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Personality, affect and EEG: predicting patterns of regional brain activity related to extraversion and neuroticism

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Abstract

An integration of Heller's model of brain activity based on the affect circumplex and findings from personality research resulted in predictions for patterns of frontal and posterior EEG alpha related to basic dimensions of personality, extraversion and neuroticism (Heller, 1990, 1993). Extraversion was predicted to be associated with greater relative left frontal and increased right posterior region activity, and introversion with greater relative right frontal and decreased right posterior region activity. Neuroticism was predicted to be associated with greater relative right frontal and increased right posterior region activity, and emotional stability with greater relative left frontal and decreased right posterior activity. Measures of extraversion and neuroticism (NEO-PI-R) were collected, and resting EEG was recorded for males and females on one occasion for eight 60-s periods. Mean log-transformed alpha power was extracted from the EEG for each electrode site and repeated-measures multiple regression analyses were conducted. As predicted, neuroticism was associated with greater relative right posterior activity. Predicted effects for neuroticism with frontal regions and for extraversion with brain activity were not significant. Results partially support the model of brain activity and affect proposed by Heller (1990, 1993), and suggest that it may be extended to include basic dimensions of personality such as neuroticism.

Keywords: Personality; Emotion; Psychophysiology; EEG

1. Introduction

Eysenck's (1967) theory relating extraversion and neuroticism to neural processes stimulated a great deal of research examining the connections between brain activity and personality,

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particularly extraversion's relation to cortical arousal. Unfortunately, these investigations of brain functioning, which focused primarily on global measures of cortical activity, were generally unsuccessful in finding clear relations between neural activity and traits (for reviews see Eysenck, 1990; Gale, 1983; Stelmack, 1990). However, recent theoretical and empirical advances in the areas of emotion, neuropsychology (Heller, 1990, 1993) and psychophysiology (e.g. Davidson & Tomarken, 1989) have generated new ideas and a better understanding of the theoretical relations between brain activity, emotion, and personality.

The goal of the current study was to integrate theories of affect, brain activity and personality into a single model to predict differences in regional patterns of electroencephalography (EEG) associated with trait extraversion and neuroticism. Orthogonal two-dimensional models representing mood, emotional states, and personality were integrated with models of brain activity that predict differences in hemispheric activity during different emotional states. The resulting theoretical framework generated predictions for patterns of activity in the left and right frontal and posterior hemispheres related to extraversion and neuroticism.

1.1. The basic dimensions of affect

Years of research in self-reported emotion and mood have resulted in a general consensus among most researchers that affective experience can be broadly represented in a two-dimensional structure (Meyer & Shack, 1989). These dimensions are considered to be independent and orthogonal and have been described as "valence" and "arousal," (Russell, 1980), or alternately, "Positive Affect" (PA) and "Negative Affect" (NA) (Watson & Tellegen, 1985). These two sets of dimensions have been demonstrated to be 45° rotations of each other, and are both represented in a circumplex structure.

1.2. The basic dimensions of personality

Although there is no general consensus on the total number of traits required to accurately capture and describe normal personality, two major dimensions of personality, extraversion and neuroticism, have been repeatedly identified by investigators across many diverse methodologies.

Eysenck regarded extraversion and neuroticism as fundamental traits, each deriving from a specific biological substrate. Extraversion was believed to be a product of the functioning of the reticular activating system, and neuroticism a product of the limbic system (Eysenck, 1967; Eysenck & Eysenck, 1985; Geen, 1997). Eysenck created an organizational model of personality by placing these bipolar dimensions at a 90° angle to each other, based on the idea that although extraversion and neuroticism are by no means the sole dimensions of personality, they are of sufficient scope to provide a comprehensive account of human behavior. He later added a third dimension to his personality theory, Psychoticism, but did not relate it to this model.

Other similar two-factor models have been proposed; Gray (1987a, 1987b) and Wiggins (1968) are among other researchers who have hypothesized that personality arises from a combination of two main dimensions that can be mapped onto a circumplex structure. Whereas Wiggins' traits, love and dominance, have been directly related to extraversion and neuroticism, Gray's impulsivity and anxiety have been shown to be rotational variants of these traits (see Matthews &

Gilliland, 1999). Gray (1987a, 1987b) demonstrates how impulsivity and anxiety spatially map onto Eysenck's extraversion and neuroticism dimensions.

Matthews and Gilliland (1999) have argued that the theories proposed by Eysenck and Gray may be referring to the same underlying physiological mechanisms at different levels of description. The appropriateness of one model over the other has been a continuing source of debate (e.g. Rusting & Larsen, 1997; Jackson, 2002; Gomez, Cooper, & Gomez, 2000), although more evidence thus far supports Eysenck's theory as more explanatory of variations in "normal" personality. In general, theoretical approaches to personality have hypothesized that at least two main dimensions arranged in a circumplex structure combine to represent fundamental aspects of personality.

