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Prefrontal brain electrical asymmetry predicts the evaluation of affective stimuli☆

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Abstract

Measures of left–right asymmetry in resting brain activity were derived from spectral estimates of electroencephalogram (EEG) α-band power density in 13 homologous scalp electrode pairs from 81 right-handed individuals (43 F) on two occasions separated by 6 weeks. At a third, later session, these individuals completed a cognitive task, comparing word-pairs that systematically differed in affective tone. For an extended series of paired-comparisons, the subject chose the one word-pair that 'went together best'. Objectively, associative strength was comparable for both word-pairs. Individuals with relatively greater left-sided anterior frontal resting activity were more likely to select the more pleasant word-pair. Relations between word-pair selection and asymmetry in resting brain activity at central and posterior sites were not significant.

Keywords: Brain asymmetry; Affective style; Individual differences; Cognitive bias

1. Introduction

Research on the neural circuitry underlying different components of affect has flourished over the past decade, much of which is due to advances in functional neuroimaging (for a review, see Ref. [8]). An important strategy in this work has capitalized on the examination of relations between individual differences in specific parameters of brain function and their relation to theoretically formulated affective constructs. The present study continues this exploration by assessing relations between asymmetries in resting anterior brain activity and the evaluation of stimuli that differ in affective tone. Such relations have implications for understanding affect-based biases in cognition. This is important because cognitive bias has been implicated in the development and maintenance of psychopathology (see Refs. [26,29,39]) and has been hypothesized to be associated with major dimensions of personality [15]. Understanding the neurobiological substrates of these associations will advance the understanding of the relations between cognition and affect, as well as the processes underlying personality and psychopathology.

1.1. Brain asymmetry, cognition and affect

This study is based upon a tradition of individual differences research investigating relations between posterior cortical activation asymmetry and cognitive function hypothesized to be, at least in part, implemented in these posterior cortical zones [25]. Davidson and Hugdahl [11] for example, have observed that individual differences in electrophysiological measures of posterior activation asymmetry predicted performance differences on a verbal dichotic listening task that has been associated with posterior temporal functioning. Those individuals with greater relative left-sided posterior activation showed a significantly larger right ear advantage on the dichotic task.

Other studies have found relations between individual differences in resting *anterior* brain activity asym-

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metry and characteristic *levels* of affect. Using electrophysiological measures of resting brain activity, these studies find relations to be most prominent at mid-frontal EEG sites and also are observed at anterior frontal and lateral frontal sites. For example, individuals with relatively greater left-sided anterior activity while at rest report higher levels of dispositional positive affect, whereas those with relatively greater right-sided anterior activity report higher levels of dispositional negative affect [36]. Similarly, Henriques and Davidson [22,23] have reported lower levels of left-sided anterior brain activity in individuals who are currently or have previously been diagnosed with clinical depression (i.e. those who chronically experience relatively high levels of negative affect and low levels of positive affect).

Anterior resting EEG asymmetry has also been related to affective *reactions* to pertinent stimuli. Individuals exhibiting relatively greater left anterior activity while at rest report stronger tendencies to engage in appetitively motivated approach behavior [20,35]. Individuals with relatively greater right-sided activity report stronger tendencies to inhibit behavior, or engage in withdrawal behaviors, when confronted with an aversively motivating situation. Similarly, greater left-sided asymmetry in resting anterior brain activity has been related to more intense positive affect in response to a pleasant film clip; whereas greater right-sided asymmetry has been related to more intense negative affect in response to an unpleasant film clip [38]. Furthermore, Davidson and Fox [10] showed that 10-month-old infants with greater right-sided resting anterior brain activity were more likely to cry during a laboratory episode of maternal separation.[1]

[1] Other research has not always matched this pattern of relations between resting anterior cortical activity and affective style or disorders. For example, Heller et al. found that individuals with anxiety disorders exhibited relatively higher levels of right posterior cortical activity [21]. Furthermore, Hagemann et al. reported that individuals with relatively higher levels of negative affect exhibited relatively higher levels of resting *left* temporal cortical activity [19]. Such results highlight the potential complexity of relations between resting brain activity and affective style or disorders. Other studies have failed to replicate the findings reported in our laboratory. For example, Hagemann et al. [18] failed to replicate the findings of Wheeler et al. [37] where resting anterior brain activity was related to reactivity to positive and negative emotional stimuli. Similarly, Reid et al. [32] failed to replicate the findings of Henriques and Davidson [22,23] linking depression with lower levels of resting left frontal activity. In a detailed analysis of each of these studies, Davidson [6] points out a number of critical methodological and conceptual weaknesses that call into question their adequacy as replications. For example, the Hagemann et al. [18] study relied upon a single measure of anterior activation asymmetry, while the Wheeler et al. [37] study it was intended to replicate aggregated over two independent sessions. This study specifically included two sessions, since we have argued that this variable is an important one in deriving a more reliable index of an individual's baseline anterior activation asymmetry [6].

