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Personality traits and its association with resting regional brain activity☆

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Abstract

The association between personality and resting brain activity was investigated. Personality was assessed using the NEO-Five-factor Inventory (NEO-FFI) and resting brain activity was indexed by eyes closed EEG spectral magnitude from four frequency bands over the entire cortex. Results suggest that there are differences between males and females in the NEO-FFI personality traits. The NEO FFI traits were associated with lower frequency brain activity in both males and females. Mild significant and consistent associations were found between delta and theta activity across all cortical regions with Extraversion and Conscientiousness. There were few associations between personality traits and alpha and beta activity, this was shown in males only. Fewer associations between personality and faster frequency bands such as alpha may be due to the methodological problem of using fixed alpha bands. Multiple regression analyses showed that individual alpha frequencies had a greater contribution to personality traits than fixed band alpha waves.
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1. Introduction

Many studies have investigated the association between personality and brain activity, mostly in the alpha wave band, using what are believed to be two basic personality dimensions, namely, extraversion and neuroticism (Schmidtke and Heller, 2004; Tran et al., 2001). The interest in exploring extraversion/neuroticism and brain activity was stimulated by Hans Eysenck's theory of personality (Eysenck, 1967, 1990), which postulated that the biological explanation of extraversion can be described in terms of cortical arousal via the ascending reticular activating system (ARAS). Activity in the ARAS stimulates the cerebral cortex, which leads to higher cortical arousal. It was also postulated that introverted and extraverted personalities differ in their threshold for cortical arousal such that introverts were believed to have a lower threshold for arousal as they were assumed to be chronically "over-aroused", seeking a state of lower arousal. Conversely, extraverts were believed to have a higher threshold for arousal, as they are assumed to be chronically "under-aroused" and seeking a state of higher arousal (Eysenck, 1967, 1990). Neuroticism was explained in terms of activation thresholds in the sympathetic nervous system or visceral brain (the limbic system). Individuals with higher scores in neuroticism had greater activation levels and lower thresholds within subcortical structures such as the septum, amygdala and hypothalamus (Eysenck, 1990).

Since alpha waves were traditionally considered as a thalamocortical rhythm (Knyazev and Slobodskaya, 2003), it was assumed that cortical arousal was linked to the amplitude and frequency of the alpha rhythm (Golan and Neufield, 1996), with high amplitude low frequency activity associated with low cortical arousal and low amplitude high frequency activity associated with high cortical arousal (Tran et al., 2001).

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However, studies that have explored the associations between brain activity and extraversion/neuroticism have found equivocal and often conflicting results, due in part to weaknesses in methodology (Gale and Edwards, 1983; Tran et al., 2001). Common problems have been for instance, low subject numbers resulting in low statistical power, use of subjects with narrow and younger age ranges, inappropriate subject selection and failure to control cortical activation in subjects (Fink and Neubauer, 2004; Gale et al., 2001; Tran et al., 2001). Nevertheless, recent studies that have addressed many of the methodological weaknesses are finding support for an association between EEG alpha wave activity and extraversion (Fink and Neubauer, 2004; Gale et al., 2001; Tran et al., 2001), especially in frontal-temporal regions. Gale et al. (2001) found extraverts to be less cortically aroused than introverts, and that neuroticism was associated with larger left versus right hemisphere differences in alpha wave activity related to mood. Tran et al. (2001) showed extraverted persons to be at least three times more likely to have larger peak amplitudes in frontal alpha wave activity. However, they found no association between extraversion and alpha activity in posterior regions, and there were no alpha wave activity differences found between those with high and low anxiety levels. Studies have found associations between EEG and neuroticism/negative affect scores with alpha band asymmetry in the frontal regions (Hagemann et al., 1999; Minnix and Kline, 2004). Theta band power changes have also been found during threatening and pleasant visual stimuli in people with different trait anxiety levels (Aftanas et al., 2003). Fink and Neubauer (2004) showed that the complexity of the task (the experimentally induced cortical arousal levels) was an important factor when investigating the association between extraversion and brain activity. They showed that extraverted persons had lower cortical activation levels, but only in more arousing experimental conditions. It is important to note that in studies by Fink et al. (2002) and Fink and Neubauer (2004), only associations between extraversion and brain activity in lower EEG frequency ranges were found (mostly 6–8 Hz), which Klimesch (1999) argues is more than likely low alpha frequency activity, depending on factors such as age, task demands, thickness of the skull, and so on. For this reason, Klimesch (1999) suggests individually defined frequency bands be used rather than fixed EEG bands when studying associations between alpha activity and personality or cognitive performance.

The above demonstrates that research has more commonly investigated the relationship between personality and alpha wave activity. However, there is evidence to suggest that delta and theta activity are linked with activity from the brainstem and limbic systems, respectively (Knyazev and Slobodskaya, 2003). Both these structures play an important role in maintaining arousal (Joseph, 1990). Theta activity has also been shown to synchronize as a function of increased task demands (Klimesch, 1999). The evidence cited above also suggests that low frequency alpha wave activity (6–8 Hz) in some individuals is associated with extraversion (Fink and Neubauer, 2004; Fink et al., 2002). Therefore, a strong case for exploring the relationship between lower EEG frequencies such as delta/theta and personality exists. This is a major aim of this study. Furthermore, as there have been few studies that have examined the association between alternative personality factors and brain activity, a further aim of this study was to explore the possible relationships with additional personality dimensions to extraversion and neuroticism.