Empirically driven personality researchers have also consistently replicated traits identified as extraversion and neuroticism (for a review see John, 1990). Cattell, one of the foremost empirical personality researchers, was one of the first to discover statistically derived traits identified as extraversion and neuroticism (Cattell & Kline, 1977). Other empirical researchers (e.g. Fiske, 1949; Norman, 1963) identified five-factor models in which two of the factors closely resemble the extraversion and neuroticism constructs proposed by Eysenck, and there is strong evidence to support this model of personality (e.g. Digman & Inouye, 1986; McCrae & Costa, 1987). Recently, Almagor, Tellegen, and Waller (1995) argued that seven dimensions provide a more accurate representation of personality than five; however, extraversion and neuroticism emerge as two of the seven factors. Although the number of traits required to comprehensively capture personality has yet to be concluded, there is substantial evidence that extraversion and neuroticism are the two most basic and significant dimensions.

Theoretically and statistically driven investigations of personality have thus invariably identified two major collections of traits, extraversion and neuroticism. As in the emotion domain, the alternatives to the Eysenck model (e.g. Gray, 1987a, 1987b) can be demonstrated to be rotational variants of these traits. Research across diverse methodological approaches has provided strong support for the idea that the two personality traits of extraversion and neuroticism are reliable and fundamental aspects of human behavior which provide an adequate description of "normal" personality in its broadest representation (Meyer & Shack, 1989).

1.3. Relations between affect and personality

There is evidence that the emotion and personality circumplex structures are systematically related (Diener, Larsen, Levine, & Emmons, 1985; Larsen & Diener, 1992). Diener and colleagues demonstrated that the basic dimensions of affect, valence (pleasant–unpleasant) and arousal or activation (activated–unactivated), are related to historical temperament types, and therefore are also related to Eysenck's basic dimensions of personality, extraversion and neuroticism. The dimensions of affect proposed by Watson and Tellegen can also be mapped onto extraversion and neuroticism, and empirical research supports the idea that they are linked. Extraversion and neuroticism traits have consistently been related to pleasant and unpleasant mood states, respectively (e.g. Canli, Zhao, Desmond, Kang, Gross, & Gabrieli, 2001; Costa & McCrae, 1980; Gross, Sutton, & Ketelaar, 1998; Larsen & Ketelaar, 1989; Meyer & Shack, 1989; Rusting & Larsen, 1997). It can be argued that these personality and affective dimensions are simply alternative ways of describing the same phenomena, possibly manifested by the same underlying structures.

Diener, Smith, and Fujita (1995) suggested that extraversion and neuroticism may reflect differences in the activity of two central brain mechanisms, one involved in pleasant and the other unpleasant emotions. If personality traits genuinely reflect differences in the activity of two central, neural structures, then measures intended to index the physiological activity of these hypothesized neural structures should vary with extraversion and neuroticism.

1.4. Brain activity and affect

Two general models of brain activity related to affective mood states have been developed—one resembles that of Watson and Tellegen (1985) which asserts that differences in brain activity related to affect can best be characterized as resulting from the activity of two main systems, one responsible for pleasant affect and one for negative affect. The other model corresponds more closely with that of Russell (1980), in which brain activity associated with affect is best represented by two alternative dimensions, activation (or arousal), and pleasantness. It is entirely possible that both models provide accurate representations of the data but differ simply in the dimensions chosen or rotation of factors.

The model proposed by Davidson (1992a) and colleagues (Davidson & Tomarken, 1989; Sutton & Davidson, 2000) hypothesizes that the frontal regions of the brain house a "convergence zone" for two separate systems involved in emotion: the approach and withdrawal systems. The approach system has been predominantly associated with pleasant affect, although recent research by Harmon-Jones and colleagues (Harmon-Jones & Allen, 1998; Harmon-Jones & Sigelman, 2001) has extended this to include anger as an approach-related emotion. The withdrawal system has generally been associated with unpleasant affect. These systems are hypothesized to be lateralized to the left and right hemispheres, respectively. This model predicts that resting levels of anterior activity in the left and right frontal regions should be associated with variations in pleasant and unpleasant affect.

Davidson (1993) and colleagues (Davidson & Tomarken, 1989; Wheeler, Davidson, & Tomarken, 1993) also assert that individual differences in the asymmetry of baseline frontal activity are present early in life (Davidson & Fox, 1989), are relatively stable over time (Davidson, 1992b), and should be associated with differences in vulnerability to pleasant and unpleasant moods.

