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A capability model of individual differences in frontal EEG asymmetry

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Abstract

Researchers interested in measuring individual differences in affective style via asymmetries in frontal brain activity have depended almost exclusively upon the resting state for EEG recording. This reflects an implicit conceptualization of affective style as a response predisposition that is manifest in frontal EEG asymmetry, with the goal to describe individuals in terms of their general approach or withdrawal tendencies. Alternatively, the response capability conceptualization seeks to identify individual capabilities for approach versus withdrawal responses during emotionally salient events. The capability approach confers a variety of advantages to the study of affective style and personality, and suggests new possibilities for the approach/withdrawal motivational model of frontal EEG asymmetry and emotion. Logical as well as empirical arguments supportive of this conclusion are presented.

Keywords

Frontal EEG asymmetry; Emotion; Personality

Despite the increased use of asymmetries in brain activity over the frontal cortex as a putative trait measure of affective style (Allen and Kline, 2004), progress in our conceptual understanding of these asymmetries is at something of an impasse (Coan and Allen, 2004). Inconsistencies in statistical associations between frontal EEG asymmetry and other trait measures of personality are abundant in the literature, as are discussions of the methodological differences across laboratories that may (or may not) account for those inconsistencies (Allen et al., 2004a; Coan and Allen, 2004; Davidson, 1998b; Hagemann and Naumann, 2001; Hagemann et al., 1998, ¹⁹⁹⁹, 2001, 2002; Kline et al., 2002; Reid et al., 1998).

A potential and thus far unaddressed difficulty in this domain of inquiry may be the use of the resting condition as the primary context within which individual differences in frontal EEG asymmetry are measured. The use of the resting condition in studies of individual differences in frontal EEG asymmetry derives from a near axiomatically accepted dispositional model of frontal affective style, whereby individuals are thought to possess a general tendency to predominantly respond with either approach (indexed by relatively greater left frontal activity) or withdrawal (indexed by relatively greater right frontal activity) related affect across all or most situations (Davidson, 1998a). Dispositional models of personality hold that “people’s behavior across different situations shows the imprint of who they are and what they are” (Ross and Nisbett, 1991,p.92), and have often been contrasted with situational models,

which hold that people's behavior across a variety of situations is predominantly a function of those situations.

In this article, we propose a capability model of frontal EEG asymmetry and personality (cf., Wallace, 1966) that occupies a conceptual middle ground. The capability model posits that meaningful individual differences in frontal EEG asymmetry exist, but that those individual differences are best thought of as interactions between the emotional demands of specific situations and the emotion-regulatory abilities individuals bring to those situations. That is, while the dispositional model of frontal EEG asymmetry aims to measure individual approach versus withdrawal dispositions regardless of the situation, the capability model aims to measure the degree to which individuals are capable of approach versus withdrawal responses, or, importantly, of inhibiting those responses, depending on the demands of the situation.

According to theorists such as Wallace (1966, 1967) and Mischel (1968; Mischel et al., 2002) dispositional models encourage testing conditions that avoid situational demands. In Wallace's time, the dispositional approach manifested itself methodologically in projective tests such as the Rorschach, which sought to elicit underlying personality dimensions in an open-ended, ambiguous testing situation. The purpose of such tests has been to provoke and observe peoples' biases and assumptions – their personality traits – by requiring them to disambiguate ambiguous stimuli. That is, the assumption underlying projective testing has been that asking subjects to describe their impressions of ambiguous stimuli will require those subjects to reveal their “core,” “underlying” or “baseline” biases, assumptions, worldviews, or simply general “tendencies,” and that these characteristics will hold consequences for their emotional behavior and level of risk for psychopathology. “Resting” measures of frontal EEG asymmetry as a means of measuring trait differences in affective style likely derive from a similar conceptual tradition. Under resting conditions, subjects are instructed to relax, or focus their attention on a fixation point, or one way or another avoid engaging in any particular state of mind, thus allowing their “underlying” or “baseline” biases in cortical brain activity to manifest. This baseline brain activity is then thought to hold consequences, in interaction with environmental demands, for emotional responding and risk for psychopathology (Davidson, 1998a).

By contrast, Wallace argued that it was preferable to conceptualize personality attributes as abilities, an approach he termed the “capability model” of personality. The capability model encourages the measurement of individual differences along dimensions of personality during controlled laboratory challenges, much as one might test intelligence or high jumping ability (Wallace, 1966). Wallace (1967), and many others after him (cf. Lilienfeld et al., 2000), noted that projective forms of personality assessment have largely been a failure, and argued that this failure stemmed from a broader failure to conceptualize personality traits as abilities.

A concrete example can clarify the methodological consequences of such a conceptual shift. If, for instance, one were interested in predicting the extent to which individuals will respond with withdrawal related affect to frightening situations, the dispositional model would appeal to individual differences in patterns of frontal brain activity recorded under resting conditions, while the capability model would appeal to individual differences in patterns of frontal brain activity recorded during fear-related emotional challenges. Moreover, the dispositional model would propose (explicitly or not) that individuals with, for example, greater relative right frontal activity at rest will respond with more withdrawal related affect (or less approach related affect) not only to fear, but to other emotional situations—even positive ones (e.g., an enjoyable social event). This follows from conceptualizing resting patterns of frontal EEG asymmetry as the one or primary manifestation of a given individual's affective style. The capability model would not make such a forceful claim. Indeed, in the context of the above example, the capability model of frontal EEG asymmetry would propose only that those individuals with

relatively greater right frontal activity during a controlled fear-related laboratory challenge should respond with more withdrawal related affect during that challenge, as well as during similarly frightening situations that manifest in the “real-world”. The capability model would not additionally require that such individuals show approach related deficits in other contexts (e.g., during an enjoyable social event), although it allows for the possibility. Thus, dispositional and capability models offer different heuristics for how individual differences in frontal EEG asymmetry may be both conceptualized and, importantly, optimally measured. Logical and empirical arguments supporting the capability model are given below.