Based upon these and other data, we have proposed that left and right anterior brain regions are lateralized components of the appetitive and aversive motivation systems, respectively [5,7,12]. In an extension of this idea and the research described above, we propose that individual differences in the relative strengths of these systems are related to individual differences in the processing of stimuli that differ in affective tone. We expect processing of information to be consistent with the relative strength of the systems as indexed by anterior EEG asymmetry. That is, those who show relatively greater left-sided activity (who tend to be more incentive-oriented, and experience higher levels of positive affect) are more likely to direct information processing resources toward incentives and pleasant stimuli relative to neutral or negatively valenced stimuli. In contrast, those who show relatively greater right-sided activity (who tend to be more threat-oriented and experience higher levels of negative affect) are more likely to direct information processing resources toward threats and unpleasant stimuli. We expect these relations to be most prominent when one must allocate limited resources to processing one piece of information over others, or when one must decide among stimuli that vary in affective tone.

1.2. Personality, cognition and affect

Individual differences in general levels of affect and affective reactivity has long been a fundamental concern of personality theory and research. The most commonly investigated descriptive personality dimensions are extraversion and neuroticism, which have been related to general levels positive and negative affect, respectively [17,28]. More recently, researchers emphasizing the development of personality theory have investigated relations among descriptive personality dimensions and the information processing of affective stimuli using a variety of tasks [14,31,33]. It is this line of research to which we add individual differences in the strength of the appetitive and aversive motivation systems as indexed by resting brain activity using EEG.

The selection of the cognitive task is important. Cognition is complex and the opportunities for the affective tone of the stimuli to influence information processing of those stimuli are numerous. In this study, we selected a judgment task recently developed by Rogers and Revelle [33]. The reasons are both conceptual and methodological. The EEG asymmetry metric provides an index of relative levels of brain activity; for example, left mid-frontal activity relative to right mid-frontal. This metric is important methodologically because it is an excellent way to control for non-neurogenic sources of individual differences in power values. This metric is also important for conceptual reasons. It is common for organisms to confront environments that present a mix of pleasant and unpleasant stimuli, yet require a choice concerning the single direction of one's actions. Therefore, we selected a task that required a single choice among competing stimuli that differed in terms of relative (un)pleasantness.

Rogers and Revelle [33] assessed relations among self-reported extraversion and neuroticism, self-report mood and the processing of affective stimuli. They developed a forced-choice, paired-comparison task that requires judgments of relative associative strength between two sets of word-pairs. The word-pairs were initially selected and matched for: (1) comparable levels of associative strength using normative data [1]; and (2) conceptual categorization into pleasant (e.g. happy/glad), unpleasant (e.g. war/gun) and neutral (e.g. kitchen/stove) sets. The extended series of paired-comparisons were of three types: pleasant–unpleasant, pleasant–neutral and neutral–unpleasant. Participants were instructed to select the word-pair, that 'went together best.' In essence, participants performed a cognitive task where the stimuli did not differ along the dimension specified by the task demands (i.e. associative strength), but systematically differed in terms of affective tone. The logic is that relations among affect, personality and the processing of affective stimuli will be reflected in the judgments of association.

The results of the Rogers and Revelle [33] study are complex, but two findings are noteworthy. First, neuroticism was related to greater probability of selecting the unpleasant word-pair, but only for those individuals with higher levels of extraversion. Second, extraversion was related to greater probability of selecting the pleasant word-pair, but only for those with lower levels of neuroticism. The complexity of these findings may be due to the use of extraversion and neuroticism as the affect-relevant dimensions of personality. We think that incentive and threat motivation strength is more directly related to the processing of stimuli differing in affective tone. In addition, we think that relative strength of incentive and threat motivation is more likely to be related to word-pair choice. The Rogers and Revelle results are partially consistent with the notion of relative strength. That is, when extraversion was relatively greater than neuroticism, individuals were more likely to select the pleasant word-pair.

1.3. Anterior brain asymmetry and the evaluation of associative strength

We predicted that resting anterior EEG asymmetry, a measure of affective style reflecting the relative strength of reactivity to pleasant and unpleasant stimuli, would be related to the tendency to select the word-pair that is more consistent with the affective style. In other words, those with relatively greater left-sided asymmetry would be more likely to select the relatively more pleasant of the two word-pairs. Similarly, relatively greater right-sided asymmetry would be associated with the tendency to select the relatively more unpleasant word-pair. This is not specific to pleasant and unpleasant word-pairs, but rather the relative pleasantness of the two word-pairs being compared.

To test this hypothesis, participants initially completed two sessions separated by 6 weeks, where resting EEG from anterior, central and posterior brain regions was collected. At a third session, from 4 to 28 months later, participants performed the paired-comparisons task. The tendency to select the more pleasant word-pair (either pleasant over unpleasant, pleasant over neutral, or neutral over unpleasant) was indexed by a single measure, the Positivity Index. Correlation analyses focused on three anterior electrode pairs (mid-frontal, anterior frontal and lateral frontal) because previous research showed relations between resting brain asymmetry at these sites and measures of affective traits and states [20,35,36]. It was predicted that EEG asymmetry at these three homologous pairs would be positively correlated with the Positivity Index, the number of times the more pleasant word-pair was selected (including neutral over unpleasant). In order to assess the specificity of these relations, correlations between anterior asymmetry and the Positivity Index were compared to the correlation between parieto-occipital asymmetry and the Positivity Index.

