagged partial correlations between frontal asymmetry measured at the

[2] The RPE is a subjective interpretation of the strain experienced during physical work (Borg, 1998). The CR-10 (category-ratio) scale allows individuals to make relatively simple ratings of exertional perceptions regarding exercise yet allows ratio relationships between perceptual responses to be made.

Table 1. *Hierarchical Regression Analyses Using Pre-Exercise Frontal Asymmetry Scores to Predict Postexercise Energetic Arousal (top) and Energy (bottom) in Total Group*

Dependent variable	Predictor	Beta	R^2	R^2_{change}	F_{change}	p
EA						
10 min postexercise	Pre-exercise EA	.613	.367	.367	38.79	<.001
	Frontal asymmetry	.173	.397	.030	3.27	.075
20 min postexercise	Pre-exercise EA	.533	.272	.272	25.08	<.0001
	Frontal asymmetry	.254	.337	.064	6.40	.014
30 min postexercise	Pre-exercise EA	.578	.324	.324	32.17	<.0001
	Frontal asymmetry	.187	.359	.035	3.61	.062
Energy						
10 min postexercise	Pre-exercise energy	.610	.362	.362	37.96	<.001
	Frontal asymmetry	.262	.430	.068	7.91	.006
20 min postexercise	Pre-exercise energy	.571	.314	.314	30.60	<.001
	Frontal asymmetry	.339	.411	.115	13.25	.001
30 min postexercise	Pre-exercise energy	.673	.441	.441	52.85	<.001
	Frontal asymmetry	.259	.508	.067	8.98	.004

Note: $n = 69$. EA = energetic arousal.

various times pre- and postexercise and the concurrent and future-lagged self-reported affect. As seen in Figure 2, frontal asymmetry was significantly related to the self-reported energy (i.e., activated pleasant affect) at the next timepoint when it was assessed (e.g., post-10 asymmetry was related to post-20 energy). The significant relationship occurred for each postexercise measurement while partialling out pre-exercise energy (this was done because pre-exercise energy was moderately correlated with each postexercise energy measure, $r_s = .62–.68$, $p_s \leq .001$). Furthermore, these relationships grew in strength over time. In addition, frontal asymmetry was significantly related to concurrent energy at 10-, 20-, and 30-min postexercise again controlling for pre-exercise energy (partial $r_s = .62$, .60, and .61, $p_s \leq .005$). These relationships were found only for energy and only in the high-fit group. Thus, the findings support the notion that greater relative left anterior activation at rest can be predictive of EA postexercise, specifically energy (i.e., activated pleasant affect). Furthermore, this relationship appears to be influenced by some factor(s) related to the fitness level of participant.

Group Analysis Based on Brain Activation

It was also of interest to determine whether subjects with either greater relative right- or left-sided asymmetry scores would respond differently to an acute bout of aerobic exercise. It was hypothesized that individuals with greater relative resting left-sided anterior activation would respond more favorably (i.e., increased positive/decreased negative affect) to an acute bout of aerobic exercise than individuals with greater relative right-sided resting activation patterns. A median split was used to derive a group of left-activated subjects ($n = 36$; $M \pm SEM$ asymmetry $= 0.069 \pm .007$) and a group of right-activated subjects ($n = 33$; $M \pm SEM$ asymmetry $= -0.020 \pm .004$). As expected, the groups had significantly different asymmetry values, $F(1,67) = 48.64$, $p < .0001$. A Group (2: left-activated, right-activated) × Time (5: pre-, immediate-post, post-10, post-20, post-30) MANOVA examining changes in self-reported affect (energy, tiredness, tension, calmness, SA) revealed a significant interaction, Wilks' $\lambda = 0.572$, $F(20,47) = 1.76$, $p = .057$. Inspection of the effects for the various scales with univariate ANOVAs revealed that the interaction

Table 2. *Hierarchical Regression Analyses Using Pre-Exercise Frontal Asymmetry Scores to Predict Postexercise Energetic Arousal (top) and Energy (bottom) in High Fitness Group*