There is substantial evidence to support his theory (for a review see Gale, Edwards, Morris, Moore, & Forrester, 2001). Research investigating brain activity using EEG has demonstrated that frontal asymmetries are strongly related to dispositional mood, temperament, psychopathology, and reactivity to emotion-eliciting stimuli (Davidson, 1992b; Tomarken, Davidson, & Henriques, 1990; Wheeler et al., 1993; Tomarken, Davidson, Wheeler, & Doss, 1992).

An alternative model, proposed by Heller (1990, 1993) focuses on the valence and activation dimensions of emotion, allowing predictions of brain activity to be generated for all affects on the emotion circumplex. This model, similar to that proposed by Davidson, implicates the frontal regions as important for the valence dimension. Increased left frontal activity, relative to right, indicates the experience of pleasant affect, whereas increased right frontal activity, relative to left, indicates negative affect. However, Heller's model allows for predictions of patterns of brain activity not only for the frontal, but the posterior regions of the brain as well, which are hypothesized to be influential in the activation/arousal component of affect (for a review see Heller, 1993). The right parietotemporal regions are believed to play a role in autonomic arousal functioning and are instrumental in generating or regulating autonomic arousal associated with emotional states. These regions appear to be integrally involved not only in the processing of emotional information, but also the experience of affect, as variations in the activity of the right hemisphere have been associated with emotional states such as depression and anxiety (Heller, Nitschke, Etienne, & Miller, 1997; Isotani et al., 2001). Research has generally supported Heller's model for brain activity associated with depression and unpleasant moods (for a review see Heller, 1993), as well as aroused or activated mood states (Heller, Nitschke, & Lindsay, 1997).

Because of the right hemisphere's role in the arousal component of emotion, Heller hypothesizes that activated affect should be associated with increased right posterior activity, and inactivated affect with decreased activity in this region. Heller's theory is based on the right posterior hemisphere's involvement in arousal or activated emotion; therefore, it is currently unclear whether increased activity should be considered solely within the right or measured relative to the left posterior hemisphere.

Heller's model predicts that different patterns of brain activity will be associated with each of the four quadrants delineated by the valence and activation dimensions of the emotion circumplex. As shown in Fig. 1, activated pleasant affect (e.g. elation) should be associated with increased left, relative to right, frontal as well as increased right posterior activity. Activated unpleasant affect (e.g. anxiety) should be associated with increased right, relative to left, frontal, as well as increased right posterior activity. Unactivated pleasant affect (e.g. relaxation) should be associated with increased left, relative to right, frontal combined with decreased right posterior

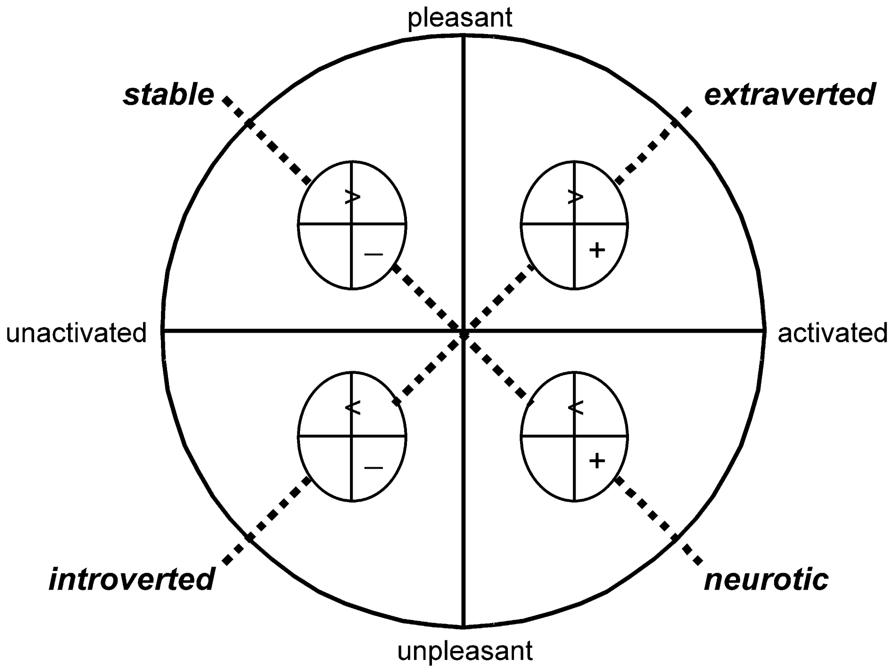

Fig. 1. Overlay of Heller's (1990, 1993) model of brain activation associated with affect on the circumplex structures of personality (Eysenck) and affect (Watson & Tellegen). The ovals indicate a schematic brain, with the top two quadrants representing the left and right frontal regions, and the bottom two quadrants representing the left and right posterior regions. Symbols indicate predictions for brain activity.

activity. Finally, unactivated unpleasant affect (e.g. depression) should be associated with increased right, relative to left, frontal and decreased right posterior activity.

