

Resting Frontal Asymmetry Predicts Self-Selected Walking Speed But Not Affective Responses to a Short Walk

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Davidson (1994, 1998) proposed that resting asymmetrical activation of the anterior regions of the brain reflect two different neural circuits of motivation and emotion. Greater relative left anterior activation is related to the approach motivational system that facilitates appetitive behavior and the generation of positive affect when moving toward a desired goal. Greater relative right anterior activation is related to the withdrawal motivational system that facilitates withdrawal from aversive stimulation and the generation of negative affect.

In this theoretical framework, baseline measures of asymmetrical anterior (frontal, anterior temporal brain regions) activation, usually assessed via electroencephalography (EEG), are associated with a vulnerability or propensity to experience positive or negative emotions, given requisite environmental elicitors (Davidson, 1994). Frontal brain asymmetry is, thus, hypothesized 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, people who show greater right relative to left frontal activation may be more vulnerable to depression and may display more intense negative affect in response to negative affect elicitors (e.g., death of a loved one, watching a sad movie; Davidson, 1994). Previous work has used exercise as an

affect-eliciting stimulus and found resting EEG asymmetry to predict postexercise affective responses (Petruzzello, Hall, & Ekkekakis, in press; Petruzzello & Landers, 1994; Petruzzello & Tate, 1997).

Petruzzello and Landers (1994) found that resting EEG asymmetry was able to predict 30% of the variance in the observed state anxiety reduction that occurred postexercise. Petruzzello and Tate (1997) demonstrated that EEG asymmetry could predict increased positive affect and reductions in state anxiety following cycling at 70% maximum oxygen intake (VO_{2max}); however, EEG asymmetry was unable to predict affective changes in a control condition and following cycling at 55% VO_{2max} . A recent investigation has found that fitness level influences the ability of EEG to predict affect following exercise, with EEG asymmetry accounting for a significant amount of the variance only in the high fitness group (Petruzzello et al., in press). It should be noted that the exercise intensities used in these studies have been relatively high (i.e., 70% VO_{2max} or higher) and for durations of 30 min. One way to extend these results is to examine lower intensity bouts of exercise occurring for shorter durations. Given that recent health recommendations have advocated brief walks because of the associated health and affective benefits, it is of interest to determine if anterior EEG asymmetry can predict these affective changes. In the one study involving exercise of a more moderate intensity (i.e., 55% VO_{2max}), resting EEG asymmetry was unable to predict postexercise affect (Petruzzello & Tate, 1997). In addition, none of the previous exercise research has attempted to link behavior to such brain activation measures.

The present study examined whether resting EEG asymmetry could predict affective responses to a relatively low-intensity and short duration bout of exercise (10-min walk) and whether it would reflect the level of engage-

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ment in the task. Greater relative left frontal activation, hypothesized to reflect greater approach motivation, should predispose the individual to engage in a task (e.g., walking) at a more challenging level (i.e., faster walking speed and greater perceptions of effort).

Methods

Participants

Forty-two (19 women, 23 men; *M* age = 22.4 years, *SD* = 2.2) college-aged students participated in this study. All participants signed a statement of informed consent approved by the University's Institutional Review Board.

Measures

Affect was assessed via the Activation Deactivation Adjective Check List (ADACL; Thayer, 1986) and the 10-item short form of the state anxiety subscale of the State-Trait Anxiety Inventory (STAI; Spielberger, 1983). The ADACL is a 20-item self-report measure that assesses two arousal dimensions: energy-tiredness (Energetic Arousal; EA) and tension-calmness (Tense Arousal; TA). The reliability and construct validity of the ADACL (Thayer, 1986) and STAI (Spielberger, 1983) are well established. Borg's (1998) 15-point Rating of Perceived Exertion (RPE) scale was also used to measure perceived effort during the walk. On this scale, 7 = very, very light, and 19 = very, very hard.

EEG Recording

A stretchable Lycra electrode cap (Electro-Cap, Inc., Eaton, OH) was fitted on the participant's head for electrode application and assessment of regional brain activation via EEG. EEG activity was recorded from the left and right midfrontal (F3, F4) regions.¹ In keeping with both the theoretical predictions (cf. Davidson, 1998) and previous empirical findings (Petruzzello & Tate, 1997), only activity in the anterior regions was examined. All leads were referenced to linked earlobes, and all electrode impedances were below 5 K Ω . 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 electro-oculogram (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 (Grass Instruments, West Warwick, RI) acquisition system equipped with Model 12A5 amplifiers. All bioelectric signals were amplified 20,000x, and high and low pass filters were set at 1 and 100 Hz, respectively (rolloff = 6 dB/octave; 60 Hz notch filter in). The ampli-

fied and filtered signal was digitized at 256 samples/s and stored on a computer for later analysis.