To achieve this aim, personality was assessed in the present study by an inventory that measures five broad personality dimensions, developed by McCrae and Costa (1990). The test is called the NEO-five-factor inventory (NEO-FFI) and is based upon the so-called five factor model (FFM), which posits five major domains of personality (Costa and McCrae, 1992; Goldberg, 1992; Mauran, 1997; McCrae and John, 1992), including Neuroticism (tendency to experience negative affect), Extraversion (gregarious, excitement seeking), Openness to experience (adventurous and broad-mindedness), Agreeableness (helpfulness, compassion) and Conscientiousness (dependability, responsibility) (Saulsman and Page, 2004; Theakston et al., in press). The FFM is a hierarchical model, with more specific personality traits comprising each of the five dimensions. For example, the neuroticism score is comprised of anxiety, anger, hostility, depression, self-consciousness, impulsiveness, and vulnerability subdimensions (Costa and McCrae, 1992). Schmidtke and Heller (2004) studied the association between alpha activity and extraversion/neuroticism as measured by the NEO personality inventory (revised). They predicted associations based on Heller's (1993) model which provides a framework for exploring the relationship between extraversion/neuroticism and patterns of brain activity over the left and right/anterior and posterior regions of the cortex. They found that neuroticism was significantly related to greater right hemisphere posterior alpha activity. However, they did not find an association between alpha activity and extraversion in frontal regions. Stough et al. (2001) investigated the psychophysiological association between brain activity as a function of photic stimulation and the NEO-FFI personality dimensions Openness to experience, Agreeableness and Conscientiousness. While subject numbers were small in their study (16 participants), they found significant associations between these traits and theta, alpha and beta-1 activity. Given the small subject numbers, the findings of Stough et al. (2001) can only be considered preliminary findings. Therefore, a further aim of this study was to explore the association between the five NEO-FFI personality traits and brain wave activity across all cortical regions in a large group of adults.

2. Materials and methods

2.1. Database

Data for the present study was obtained from the Brain Resource International Database, a fully standardized International Database compiled on the human brain (BRID; Gordon, 2003). This consists of data from over 1200 non-diseased subjects ranging in age from 6 to over 80 years. The BRID data has been collected over 10 laboratories around the world (Gordon, 2003) using standardized hardware and software, as well as standard assessment protocol and procedures. The database consists of psychological and cognitive assessments of over 1200 normative participants with data on demographic, neuropsychological (cognitive), electrical brain–body function, and lifestyle.

2.2. Participants

For the purposes of this study, it was important to investigate the association between brain activity and personality in non-diseased/psychiatric adults, and therefore only participants 18 years or over, without missing data was included in the analysis. Data was drawn anonymously for this age range from the BRID and this resulted in 699 non-diseases/psychiatric adult participants (mean age = 36 years, range 18–82 years, 359 females and 340 males), recruited from 4 countries (Australia, UK, USA and The Netherlands) as part of the standardized Brain Resource International Database acquisition (http://www.brainresource.com). All 699 participants selected from the BRID database had completed the NEO-FFI personality test as well as an EEG session. All subjects were asked to refrain from drinking caffeine and smoking cigarettes 2 h before the study session. Written informed consent was provided by all subjects contributing data to the Brain Resource Company's International Brain Resource Database, in accordance with national health and medical research council (NHMRC) guidelines. Data is held anonymously.

2.3. Personality measures

The NEO-FFI Scale consists of 60 items in which respondents decide whether they agree or disagree with each question, on a 1 (strongly disagree) to 5 (strongly agree) Likert scale. Responses are then summed to determine the scores for five personality constructs: neuroticism, extraversion, openness, agreeableness and conscientiousness. Empirical support for the validity of the scale is extensive, with evidence for its construct and discriminant validity, internal consistency (from 0.86 to 0.95), reliability and stability arising from (i) self, peer and spouse ratings (Costa and McCrae, 1988), (ii) longitudinal studies (Costa and McCrae, 1994), (iii) cross-cultural replication (De Raad et al., 1988; McCrae et al., 2004), (iv) heritability studies (Jang et al., 1998), (v) associations with risky sexual behavior (Miller et al., 2004), (vi) substance use studies (Miller and Lynam, 2001) and (vii) personality disorder studies (Lynam and Widiger, 2001; Saulsman and Page, 2004). However, some investigators have failed to replicate the five-factor structure (Panayiotou et al., 2004). All tests for the 699 subjects were administered using a standardized assessment protocol in which subjects completed the personality questionnaire immediately prior to the EEG session.