Heller's model resembles that of affect proposed by Russell (1980) and Diener and colleagues (Diener et al., 1985), as it represents neural activity with the orthogonal dimensions of pleasantness–unpleasantness and activation–unactivation. Davidson's model, conversely, is analogous to the model proposed by Watson and Tellegen (1985) in which affective states are conceptualized as resulting from two independent positive and negative affective systems. Heller's model appears to be more useful for the present purposes for several reasons. First, all affects represented in the circumplex model of emotion are related to specific patterns of brain activity. In contrast, the model proposed by Davidson and colleagues considers only the valence aspect of emotion, and does not distinguish between the activated and unactivated forms of pleasant and unpleasant affect, leaving brain activity for sections of the circumplex unpredicted, unexplained, and untested. Second, Heller's model includes the posterior regions thought to be involved in the regulation of behavioral activation and arousal, and generates predictions for posterior, as well as frontal, asymmetries in brain activity during affective states and moods. Finally, Heller's model, because it uses the emotion circumplex to represent the relations between affective states and brain activity, provides a framework for making predictions for patterns of brain activity that should correspond to the "big two" (Wiggins, 1968) personality traits, extraversion and neuroticism.

1.5. Brain activity, affect and personality

Research investigating EEG activity and personality has historically failed to illuminate clear relations between these constructs (Stelmack, 1990). However left/right hemisphere differences in combination with frontal/parietal differences for extraversion and neuroticism have only just begun to be investigated (e.g. Hagemann, Naumann, Lurken, Becker, Maier, & Bartussek, 1999). The circumplex model developed for the current study provides a theoretical basis for making predictions for patterns of frontal and posterior brain activity that may have been obscured in past studies which only investigated more global changes in EEG activity related to these traits. Extraversion and neuroticism have been found to be strongly related to pleasant and unpleasant affective states, and pleasant and unpleasant affective states have been shown to be related to different patterns of brain activity; therefore, it follows that these basic traits should also be associated with different patterns of neural activity.

1.6. Hypotheses for the current study

To assess whether individual differences in personality would be associated with variations in patterns of brain activity, Heller's (1990, 1993) model of affect-related brain activity was integrated with the circumplex structure of emotion and personality traits. This integrated model was then used to generate predictions for patterns of EEG associated with extraversion and neuroticism for both the frontal and posterior regions (see Fig. 1). In general, it was hypothesized that patterns of brain activity associated with pleasant and unpleasant affective states on the circumplex would also be strongly associated with extraversion and neuroticism. To test the hypotheses, each hemisphere was divided caudally, creating a total of four regions that correspond to those in Heller's model: left frontal, right frontal, left posterior, and right posterior. Four predictions were made for activity in the four regions related to extraversion and neuroticism based on the placement of each in the circumplex model. First, extraversion was expected to be associated with greater relative left frontal activity, as well as increased right posterior region activity, and introversion to be associated with greater relative right frontal activity, as well as decreased right posterior region activity. Neuroticism was predicted to be associated with greater relative right frontal and increased right posterior region activity. Finally, emotional stability was predicted to be associated with greater relative left frontal and decreased right posterior activity. Brain activity was quantified as voltage in the alpha band (8–13 Hz) of scalp-recorded EEG, as decreased alpha has been related to increased cortical activity (Davidson, Chapman, Chapman, & Henriques, 1990), and prior investigations have linked log-transformed alpha power asymmetries for the left and right hemispheres in this band most consistently with individual differences in affective states (Davidson et al., 1990), affective predispositions (Tomarken et al., 1990; Tomarken, Davidson, Wheeler, & Doss, 1992; Tomarken & Davidson, 1994), and affective information processing (Sutton, Davidson, & Rogers, 1996).

2. Method

2.1. Participants

Participants for the study were 116 university undergraduates ranging from 17 to 21 years of age (Mean = 18.44, S.D. = 0.75) who received class credit for participation. All reported being free from current or past depression, history of head injuries, neurological disorders, and psychoactive drugs. Because of technical problems, EEG measures for nine participants were dropped from the final analysis. The final sample of 107 consisted of 55 females and 52 males.