2. Method

2.1. Participants

Participants were 81 University of Wisconsin undergraduate volunteers (43 female). There were three cohorts based upon the time of participation in the initial resting EEG sessions: $n_1 = 12$ (6 F), $n_2 = 23$ (14 F) and $n_3 = 46$ (23 F). All were right-handed with no history of psychological or neurological disorder or injury. Data from eight additional subjects were not included in the analyses due to concerns about the collected resting EEG data (e.g. reliable data from only one of two sessions). Participants received course credit for the two initial resting EEG sessions and were paid US$25 for subsequent participation in two non-EEG sessions during the first of which the word-pairs task was administered.

2.2. Design and procedure overview

For this within-subject design, all participants completed two resting (baseline) EEG sessions and the word-pairs task.

Each Introductory Psychology volunteer was contacted via telephone for screening purposes. Potential participants received a brief description of the EEG sessions, were administered a 13-item handedness inventory [3], and responded to questions concerning medical and psychiatric history. Those individuals who were not clearly right-hand dominant (11 or more of 13 items) or who had a history of psychiatric disorder or head/brain trauma, were not invited to participate.

Each subject participated individually. The first of two EEG sessions was completed during the first 7 weeks of the Fall semester. Following written informed consent and placement of electrodes (requiring < 50 min), there was a series of eight 1-min periods where EEG was recorded while the subject sat quietly with eyes opened or closed (total time < 15 min). Following the removal of electrodes, the subject completed a set of self-report inventories. The second EEG session was completed 6 weeks later. It was virtually identical to the first session except for the counterbalanced order of eyes opened/closed and the administered self-report inventories.

Participants later returned to the laboratory to perform a battery of cognitive and behavioral tasks. The word-pairs task (see below) was administered during the first of these two sessions, completed ≈ 28 ($n_1 = 12$), 16 ($n_2 = 23$) and 4 ($n_3 = 46$) months following the second EEG session. Informed consent was obtained at the start of each session. At the end of the second non-EEG session (≈ 4 weeks later), participants were fully debriefed.

2.3. EEG data acquisition and reduction

EEG was recorded from 13 homologous electrode pairs and three mid-line sites of the 10–20 electrode system using a modified lycra stretchable cap (Electro-Cap International, Inc., Eaton, OH) positioned according to standard anatomical landmarks. All electrode impedances were < 5000 ohms. Impedances for homologous sites were within 2000 ohms. All EEG signals were referenced to an electrode placed on the left ear lobe (A1). An electrode was also placed on the right ear lobe (A2) so that a derived averaged-ears reference could be used in analyses. Electrode pairs were placed at the supra- and sub-orbit of one eye (randomly selected) and at the external canthi of each eye for the electro-oculographic (EOG) recording of eye movements to be used later for the purposes of artifact scoring. EEG was amplified 30 000 times with Grass Model 12 Neurodata System amplifiers after passing through Model 12A5 pre-amplifiers with bandpass filters set at 1 and 300 Hz and the 60 Hz notch filter in and passing through anti-aliasing, low-pass, 36 dB/octave roll-off filters set at 200 Hz (MF6, National Semiconductor Corp., Santa Clara, CA). EOG was acquired similarly, with the exception of no anti-aliasing filtering and amplification occasionally lowered to 20 000. EEG and EOG signals were digitized at 500 Hz using SnapStream (HEM Data Corp., Springfield, MI) and a 486 DX2-66 computer. Digitized EEG signals were calibrated using 25- and 50-μV 10 Hz signals recorded immediately before and after each session. These signals were visually reviewed off-line by a trained assistant. Portions of each 1-min baseline containing eye movement, muscle movement or other sources of artifact were removed prior to further analysis. The designation of artifact in any one channel resulted in the removal of data in all channels to ensure that data preserved in each channel is derived from the identical time periods. Chunks of artifact-free EEG (1.024-s) were then used for spectral analysis. If fewer than ten chunks of artifact-free data were available in a 1-min baseline, the baseline was dropped from further processing and analysis ($< 2\%$ of baselines).

The derived-averaged-ears reference was used for all further EEG data reduction. Chunks of artifact-free EEG were extracted through a Hamming window and adjacent chunks were overlapped by 50%. For each chunk, a Fast Hartley Transform [2] was used to derive estimates of spectral power (μV^2) in 1-Hz frequency bins.[2] Spectral power values were averaged across all chunks within a single baseline and then converted to power density values (μV^2/Hz) for the standard EEG bands. Average power density values were normalized via log-transformation. Analyses focused on the α-band (8–13 Hz) because data indicate that power in the α-band is inversely related to activity [34] and is more strongly related to behavior than power in other frequency bands [11].