2.4. EEG procedure

The BRID database contains extensive EEG data that was obtained using a NuAmps system (Neuroscan, USA). An electrode cap (Quik-cap) was used to acquire data from 39 electrode sites, corresponding to the International 10–20 montage system. Scalp sites were referenced offline to linked mastoids of A1 and A2. Horizontal eye movements were recorded with electrodes placed 1.5 cm lateral to the outer canthus of each eye. Vertical eye movements were recorded with electrodes placed 0.3 cm below the middle of the left bottom eyelid. Scalp impedance was kept below 5 kΩ. EEG was sampled at 500 Hz with 22-bit resolution. A low pass filter with an attenuation of 40 dB per decade above 100 Hz was employed prior to digitization. Participants were seated in a sound and light attenuated room, set at an ambient temperature of 24 °C. For the purposes of the present study, that is, to investigate possible associations between personality and brain activity, EEG magnitude data was taken from fixed EEG frequency bands during 3 min of an eyes closed relaxed condition. These frequency bands were for delta (1.5–3.5 Hz), theta (4–7.5 Hz), alpha (8–13 Hz) and beta activity (14.5–30 Hz). In order to normalize the magnitude data from the EEG bands, all data was log(e) transformed before statistical analysis.

Also, since most studies have investigated the alpha wave band and the personality dimensions extraversion and neuroticism, further study in the alpha frequency range was also explored. For reasons given by Klimesch (1999), individually defined alpha frequency band (IAF) was also used in this study. IAF was determined individually for each participant by using the dominant EEG frequency (indicated by the highest amplitude peak) and used as the anchor point (Fink et al., 2005; Klimesch, 1999). Once the IAF was determined, three different frequency windows with a bandwidth of 2 Hz were defined these are: lower1 alpha (IAF-4 Hz to IAF-2 Hz), lower2 alpha (IAF-2 Hz to IAF), and upper alpha band (IAF to IAF + 2 Hz). In a previous study we found that peak amplitudes at up to 20 s of eyes closed data to be related to extraversion (Tran et al., 2001), by using 3 min of uninterrupted eyes closed data may well cause the subject to become sleepy, resulting in decreased alpha activity. That is, alpha peaks will tend to attenuate during long periods when a person keeps their eyes closed, and this could result in altered alpha magnitudes that may have little relationship with personality (Schmidtke and Heller, 2004). Therefore, analyses using the IAF method was conducted on 20 s of eye closed EEG data.

2.5. Analysis

2.5.1. Testing for difference personality traits between males and females

Given the known personality differences in gender, especially with women consistently scoring higher than men on self-report measures of trait anxiety (Costa et al., 2001; Feingold, 1994), the first analysis was to determine if there are any differences in personality traits between the males and females in this sample. A MANOVA was used to test for differences, followed by post-hoc analysis using Scheffé test.

2.5.2. Testing for associations between personality traits and EEG activity

To determine associations between personality dimensions and brain activity, Pearson correlations were ascertained for 12 cortical sites (F3, F4, Fz, C3, C4, Cz, P3, P4, Pz, O2, O1, and Oz) in each fixed EEG frequency bands delta (1.5–3.5 Hz), theta (4–7.5 Hz), alpha (8–13 Hz), and beta activity (14.5–30 Hz) with the five NEO variables.

2.5.3. Multiple regression analyses

To determine a complete picture of the association between personality and EEG, two sets of multiple regression analyses were performed. First, standard multiple regressions were performed with the five NEO personality traits as the independent variables. From this a set of 12 multiple regressions was conducted using the 12 EEG sites as the dependent variable (F3, F4, Fz, C3, C4, Cz, P3, P4, Pz, O2, O1, and Oz). These sites were chosen as it was considered an appropriate spread of cortical positions to determine the unique contribution of the personality trait to brain activity. A second set of multiple regression analyses using forward stepwise multiple regressions was also performed. The sites from the 39 EEG channels were used as the independent variables. Because there were 39 EEG channels it was necessary to use a multiple regression technique that selected what it determined to be significant sites. EEG data was entered into a series of forward deletion stepwise multiple regression analyses (entry criteria set at F of 1.5; removal criteria set at $F=0$) against the five NEO personality traits as dependent variables. All analyses were performed using Statistica software (Version 7, Statsoft).

3. Results

3.1. Differences in personality traits between males and females

The mean scores for the five NEO personality traits are: neuroticism (males = 15.5 (S.D. = 7.3) and females = 18.5 (S.D. = 8.1)), extraversion (males = 28.0 (S.D. = 9.2) and females = 28.6 (S.D. = 8.8)), openness (males = 28.0 (S.D. = 9.4) and females = 29.2 (S.D. = 9.1)), agreeableness (males = 28.8 (S.D. = 9.3) and females = 31.5 (S.D. = 9.0)) and conscientiousness (males = 29.4 (S.D. = 10) and females = 31.0 (S.D. = 9.9)). Using a MANOVA, the NEO-five-factor personality traits were found to be significantly different between males and females ($F(5,693)=9.31$, $p<0.001$). Further analyses using Scheffé test found the significant differences were found with the traits neuroticism ($p<0.001$), agreeableness ($p<0.001$) and conscientiousness ($p<0.001$). Since there were differences in the personalities of males versus females, further analyses were conducted on both genders separately rather than combined.