2.2. Procedure

Participants were informed that the purpose of the study was to investigate the relations between brain activity and personality traits. They were told they would be asked to fill out a series of questionnaires assessing various personality traits, and brain activity would be recorded using EEG. After written and verbal informed consent was obtained, electrodes were applied while personality questionnaires were administered.

EEG was recorded for each individual by a female experimenter in a sound-attenuated, air-conditioned room. It was explained to participants that a total of 8 min of resting brain activity would be recorded in 1-min periods, during which they would be instructed to keep their eyes either open or closed. No detailed or specific instructions were given, other than a request to focus on a spot on the bare wall, to minimize blinking during the "eyes-open" periods, and to be "as restful and relaxed as possible" during the EEG recording. Following standard procedures employed in previous studies investigating baseline EEG and individual difference variables (e.g. Hagemann et al., 1999; Sutton & Davidson, 1997), two randomly assigned, counterbalanced orders were used for the eyes-open [O] and eyes-closed [C] trials [O–C–C–O–C–O–O–C and C–O–O–C–O–C–C–O].

2.3. EEG recording and quantification

EEG was measured using a lycra cap (Electro-Cap International, Eaton, OH) containing tin electrodes filled with Electro-Gel (Electro-Cap Inter.). EEG was recorded from the following locations: left and right medial frontal (F3 and F4), left and right lateral frontal (F7 and F8), left and right central (C3 and C4), left and right parietal (P3 and P4), left and right posterior temporal (T5 and T6), mid-frontal (Fz), mid-central (Cz), and mid-parietal (Pz). All electrodes were referenced to linked earlobes, and earlobe impedances were reduced to within 0.1 K ohms of each other to prevent the possibility of artificial inflation of amplitude of the leads on the side of the reference electrode with the highest resistance. EOG was recorded from Ag/AgCl electrodes placed at the external canthus of each eye and supra- and suborbitally to the left eye. EEG and EOG were amplified using a Grass model 12 Neurodata System. Half-amplitude filters were set at 1–100 Hz, and a 60 Hz notch filter was used. EEG was amplified by a factor of 20 K and EOG by 10 K and was digitized at a rate of 256 samples/s by a personal computer.

Each trial of data was carefully screened and hand-scored for eye-movement artifact. All artifact screening and data analysis were completed before personality data were scored to prevent experimenter bias. Portions of data containing vertical or horizontal eye-movement artifact, muscle movement, or other artifact were removed prior to further analysis, and the identification of artifact in any one channel for a given trial resulted in the deletion of all channels for that trial in order to insure that data obtained for each site were derived from identical time periods. Slow drift activity was filtered using an autoregressive high-pass filter with a time constant of 200 ms. The average number of seconds of artifact-free data for each 60-s baseline for the sample as a whole was 43.8 s, comparable with 43 s per 60-s baseline reported by Tomarken, Davidson, Wheeler, and Kinney (1992). No significant relations were found between personality measures and the number of artifact-free trials retained. Each 2-s chunk of artifact-free data was spectral analyzed using a Fast Fourier Transform with a Hanning window, and estimates of absolute spectral power were generated for the alpha band (8–13 Hz). Power density values (in $\mu v^2/Hz$) for each 1-min baseline were computed by dividing by the number of Hz estimates within each band, providing an index of the mean power density within the alpha frequency range. Alpha power densities were log-transformed to normalize the distributions for parametric statistics, and a grand mean was created for each electrode site by averaging across all eight log-transformed baselines. Statistical analysis focused on power values for individual sites as well as asymmetry scores indicating relative differences among homologous sites when needed to clarify analyses. Asymmetry scores were created for homologous sites by subtracting the log-transformed alpha power density grand mean from the left site from that of the right (i.e. log R−log L).

Caution must be taken in directly inferring EEG activity measured at each scalp site as representative of activity in a particular area of the brain, as a unique dipole source cannot be conclusively determined from scalp data (Lutzenberger, Elbert, & Rockstroh, 1987). However, the current study assumed the traditional notion (e.g. Davidson, 1988) that EEG alpha power measured at each specific site is inversely related to the activity in the brain region near that electrode site in order to make inferences about regional brain activity.

2.4. Self-report measures

2.4.1. Screening questionnaire

A brief questionnaire was created to screen for neurological disorders, head traumas, recent drug and alcohol use, depression, unusual sleeping/eating patterns and adequate sleep prior to the procedure.

2.4.2. NEO-PI-R

Extraversion and neuroticism were assessed using a well-validated inventory of the five-factor model of personality, the Neuroticism, Extraversion, and Openness Personality Inventory Revised (NEO-PI-R, Costa & McCrae, 1992). The NEO-PI-R consists of items rated on a five-point Likert scale ranging from ''strongly disagree'' to ''strongly agree.'' Internal consistency reliability coefficients for the major traits have been reported to range from 0.86 to 0.95. Several other personality questionnaires were administered but are not included in the current analysis.