1. Frontal EEG asymmetry: trait or state?

Little is known about the degree to which frontal EEG asymmetries represent variance attributable to individuals (traits) versus specific emotional or cognitive states. “Resting” measures do show evidence of trait-like heritability (Coan, 2003), and have been associated with measures of temperament, mental health, emotional reactivity, and stress hormones (Coan and Allen, 2004). Others have confirmed that frontal EEG asymmetries show “acceptable” levels of test–retest reliability (Allen et al., 2004b; Tomarken et al., 1992), and that as much as 60% of the variance in resting measures of EEG asymmetry across four occasions of measurement may be attributable to a stable latent trait (Hagemann et al., 2002). Additional studies, however, have documented state effects on frontal EEG asymmetries (Coan and Allen, 2003c; Coan et al., 2001; Davidson et al., 1990; Ekman and Davidson, 1993; Harmon-Jones et al., 2002; Harmon-Jones and Sigelman, 2001). In this literature, relatively greater left frontal activity is thought to index approach-oriented emotional states, such as anger or joy, and relatively greater right frontal activity is thought to index withdrawal-oriented emotional states such as disgust, fear or sadness (Coan and Allen, 2004; Coan et al., 2001; Harmon-Jones and Sigelman, 2001). Recently, questions have arisen about the degree to which patterns of individual differences in frontal EEG activity recorded during one condition are preserved during another. For example, Coan and Allen (2003b) observed that individual differences recorded at rest were positively and significantly correlated with those recorded during emotional states.

One might in any case argue that at “rest,” individuals assume a variety of mental and physiological states, states that might reflect their general predisposition if viewed from the dispositional model, or states of which they are capable – given the recording environment – if viewed from the capability model. Indeed, the latter conceptualization suggests the recording situation and experimental milieu might elicit idiosyncratic responses that reflect a relatively poorly controlled interaction between the individuals being measured and either the laboratory setting (as in Blackhart et al., 2002) or the experimenter (as in Kline et al., 2002). Such idiosyncratic responses could be partially or even largely responsible for inconsistencies in this work observed across different laboratories.

Ultimately, at least three lines of research suggest the dispositional model of frontal EEG asymmetry may not be optimal. They include: (1) evidence that uncontrolled experimental conditions affect resting measures of EEG asymmetry (Blackhart et al., 2002; Kline et al., 2002); (2) evidence that individual differences in EEG asymmetries during emotional challenges predict other traits and behaviors (Harmon-Jones et al., 2002; Harmon-Jones and Sigelman, 2001); and (3) evidence from hemodynamic imaging studies suggesting that individuals engage in a variety of mental behaviors that are themselves ultimately uncontrolled during resting tasks (Binder et al., 1999; McKiernan et al., 2003).

2. Approach and hypotheses

The capability model suggests the following hypotheses: (1) individual differences will be more pronounced during emotional challenges than during “resting” tasks; (2) individual

differences will be more resistant to measurement error during emotional challenges than during “resting” tasks; (3) individual differences will show stronger relationships with important criterion variables if measured during emotional challenges than during “resting” tasks; and (4) individual differences derived from emotional challenge tasks will be more stable across time than those derived from “resting” tasks. An extant data set, reported previously in Coan et al. (2001), provided an opportunity to empirically investigate hypotheses 1 through 3. (We are not aware of any currently available data with which one might test hypothesis 4.) In Coan et al. (2001), subjects were instructed to engage in directed facial action (DFA) tasks in order to track state changes in frontal EEG asymmetry related to emotional facial expressions. DFA tasks resulted in patterns of frontal EEG asymmetry that closely tracked the predictions of the approach/withdrawal model of frontal cortical asymmetry. Further analyses established that these effects were not attributable to obvious potential confounds such as facial muscle (electromyography, or EMG) contamination, performance differences, face difficulty, or demand characteristics. Moreover, the average rate of reporting the target emotional experience following DFA tasks was well above chance, approaching 60%. Finally, previously unreported data associated with this data set, trait positive and negative affectivity (PA and NA, respectively, Watson et al., 1988), provide criterion measures for hypothesis 3.

3. Method

3.1. Overview

A detailed description of the methods of this study is provided in Coan et al. (2001); an abbreviated description is provided here with information relevant to the analyses of this particular report.

3.2. Participants

Thirty-six introductory psychology students served as participants (10 male, 26 female). All participants were strongly right handed (scoring over 35 on the 39 point scale; Chapman and Chapman, 1987), because asymmetries in hemispheric activity may be a function of handedness (see Bryden, 1982). Participants ranged in age from 17 to 24 years, with a mean age of 19.1. The ethnic composition of the sample was 2.7% African American, 2.7% Asian, 18.9% Hispanic and 75.7% Caucasian. Due to missing data in resting EEG files and/or questionnaires, four participants had to be dropped from analyses reported here. Thus, the final sample included 32 participants.

3.3. Procedure

After arriving, participants were informed of the laboratory tasks, which included a baseline resting assessment and a state manipulation component (reported in Coan et al., 2001, and described in detail below). After providing informed consent, participants completed questionnaires, including the Positive and Negative Affect Scales, general version (PANAS, Watson et al., 1988), while electrodes were affixed to their face and scalp. Resting EEG was recorded while participants sat quietly in a sound-attenuated room for an 8-min resting period, consisting of a counter-balanced sequence of minute-long eyes-open and eyes-closed segments.

3.3.1. Emotional states using directed facial action—The Directed Facial Action Task (see Coan et al., 2001; see Levenson et al., 1990) was then used to evoke emotional states. For the facial movement task, participants were seated in a sound-attenuated room, separate from the experimenter. The experimenter communicated with participants via microphone, and participants' faces were closely monitored at all times via video monitor. The experimenter gave explicit instructions to participants concerning how to make each facial movement,

observing participants on the video monitor to ensure that each movement was performed correctly.

The facial movements described below are numbered according to Ekman and Friesen's Facial Action Coding System (FACS; 1978). Facial expressions were each held for 2 min, separated by 30 s resting intervals during which no EEG was recorded.

3.3.2. Facial action coding system (FACS)—In FACS, individual movements are referred to as action units (AUs). In all, five complete facial expressions were performed (in addition to three control faces, not discussed here) representing each of the following emotions: Anger (AUs 4 + 5 + 7 + 23/24), Disgust (AUs 9 + 15 + 26 + tongue show), Fear (AUs 1+2+4 +5+15+20), Joy (AUs 6+12+25), and Sadness (AUs 1+6+15 +17).¹ Facial expression performance was rated by two FACS trained (but not FACS certified) observers during the experiment on a 7-point scale, where 1 meant that no target facial movements were achieved, and 7 meant that the participant's performance of the target facial configuration was perfect and prototypic. Overall, mean levels of task quality were quite high (Coan et al., 2001), averaging 5.22. Reliabilities between two independent raters who observed the videotapes were calculated on a sub-sample of 10 participants. Intraclass correlation coefficients ranged from 0.55 (sadness) to 0.85 (anger) averaging 0.68.