An asymmetry score was calculated for each of the 13 homologous electrode pairs by subtracting the log-transformed power density value for the left site from that of the right site (e.g. log F4 − log F3). This was done because absolute power density values will most directly reflect any non-neurogenic sources of individual differences (e.g. skull thickness, brain volume) which can be reduced by calculating the asymmetry score (see Ref. [30,37] for further details). For the α-band, positive asymmetry scores reflect greater left-side activity (less log-transformed power density on left than right). Resting α-band EEG asymmetry scores have been shown to have good internal consistency reliability and adequate test–retest reliability [35,37]. A single mean based upon session 1 and 2

[2] The Fast Hartley Transform method of spectral analysis is conceptually analogous to the Fast Fourier Transform, provides identical output, and is computationally more efficient.

weighted averages were calculated as the final, aggregate estimate of EEG asymmetry for all 13 homologous electrode pairs.[3]

2.4. Word-pairs data acquisition and reduction

Subjects performed a repeated, simple choice task where two word-pairs were presented simultaneously. The participant was seated ≈ 60 cm from a 14-inch color monitor. Each word-pair was presented with one word above the other and both words centered vertically ≈ 2.5 cm from the edge of the monitor. The visual angle of the two word-pairs was $\approx 23°$. The subject was instructed to choose the word-pair that 'went together best.' For each individual paired comparison, the two word-pairs were displayed until the subject selected the word-pair that s/he thought 'went together best' by pressing the 'z' or '/' key to select the left or right word-pair, respectively.

Previously, Rogers and Revelle [33] intuitively categorized 144 word-pairs as either unpleasant, neutral or pleasant; with 48 word-pairs in each valence category. These word-pairs were grouped for paired comparison based upon valence category while matching for associative strength using the Connecticut Free Association Word Norms [1]. This culminated in a quasi-random sequence of 24 unpleasant–neutral, 24 unpleasant–pleasant and 24 neutral–pleasant comparisons. For each comparison type, each valence category was presented 12 times on the left and right side. The same pairings in the same sequence were presented to each participant. The entire set of paired comparisons is presented in Appendix A.

2.5. Word-pair valence ratings

Although these word-pairs were intuitively categorized by Rogers and Revelle [33], we collected valence ratings from a separate set of individuals in order to verify that the specific word-pairs in each comparison differed in affective tone. One hundred and fifteen University of California, Berkeley students (79 females) served as raters. Several groups of three to eight individuals rated each of the 144 word-pairs (72 comparisons of two word-pairs) on a single valence scale ranging from -4 (extremely unpleasant) to 0 (neutral) to $+4$ (extremely pleasant) using a paper-and-pencil inventory.

[3] Due to technical problems at the time of acquisition, there were five instances where data from Fp1 or Fp2 were unusable, one instance where data from FC7 were unusable and two instances where data from T3 were unusable. Asymmetry scores were not computed in these instances. Therefore, analyses involving these variables were based upon 76, 80 and 79 observations, respectively.

Table 1
Mean valence ratings of word-pairs by category for males and females[a]

	All subjects	Males	Females
Unpleasant	−1.10 (0.88)	−0.78 (0.80)	−1.43 (0.84)
Neutral	0.84 (0.66)	0.87 (0.58)	0.81 (0.69)
Pleasant	1.96 (0.64)	1.80 (0.62)	2.11 (0.63)

[a] The valence rating scale ranged from −4 (extremely unpleasant) to 0 (neutral) to +4 (extremely pleasant).

Table 1 shows the mean self-report valence ratings for the three categories of word-pairs (48 word-pairs per category). Average valence ratings for word-pairs were submitted to a 2×3 (Sex $\times$ Category) mixed-design ANOVA, which revealed a significant main effect for Category, $F(2,282) = 471.09$, $P < 0.0001$. This main effect was moderated by a significant Sex $\times$ Category interaction, $F(2,282) = 11.68$, $P < 0.0001$. Follow-up analyses showed that, for both males and females, mean valence ratings for word-pairs in the three categories were significantly different from each other, $|t(47)| > 7.50$, $P < 0.0001$. However, females rated the 'unpleasant' word-pairs as more unpleasant than males did ($t(94) = -3.87$, $P < 0.005$). Females also rated the 'pleasant' word-pairs as more pleasant than males did ($t(94) = +2.52$, $P < 0.02$).

2.6. The Positivity Index

Based upon these ratings, 11 of the 72 word-pair comparisons were dropped prior to data reduction because the two word-pairs received comparable valence ratings (mean difference $\leqq 1$) by the set of independent raters. Two of 24 pleasant–unpleasant comparisons were dropped. Seven of 24 pleasant–neutral comparisons were dropped. Two of 24 unpleasant–neutral comparisons were dropped. These word-pairs are marked in Appendix A.

Selection of word-pairs were converted to a single word-pairs performance measure — the Positivity Index — for assessing relations with resting EEG asymmetry. The Positivity Index is the total number of times the subject selected the more pleasant, or positive, of the two word-pairs presented. This is the sum of: (1) the number of pleasant pairs selected in the 17 pleasant–neutral comparisons; (2) the number of pleasant pairs selected in 22 pleasant–unpleasant comparisons; and (3) the number of neutral pairs selected in the 22 neutral–unpleasant comparisons. This variable has the advantage of using all of the word-pairs responses, as well as being an index of cognitive bias that is conceptually and psychometrically most similar to the EEG asymmetry metric.