3. Results

3.1. Reliability analyses

Reliabilities computed for the extraversion and neuroticism scales demonstrated strong internal consistency and were both = 0.91. Means and standard deviations for extraversion and neuroticism were 122.98 (S.D. = 21.27) and 88.88 (S.D. = 22.87), similar to normative values. As expected, the extraversion and neuroticism scales were not significantly correlated ($r = -0.10$, $P > 0.05$). For brain activity, internal consistency Cronbach's alpha coefficients for log-transformed alpha power at each individual site across the eight baseline trials were excellent and ranged from 0.90 to 0.95. Alpha coefficients, alpha power density means and standard deviations for each site are listed in Table 1. Correlations between personality traits and asymmetry scores are listed in Table 2.

Table 1
Alpha reliabilities and alpha power density means and standard deviations for brain activity measures

Site	α	Mean (S.D.) overall ($n = 107$)
F7	0.92	0.475(0.61)
F8	0.91	0.486(0.61)
F3	0.92	1.062(0.64)
F4	0.91	1.074(0.63)
P3	0.91	1.752(0.82)
P4	0.91	1.775(0.82)
T5	0.90	1.438(0.84)
T6	0.90	1.574(0.86)
F7/F8 Asymmetry	–	0.011(0.26)
F3/F4 Asymmetry	–	0.013(0.09)
P3/P4 Asymmetry	–	0.023(0.17)
T5/T6 Asymmetry	–	0.136(0.39)

Table 2
Correlations between asymmetry scores and personality traits

Site	Extraversion	Neuroticism
F7 / F8	0.05	−0.01
F3 / F4	−0.02	−0.07
P3 / P4	−0.05	−0.26*
T5 / T6	−0.05	−0.31*

* $P<0.01$.

3.2. Multivariate analyses

Increased left frontal activity was expected for extraversion and decreased left frontal activity was expected for higher neuroticism. Conversely, increased right frontal activity was expected for higher neuroticism and decreased right frontal activity was expected for higher extraversion. Therefore, extraversion and neuroticism were predicted to interact within each hemisphere in the frontal regions. In the posterior regions, the model can only be used to make predictions for the right posterior hemisphere; therefore, predictions were limited to right hemisphere sites. Increased right posterior activity was predicted for both higher extraversion and higher neuroticism. Lower personality scores were expected to be associated with decreased activity in this region. Therefore, only main effects were predicted for the posterior right hemisphere. As a result of the different predictions for the effects of extraversion and neuroticism in the frontal and posterior regions, separate analyses were conducted for each region.

Because differences for males and females have been found in previous studies of brain function and affect (Heller, 1993; Levy & Heller, 1992; Taitano & Heller, 1998), sex was included as a factor in the statistical models. However, there were no a priori hypotheses for sex-related effects, and no sex-related effects were obtained in any of the analyses.

3.3. NEO-PI-R extraversion and neuroticism: frontal regions

To test the predicted extraversion by neuroticism interaction for the frontal regions, a repeated-measures multiple regression analysis of activity was conducted using SPSS General Linear Model (GLM) procedure with EXTRAVERSION, NEUROTICISM and their interaction as continuous between-subjects variables, and REGION (lateral frontal, medial frontal) and HEMISPHERE (left, right) as within-subjects variables. The dependent variable was frontal EEG alpha.

Results revealed no significant main effects or interactions for any of the personality or within-subjects variables (all Ps >0.09). More importantly, the predicted EXTRAVERSION× NEUROTICISM×HEMISPHERE interaction, which would indicate that activity in each frontal hemisphere varied as a result of extraversion and neuroticism was not significant ($P>0.15$).

3.4. NEO-PI-R extraversion and neuroticism: posterior regions

The results of the GLM for the posterior regions indicated a significant predicted HEMISPHERE×NEUROTICISM effect, $F(1, 104)=11.65$, $P<0.01$. Fig. 2 demonstrates that as