3.3.3. Assessment of EEG and EOG—Tin electrodes in a stretch-lycra cap were used to record EEG at sites FP1, FP2 F3, F4, F7, F8, Fz, FTC1, FTC2, C3, C4, T3, T4, TCP1, TCP2, T5, T6, P3, P4, Pz, O1, O2, Oz, A1, and A2. All sites were referenced online to Cz, and re-referenced off-line using different reference schemes, as recommended by Reid et al. (1998), who noted that data from different references schemes do not necessarily correlate highly.

3.3.4. Data reduction—Signal processing was conducted using Neuroscan's Edit software to complete procedures typical in EEG asymmetry research (for review, see Allen et al., 2004a,b). Prior to artifact screening, data files were filtered with a finite impulse response zero phase shift 161-point digital 60-Hz notch filter. The file was visually screened for gross movement artifacts and for clipped signals; time periods containing such artifacts were removed from further analyses. Epochs with eye blinks were rejected automatically, when ocular signals exceeded 100 mV. For resting data, each 1-min segment of data was epoched into 119 2-s epochs that overlapped by 1.5 s. For state effects, data from each of the 2 min of each facial expression were divided into thirds, and these 20-s epochs were then divided into 40 2-s epochs that also overlapped by 1.5 s. The overlap of 75% was selected for both resting and state tasks to compensate for the loss of data due to the imposition of a Hamming window prior to spectral analysis. The average percentage of rejected epochs per subject was 27%, ranging from 1.4 to 60%. Data were re-referenced off-line to an average montage and to computer-linked mastoids. Data from the online Cz reference and both off-line reference schemes were included in the analyses.

A fast Fourier transform (FFT), using a Hamming window that tapered data at the distal 10% of each 2-s epoch (frequency resolution of 0.5 Hz), transformed data to power spectra, and the average power spectrum for each 1-min period was obtained. Total power within the alpha frequency band (8–13 Hz) was extracted, and these values were averaged across segments, weighted according to the number of artifact-free epochs in each segment. Average alpha power values at each site were then log transformed using the natural log. A measure of EEG hemispheric asymmetry (right hemisphere compared to left hemisphere) was derived ($\ln[\text{right}] - \ln[\text{left}]$) for the mid-frontal region (F4 and F3). Because cortical alpha power is considered inversely correlated with cortical activity (see Allen et al., 2004a, for a more extensive discussion), lower scores on this metric suggest relatively less left frontal activity. Internal consistency reliability estimates (Cronbach's alpha) were obtained for both state and resting

alpha asymmetry scores at the mid-frontal region. For resting measurements, 8 min of resting EEG activity yielded internal consistency reliability estimates of 0.76, 0.76 and 0.91 for the average, Cz and linked mastoid reference schemes, respectively. For state measurements, internal consistency estimates were obtained by treating each 20-s segment of EEG as if it were an individual item on a 6-point scale. With this method, 2 min of EEG activity yielded internal consistency estimates ranging from 0.62 (Disgust from the Cz reference) to 0.94 (Fear from the Cz reference), depending on the emotion and reference scheme, with a median reliability coefficient of 0.87, a mean of 0.82 and a standard deviation of 0.10.

3.3.5. Assessment of positive and negative affectivity—To assess PA and NA, participants completed the PANAS-GEN (Watson et al., 1988). This instrument is comprised of 20 positive and negative emotion terms, 10 of which are intended to reflect positivity and 10 of which are intended to reflect negativity. Participants are asked to rate the extent to which they experience each feeling “in general, that is on the average” on a Likert-type scale ranging from 1 to 5. Early studies (Watson et al., 1988) of the PANAS GEN have derived high estimates of internal consistency for PA and NA (Cronbach’s alphas of 0.88 and 0.87, respectively) and reasonably high test–retest reliabilities (0.68 and 0.71, respectively, over an 8 week period). In the present smaller sample, internal consistency estimates were somewhat lower for PA (0.69) although very similar to reported values for NA (0.84). Means for PA and NA in this sample were 33 (S.D. = 7.24) and 22 (S.D. = 8.22), respectively.

3.4. Data analysis

In Coan et al. (2001), data reported here were used to test differences among the different emotional face tasks in mean levels of left versus right frontal activity, and to characterize those mean differences in terms of the prevailing approach/ withdrawal model of frontal EEG asymmetry and emotion. In this paper, these data were revisited first for the purpose of understanding the ways in which individual differences in frontal EEG asymmetry are expressed during those same emotional face tasks, especially as compared to individual differences in frontal EEG asymmetry manifest during a standard resting condition. Moreover, data originally reported in Coan et al. (2001) are here used to investigate how relationships among frontal EEG asymmetry, NA and PA may vary as a function of the emotional state under which frontal EEG asymmetries are recorded. These data have not been analyzed in these ways or for these purposes before.

3.4.1. EMG contamination—One obvious potential difficulty in using EEG data obtained during periods of emotional facial expression concerns the possibility of contamination of alpha power from muscle contractions in the face and across the scalp. Such muscle contractions can introduce electrical activation in the alpha range that is unrelated to cortically derived alpha power. In the original report of these data, Coan et al. (2001) took two approaches to cope with this possibility. First, asymmetry scores based on EMG frequencies (70–90 Hz) extracted from power spectra at all cortical sites of interest were calculated and used as covariates in all analyses of alpha power asymmetries. Second, alpha power was extracted from EMG activity over the frontalis and temporalis muscle regions and similarly used as covariates in tests of alpha power asymmetries at cortical sites. In neither approach could EMG effects account for the effects of emotional facial expressions on frontal EEG asymmetries.

3.4.2. G-theory—Generalizability theory (hereafter “G-theory,” Cronbach et al., 1972) was used to delineate sources of variance in frontal EEG asymmetry attributable to individual differences, state conditions (rest, anger, disgust, fear, joy and sadness), and reference schemes (average, Cz and linked mastoid). Reference scheme was selected as a known source of undesirable variability in EEG measurement (Hagemann et al., 2001; Reid et al., 1998). G-theory (Cronbach et al., 1972) was originally developed for the purpose of identifying the

generalizability (r^2) and dependability (f or ϕ) of different independent variables thought to contribute to a given measure's score (see Di Nocera et al., 2001, for an excellent introduction written for psychophysicists).