Table 1
Correlation results between NEO-FFI personality scores and delta brain activity in frontal, central and posterior regions from 12 EEG sites

	Neuroticism		Extraversion		Openness		Agreeableness		Conscientiousness	
	M	F	M	F	M	F	M	F	M	F
F3	0.00	0.05	0.07	−0.02	0.01	−0.05	0.01	−0.09	−0.07	−0.13*
FZ	0.07	0.03	0.13*	−0.01	0.08	−0.05	0.08	−0.09	0.07	−0.14*
F4	0.02	0.06	0.08	0.02	0.01	−0.05	0.01	−0.07	−0.01	−0.09
C3	0.02	0.05	0.11*	0.00	0.02	−0.07	0.03	−0.11*	0.00	−0.15**
Cz	−0.01	0.05	0.13*	0.04	0.02	−0.04	0.04	−0.07	0.00	−0.12*
C4	0.00	−0.01	0.14*	0.02	0.03	−0.05	0.04	−0.07	0.02	−0.10
P3	−0.08	0.08	0.16**	0.05	0.11*	0.00	0.09	−0.05	0.11*	−0.07
Pz	−0.01	0.07	0.15**	0.06	0.07	−0.01	0.04	−0.07	0.00	−0.13*
P4	−0.04	0.03	0.10	0.05	0.03	−0.01	−0.00	−0.07	0.05	−0.12*
O1	−0.01	0.06	0.14*	−0.01	0.09	−0.03	0.01	−0.14*	0.00	−0.16**
Oz	0.00	−0.01	0.12*	−0.03	0.09	−0.07	0.02	−0.10	−0.01	−0.14*
O2	0.07	0.00	0.00	0.06	−0.07	−0.03	−0.03	−0.08	0.00	−0.10

M = males ($n=340$) and F = females ($n=359$).
* $p<0.05$.
** $p<0.01$.

Table 2
Correlation results between NEO-FFI personality scores and theta brain activity in frontal, central and posterior regions from 12 EEG sites

	Neuroticism		Extraversion		Openness		Agreeableness		Conscientiousness	
	M	F	M	F	M	F	M	F	M	F
F3	−0.03	0.04	0.09	−0.04	0.05	−0.07	0.03	−0.11*	−0.03	−0.14*
FZ	−0.02	0.11*	0.11*	0.04	0.07	0.00	0.04	−0.06	0.00	−0.12*
F4	−0.03	0.06	0.11*	0.02	0.04	0.01	0.03	−0.04	−0.03	−0.12*
C3	−0.03	0.02	0.11*	−0.03	0.04	−0.06	0.02	−0.12*	0.01	0.17**
Cz	−0.03	0.06	0.12*	−0.03	0.06	−0.04	0.03	−0.10	0.00	−0.16**
C4	−0.03	0.04	0.12*	0.04	0.05	0.00	0.04	−0.04	0.01	−0.09
P3	−0.10	0.03	0.13*	−0.02	0.09	−0.05	0.08	−0.09	0.08	−0.13*
Pz	−0.05	0.01	0.11*	−0.01	0.04	−0.03	0.02	−0.08	−0.03	−0.13*
P4	−0.06	0.00	0.10	−0.02	0.03	−0.05	0.01	−0.10	−0.03	−0.13*
O1	−0.05	0.01	0.14*	−0.04	0.06	−0.08	0.04	−0.13*	−0.02	−0.14*
Oz	−0.04	0.00	0.11*	−0.07	0.07	−0.10	0.02	−0.13*	−0.01	−0.16**
O2	0.07	0.00	0.00	0.00	−0.07	−0.06	−0.07	−0.12*	0.00	−0.14*

M = males (n = 340) and F = females (n = 359).
* $p < 0.05$.
** $p < 0.01$.

3.2. Correlation analyses

In males the trait extraversion was found to positively correlate with delta activity while in females there were mild negative correlations with conscientiousness (Table 1). The associations were small but significant and were found in all cortical regions (frontal, central and posterior). No other NEO-FFI traits were found to correlate consistent with EEG delta activity. Similar associations were found with EEG theta activity and NEO-FFI traits. Once again, in males positive associations were found between extraversion and theta activity while in females, negative associations were found between conscientiousness and theta activity (Table 2). There were also some negative associations found between agreeableness and theta activity in females. Significant correlations between alpha activity were only found with neuroticism in males (Table 3). This was mainly found in the frontal, central and parietal regions, not in any of the occipital sites. No other consistent associations were found between alpha activity and NEO-FFI traits. Similar consistent negative associations were found between beta activity and neuroticism in males (Table 4). Significant correlations were found in all cortical regions. No other consistent associations were found between beta activity and NEO-FFI traits.

3.3. Multiple regression analyses

To test the contribution of personality traits to brain electrical activity in delta, theta, alpha and beta bands, standard multiple regression analyses were performed for the selected 12 representative sites (F3, F4, Fz, C3, C4, Cz, P3, P4, Pz, O2, O1, and Oz) with the five NEO personality traits as the independent variables. Tables 5 and 6 show the summary of the 12 multiple regression analyses in the male and female groups respectively. Significant multiple regressions were found mainly with the theta and delta frequency bands for both males and females. There were some significant multiple regressions in the alpha and beta

Table 3
Correlation results between NEO-FFI personality scores and Alpha brain activity in frontal, central and posterior regions from 12 EEG sites