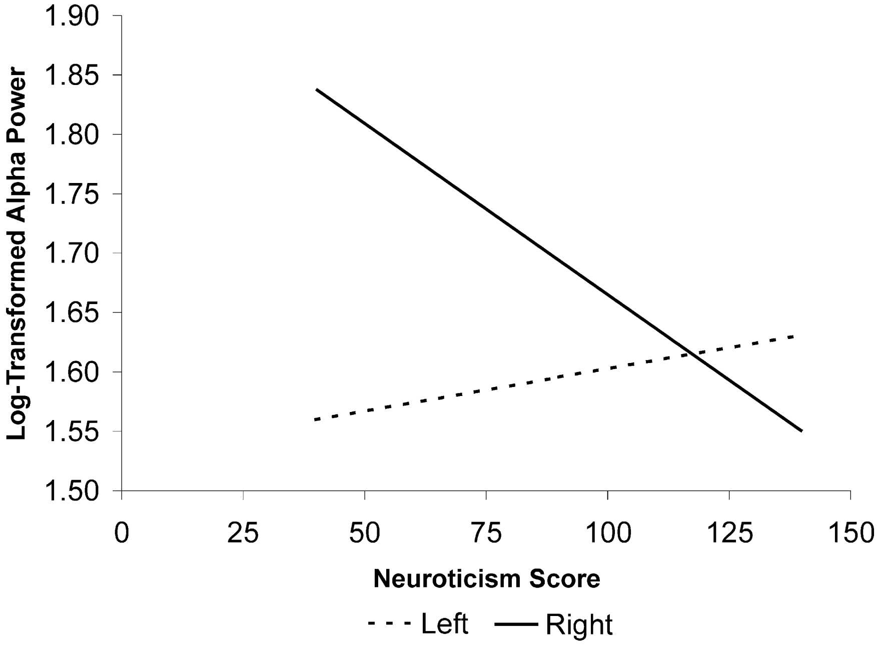

Fig. 2. Hemisphere by neuroticism interaction.

expected by the model, the relations between the two hemispheres with neuroticism differed; activity in the right posterior hemisphere increased as neuroticism scores increased, whereas activity in the left posterior demonstrated the reverse pattern. There was also a significant HEMISPHERE×REGION×NEUROTICISM effect, $F(1, 104)=9.19$, $P<0.01$). To further investigate this effect, asymmetry scores between hemispheres were computed by subtracting power in the left hemisphere from that of the right (logR−logL). An additional GLM was conducted with NEUROTICISM as a continuous between-subjects variable, REGION (parietal, posterior temporal) as the repeated-measures factor, and asymmetry score as the dependent variable. This analysis revealed a main effect for REGION, $F(1, 105)=15.76$, $P<0.01$, and a REGION×NEUROTICISM interaction, $F(1, 105)=8.92$, $P<0.01$). The individual regression lines for asymmetry at the parietal and posterior temporal sites with neuroticism scores were significantly different; a stronger relationship was found between neuroticism scores with asymmetry scores in the posterior temporal region than the parietal region. However, individual univariate regressions indicated that, as predicted, both were significant ($P<0.01$). There were no significant effects involving extraversion.

4. Discussion

4.1. Frontal EEG activity, extraversion and neuroticism

Based upon the model for brain activity and personality presented, we hypothesized that extraversion and neuroticism would interact to predict EEG activity in the frontal regions.

Greater relative left frontal activity was predicted for higher extraversion scores, while greater right frontal activity was predicted for higher neuroticism scores. Our data did not support these predictions, and are consistent with those reported by Hagemann et al. (1999) who also failed to identify significant relations between lateralized cortical activation and personality traits.

Although no significant findings for personality and frontal EEG were obtained in the current study, previous investigations have found significant effects between extraversion and frontal activity in the direction predicted by our model. Stenberg, Risberg Warkentin, and Rosen (1990) found that while introversion was related to higher bilateral blood flow in the temporal lobes, extraversion was related to elevated blood flow in the left frontal region at rest. In addition, Schmidt (1999) recently found that sociability, a component of extraversion, was associated with greater relative left frontal activity, whereas shyness was associated with greater relative right frontal activity.

4.2. Posterior EEG activity, extraversion and neuroticism

We predicted greater relative right hemisphere activity in the posterior regions for both higher neuroticism and extraversion. Although the predictions for extraversion were not supported by the data, significantly greater activity in the posterior right hemisphere was observed for increased neuroticism. These findings were as predicted by the model of brain activity and personality in the current study based on Heller's (1990, 1993) model of brain activity associated with affect. Based on theoretical assumptions and empirical findings relating personality to affect, it was expected that the quadrant delineated in Heller's model by the unpleasant and high activation axes, which she defines as ''anxious'' (Heller, 1993), would also delineate those participants scoring high on neuroticism in the current study. Further, our data also support the prediction that the opposite quadrant, delineated by the pleasant and low activation axes, would be representative of those individuals with low neuroticism, defined as ''stable'' in the current research. Although not significant, data reported by Hagemann et al. (1999) also indicate a correlation between parietal region asymmetry and neuroticism in the direction that is consistent with our model of brain activity and personality (higher neuroticism related to increased right posterior activity). In contrast to our findings, Gale et al. (2001), using left/right ratio scores, identified a significant relationship between activity in the frontal and posterior right hemisphere with neuroticism in the opposite direction—neuroticism was associated with increased cortical activity in the left hemisphere. In this study, participants were asked to empathize with pictures of happy and sad faces and to rate each face following its presentation. However, as the authors note, participants may have been engaging in sub-vocal self instruction or rumination in an effort to empathize with, as well as in preparation to verbally rate, each happy and sad face. The left hemisphere's involvement in verbal abilities is well established and it is possible that increased left hemisphere activity was a by-product of these processes.