Both instances of the intraclass correlation, the r^2 (generalizability) coefficient indicates the reliability of the rank ordering of scores attributable to one source of variance over other sources, while the f (dependability) coefficient indicates the reliability of the absolute value of scores attributable to one source of variance across other sources. In addition to estimates of generalizability and dependability, actual variance components may be estimated for each independent variable hypothesized to contribute to an individual's score at any one time, including variance components attributable to the interaction of independent variables. G-theory is based fundamentally on an analysis of variance (ANOVA) model in the estimation of variance components. A critical difference between G-theory analyses and classical ANOVA models is that G-theory allows for the computation of expected, as opposed to observed, variance components. For this study, a minimum variance quadratic unbiased estimation (MIVQUE) procedure was used to estimate variance components using SAS's PROC VARCOMP module.

G-theory provides variance component estimates (percent of variance accounted for by each component), coefficients of generalizability (r^2), as well as coefficients for dependability (f or ϕ), for each independent variable of interest. G-theory models defined variance components as expected mean squares, estimated by observed mean squares. As applied to questions of state and interindividual variance in frontal EEG asymmetry, the G-theory model specified was as follows (cf. Di Nocera et al., 2001):

$$\sigma_y^2 = \sigma_i^2 + \sigma_e^2 + \sigma_r^2 + \sigma_{ie}^2 + \sigma_{ir}^2 + \sigma_{er}^2 + \sigma_{ier,error}^2$$

where,

σ_y^2 = total variance for a given variable, in this case frontal EEG asymmetry, across all measurements.

σ_i^2 = variance in frontal EEG asymmetry attributable to individuals.

σ_e^2 = variance in frontal EEG asymmetry attributable to experimentally manipulated emotional states.

σ_r^2 = variance in frontal EEG asymmetry attributable to reference scheme.

And combinations of subscripts correspond to interactions between variance sources. Note that the individual by emotion by reference scheme interaction ($\sigma_{ier,error}^2$) also includes variance attributable to random error.

As applied to questions of interindividual variance in frontal EEG asymmetry within emotion conditions, the G-theory model specified was:

$$\sigma_y^2 = \sigma_i^2 + \sigma_r^2 + \sigma_{ir,error}^2$$

where,

σ_y^2 = total variance for a given variable, in this case frontal EEG asymmetry, across all measurements.

σ^2_i = variance in frontal EEG asymmetry attributable to individuals.

σ^2_r = variance in frontal EEG asymmetry attributable to reference scheme.

$\sigma^2_{ir,error}$ = variance in frontal EEG asymmetry attributable to the individual by reference scheme interaction, plus error.

3.4.3. Hierarchical linear models—Using SPSS's Mixed Model routine, two hierarchical linear models were tested, one each for PA and NA, where frontal EEG asymmetries recorded at rest, and during each emotional state, were entered hierarchically as continuous predictors. In both models, continuous EEG asymmetries were repeated for each of three levels of reference scheme (average, Cz and linked mastoid). In the specification of the models, subject ID was nested within reference scheme in order to estimate the appropriate within-subjects error term.

In both G-theory and hierarchical linear models, only EEG asymmetries in the mid-frontal region were used, since (1) this region demonstrated robust differences in asymmetry scores as a function of emotional state (as reported in Coan et al., 2001), (2) this is the region most commonly used in investigations of trait frontal EEG asymmetry, and (3) these analysis are intended to demonstrate a comparison of the predictive validity of individual differences during state manipulations versus resting conditions, as opposed, for example, to comparing different regions (cf., Coan and Allen, 2004).

4. Results

4.1. G-theory models

4.1.1. Individuals and conditions—Using data collected during various experimental conditions, a G-theory model consisting of factors attributable to individual, condition (rest, anger, disgust, fear, joy and sadness) and reference scheme (average, Cz and linked mastoid) was estimated. As summarized in Table 1, stable individual differences accounted for approximately 26% of the variance across all conditions, while conditions per se accounted for approximately 5%. Small contributors included reference scheme (1%) and the emotional state by reference scheme interaction (virtually 0%). The individual by reference scheme interaction accounted for approximately 8%, and the individual by state by reference scheme (plus error) interaction (10%). Of greatest interest was the individual by state interaction, which accounted for 50% of the explained variance in the model.

In terms of reliability, the r^2 coefficient for individual difference variance refers to the degree to which the rank ordering of individuals is preserved across all conditions (rest, plus the various emotions) and reference schemes simultaneously. The r^2 and f coefficients (Table 1) for individual variance were moderate, at 0.69 and 0.67, respectively. Another way to consider these generalizability and dependability coefficients for individual differences are as test–retest reliability coefficients over a short interval and different recording contexts. These numbers indicate that, though variance attributable to solely individuals is a relatively small proportion (i.e. 26%) of the total variance across conditions, it appears to be quite stable.

The r^2 and f coefficients (Table 1) for condition variance were similar, from 0.73 to 0.61, respectively. The rank ordering of variance attributable to reference scheme was moderate as well (0.76), but the reliability of absolute values attributable to reference scheme were, not surprisingly, quite low indeed (0.36). In aggregate, this pattern of results suggests that variance contributed by different experimental conditions per se is small (5%) but reliable.

4.1.2. Interindividual variance within emotional states—Another approach to investigating the interaction between individual and state variance is to identify the reliability of individual differences within emotional states, as opposed to across them as was done above; such estimates assess the reliability of the individual differences across reference schemes for each experimental condition. Table 2 contains proportions of variance, and r^2 and f coefficients for individual differences within the resting and emotional state conditions. It is readily apparent that the proportion of variance attributable to individuals as opposed to reference scheme and measurement error, varies considerably, from 16% (during rest) to 91% (during sadness). Two other points are specifically noteworthy, however. First, although there is variability in the proportions of variance attributable to individuals across specific emotional states, those proportions are uniformly much higher than the proportion of variance attributable to individuals during rest. Second, individual differences during the fear and sadness conditions accounted for 88 and 91% of the total variance in frontal EEG asymmetry respectively, with the impact of reference scheme correspondingly minimized under these conditions. These two conditions also produced the most robust effects across subjects in Coan et al. (2001).

Reliability coefficients tell a similar story. The r^2 and f coefficients for the resting condition (Table 2) were both quite low, at 0.38 and 0.39, respectively. Most of the variance in the resting condition appears to be attributable to an interaction between individual and reference scheme, indicative that the effect of reference scheme variance is largely idiosyncratic. By contrast, the r^2 and f coefficients for individual within each of the emotion conditions are higher, in some cases markedly so. Indeed, just as proportions of variance attributable to individual were highest during fear and sadness, so too are the r^2 and f coefficients. For fear, r^2 and f coefficients are both hovering around 0.96, for sadness, 0.97. The lowest r^2 and f coefficients during an emotional state were those attributable to Joy, each at approximately 0.68—nearly twice as high as those derived from the resting condition.