Dependent variable	Predictor	Beta	R^2	R^2_{change}	F_{change}	p
EA						
10 min postexercise	Pre-exercise EA	.681	.513	.513	21.06	<.001
	Frontal asymmetry	.343	.630	.117	5.98	.024
20 min postexercise	Pre-exercise EA	.717	.561	.561	25.56	<.001
	Frontal asymmetry	.305	.653	.092	5.05	.037
30 min postexercise	Pre-exercise EA	.621	.425	.425	14.78	.001
	Frontal asymmetry	.295	.511	.086	3.35	.083
Energy						
10 min postexercise	Pre-exercise energy	.684	.467	.467	17.55	<.001
	Frontal asymmetry	.500	.711	.244	16.04	.001
20 min postexercise	Pre-exercise energy	.661	.437	.437	15.53	.001
	Frontal asymmetry	.488	.669	.232	13.31	.002
30 min postexercise	Pre-exercise energy	.658	.433	.433	15.24	.001
	Frontal asymmetry	.421	.606	.173	8.33	.009

Note: $n = 33$. EA = energetic arousal.

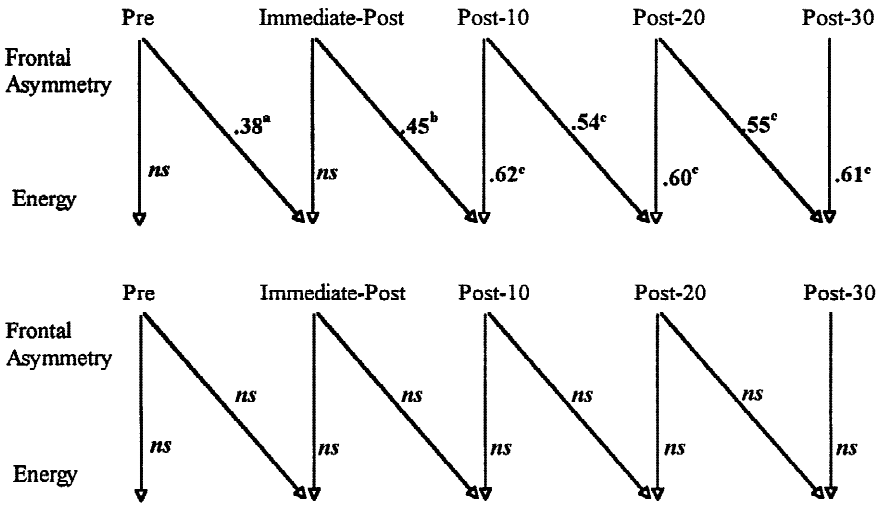

Figure 2. Lagged correlations controlling for pre-exercise energy in high-fit group (top) and low/moderate-fit group (bottom). [a]$p < .05$; [b]$p < .02$; [c]$p < .005$.

was driven by energy, $F(4,264) = 3.54$, $p = .008$. The left-activated group had a significantly greater increase in energy immediately following exercise; energy remained elevated to a greater extent for a longer time during the postexercise period than it did for the right-activated group (see Figure 3). Effect sizes at 0-, 10-, 20-, and 30-min postexercise were 1.91, 1.08, 0.85, and 0.60 for the left-activated group and 0.94, 0.34, −0.04, and 0.11 for the right-activated group.[3] Fitness level was apparently unrelated to these effects, with aerobic capacity ($M \pm SD$) being 49.83 ± 7.91 ml·kg^{-1}·min^{-1} for the men ($n = 17$) in the left-activated group and 50.00 ± 7.91 ml·kg^{-1}·min^{-1} for men ($n = 20$) in the right-activated group; for left-activated women ($n = 17$) aerobic capacity was 45.72 ± 5.32 ml·kg^{-1}·min^{-1} whereas for the right-activated women ($n = 13$) it was 44.63 ± 7.36 ml·kg^{-1}·min^{-1}.

Discussion

The primary purpose of the present study was to determine whether level of aerobic fitness had any differential effect on the relationship between resting brain activation and affective responses to acute aerobic exercise. A secondary objective was to examine the relationship between resting brain activation and affective responses to acute aerobic exercise independent of fitness as a replication of earlier work. It was found that individuals classified as high-fit (top 30% of sample) had a more positive affective response to 30 min of treadmill running at 75% VO_2max than low/moderate-fit individuals. Specifically, the high-fit individuals had a greater increase in activated, pleasant affect following exercise than the low/moderate-fit individuals and this increase persisted during the recovery period for up to 30 min.