Table 2
EEG asymmetry scores for the 13 homologous electrode pairs[a]

	All subjects	Males	Females	Test–retest
Fp1/Fp2	0.016**	0.025**	0.009	0.208
	(0.044)	(0.039)	(0.047)	
FpF1/FpF2	0.023***	0.026**	0.021*	0.459
	(0.059)	(0.052)	(0.065)	
F3/F4	0.027***	0.031*	0.024*	0.621
	(0.072)	(0.074)	(0.070)	
F7/F8	0.026	0.036	0.018	0.462
	(0.129)	(0.122)	(0.137)	
FC3/FC4	0.004	0.012	−0.002	0.529
	(0.052)	(0.056)	(0.048)	
FC7/FC8	0.009	0.035	−0.013	0.572
	(0.169)	(0.182)	(0.155)	
C3/C4	0.020	0.016	0.024	0.572
	(0.170)	(0.173)	(0.170)	
T3/T4	0.020	0.041	0.000	0.694
	(0.251)	(0.250)	(0.254)	
CP3/CP4	−0.008	−0.005	−0.012	0.756
	(0.104)	(0.111)	(0.098)	
CP5/CP6	0.023	0.058	−0.008	0.587
	(0.253)	(0.209)	(0.285)	
P3/P4	0.031	0.071	−0.004	0.656
	(0.183)	(0.182)	(0.179)	
T5/T6	0.172***	0.251***	0.101*	0.529
	(0.334)	(0.358)	(0.297)	
PO3/PO4	0.056*	0.094*	0.022	0.800
	(0.239)	(0.258)	(0.217)	

[a] $N = 81$, $N_{male} = 38$, $N_{female} = 43$; except for Fp1/Fp2 with 76/36/40, FC7/8 with 80/37/43 and T3/4 with 79/38/41.

* $P < 0.05$. Mean is significantly different than 0.0, the expected asymmetry score.

** $P < 0.005$. Mean is significantly different than 0.0, the expected asymmetry score.

*** $P < 0.001$. Mean is significantly different than 0.0, the expected asymmetry score.

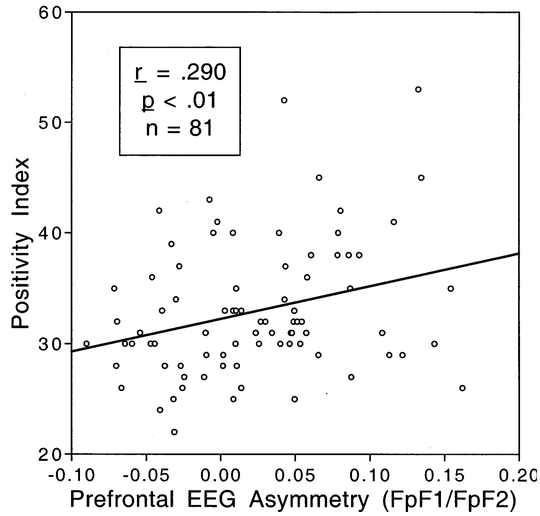

Fig. 1. Scatter plot of the relations between resting prefrontal EEG asymmetry (FpF1/FpF2) and the Positivity Index. Prefrontal EEG asymmetry is calculated by subtracting the logarithm of α power density at FpF1 from logarithm of α power density at FpF2. Positive values reflect relatively greater left-sided activity. Thus, higher numbers on the asymmetry index reflect greater relative left-sided activity. The Positivity Index is the number of times the more pleasant word-pair was selected: 'pleasant' selected over 'unpleasant', plus 'pleasant' selected over 'neutral' plus 'neutral' selected over 'unpleasant'.

3. Results

Table 2 presents means, standard deviations and test–retest correlations for the 13 resting α-band EEG asymmetry measures. For the brain regions assessed by these homologous electrode pairs, subjects exhibited relatively greater left-sided than right-sided resting brain activity, consistent with our previous findings [35]. Male subjects exhibited a more consistent pattern of left-sided asymmetry. However, male and female asymmetry scores were significantly different only at T5/T6, $t(79) = 2.05$, $P < 0.05$. Test–retest (intra-class) correlations ranged from small to large. All supported aggregation of the sessions 1 and 2 measures in a single asymmetry score for a more reliable index of affective style.

The mean Positivity Index was 32.94 with a *S.D.* of 6.00. This average was significantly greater than the expected value of 30.50 (one-half of 61), $t(80) = 3.66$, $P < 0.0005$. The average Positivity Index for males ($M = 33.47$, $S.D. = 5.58$) and females ($M = 32.47$, $S.D. = 6.37$) were both significantly greater than the expected value ($t(37)$ and $t(42) > 2.02$, $P < 0.05$). The male and female means were not significantly different from each other ($t(79) < 1$, ns).

As shown in Fig. 1, individuals with greater left anterior frontal (FpF1/FpF2) resting EEG asymmetry were more likely to select the more pleasant of the two word-pairs presented ($r(79) = 0.290$, $P < 0.01$).[4] To further highlight this relation, we compared a group of individuals who exhibited relatively greater left-sided prefrontal activation with a group who exhibited relatively greater right-sided prefrontal activation. Using a

[4] Analyses of more specific word-pair selection variables (e.g. the number of times the pleasant word-pair was selected over the unpleasant word-pair) revealed similar results, although the correlations were smaller. For example, the correlation between FpF1/FpF2 asymmetry and these more specific selection variables were as follows: (1) with the selection of pleasant over unpleasant word-pairs, $r = 0.181$, $P = 0.105$; (2) with the selection of pleasant over neutral word-pairs, $r = 0.281$, $P = 0.011$; and (3) with the selection of neutral over unpleasant word-pairs, $r = 0.183$, $P = 0.103$. Analyses assessing relations between the Positivity Index and EEG asymmetry using other standard EEG bands (i.e. δ, θ, β-1 and β-2) did not reveal any significant correlations. For all but two of these correlations, $|r| < 0.169$, $P > 0.13$. The two correlations approaching significance were between the Positivity Index and CP3/4 asymmetry in the θ-band ($r = 0.212$, $P = 0.057$) and in the β-1 band ($r = 0.205$, $P = 0.066$).