4.1.3. Reference scheme correlations—The r^2 and f coefficients described above provide estimates of the reliability of the rank ordering and absolute values of individuals across all three reference schemes reported here, within each of six experimental conditions. In Table 3, these relationships are described in terms of zero order correlations between asymmetry scores assessed with different reference schemes during these conditions. It is apparent from this table that mid-frontal EEG asymmetries recorded during the resting condition intercorrelate poorly, while those asymmetries recorded during various state manipulations correlate substantially higher. In particular, during the resting condition, only the average and linked mastoid conditions are significantly correlated, as expected based on published results; neither the average nor the linked mastoid reference schemes were significantly correlated with the Cz reference, a pattern of results that has been noted elsewhere (Allen et al., 2004a; Coan and Allen, 2003a; Davidson, 1998b; Hagemann et al., 1998, 2001; Reid et al., 1998). By contrast, the average reference scheme is significantly correlated with both the Cz and linked mastoid references in all emotion conditions. Indeed, the Cz and linked mastoid references are, among the emotion conditions, only uncorrelated during disgust and joy. Striking, however, are the high correlations among all reference schemes during fear and sadness conditions—again, the condition during which emotion manipulations appeared to be most powerful. These patterns of results suggest that employing state manipulations may minimize concerns about reference scheme variance. Indeed, during strong state manipulations, reference scheme may have little appreciable effect.

4.1.4. Hierarchical linear models—In order to provide comparisons of the predictive validity of resting versus state-dependent measures of frontal EEG asymmetry, asymmetries in brain activity derived from resting conditions and from all emotional conditions were entered into two hierarchical linear models. In all models, resting mid-frontal EEG asymmetry was entered as the first predictor to give it first priority in predicting criterion personality variables.

Following the resting conditions, approach related emotions (anger and joy) were given priority in the prediction of PA, and withdrawal related emotions (disgust, fear and sadness) were given priority in the prediction of NA. Tests of interactions with reference scheme were included for all predictors to test for reference scheme dependence.

Table 4 lists significant effects for this model, in addition to test statistics for the resting condition regardless of whether the resting condition was statistically significant. Mid-frontal EEG asymmetry during the Joy state was the only statistically significant predictor of PA scores, $F(1,64) = 5.30$, $p < 0.03$, although mid-frontal EEG asymmetry during the resting condition did nearly as well, $F(1,72) = 3.63$, $p < 0.06$. Both resting and joy condition frontal EEG asymmetries were positively correlated with PA, such that relatively greater left frontal activity corresponded with higher PA scores. A linear mixed model including frontal EEG asymmetry, reference scheme (average, Cz and linked mastoid) and condition (rest versus joy) was used to test the difference between resting and joy condition measures of frontal EEG asymmetry in the prediction of PA, confirming that the two conditions did not differ, $F(1,167) = 0.137$, $p = 0.71$. By contrast, mid-frontal EEG asymmetry during the Fear state was the only statistically significant predictor of NA scores, $F(1,69) = 4.21$, $p < 0.05$. For NA, mid-frontal EEG asymmetry during rest did not approach significance, $F(1,69) = 0.45$, $p < 0.45$. As before, specific regression lines were plotted for each reference scheme, this time indicating that relatively greater right frontal activity during the Fear state corresponded with higher NA scores. A linear mixed model including frontal EEG asymmetry, reference scheme (average, Cz and linked mastoid) and condition (rest versus fear) was used to test the difference between resting and fear condition measures of frontal EEG asymmetry in the prediction of NA and confirmed that the difference between the two conditions approached statistical significance, with the frontal EEG asymmetry by condition interaction $F(1,112) = 2.81$, $p = 0.10$. This difference was not dependent upon reference Fig. 1 depicts regression lines graphically representing relationships between frontal EEG asymmetry and NA for both the resting and fear conditions, broken down by reference scheme.

5. Discussion

In line with the study hypotheses stated above, these results suggest that (1) individual differences in frontal EEG asymmetries are indeed more pronounced during emotional challenges than during “resting” tasks; (2) individual differences in frontal EEG asymmetries are more resistant to undesirable variance attributable to reference scheme (our proxy for measurement error) during emotional challenges than during “resting” tasks; and (3) individual differences in frontal EEG asymmetry recorded during emotional challenges may show more reliable relationships with criterion measures than those recorded at rest. Taken collectively, and in concert with logical arguments formulated above, these findings constitute preliminary support for the capability model proposed here.

5.1. Individual differences

5.1.1. Across emotional states—In past research, resting measures of frontal EEG asymmetry have been moderately reliable across multiple occasions of measurement in both normal (Tomarken et al., 1992) and depressed (Allen et al., 2004b) populations. Data reported here suggest the stability of individual differences in frontal EEG asymmetry across resting and experimentally manipulated emotion conditions is reasonably high (0.69). Nevertheless, individual differences per se accounted for only 26% of the variance across emotions, with the largest portion of the variance (50%) owing to an individual by condition interaction.

5.1.2. Within emotional states—G-theory models revealed that individual differences in frontal EEG asymmetry made up the smallest proportion of the total variance, and were most

vulnerable to the effects of reference scheme, during the resting condition—the condition most frequently used to assess frontal EEG asymmetry as a putative trait. Indeed, in the resting condition, the individual by reference scheme interaction (essentially noise) accounted for nearly 80% of the total variance. A glance at the zero order correlations among reference schemes (Table 3) emphasizes the point. During rest, the only reference schemes to correlate with each other were the average and linked mastoid ones, a finding that has been reported elsewhere in a different sample (Reid et al., 1998). By contrast, individual differences were most reliable across reference schemes, and made up the largest proportion of variance, during emotion conditions.

Of course, it should be noted that any of this between subjects variance may include a variety of unmeasured sources of state-like variance, such as level of hunger, fatigue, etc., that have gone unmeasured. Because these data represent only one occasion of measurement, care must be taken in interpreting the between subjects variance in any of these conditions as being due to a stable trait. Indeed, estimates of the proportion of variance attributable to individual differences may be interpreted as reflecting the upper boundary of the portion of the variance that is due to such a trait. That said, the same reflections on differences in this upper boundary across resting and state conditions should apply.