Offline, EEG waveforms were visually inspected for artifact by comparing activity at the scalp leads with the EOG. EEG epochs containing artifact were marked and excluded from each EEG trial prior to further analysis of the data. All artifact-free data at least 2.0-s in duration were subjected to a fast Fourier transform (FFT) for decomposition of the EEG waveform into sine wave components. These components were used to estimate spectral power (in μV^2), which was then converted to a power density function (in $\mu\text{V}^2/\text{Hz}$) as a measure of the average spectral power in the alpha frequency band (8–13 Hz) across the trial. A natural log transformation was applied to all power density values to normalize the distribution (Gasser, Bacher, & Mocks, 1982). All participants had a minimum of 20 artifact-free epochs (or seconds) for each trial (Gasser, Bacher, & Steinberg, 1985; Mocks & Gasser, 1984).

Analyses of power density were conducted for the alpha (8–13 Hz) frequency band. The alpha band was of interest due to its inverse relationship with activation (Andreassi, 1989) and its more consistent association with affective processes (Davidson, 1992)². An EEG asymmetry index was also derived (Pivik et al., 1993). This index 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 alpha activity and relatively greater activation in the left frontal region. This asymmetry score was demonstrated to have acceptable psychometric properties (Tomarken, Davidson, Wheeler, & Kinney, 1992).

Procedures

Participants visited the laboratory on two separate occasions and followed identical procedures each time. On entering the lab, participants were fitted with a heart rate monitor (Model Accurex Plus, Polar Electro, Finland) and sat on a chair while an experimenter prepared them for the EEG assessment. When EEG signal integrity was established, participants completed the STAI and ADACL. Following completion of these measures, baseline EEG was recorded for four 1-min trials, with the participant's eyes closed and an approximate interval of 15–30 s between recording trials³. Participants then walked on a treadmill; it was explained to them that they would walk for 10 min and were free to adjust the treadmill speed using the buttons on a control panel directly in front of them. It is important to note that no specific instructions were given about how fast or slow they should set the treadmill speed (i.e., resulting speed was self-selected). Heart rates, RPEs, and walking speed were recorded on the 5th and 10th (final) minute of the walk. On completing the walk, participants returned to their chair, where they again sat and completed the STAI and

ADACL. They completed the STAI and ADACL a final time 15 min postwalk.

Results

Means and standard deviations for heart rate, RPE, and walking speed on each day are presented on Table 1. Means and standard deviations for EEG (F3, F4 alpha power) and EEG alpha asymmetry scores are presented in Table 2.

Affective Responses to Walk

On Day 1, Energetic Arousal increased significantly from pre- to immediately postwalk ($p < .001$) and remained significant at 15 min postwalk ($p < .05$). There were no significant changes in either state anxiety or Tense Arousal.

Again on Day 2, Energetic Arousal increased significantly from pre- to immediately postwalk ($p < .001$) and remained significant at 15 min postwalk ($p < .01$). Both Tense Arousal and state anxiety showed significant increases from pre- to immediately postwalk ($p < .01$), and both are described in more detail elsewhere (see Ekkekakis, Hall, VanLanduyt, & Petruzzello, in press).

Resting EEG Predicting Anxiety and Affect

To assess the predictive influence of resting frontal EEG asymmetry on affect and state anxiety following the walk, a set of hierarchical regression analyses were performed. Resting frontal EEG asymmetry was unable to predict postwalk affect (i.e., state anxiety, Energetic or Tense Arousal) either immediately postwalk or at 15 min postwalk ($p > .05$ on both days) after partitioning out prewalk affect.

Table 1. Mean heart rate, rating of perceived exertion, and walking speed on each day and correlations between Days 1 and 2

	Day 1		Day 2		<i>r</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Resting heart rate	74.3	10.9	73.3	10.6	.635	<.001
5-min heart rate	95.1	14.7	96.6	14.1	.728	<.001
10-min heart rate	99.3	19.0	99.1	18.2	.811	<.001
5-min RPE	8.6	1.5	8.8	1.8	.640	<.001
10-min RPE	9.6	2.2	9.6	2.4	.787	<.001
5-min walking speed (mph)	2.6	.8	2.8	.8	.800	<.001
10-min walking speed (mph)	2.8	.9	2.8	.9	.830	<.001

Note. *M* = mean; *SD* = standard deviation; RPE = rating of perceived exertion.