	Neuroticism		Extraversion		Openness		Agreeableness		Conscientiousness	
	M	F	M	F	M	F	M	F	M	F
F3	−0.11*	0.00	0.01	−0.03	−0.05	−0.10	−0.05	−0.08	−0.06	−0.08
FZ	−0.06	−0.02	0.04	−0.04	−0.05	−0.12*	0.01	−0.07	0.00	−0.06
F4	−0.11*	−0.03	0.02	−0.05	−0.05	−0.12*	−0.04	−0.08	−0.06	−0.06
C3	−0.10	−0.01	0.04	−0.03	−0.07	−0.10	−0.03	−0.08	−0.06	−0.07
Cz	−0.11*	0.02	0.01	−0.02	−0.04	−0.07	−0.05	−0.07	−0.06	−0.06
C4	−0.11*	−0.04	0.05	−0.04	−0.05	−0.09	−0.03	−0.09	−0.05	−0.08
P3	−0.13*	−0.03	0.07	0.01	0.00	−0.05	0.03	−0.05	−0.03	−0.05
Pz	−0.12*	0.01	0.01	0.02	−0.01	−0.04	−0.05	−0.04	−0.07	−0.07
P4	−0.11*	−0.04	0.05	0.03	−0.01	−0.05	0.00	−0.03	−0.05	−0.06
O1	−0.06	0.01	0.09	−0.01	−0.03	−0.04	0.07	−0.04	−0.03	−0.03
Oz	−0.07	0.02	0.08	−0.01	−0.07	−0.05	0.06	−0.06	−0.03	−0.04
O2	0.07	0.04	0.01	0.01	−0.03	−0.03	−0.07	−0.06	0.00	−0.04

M = males (n = 340) and F = females (n = 359).
* $p < 0.05$.

Table 4
Correlation results between NEO-FFI personality scores and Beta brain activity in frontal, central and posterior regions from 12 EEG sites

	Neuroticism		Extraversion		Openness		Agreeableness		Conscientiousness	
	M	F	M	F	M	F	M	F	M	F
F3	−0.13*	−0.05	0.01	−0.09	−0.08	−0.09	0.02	−0.09	0.01	−0.08
FZ	−0.10	−0.04	0.04	−0.08	−0.04	−0.07	0.00	−0.08	0.03	−0.06
F4	−0.15**	−0.05	0.00	−0.07	−0.10	−0.07	0.01	−0.07	0.00	−0.06
C3	−0.14*	−0.08	0.02	−0.06	−0.05	−0.09	0.04	−0.05	0.05	−0.01
Cz	−0.11*	0.01	0.02	−0.04	−0.09	−0.11*	0.02	−0.08	0.03	−0.08
C4	−0.12*	−0.03	0.02	−0.09	−0.07	−0.12*	0.04	−0.11*	0.04	−0.09
P3	−0.13*	0.00	0.03	−0.03	−0.04	−0.02	0.04	−0.02	0.04	0.00
Pz	−0.14*	−0.03	0.03	−0.01	−0.04	−0.05	0.04	−0.04	0.03	−0.05
P4	−0.16**	−0.03	0.00	0.00	−0.07	−0.06	0.02	−0.06	0.02	−0.04
O1	−0.16**	−0.01	0.03	−0.04	−0.03	−0.06	−0.01	−0.07	−0.05	−0.08
Oz	−0.12*	0.01	0.01	−0.06	−0.03	−0.05	−0.02	−0.10	−0.04	−0.09
O2	0.07	0.03	0.00	0.01	−0.07	−0.02	−0.03	−0.06	0.00	−0.06

M=males (n=340) and F=females (n=359).
* $p<0.05$.
** $p<0.01$.

frequency bands for these 12 sites in males but there were no significant results in these frequency bands for females. The mean contribution of the NEO-FFI personality traits to delta activity in males was calculated as R^2=4.05 with the highest contribution to the EEG site O1 at R^2=4.8. Table 7 shows the multiple regression analysis for personality traits contributing to EEG delta activity in the O1 site (in males). Only the trait extraversion was found to contribute significantly to delta activity in this site (Semi-partial correlations squared (Spc^2) shows the amount that each factor individually contributes, in this case extraversion contributes to the multiple regression by 3.2%). In females, Table 6 showed that the mean contribution of personality to delta activity was calculated as R^2=4.37, with the highest contribution also to the EEG site O1 at R^2=6.2. Table 8 shows the multiple regression analysis for personality traits contributing to EEG delta activity in the O1 site (in females). Three of the five NEO-FFI personality traits (extraversion, agreeableness and conscientiousness) were found to contribute significantly to delta activity in this site. The Spc^2 showed that extraversion contributed to the multiple regression by 2.25% and agreeableness and conscientiousness both contributed by 1.7%. Table 5 shows that the mean contribution of the NEO-FFI personality traits to theta activity in males was calculated as R^2=3.97 with the highest contribution to the EEG site O1 at R^2=5.4. The traits extraversion and conscientiousness both significantly contributed to O1 theta activity (Table 9). In females the mean contribution of personality to theta activity was calculated as R^2=4.06, with the highest contribution also to the EEG site Fz at R^2=5.2. Three of the five personality traits, namely neuroticism, extraversion and conscientiousness, significantly contribute to Fz theta activity (Table 10). In males only, the mean contribution of personality traits to

Table 5
A summary of the 12 multiple regressions in each frequency band (delta, theta, alpha and beta) for males