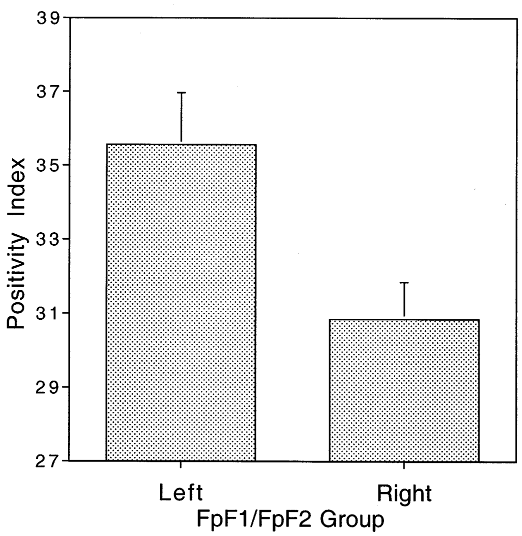

Fig. 2. Mean Positivity Index for individuals exhibiting relatively greater left-sided ($n = 23$) versus right-sided ($n = 27$) prefrontal resting activity.

criterion of one-half ω above or below the mean, 23 individuals were classified as left-activated ($M = 0.095$, $S.D. = 0.034$) and 27 individuals were classified as right-activated ($M = -0.041$, $S.D. = 0.021$). These two groups, essentially top and bottom tertiles, had significantly different left anterior frontal asymmetry scores by definition ($t(48) = 17.33$, $P < 0.0001$). Furthermore, as displayed in Fig. 2, the group of individuals exhibiting greater left-sided anterior frontal resting activity selected the more pleasant word-pair ($M = 35.56$, $S.D. = 6.77$) significantly more often than the group of individuals exhibiting greater right-sided anterior frontal resting activity ($M = 30.85$; $S.D. = 5.20$; $t(48) = 3.11$, $P < 0.005$).

The correlations between the Positivity Index and resting EEG asymmetry at mid-frontal (F3/F4, $r(79) = 0.202$) and lateral (F7/F8, $r(79) = 0.211$) frontal regions were marginally significant ($P < 0.07$). To evaluate the specificity of the relation among anterior resting EEG asymmetry and the selection of word-pairs, we specifically compared the correlation between anterior frontal asymmetry and the Positivity Index to the correlation between parieto-occipital EEG asymmetry and the Positivity Index ($r(79) = -0.084$, $P > 0.44$) using the method presented by Cohen and Cohen [4]. Analyses showed that the anterior frontal correlation was significantly greater than the parieto-occipital correlation ($t(78) = 2.33$, $P = 0.01$). To further highlight the specificity of these relations to anterior brain asymmetry, Fig.