Resting Frontal Asymmetry, Walking Speed, and RPE

Hierarchical regression analyses were completed to determine the ability of frontal EEG asymmetry to predict RPE and walking speed (i.e., behavior) on both days. In these regression analyses, self-reported physical activity and resting heart rate were partialled out in a first step because of the possible influence these variables might have on self-selected walking speed and RPE⁴. Because of the exploratory nature of this research and the fact that the predicted direction of the relationship was based on a theoretical model, tests of significance were based on a one-tailed *t* test of the beta coefficient. Therefore, *p* values less than .10 were considered significant.

In sum, Day 1 frontal EEG asymmetry predicted Day 1 RPE at 5 min ($\Delta R^2 = .125$, $p = .041$), Day 1 walking speed at 5 min ($\Delta R^2 = .140$, $p = .018$) and 10 min ($\Delta R^2 = .124$, $p = .032$), and Day 2 walking speed at 5 min ($\Delta R^2 = .108$, $p = .062$) and 10 min ($\Delta R^2 = .091$, $p = .088$). Day 2 frontal EEG asymmetry predicted Day 2 RPE at 10 min ($\Delta R^2 = .079$, $p = .097$), with a trend for predicting walking speed at 5 min ($\Delta R^2 = .063$, $p = .144$) and 10 min ($\Delta R^2 = .068$, $p = .131$). Complete results for the walking speed data are presented in Table 3. The findings show that greater relative left frontal activation on Day 1 could predict faster walking speeds on Days 1 and 2 and RPE (at 5 min) on Day 1. Greater relative left frontal activation on Day 2 was able to predict RPE (at 10 min) on Day 2, with a nonsignificant trend for predicting walking speed.

Discussion

These data show that, although a short bout of walking led to some significant affective changes, resting EEG frontal asymmetry was unable to predict them. The inability to predict affective responses may be due to the fact that the only consistent affective change seen in this study was an increase in Energetic Arousal (reflective of a more activated, pleasant state) immediately following the walk on both days. The only other change in affect was an increase in tense arousal and state anxiety imme-

Table 2. Mean F3 and F4 alpha power and frontal alpha asymmetry on each day

	Day 1		Day 2	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
F3 alpha power	1.278	.660	1.214	.476
F4 alpha power	1.264	.652	1.221	.485
Frontal alpha asymmetry	-.0094	.059	.0054	.063

Note. *M* = mean; *SD* = standard deviation.

diately following the walk on Day 2. However, these increases may reflect an increase in activation commonly seen with exercise (see Ekkekakis, Hall, & Petruzzello, 1999). Because frontal asymmetry has been hypothesized to be a better predictor of valence but not activation (Heller, 1993), this may account for the inability of frontal asymmetry to predict affect in this study. However, the inability of frontal asymmetry to predict affective responses replicates and extends a similar finding concerning a 30-min bout of cycling at 55% VO_2max reported by Petruzzello and Tate (1997). The exercise intensity of the present study was approximately 20% of heart rate reserve, which is well below that seen in Petruzzello and Tate (1997). Studies involving exercise performed at higher intensities (i.e., 70–75% VO_2max), however, have shown that frontal asymmetry could predict the affective changes associated with the activity (Petruzzello et al., in press; Petruzzello & Landers, 1994; Petruzzello & Tate, 1997).

In combination, these findings indicate that there may be important dose-dependent differences in the processes underlying the generation of exercise-associated affective responses. For example, affective responses associated with exercise stimuli of moderate dose (i.e., intensity, duration) characteristics, such as a short, moderate-pace walk, might be primarily cognitively mediated, whereas responses to more strenuous activities might have stronger somatosensory inputs. Furthermore, indi-

vidual differences are likely to influence this dose-dependent interplay between different modes of affect induction. Davidson (1998) suggested something similar: "There are likely individual differences in the *threshold* for eliciting components of a particular emotion, given a stimulus of a certain intensity [...]. This suggestion implies that dose-response functions may reliably differ across individuals" (p. 309). The issues of multiple affective pathways, the role of somatosensory input in their interaction, and the role of individual differences in this interaction are at the heart of contemporary theoretical debates in cognitive psychology and affective neuroscience (Damasio, 1995; Izard, 1993; LeDoux, 1994; Van Reekum & Scherer, 1997). The acute exercise paradigm might be a fruitful arena for exploring these questions.