	Channel	R^2	Channel	R^2	Channel	R^2	Channel	R^2
Delta	F3	3.2%	C3	NS	P3	4.4%	O1	4.8%
	FZ	NS	CZ	3.8%	PZ	4.7%	Oz	4.05%
	F4	NS	C4	3.5%	P4	4.1%	O2	NS
Theta	F3	NS	C3	NS	P3	4.0%	O1	5.4%
	FZ	NS	CZ	NS	PZ	3.7%	Oz	3.5%
	F4	3.7%	C4	NS	P4	3.5%	O2	NS
Alpha	F3	NS	C3	NS	P3	3.9%	O1	3.5%
	FZ	NS	CZ	NS	PZ	NS	Oz	NS
	F4	NS	C4	NS	P4	NS	O2	NS
Beta	F3	3.2%	C3	3.3%	P3	NS	O1	4.0%
	FZ	NS	CZ	3.3%	PZ	NS	Oz	NS
	F4	3.7%	C4	NS	P4	3.3%	O2	NS

The independent variables used were the five NEO-FFI personality traits (neuroticism, extraversion, openness, agreeableness and conscientiousness). The results show the amount of variance explained by the personality trait to each EEG site (R^2) and was only presented in significant multiple regression results.

Table 6
A summary of the 12 multiple regressions in each frequency band (delta, theta, alpha and beta) for females

	Channel	R^2	Channel	R^2	Channel	R^2	Channel	R^2
Delta	F3	3.3%	C3	5.5%	P3	3.3%	O1	6.2%
	FZ	3.5%	CZ	4.8%	PZ	5.8%	Oz	3.0%
	F4	3.2%	C4	NS	P4	5.1%	O2	4.37%
Theta	F3	NS	C3	4.4%	P3	NS	O1	3.6%
	FZ	5.2%	CZ	4.0%	PZ	NS	Oz	3.3%
	F4	3.4%	C4	NS	P4	NS	O2	4.5%
Alpha	F3	NS	C3	NS	P3	NS	O1	NS
	FZ	NS	CZ	NS	PZ	NS	Oz	NS
	F4	NS	C4	NS	P4	NS	O2	NS
Beta	F3	NS	C3	NS	P3	NS	O1	NS
	FZ	NS	CZ	NS	PZ	NS	Oz	NS
	F4	NS	C4	NS	P4	NS	O2	NS

The independent variables used were the five NEO-FFI personality traits (neuroticism, extraversion, openness, agreeableness and conscientiousness). The results show the amount of variance explained by the personality trait to each EEG site (R^2) and was only presented in significant multiple regression results.

Table 7
The multiple regression analysis for personality traits contributing to EEG delta activity in the O1 site (in males)

Personality traits	β	SE β	B	t-ratio	p-value	Spc	Spc²
Neuroticism	−0.024	0.06	−0.009	−0.39	0.69	−0.02	0.04%
Extraversion	0.307	0.09	0.092	3.40	<0.001	0.18	3.2%
Openness	0.081	0.09	0.024	0.94	0.34	0.05	0.25%
Agreeableness	−0.152	0.09	−0.045	−1.74	0.08	−0.09	0.81%
Conscientiousness	−0.155	0.08	−0.043	−1.91	0.06	−0.10	1.0%

Table 9
The multiple regression analysis for personality traits contributing to EEG theta activity in the O1 site (in males)

Personality traits	β	SE β	B	t-ratio	p-value	Spc	Spc²
Neuroticism	−0.07	0.06	−0.027	−1.22	0.222	−0.07	0.5%
Extraversion	0.318	0.09	0.092	3.53	<0.001	0.19	3.6%
Openness	0.024	0.08	0.006	0.28	0.779	0.015	0.02%
Agreeableness	−0.020	0.09	−0.005	−0.23	0.817	−0.01	0.01%
Conscientiousness	−0.229	0.08	−0.061	−2.83	0.005	−0.15	2.2%

alpha and beta waves were R^2=3.7 and R^2=3.5 respectively (Table 5).

In order to further our investigation a second set of multiple regressions were performed to determine the unique contribution of brain activity to each of the five NEO-FFI personality traits. Twenty-five forward stepwise multiple regression analyses were performed and significant contributing EEG sites for each frequency band were determined. Tables 11 and 12 shows a summary of the results for all 25 multiple regressions in the male and female groups respectively. The variance explained (R^2) for each of the frequency bands was presented. For the male group, the fixed band EEG brain activity was found to contribute from 1.8% to 11% to these five NEO personality traits (Table 11). For the female group, the fixed band EEG brain activity was found to contribute from 2.2% to 9.8% to these five NEO personality traits (Table 12). The amount of variance explained from EEG frequency bands tended to be lower in the alpha and beta frequency ranges, especially in females. However, to further investigate the role of brain activity in the alpha frequency range, IAF bands following Klimesch (1999) was used. The results showed in alpha activity the R^2 range increased from a range of 4.8–11% to 9.7–16.9% in males and from 2.2–5.2% to 7.1–21.9% in females. The greatest change in R^2 from fixed to IAF band occurred with the trait conscientiousness, in both males and females.