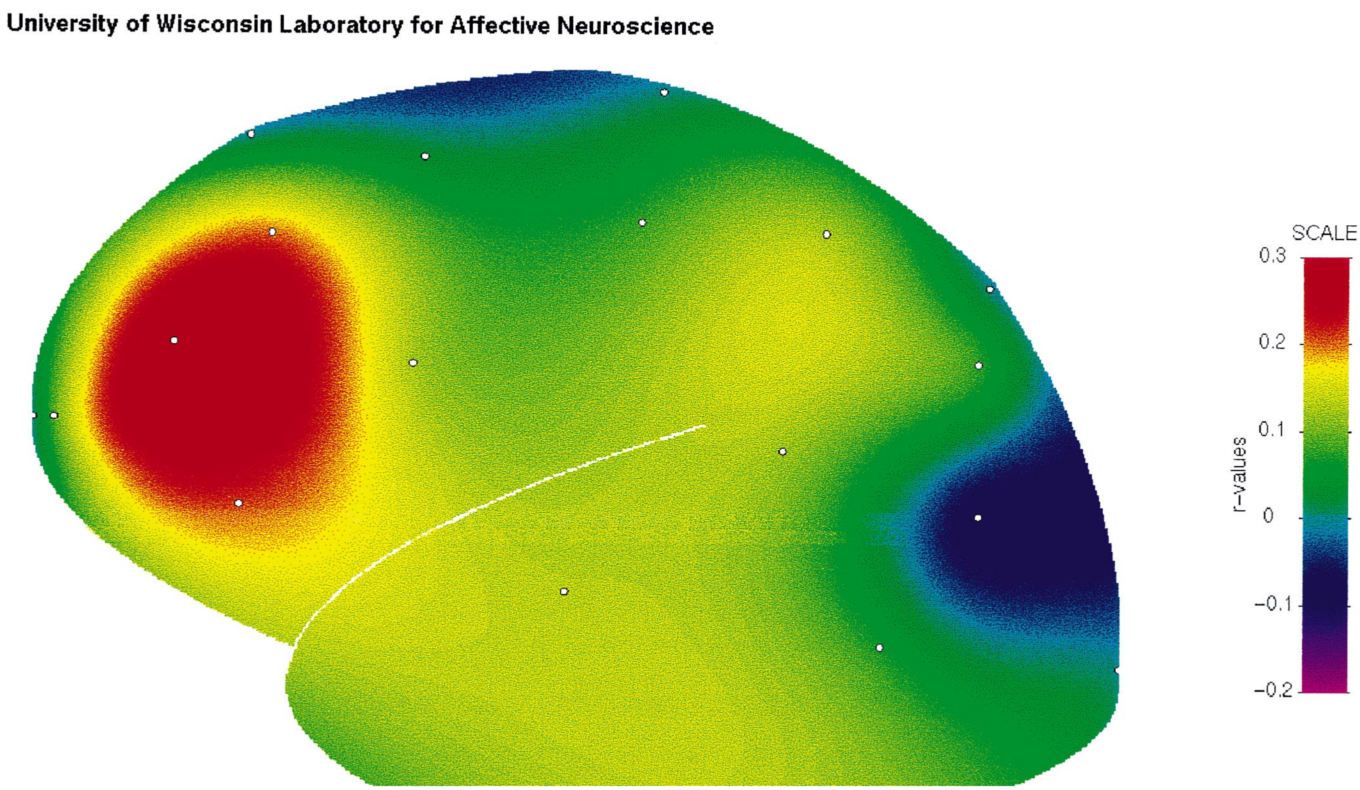

Fig. 3. Topographic map of the relation between resting EEG asymmetry and the Positivity Index. The asymmetry score for the 13 homologous electrode pairs (represented by small circles) were correlated with the Positivity Index. Correlations between the Positivity Index and five mid-line electrodes were set to 0.0. These correlations were used to generate a spline-interpolated map across a left lateral view of the head. Significant relations between EEG asymmetry and the Positivity Index ($r \geq 0.22$) are only found in anterior scalp regions. This map is used for display purposes only. All inferential statistics are based upon actual measured values at specific scalp electrode sites.

3 is a spline-interpolated map of correlations among measures of resting EEG asymmetry and the Positivity Index. As can be seen in the figure, resting EEG asymmetry from central and posterior regions was not significantly related to the Positivity Index ($r(79)$ ranged from 0.135 to -0.084, $P > 0.22$).

As described above, analyses of valence ratings by an independent set of raters showed that females, relative to males, rated word-pairs in the unpleasant category as more unpleasant, as well as word-pairs in the pleasant category as more pleasant. These differences suggest that males and females may be processing the pleasant and unpleasant word-pairs differently, which may extend to the paired comparison task where valence may be a more salient dimension in the evaluation of the word-pairs for females. Therefore, correlations among resting EEG asymmetry and the Positivity Index were assessed separately for males and females. The correlation between FpF1/FpF2 asymmetry and the Positivity Index was significant for females ($r(41) = 0.389$, $P = 0.01$), but not for males ($r(36) = 0.124$, $P = 0.45$). These correlations, however, were not significantly different ($z = 1.23$, $P > 0.20$).

4. Discussion

These data show that resting activity in anterior brain regions predict judgments of associative strength when contrasting stimuli that systematically differed in affective tone. Individuals with relatively greater resting left anterior frontal activity more often selected the more pleasant of the two word-pairs. As shown in Fig. 3, this relation was specific to anterior scalp regions. These data extend previous research by demonstrating that resting prefrontal activation asymmetry predicts performance on a cognitive task that reflects affective bias. These results also highlight the trait-like nature of affective style given the extended time between the resting EEG sessions and the performance of the word-pairs task (at least 4 and as many as 28 months). The results of this study advance our understanding of fundamental personality processes by incorporating biological data and concepts into research on the predictors of individual differences in cognitive tasks that contain stimuli differing in affective tone.

The mechanisms accounting for the association between resting anterior brain activity asymmetry and the Positivity Index require additional study. Both our measure of anterior brain activity and the cognitive processes involved in the associative judgment are complex. It is highly desirable to assess brain activity more precisely and also to delineate the specific subcomponents of information processing that constitute the associative judgment task. However, it should be acknowledged that the influence of affective style on information processing of pleasant and unpleasant stimuli may emerge from a collection of influences, none of which is necessary or sufficient, that will be best observed using complex tasks and contrasting stimuli.

With that said, we put forth the possibility that dispositional left-sided anterior activity biases attention toward and/or elaboration of pleasant stimuli. Davidson [5] has suggested that certain regions of the lateral prefrontal cortex play a role in affect that is conceptually similar to the role of dorsolateral prefrontal cortex in working memory. Specifically, on the basis of neurophysiological data in animals, Davidson has argued that the prefrontal cortex plays an important role in maintaining affective representations on-line for the purpose of guiding behavior in motivationally significant contexts. If regions of the left prefrontal cortex were selectively involved in the maintenance of positive affective representations in working memory, then we would expect that individuals who show dispositional activation of this cortical zone would be biased toward the representation of positive affective stimuli. This bias would be reflected in higher scores on the Positivity Index.