5.2. The individual by condition interaction

Fifty percent of the variance in frontal EEG asymmetries recorded for this study was attributable to an individual by condition interaction, suggesting that individuals responded to conditions somewhat idiosyncratically. From a dispositional perspective, this interaction is difficult to interpret. What is an individual's trait predisposition when the evidence points predominantly to different patterns of individual differences across different states? The capability model, however, provides a likely interpretation: personality attributes represent behaviors that individuals are differentially capable of, given the demands of the situation. From this perspective, the individual by condition interaction observed in the data presented here is not troublesome. Indeed, it is expected. Others have proposed very similar formulations for understanding and measuring personality, based on very similar patterns of results (Mischel, 1968). Such findings have led Mischel, Shoda and colleagues (Mischel et al., 2002; Shoda and Mischel, 1996, 2000; Shoda et al., 1994) to advocate the use of situation–behavior profiles in the attempt to promote a more dynamic conceptualization of personality that focuses on the stability of patterns of behavior within specific situations.

5.3. Predictive validity

The joy condition reliably predicted PA, although the resting condition predicted PA only at the margin of statistical significance. Statistically speaking, however, the joy and resting conditions predicted PA equally well. Nevertheless, and in a manner consistent with the capability model, individual differences in frontal EEG asymmetry during the fear condition predicted NA but individual differences during rest did not, and the difference between fear and rest conditions in the prediction of NA was itself marginally significant in this modest-sized sample. It remains somewhat puzzling that among negative emotional states, only individual differences during fear predicted NA. Why not sadness, in particular, since, like fear, it appeared to strongly mobilize trait variance in frontal EEG activity? It is reasonable to speculate that fear mobilized trait variance particularly related to NA, while sadness, disgust and anger did not. For example, using a structured interview to probe components of emotional experience in this sample, Coan and Allen (2003c) reported that fear was the emotion most likely to elicit somatic sensations (as opposed, say, to behavioral action tendencies or emotional memories), and also that the overall likelihood of reporting somatic sensations associated with any emotion was higher in individuals with higher NA scores. Thus, fear states may be the best probe for NA by virtue of the common relationship fear and NA share with somatic sensations

as a quality of emotional experience. This view is certainly in line with the capability model, which would not assume that all negative states measured by frontal EEG asymmetries are the same in terms of their functional or predictive relevance. In any case, this particular pattern of results, although generally supportive of hypothesis three and useful as a methodological illustration, is not strongly or unambiguously conclusive. More evaluation of this question is needed.

5.4. Implications and recommendations

To date, individual differences in frontal EEG asymmetry have derived from the prevailing dispositional model that, explicitly or not, fixes as its goal the identification of global approach versus withdrawal tendencies. While in no way a failure, this approach has also met with limited success, requiring burdensome investments in data collection (such as averaging across multiple occasions of measurement or selecting very stable or extreme groups from large and expensive samples) and sometimes resulting in inconsistent or null results (Coan and Allen, 2004).

Nevertheless, frontal EEG asymmetry continues to show promise as an indicator of affective and motivational personality traits as well as, perhaps, a trait liability marker for affective disorders such as depression and anxiety (Cacioppo, 2004). The results reported here provide tentative evidence that the capability model (Boele and Kokkonen, 2000; Paulhus and Martin, 1987; Wallace, 1966, 1967) may improve the predictive and practical utility of frontal EEG asymmetry.

With regard to the study of EEG and personality, results conforming to the capability model are not entirely without precedent. In his history of the impact of EEG measurement on experimental psychology, Rosler (2005) reviewed a number of studies conducted from the mid-1960s to the mid-1970s that examined EEG in the frequency domain (typically alpha) from a variety of scalp locations as a predictor of personality features. In his own work, which, it should be noted, did not examine asymmetries and did not locate signals over the frontal cortex specifically, Rosler found that effects in alpha “did not appear as habitual differences between participants, but rather as dynamic differences; that is, extraverts and introverts did not differ at rest, but only if they were challenged by an arousing situation” (Rosler, 2005, p. 100). (Rosler did not explain his lack of continuing research to follow-up on these results, although he did emphasize that these effects were quite small.) Although a capability approach has not yet been applied to the study of frontal EEG asymmetry and psychopathology, its potential is suggested by recent findings reported by Allen and Di Parsia (2002), who found that autonomic indexes of affective processing could not distinguish between remitted depressives and never depressed controls if assessed in the absence of a mood manipulation, but that differences were apparent if depressed moods were induced.

The capability model may also expand theory in frontal EEG asymmetry research. Whereas the dispositional model suggests individuals vary along an approach-withdrawal continuum, the capability model does not dictate that an individual’s asymmetry score obtained during one situation generalize to another. For example, the capability model would not suggest that individuals, who are highly capable of relatively greater right frontal activity during fear, are also of necessity deficient in some way when it comes to responding normatively to joy, although it allows that they might be. It indeed allows that the ability to experience various emotions and motivational tendencies can vary from one situation to another, so that a given individual could, for example, be highly capable of left frontal activity – and humor and social facility – during recreational social situations, but also highly capable of right frontal activity – and deference and fear – while interacting with supervisors in the workplace. Such an individual could be said to have at least two opportunities for interacting with aversive environments such that he or she is more likely to experience dysphoric affect: the individual

could lack recreational social activity, or could be required to spend a large proportion of their daily life in close supervision at work. Neither possibility requires a global approach or withdrawal disposition.

In this way, the capability model increases flexibility in adapting theory to more real-world contexts in which individuals are likely to encounter and differentially respond to a wide variety of situations (Ross and Nisbett, 1991). It further suggests that EEG asymmetries may be alterable in ways that are analogous to learning to play a musical instrument through practice or building muscle strength through exercise. Of course, before these benefits can be anticipated with confidence, more tests of the capability model are needed.

The results reported above require replication, and the test–retest stability of individual differences recorded during emotional states on multiple occasions also remains to be evaluated. The latter has rarely been attempted, and even when it has, it has been only in the context of cognitive tasks. For example, Ehrlichman and Wiener (1979) recorded temporoparietal EEG bilaterally while subjects performed four verbal and four spatial tasks on two measurement occasions, and found (1) that EEG asymmetries in alpha differed as a function of verbal and spatial tasks in both sessions, and (2) that verbal-minus-spatial differences in the ratio of left to right power values were highly reliable both between and within subjects (Chronbach's alphas = 0.88 and 0.75, respectively).

6. Conclusion

To date, the literature on individual differences in frontal EEG asymmetry has, perhaps unwittingly, supported the analogy trait is to state as rest is to experimental manipulation. Results reported here suggest this analogy is incomplete at best, and potentially limiting at worst. If the capability model is correct, and this remains to be fully evaluated, then the best conditions under which to reliably measure individual differences in frontal EEG asymmetry may be during various emotional states. If true, the development of standardized, asymmetry-sensitive emotional challenges will greatly enhance the measure's theoretical and practical value.