4. Discussion

Initial analysis found significant differences in the NEO-FFI personality scores between males and females ($F(5,693)=9.31$, $p<0.001$). Significant differences were found in the trait neuroticism, this was consistent with other studies that suggest women consistently score higher than men on self-reported trait anxiety (Costa et al., 2001; Egloff and Schmukle, 2004; Feingold, 1994). The other two personality traits found to be significantly different in males and females were agreeableness and conscientiousness. This study and others have found that females scored significantly higher in agreeableness and conscientiousness compared to males (Rubinstein, 2005). Given the differences in personality and gender, further analyses were conducted in males and females separately. However, it should be noted that the largest differences in the personality scores were in the traits neuroticism and agreeableness, with a mean score difference between males and females of only three points.

The association between NEO-FFI personality traits and resting cortical activity was first determined by correlation analyses. Results showed mild and consistent associations between some of the NEO-FFI personality traits and resting regional brain activity. In both males and females, resting low frequency brain activity, delta and theta EEG activity, was found to be associated with NEO-FFI personality traits (extraversion and conscientiousness) across all regions. Higher frequency brain activity such as alpha and beta activity was found to correlate with personality traits in males only. Delta wave activity was found to be mildly and positively related to the extraversion in males and negatively related to conscientiousness in females. That is, greater amounts of low frequency activity, such as delta and theta activity during relaxed wakefulness (resting) conditions were shown to be associated with higher levels of extraversion in males. In contrast, greater amounts of delta and theta activity during relaxed wakefulness (resting) conditions were shown to be weakly associated with lower amounts of conscientiousness in females. Further analyses using multiple regressions showed that in males, the five NEO-FFI personality traits contributed around 3.2–4.8% to resting delta activity, with extraversion contributing 3.2% (semi-partial correlation=0.18). This was mostly found in the central and parietal regions. In females, however, the

Table 8
The multiple regression analysis for personality traits contributing to EEG delta activity in the O1 site (in females)

Personality traits	β	SE β	B	t-ratio	p-value	Spc	Spc²
Neuroticism	0.071	0.06	0.025	1.25	0.212	0.06	0.36%
Extraversion	0.227	0.08	0.075	2.85	0.004	0.15	2.25%
Openness	0.044	0.07	0.014	0.61	0.541	0.03	0.09%
Agreeableness	−0.219	0.08	−0.071	−2.59	0.009	−0.13	1.7%
Conscientiousness	−0.190	0.08	−0.056	−2.53	0.011	−0.13	1.7%

Table 10
The multiple regression analysis for personality traits contributing to EEG theta activity in the Fz site (in females)

Personality traits	β	SE β	B	t-ratio	p-value	Spc	Spc²
Neuroticism	0.121	0.06	0.046	2.12	0.035	0.11	1.2%
Extraversion	0.224	0.08	0.077	2.80	0.005	0.15	2.3%
Openness	−0.015	0.07	−0.004	−0.20	0.839	−0.01	0.01%
Agreeableness	−0.103	0.09	−0.035	−1.21	0.229	−0.06	0.36%
Conscientiousness	−0.201	0.08	−0.062	−2.66	0.008	−0.14	1.96%

Table 11
Multiple regression results between NEO-FFI traits as the dependent variable and 39 EEG sites from the four frequency bands as the independent variable

Personality traits	Delta (R^2)	Theta (R^2)	Alpha (R^2)	IAF (R^2)	Beta (R^2)
Neuroticism	8.7%	5.0%	7.5%	9.7%	9.7%
Extraversion	6.3%	3.9%	7.2%	12.2%	6.3%
Openness	6.3%	6.1%	11.0%	15.1%	10.5%
Agreeableness	3.6%	1.8%	7.3%	11.7%	8.4%
Conscientiousness	6.2%	3.8%	4.8%	16.9%	7.6%
% Range	3.6–8.7%	1.8–6.2%	4.8–11.0%	9.7–16.9%	6.3–10.5%

This table shows the amount of variance explained in NEO-FFI traits (R^2) by EEG activity in males.

five NEO-FFI personality traits contributed around 3.2–6.2% to resting delta activity, with extraversion contributing 2.25% (semi-partial correlation = 0.15) and agreeableness and conscientiousness each contributing 1.7% (semi-partial correlation = 0.13). This was observed in all the cortical regions (frontal, central and posterior). Similar multiple regression results were found in theta activity (see Tables 9 and 10).

It has long been known that EEG recorded from the scalp mostly reflects cortical events, however, it is also recognised that subcortical systems can exert its influence upon cortical EEG (Knyazev and Slobodskaya, 2003). Recently, it has been proposed that delta waves are related to the brainstem and theta waves to the limbic system, while alpha rhythms are traditionally considered as thalamocortical rhythms, although the generation of these signals is not linked exclusively to these brain regions (Knyazev and Slobodskaya, 2003; Steriade et al., 1993). Furthermore, since resting EEG has been shown to have comparable test–retest reliability with personality questionnaires, it is possible to speculate that the spectral power of brain oscillations in different frequency bands may serve as a measure of predisposition to a specific style of behavior (Kondacs and Szabo, 1999; Knyazev and Slobodskaya, 2003). The findings in this study would support an active association between low frequency EEG such as delta and theta activity with personality traits in the NEO-FFI. In females, the findings suggest stronger associations between personality traits and delta and theta activity, perhaps indicating that deeper brain structures such as the brainstem and the limbic system have a stronger influence on personality traits in females. In males, the delta and theta activity was associated with the trait extraversion. However, there was also a negative association between neuroticism with alpha and beta activity. This finding may also be associated with the sub-trait impulsivity. The NEO-FFI personality questionnaire includes impulsivity within the construct of neuroticism, rather than extraversion (Schmidtke and Heller, 2004). This is similar to previous findings showing impulsivity to be associated with diminished alpha activity and prevalence of slow-wave oscillations (Knyazev and Slobodskaya, 2003).