Although unable to predict affective response, frontal asymmetry was able to predict behavior as assessed via self-selected walking speed, with greater relative left frontal activation being associated with selecting a faster pace (i.e., greater engagement with the task). This finding was strongest on Day 1 and approached significance on Day 2. Greater left frontal activation also predicted greater perceptions of effort (RPE) on each day. Although the relationship between frontal asymmetry and walking speed was not significant on Day 2, future research should attempt to replicate and extend these findings. While fitness was not directly measured, the finding that self-reported physical activity did not predict walk-

Table 3. Regression analyses: Predicting walking speed from frontal alpha asymmetry after partialling out self-reported physical activity and resting heart rate

Predicting	Variables entered	R^2	β	t	p ($\alpha = .10$) ^a
Day 1 speed (Min 5)	Step 1: PA and HR ^b	.135			.433
	Step 2: Day 1 frontal asymmetry	.144	.419	2.490	.018
Day 1 speed (Min 10)	Step 1: PA and HR	.111			.559
	Step 2: Day 1 frontal asymmetry	.124	.388	2.243	.032
Day 2 speed (Min 5)	Step 1: PA and HR	.034			.946
	Step 2: Day 2 frontal asymmetry	.063	.257	1.497	.144
Day 2 speed (Min 10)	Step 1: PA and HR	.030			.958
	Step 2: Day 2 frontal asymmetry	.068	.266	1.552	.131
Day 2 speed (Min 5)	Step 1: PA and HR	.035			.950
	Step 2: Day 1 frontal asymmetry	.108	.373	1.939	.062
Day 2 speed (Min 10)	Step 1: PA and HR	.032			.958
	Step 2: Day 1 frontal asymmetry	.091	.344	1.766	.088

Note. PA = physical activity; HR = resting heart rate.

^aBecause of the theoretical nature of this research, p values less than .10 were considered significant.

^bPhysical activity variables entered in Step 1 included frequency, duration, intensity, and length of exercise; also see Note 4. The individual betas and t values were not included for brevity; p values represent probability of F change.

ing speed suggests there may not be a relationship between fitness and self-selected walking speed, at least at lower intensities or durations or both. Future studies may want to examine the influence of fitness on this relationship, however, because recent research from our lab has shown fitness to influence relationships between frontal asymmetry and affect at higher intensities and longer durations (Petruzzello et al., in press; Petruzzello, Hall & Ekkekakis, 1999).

It is also important to note that Day 1 EEG asymmetry could predict walking speed on Day 2. This finding is consistent with a recent study by Pauli, Wiedemann, and Nickola (1999) that showed a single measurement of frontal brain asymmetry was related to pain sensitivity assessed over multiple sessions. They found that greater right relative to left frontal activation at baseline was associated with lower pain thresholds (i.e., greater sensitivity to pain). Furthermore, individuals with greater relative left frontal activation at baseline had greater weekly pain thresholds measured over the course of 6 weeks (i.e., pain sensitivity increased). Thus, single measures of a relevant biological substrate can be useful in predicting future behavior.

The findings of the present study are consistent with the notion of frontal asymmetry reflecting a propensity to approach more challenging tasks. While the ability of asymmetry to predict behavior (i.e., self-selected walking speed) was somewhat low ($\leq 14.4\%$ of variance), the findings were reliable across two different days. To the best of our knowledge, the prediction of a behavioral tendency from frontal asymmetry is a new finding—certainly in the exercise psychology literature. Future studies should seek to replicate and further elucidate this issue across a wider range of doses of physical activity.

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Notes

1. For a different purpose, EEG data were also collected from the frontal midline (Fz), and the left, right, and midline sites of the central (C3, C4, Cz) and parietal (P3, P4, Pz) regions along with the left and right temporal (T3, T4) regions.
2. Activity in other frequency bands (e.g., theta, beta) was not examined because it (a) has not been shown to be related to affective processes in other work of this kind and (b) it is not hypothesized to be related to affective processes by the theoretical framework used for this study.
3. EEG was collected with participants' eyes closed, because EEG alpha asymmetry from the midfrontal sites (F3, F4) has been shown to be more stable when the eyes are closed compared to when they are open (Tomarken et al., 1992).

4. Self-reported physical activity was measured by asking participants, on average: (a) how many days per week they exercised, (b) how many minutes they exercised per exercise session, (c) how hard, using Borg's (1998) CR10 scale, they exercised, and (d) how long they had been exercising on a regular basis. Resting HR was also included as an indicator of cardiovascular fitness level.

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