One way to more precisely specify the cognitive operations that are influenced by those components of affective style is to increase the range and specificity of cognitive tasks (e.g. goal-directed working memory, threat related vigilant attention, etc.). Similarly, one may also increase the range and specificity of the measures of affective style, going beyond EEG asymmetry measures. The gender differences observed in this study suggest another important line of investigation. The larger correlation between anterior frontal asymmetry and the Positivity Index may be related to the fact that females rated the positive words as more positive and the negative words as more negative than did males.

This study is one component of a larger body of research assessing relations among resting brain activation asymmetry and various aspects of affective reactivity, affect-related behaviors and the processing of affective stimuli. Other studies, using unselected adults, have shown that resting anterior cortical activity predicts self-reports of general levels of positive and negative affect [36], of behavioral approach and behavioral inhibition tendencies [20,35] and of emotional reactions to pleasant and unpleasant film clips [38]. Furthermore, infants' resting anterior brain activity predicted the extent and intensity of distress in response to maternal separation [10]. Recent research also indicates that baseline anterior activation asymmetry predicts peripheral biological indices related to stress including immune function [9] and cortisol [24]. Current research is attempting to extend these findings using a variety of measures, laboratory tasks and populations (i.e. infants, children and adults ranging in age from 6 months to 80 years).

The results of the current study are also important given the interest in the relations between affective disorders and biased information processing (for reviews, see Refs. [26,29,39]). Many cognitive tasks using affective stimuli have been developed to assess potential memory, attentional, judgmental, associative and response biases that may be disorder-specific. For example, depressed individuals show a memory bias for self-referential, negative information [13,16]. Clinically anxious individuals generally do not exhibit a comparable memory bias, but have been shown to exhibit an attentional bias for threatening stimuli [27]. Furthermore, clinically anxious individuals have been shown to exhibit stronger tendencies to interpret ambiguous stimuli in a threatening manner (e.g. selecting 'die' over 'dye' when hearing the homophone [15]). It is our contention that cognitive biases such as these are related to stable, broad individual differences in affective style that may, in more extreme instances, confer a vulnerability to psychopathology. This is consistent with studies showing that remitted and currently depressed individuals exhibit relatively less left-sided resting brain activity [22,23]. Based on the results of this study, such individuals would be expected to choose the more unpleasant word-pair more often, resulting in a relatively low Positivity Index.

Our findings show that biased information processing is present in normal subjects who differ in patterns of resting anterior brain activity. Those individuals with relatively more left-sided prefrontal activation (assessed between 4 and 28 months earlier) showed a bias to select the more pleasant of the presented stimuli. This is consistent with previous research linking measures of affective style with measures of affective reactivity and may provide an initial step toward better understanding of the link between affect and cognition.

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Appendix A. Paired comparison of word-pairs listed by valence category

Pleasant–unpleasant
America/home–carrot/peas*
bright/shine–weak/sick
cherry/pie–fever/ill
clean/hands–bark/bite
doctor/help–starving/hunger
flower/garden–fraud/lie
god/love–grief/death
rabbit/fur–rat/rodent
scene/view–afraid/dark
stream/brook–take/steal
sugar/spice–slime/snake
truth/honesty–dirt/filth

Pleasant–neutral
art/beauty–accordion/instrument
balloon/child–clothes/suit*
calm/serene–car/fast
candy/chocolate–bear/brown
chair/comfortable–badge/pin
copper/gold–tall/high*
dancing/fun–animal/cat
family/friends–book/cover
fancy/pretty–lamp/shade
glow/warm–beaver/tail
health/wealth–rayon/stockings
rose/smell–even/level

Neutral–unpleasant
atom/small–hungry/thirsty
bath/shower–anger/rage
buoy/float–false/wrong
close/far–abortion/illegal
dock/pier–sin/hell
head/toe–hate/despise
organ/pipe–tetanus/infection
quota/limit–leper/colony*
room/furniture–mad/insane
wheel/cart–war/gun
woman/mother–frigid/ice
Yankee/north–knife/kill

Unpleasant–pleasant
ant/bug–deer/fawn
beggar/tramp–right/good
chill/shiver–bronze/silver
criminal/prison–courage/strong
devil/Satan–dog/pet
germ/cold–sledding/hill
heavy/load–sun/tan
hurt/cry–happy/glad
maid/work–baby/cute
puddle/splash–dough/cake*
robbery/theft–silk/satin
rough/tough–cushion/pillow

Neutral–pleasant
barrel/water–cork/champagne*
basketball/gym–dream/fantasy
block/building–city/lights
bread/food–lily/Easter*
butter/milk–stars/heaven
buy/money–feather/soft*
land/tree–yachting/sailing*
mail/box–ocean/beach
mark/check–jelly/sweet
moose/call–skiing/sport
music/note–statue/marble*
sloth/slow–won/victory

Unpleasant–neutral
bitter/taste–collar/blouse
earthworm/slimy–key/chain
fat/obese–box/container
fear/fright–window/door
fishhook/bait–baseball/diamond*
jail/convict–part/section
larceny/thief–barn/farm
lizard/crawl–antelope/run
mock/ridicule–button/shirt
pain/ache–kitchen/stove
pig/mud–stem/leaf
spider/insect–doodle/scribble

Note: Asterisk indicates 11 word-pairs that were dropped from the computation of the Positivity Index due to relatively small difference in the average valence ratings.

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