There is also a growing body of evidence that supports brainstem involvement with personality traits. For instance, individual differences in auditory processing from the auditory brainstem response may contribute to introverted/extroverted tendencies (Bar-Haim, 2002). Studies have shown faster brainstem transmission is associated with adult introversion (Andress and Church, 1981). The faster brainstem transmission in introverted personalities could be a reflection of increased arousal in the ascending reticular activating system that is, higher levels of brainstem arousal (Bullock and Gilliand, 1993; Matthews and Gilliland, 1999; Swickert and Gilliand, 1998).

Generally, greater desynchronization (decreased energy in a frequency band) is associated with increased activation in the alpha band (Caulkins and Fox, 2002) whereas in adults delta and theta activity seem to synchronize in response to cognitive demands (Klimesch, 1996). Little is known about the association between low frequency brain activity such as delta and theta with personality. It has been hypothesized, that personality traits of the behavioral inhibition system (BIS), that is a combination of introversion and anxiety (Gray, 1991), should be associated with enhanced vigilance and as a result higher preparedness to the sensory processing, and hence high alpha activity with low slow wave activity (Knyazev and Slobodskaya, 2003). The results partially support this hypothesis as extraverted

Table 12
Multiple regression results between NEO-FFI traits as the dependent variable and 39 EEG sites from the four frequency bands as the independent variable

Personality traits	Delta (R^2)	Theta (R^2)	Alpha (R^2)	IAF (R^2)	Beta (R^2)
Neuroticism	9.1%	7.9%	3.5%	7.1%	4.0%
Extraversion	6.3%	4.2%	3.4%	12.2%	6.1%
Openness	6.9%	9.0%	5.2%	9.9%	7.6%
Agreeableness	5.7%	6.9%	2.2%	12.2%	6.1%
Conscientiousness	9.8%	8.4%	2.9%	21.9%	5.9%
% Range	5.7–9.8%	4.2–9.0%	2.2–5.2%	7.1–21.9%	4.0–7.6%

This table shows the amount of variance explained in NEO-FFI traits (R^2) by EEG activity in females.

persons had higher levels of theta and delta activity in both genders, but did not support this finding in alpha activity. High alpha activity was found to be negatively associated with neuroticism in males. Aside from this association, this study failed to find consistent associations between the five personality traits and fixed alpha and beta activity, especially in females. The failure to find an association between personality and alpha wave activity may have been the result of methodological problems such as using fixed EEG alpha bands rather than individually determined bands as recommended by Klimesch (1999) and the of 3 min of alpha wave eyes closed activity. Using 3 min of uninterrupted eyes closed data may well cause the subject to become sleepy, resulting in decreased alpha activity and could result in altered alpha magnitudes that may have little relationship with personality (Schmidtke and Heller, 2004).

Therefore, further analyses were conducted to investigate brain activity contribution to personality traits. Multiple regression analyses were performed with both fixed band alpha and IAF bands. The IAF analyses were performed on a 20 s interval of eyes closed data. The results showed that the level of variance explained (R^2) increase from 4.8–11% to 9.7–16.9% in males and from 2.2–5.2% to 7.1–21.9% in females. This showed that IAF bands were better predictors of personality traits than fixed alpha bands. This was especially the case for the trait conscientiousness, with the variance explained increasing from 4.8% to 16.9% in males and 2.9 to 21.9% in females. IAF contribution to extraversion also increased from 7.2% to 12.2% in males as well as increasing from 3.4% to 12.2% in females. Other studies that used either individually determined alpha bands (Tran et al., 2001) or the IAF method (Klimesch, 1999) as did Fink and Neubauer (2004) and Fink et al., 2005, have found strong associations between alpha wave activity and extraversion.

The other four traits were shown to have mostly weak relationships with resting delta or theta activity. Associations between agreeableness and conscientiousness and brain activity were only found in females. There were no associations found between openness and brain activity in both males and females. Further research is thus required to clarify whether traits such as Agreeableness, Openness and Conscientiousness have any contribution or association with EEG activity. One problem with many personality scales that go beyond the fundamental dimensions of introversion–extraversion and neuroticism is there is no consensus concerning the biological basis of additional dimensions (Robinson, 2001). Nevertheless, it is perhaps not surprising that personality was found to be only weakly associated with EEG activity. For example, we know that many factors contribute to the level of brain electrical activity such as states of consciousness, thickness of the skull, age, mental activity, artefact and so on (Klimesch, 1999). Therefore, it should be expected that personality would be shown to only explain small amounts of low frequency resting brain activity data. In spite of this, the significant and consistent relationships found across the total cortex for delta, theta, increase our confidence that at least some personality traits (e.g. extraversion, conscientiousness) are associated with resting brain activity.

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