Anterior brain activation, as assessed via EEG asymmetry, provided unique explanatory information with regard to the exercise-related affective responses. Relatively greater left frontal activation at rest predicted postexercise increases in EA, more specifically, an increase in activated, positively valenced affect (i.e., energy). These results are consistent with those of Petruzzello and Tate (1997). The findings from the present study demonstrated further that frontal asymmetry predicted postexercise levels of energy only in high-fit individuals. This result was further corroborated by the correlational analyses wherein not only did resting EEG asymmetry predict postexercise affect, but EEG asymmetry measured at 0-, 10-, and 20-min postexercise was also significantly related to the level of activated, pleasant affect that followed 10 min later, a relationship that grew stronger with time (see Figure 2). Likewise, EEG asymmetry at each postexercise timepoint (except for immediately postexercise) was significantly related to the concurrent affective state (i.e., state dependent). None of these relationships was seen in the low/moderate-fit group or for any other measure of affect. It is worth noting that no relationship was seen between resting EEG asymmetry and pre-exercise affect. In accordance with the theoretical formulations put forth by Davidson and others, a relationship between EEG and affect would not be expected if the

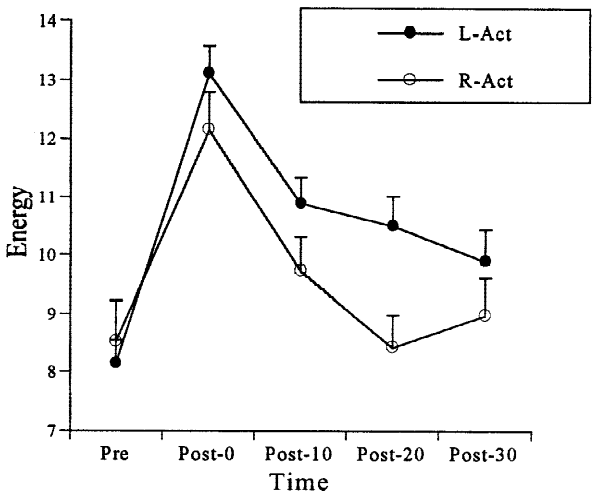

Figure 3. Changes in energy ($M \pm SEM$) from pre- to postexercise for left-activated ($n = 36$) and right-activated ($n = 33$) participants.

[3] A similar effect was seen with a more extreme analysis. Taking the individuals with the most extreme asymmetry scores (top and bottom 20%), the same interaction for energy was found, $F(4,100) = 5.20$, $p = .001$. Effect sizes at 0-, 10-, 20-, and 30-min postexercise were 1.73, 1.15, 0.88, and 0.79 for the extreme left-activated group ($n = 15$; $M \pm SEM$ asymmetry = $0.107 \pm .009$) and 1.35, 0.42, −0.06, and −0.09 for the extreme right-activated group ($n = 12$; $M \pm SEM$ asymmetry = $-0.046 \pm .004$).

organism was unchallenged. That is, it is not until a relevant stimulus is encountered that the diathesis represented by the biological marker of resting EEG asymmetry would be expected to relate to an affective response. Thus, the lack of relationship between resting EEG asymmetry and affect is not unexpected.