In theory development, new models, or new forms of older models, must predict more than the model being replaced or modified. They must also accommodate extant empirical observations obtained under the older models. The capability model outlined above satisfies both criteria by (1) accommodating the extant empirical frontal EEG asymmetry findings based on resting tasks and, (2) making predictions that the dispositional model does not. Moreover, the evidence described here provides preliminary support for those predictions.² Ultimately, both models serve as heuristics for guiding new questions about frontal EEG asymmetry (as opposed to representing “truth with a capital T”). Thus, it is in the spirit of providing a potentially fruitful alternative heuristic for new research in frontal EEG asymmetry that these remarks are offered.

References

- Allen JJB, Kline JP. Frontal EEG asymmetry, emotion and psychopathology: the first, and the next, twenty-five years. *Biological Psychology* 2004;67:1–5. [PubMed: 15130523]
- Allen JJB, Coan JA, Nazarian M. Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. *Biological Psychology* 2004a;67:183–218. [PubMed: 15130531]
- Allen JJB, Urry HL, Hitt SK, Coan JA. The stability of resting frontal electroencephalographic asymmetry in depression. *Psychophysiology* 2004b;41:269–280. [PubMed: 15032992]
- Allen NB, Di Parsia P. Effects of mood induction on startle modulation by social threat in individuals with and without a history of depression. *Psychophysiology* 2002;39:S5.

- Binder JR, Frost JA, Hammeke TA, Bellgowan PSF, Rao SM, Cox RW. Conceptual processing during the conscious resting state: a functional MRI study. *Journal of Cognitive Neuroscience* 1999;11:80–93. [PubMed: 9950716]
- Blackhart GC, Kline JP, Donohue KF, LaRowe SD, Joiner TE. Affective responses to EEG preparation and their link to resting anterior EEG symmetry. *Personality and Individual Differences* 2002;32:167–174.
- Boele DR, Kokkonen M. Traits and emotions: a review of their structure and management. *European Journal of Personality* 2000;14:477–496.
- Bryden, MP. *Laterality: Functional Asymmetry in the Intact Brain*. Academic Press; New York: 1982.
- Cacioppo JT. Feelings and emotions: roles for electrophysiological markers. *Biological Psychology* 2004;67:235–243. [PubMed: 15130533]
- Chapman LJ, Chapman JP. The measurement of handedness. *Brain and Cognition* 1987;6:175–183. [PubMed: 3593557]
- Coan, JA. Unpublished Doctoral Dissertation. University of Arizona; 2003. The heritability of trait frontal EEG asymmetry and negative emotionality: sex differences and genetic nonadditivity.
- Coan JA, Allen JJB. Frontal EEG asymmetry and the behavioural activation and inhibition systems. *Psychophysiology* 2003a;40:106–114. [PubMed: 12751808]
- Coan, JA.; Allen, JJB. The state and trait nature of frontal EEG asymmetry in emotion. In: Hugdahl, K.; Davidson, RJ., editors. *The Asymmetrical Brain*. MIT Press; Cambridge, MA: 2003b. p. 565–615.
- Coan JA, Allen JJB. Varieties of emotional experience during voluntary emotional facial expressions. *Annals of the New York Academy of Sciences* 2003c;1000:375–379. [PubMed: 14766650]
- Coan JA, Allen JJB. Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology* 2004;67:7–49. [PubMed: 15130524]
- Coan JA, Allen JJB, Harmon-Jones E. Voluntary facial expression and hemispheric asymmetry over the frontal cortex. *Psychophysiology* 2001;38:912–925. [PubMed: 12240668]
- Cronbach, LJ.; Gleser, GC.; Nanda, H.; Rajaratnam, N. *The Dependability of Behavioral Measurements: Theory of Generalizability of Scores and Profiles*. Wiley; New York: 1972.
- Davidson RJ. Affective style and affective disorders: perspectives from affective neuroscience. *Cognition and Emotion* 1998a;12:307–330.
- Davidson RJ. Anterior electrophysiological asymmetries, emotion, and depression: conceptual and methodological conundrums. *Psychophysiology* 1998b;35 (5):607–614. [PubMed: 9715104]
- Davidson RJ, Ekman P, Saron CD, Senulis JA, Friesen WV. Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology I. *Journal of Personality and Social Psychology* 1990;58:330–341. [PubMed: 2319445]
- Di Nocera F, Ferlazzo F, Borghi V. G theory and the reliability of psychophysiological measures: a tutorial. *Psychophysiology* 2001;38:796–806. [PubMed: 11577903]
- Ehrlichman H, Wiener MS. Consistency of task-related EEG asymmetries. *Psychophysiology* 1979;16 (3):247–252. [PubMed: 441219]
- Ekman P, Davidson RJ. Voluntary smiling changes regional brain activity. *Psychological Science* 1993;4 (5):342–345.
- Ekman, P.; Friesen, WV. *The Facial Action Coding System (FACS): A Technique for the Measurement of Facial Action*. Consulting Psychologists Press; Palo Alto, CA: 1978.
- Hagemann D, Naumann E. The effects of ocular artifacts on (lateralized) broadband power in the EEG. *Clinical Neurophysiology* 2001;112 (2):215–231. [PubMed: 11165523]
- Hagemann D, Naumann E, Becker G, Maier S, Bartussek D. Frontal brain asymmetry and affective style: a conceptual replication. *Psychophysiology* 1998;35 (4):372–388. [PubMed: 9643052]
- Hagemann D, Naumann E, Lirken A, Becker G, Maier S, Bartussek D. EEG asymmetry, dispositional mood, and personality. *Personality and Individual Differences* 1999;27:541–568.
- Hagemann D, Naumann E, Thayer JF. The quest for the EEG reference revisited: a glance from brain asymmetry research. *Psychophysiology* 2001;38:847–857. [PubMed: 11577908]
- Hagemann D, Naumann E, Thayer JF, Bartussek D. Does resting electroencephalograph asymmetry reflect a trait? An application of latent state–trait theory. *Journal of Personality and Social Psychology* 2002;82 (4):619–641. [PubMed: 11999928]