Our use of the NEO-PI-R to measure extraversion may also have affected our ability to identify relations between EEG and extraversion. It has been argued (Matthews & Gilliland, 1999; O'Gorman & Lloyd, 1987) that it may be extraversion's sub-trait, impulsivity, which is especially predictive of EEG. The NEO-PI-R includes impulsivity within the construct of neuroticism, rather than extraversion; therefore, it is possible that our selection of this measure to assess the construct of extraversion may have prevented us from obtaining significant results. Another potential explanation for the lack of findings for extraversion in the posterior regions is the power associated with the effects for extraversion; observed power in the posterior regions was very small (<0.15).

Our method of data collection may also have had a strong impact on the findings for EEG and personality. We collected 8 min of "resting" EEG in which participants were asked to be "restful and relaxed," as this has been the standard procedure employed in previous studies investigating baseline EEG and individual difference variables (e.g. Hagemann, Naumann, Becker, Maier, & Bartussek, 1998, 1999; Tomarken, Davidson, Wheeler, & Doss, 1992). However, as Gale et al. (2001) point out, these conditions under which EEG is collected may be criticized as exemplifying the "boring" task conditions argued by Gale (1983) that may confound data as a result of participants' compensation for the low arousing situation. Low-arousal EEG recording conditions may have interacted with varying levels of extraversion, such that introverts may have relaxed (reducing cortical activation), while extraverts engaged in mental effort in an attempt to increase cortical arousal to a more optimal level, effectively cancelling out variation for different levels of the trait.

It is also possible that the nonsignificant findings between personality measures and EEG may be explained by occasion-specific fluctuations of lateralized cortical activity that may have obscured or distorted the relations between cortical activity and trait extraversion and neuroticism. Tomarken, Davidson, Wheeler, and Kinney (1992) proposed that baseline EEG may be reflective of both stable individual differences, as well as state factors, and Davidson (1998) has argued that multiple assessments of baseline EEG are essential to obtain a reliable estimate of activation that more accurately reflects an individual's true score. A recent investigation by Hagemann, Naumann, Thayer, and Bartussek (2002) provides empirical evidence to support the recommendation of multiple assessment occasions. Hagemann et al. examined the hypothesis that resting EEG asymmetry is representative of the joint combination of trait-like activation asymmetry with substantial state-dependent influences. Their results indicated that approximately 60% of variance of the asymmetry measures was due to trait variables, and about 40% of the variance of resting EEG asymmetry was due to occasion-specific effects. They conclude that experiments that include only one occasion of measurement are subject to substantial error variance and may lead to invalid conclusions, which further contribute to inconsistencies in findings. Based on their results, it is likely that the single-occasion measurement of EEG in the current study significantly limited our ability to identify the predicted effects for extraversion, neuroticism and cortical activity.

5. Conclusions

These findings provide partial support for the hypothesis that personality traits are related to patterns of resting regional brain activity, indexed by baseline scalp EEG alpha. The results also partially support Heller's (1990, 1993) circumplex model of brain activity and affect; greater neuroticism was associated with increased activity in the right posterior hemisphere. Contrary to predictions, no significant relations were obtained for extraversion or neuroticism with activity in the frontal regions or for extraversion with activity in the posterior regions. Our findings for neuroticism with posterior activity underscore the suggestion made by Gale et al. (2001) that failure to recognize personality differences in investigations of hemispheric EEG can inflate the error variance in experimental designs.

Future research is necessary to clarify the appropriateness of Heller's model for personality and brain activity. Ideally, future investigations will include EEG measurement under conditions of varied arousal (including "resting") on multiple occasions to reduce occasion-specific effects and gain a truer score of individual difference variables. In addition, the inclusion of a measure of extraversion which contains impulsivity [such as the Eysenck Personality Inventory (Eysenck & Eysenck, 1964)] in combination with the NEO-PI-R extraversion construct will provide a direct test of the extent to which impulsivity is predictive of significant effects for extraversion.

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