The fact that both the low/moderate-fit and high-fit groups experienced changes in the same affective dimension, in the same direction, and of similar temporal patterning (albeit of somewhat different magnitude), yet frontal asymmetry was able to account for those changes only in the high-fit group, presents an interesting issue. This finding suggests that there may be important differences in the mechanisms underlying the induction of affective responses between the two fitness groups—differences not directly reflected in the measure of affect or the timing of assessments used in the present study. Note that the AD ACL is a dimensional measure of affect, thus offering the advantages of breadth of scope and parsimony but lacking in specificity. Moreover, the protocol used in this study did not include any assessments of affect *during* exercise, during which any differences between the fitness groups in the immediate affective impact of the exercise stimulus might have been more accentuated and, thus, more readily apparent. Given the intensity of exercise used in this study (i.e., 75% VO_2max), it is possible that the exercise stimulus for at least some of the low/moderate-fit participants had a substantial anaerobic component. Anaerobiosis is associated with the accumulation of lactate, which, in turn, is closely linked to the perception of exertion (see Noble & Robertson, 1996, for a review). On the other hand, high-fit participants might have completed the exercise bout while consistently under the critical lactate clearance point (CLCP; Brooks, Fahey, & White, 1995), that is, without a substantial accumulation of lactate and, therefore, without salient, inherently noxious somatovisceral influences on their affective state. This difference in the degree of somatic mediation of affective responses can have important implications for the phenomenological nature of affective responses associated with an exercise stimulus. It is assumed that affective responses to exercise are the product of a continuous interplay between cognition and the direct perception of somatovisceral cues, with cognitive factors being dominant at lower doses of exercise and somatic factors being dominant at higher doses (as has been previously hypothesized for perceptions of exertion; see Rejeski, 1981). The CLCP is perhaps the most likely candidate for determining the transition from the cognition-dominant to the perception-dominant mode of affect induction. Thus, the more mild somatic input in the high-fit participants might have permitted cognitive factors associated with frontal asymmetry (such as approach/avoidance or repressive/defensive tendencies) to exert a relatively more salient influence on affect. This hypothesis, albeit intriguing, is admittedly speculative at this point. To further examine these issues, future work should study exercise intensity relative to the CLCP, track the dynamics of affect during exercise, and, most importantly, devise a method for determining the relative salience of cognitive factors versus direct interoception in shaping affective responses.

Consistent with the finding that anterior EEG asymmetry was able to explain postexercise affect, when the sample was split into groups based on relative anterior activation patterns (i.e., left activated, right activated), significant differences were seen in the affective responses to the exercise bout. The left-activated group had a greater increase in activated, pleasant affect (i.e., energy) following exercise and levels of this activated, pleasant affect remained higher throughout the recovery period compared with the right-activated group. Tomarken and Davidson (1994) discussed the relationship between anterior brain activation and the repressive-defensive coping style. They proposed that left anterior activation may be related to better accessibility to cognitive and other regulatory processes that either inhibit or attenuate the experience of negative affect or, alternatively, accentuates or maintains positive affective experiences. Tomarken and Davidson (1994) speculate that this repressive-defensive coping style may be characterized by a cognitive process that facilitate goal-directed behavior, particularly when faced with significant challenge. It is possible that left-activated individuals were more task-focused during exercise whereas right-activated individuals became more self-focused (i.e., attending to inherently aversive or fatigue-related physiological cues arising from the exercise stimulus). This difference could have resulted in a more positive, longer lasting affective state following exercise among left-activated individuals. Obviously this point awaits further research, but could have important implications for exercise prescription.

Although it does not appear that frontal EEG asymmetry is affected by regular physical activity (i.e., more left-activated individuals were not necessarily more fit), examining such changes as a result of a specific training program (i.e., prospective design) remains to be carried out. The present sample was also relatively young and healthy and perhaps the beneficial effects of training are seen only after a much longer time course (e.g., decades; see Hall & Petruzzello, 1999). It also needs to be determined whether EEG becomes a better predictor of affective responses to exercise with training.

Future research should also continue to examine the dose–response relationship between exercise intensity and affective responsivity. In the current study, the relative intensity may have been too high for the people in the low/moderate-fit group to experience the changes in affective responsivity that were expected. For the participants in the high-fit group, on the other hand, the intensity may have been sufficient to elicit the affective responses congruent with what is to be expected from frontal EEG asymmetry.

In conclusion, aerobic fitness influenced the relationship between resting frontal asymmetry and exercise-related affective responsivity, specifically mediating a larger and longer-lasting increase in activated, pleasant affect in high-fit individuals. Future research needs to disentangle this relationship to determine what factor(s) related to fitness might mediate the influence on affective responsivity.

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(Received November 17, 1998; Accepted February 8, 2000)