- Harmon-Jones E, Abramson LY, Sigelman J, Bohlig A, Hogan ME, Harmon-Jones C. Proneness to hypomania/mania symptoms or depression symptoms and asymmetrical frontal cortical responses to an anger-evoking event. *Journal of Personality and Social Psychology* 2002;82:610–618. [PubMed: 11999927]
- Harmon-Jones E, Sigelman J. State anger and prefrontal brain activity: evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of Personality and Social Psychology* 2001;80 (5):797–803. [PubMed: 11374750]
- Kline JP, Blackhart GC, Joiner TE. Sex, lie scales, and electrode caps: an interpersonal context for defensiveness and anterior electroencephalographic asymmetry. *Personality and Individual Differences* 2002;33:459–478.
- Levenson RW, Ekman P, Friesen WV. Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology* 1990;27:363–384. [PubMed: 2236440]
- Lilienfeld SO, Wood JS, Garb HN. The scientific status of projective techniques. *Psychological Science in the Public Interest* 2000;1:27–66.
- McKiernan KA, Kaufman JN, Kucera-Thompson J, Binder JR. A parametric manipulation of factors affecting task-induced deactivation in functional neuroimaging. *Journal of Cognitive Neuroscience* 2003;15 (3):394–408. [PubMed: 12729491]
- Mischel, W. *Personality and Assessment*. Wiley; New York, NY: 1968.
- Mischel W, Shoda Y, Mendoza-Denton R. Situation–behavior profiles as a locus of consistency in personality. *Current Directions in Psychological Science* 2002;11 (2):50–54.
- Paulhus DL, Martin CL. The structure of personality capabilities. *Journal of Personality and Social Psychology* 1987;52 (2):354–365.
- Reid SA, Duke LM, Allen JJB. Resting frontal electroencephalographic asymmetry in depression: inconsistencies suggest the need to identify mediating factors. *Psychophysiology* 1998;35 (4):389–404. [PubMed: 9643053]
- Ross, L.; Nisbett, RE. *The Person and the Situation: Perspectives of Social Psychology*. McGraw-Hill; New York, NY: 1991.
- Rösler F. From single channel recordings to brain-mapping devices: the impact of electroencephalography on experimental psychology. *History of Psychology* 2005;8:95–117. [PubMed: 16021767]
- Shoda Y, Mischel W. Toward a unified, intra-individual dynamic conception of personality. *Journal of Research in Personality Special Issue: The Future of Personality* 1996;30 (3):414–428.
- Shoda Y, Mischel W. Reconciling contextualism with the core assumptions of personality psychology. *European Journal of Personality* 2000;14:407–428.
- Shoda Y, Mischel W, Wright JC. Intraindividual stability in the organization and patterning of behavior: incorporating psychological situations into the idiographic analysis of personality. *Journal of Personality and Social Psychology* 1994;67 (4):674–687. [PubMed: 7965613]
- Tomarken AJ, Davidson RJ, Wheeler RE, Kinney L. Psychometric properties of resting anterior EEG asymmetry: temporal stability and internal consistency. *Psychophysiology* 1992;29 (5):576–592. [PubMed: 1410187]
- Wallace J. An abilities conception of personality: some implications for personality measurement. *American Psychologist* 1966;21:132–138.
- Wallace J. What units shall we employ? Allport's question recited. *Journal of Consulting Psychology* 1967;31:56–64.
- Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology* 1988;54 (6):1063–1070. [PubMed: 3397865]

Figure 1.

Regression lines representing the relationship between NA and asymmetry in mid-frontal brain activity during a state Fear manipulation or resting asymmetry, with separate lines representing separate reference montages. For data obtained during Fear, all slopes ≤ -3.84 and all intercepts ≥ 20.94 ; for resting asymmetry, all slopes ≤ 25.12 and all intercepts ≥ 20.23 .

Table 1

Variance components, ρ^2 coefficients and ϕ coefficients for trait, state, reference scheme, and their interactions, obtained from mid-frontal EEG asymmetries observed during Rest, Anger, Disgust, Fear, Joy and Sadness.

Source	% Variance	ρ^2	ϕ
Individual (N=32)	26%	0.69	0.67
Condition (N=6)	05%	0.73	0.61
Reference Scheme (N=3)	01%	0.79	0.36
Individual X Condition	50%		
Individual X Reference Scheme	08%		
Condition X Reference Scheme	00%		
Individual X Condition X Reference Scheme, Error	10%		

Note: The ρ^2 (generalizability) coefficient indicates the reliability of the rank ordering of scores attributable to one source of variance over other sources, while the ϕ (dependability) coefficient indicates the reliability of the absolute value of scores attributable to one source of variance across other sources. Both are instances of the intraclass correlation.

Table 2

Variance components, ρ^2 coefficients and ϕ coefficients for trait obtained from mid-frontal EEG asymmetries observed at rest and during 5 emotional states.

Source	% Variance	ρ^2	ϕ
Rest			
Individual	16%	.38	.36
Reference	06%	.71	.67
Individual by Reference, Error	78%		
Anger			
Individual	72%	.89	.89
Reference	02%	.64	.33
Individual by Reference, Error	26%		
Disgust			
Individual	42%	.72	.69
Reference	09%	.86	.77
Individual by Reference, Error	49%		
Fear			
Individual	88%	.96	.96
Reference	01%	.69	.20
Individual by Reference, Error	11%		
Joy			
Individual	41%	.68	.68
Reference	01%	.24	.15
Individual by Reference, Error	58%		
Sadness			
Individual	91%	.97	.97
Reference	01%	.80	.25
Individual by Reference, Error	08%		

Note: N=32

Table 3

Zero order correlations between mid-frontal alpha asymmetry derived from different reference schemes during resting and state manipulation conditions.

Condition	<i>AR-Cz</i>	<i>AR-LM</i>	<i>Cz-LM</i>
<i>Rest</i>	.07	.67*	-.28
Anger	.79*	.91*	.64*
Disgust	.49*	.79*	.09
Fear	.93*	.96*	.91*
Joy	.53*	.68*	.02
Sadness	.97*	.98*	.95*

Note: N = 32,

* = $p < .01$

Table 4

Resting and Significant State Effects of two hierarchical linear mixed models, one predicting PA and the other predicting NA.

Effect	<i>df</i>	<i>F</i>	<i>P</i> <
PA			
Mid-Frontal at Rest	1, 71.58	3.63	0.06
Mid-Frontal during Joy	1, 64.35	5.30	0.03
NA			
Mid-Frontal at Rest	1, 69.01	0.69	0.45
Mid-Frontal during Fear	1, 68.49	4.21	0.05

Note: N = 32; Predictors included mid-frontal cortical activity asymmetries during rest, anger, disgust, fear, joy and sadness. In each model, reference scheme was included as a repeated measures factor, with participant ID nested within reference scheme.