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Extraversion–introversion and 8–13 Hz waves in frontal cortical regions

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Abstract

The study examined a possible relationship between electrical activity recorded from the scalp and personality, especially extraversion–introversion, in a sample of 50 male and female volunteers. EEG activity was recorded from 19 electrodes while subjects opened and closed their eyes on instruction. The participants completed Cattell's 16 Personality Factor questionnaire and from those results, second-order personality traits (extraversion–introversion, low anxiety–high anxiety, tough poise–tender mindedness, and subduedness–independence) were calculated. An association was only found between the extraversion–introversion and frontal EEG activity in the 8–13 Hz range. Results also showed that extraverts were at least 3 times more likely to have larger amplitude activity in this range. No significant associations were found in posterior regions of the brain. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Extraversion; Introversion; Alpha waves; EEG; Frontal cortex

1. Introduction

The frontal lobe of the brain, often referred to as the "senior executive" (Joseph, 1996), is known to be involved in the modulation and shaping of personality and when damaged can result in the disintegration of personality (Stuss & Benson, 1986). Numerous studies have investigated the relationship between personality and the properties of the brain's bioelectric activity. The assumption is that the electrical activity of the brain is related in some way to personality style and this has been suggested from as early as 1936 (Lemere, 1936). A prominent area has been the association of EEG 8–13 Hz wave from the posterior regions (alpha activity) and personality

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traits. However, despite the importance of the role of the frontal lobes in personality, little has been done in exploring the brainwaves in the frontal regions.

In the past three decades, studies have found a positive association between EEG alpha activity and extraversion (Gale, Coles & Blaydon, 1969; Marton & Urban, 1966; Savage, 1964; O'Gorman & Mallise, 1984; Wall, Schuckit, Mungas & Ehlers, 1990; Zuckerman, 1991). However, the association between alpha waves and extraversion is equivocal, as other studies have found increased EEG alpha activity in introverts (Broadhurst & Glass, 1969; Young, Lader & Fenton, 1971), while other studies found no differences between introverts and extraverts (Fenton & Scotton, 1967; Gale, Coles, Kline & Penfold, 1971). As reported by Gale (1973, 1981) conflicting results could partly be due to differences in subject populations, experimental situations and techniques.

According to Gale (1973, 1981) one potential confounding factor is the arousal levels elicited in the above studies. For instance, experimental conditions which are challenging, involved those that require solving problems or time-limited tasks and Gale rated these as high arousal experiments. Low arousal experiments involved conditions where participants are asked to do nothing but to keep their eyes closed and not fall asleep. From his comprehensive reviews of many of these studies, Gale (1973, 1981) believed high and low arousal experimental conditions were not suitable for studying associations between personality and EEG as differences between the two personality groups are masked at the extremes of the arousal conditions. Extraverts were likely to attempt to increase their arousal levels when ambient conditions induced low levels of arousal, whereas introverts were likely to seek to reduce their arousal levels when ambient arousal levels were high. For research investigating associations between EEG and extraversion–introversion, Gale (1973) suggests intermediate arousing conditions. This is where subjects are allowed some mild interaction with the experimenter (such as receiving instructions to open and shut their eyes). Gale believes this to be most suitable because the predicted arousal levels of both extraverts and introverts will not be affected by the experimental conditions.

In addition, neocortical levels of activation or arousal have been linked to amplitude and frequency of the alpha rhythm (Gale, 1983; Golan & Neufield, 1996). A low level of arousal is associated with high amplitudes and a low frequency rhythm, while a high level of arousal is associated with low amplitudes and a higher frequency. In experimental conditions that elicit moderate levels of arousal, for instance, when subjects are instructed to open and close their eyes, (which requires alertness but without mental concentration), it is hypothesised that extraverts will show increased amplitude in alpha wave activity (Gale, 1973, 1981). In a later study, designed to test Gale's hypothesis, O'Gorman and Mallise (1984) failed to confirm the hypothesis. Nevertheless, the extraversion–introversion dimension in personality has been commonly explored due to its link with the concept of cortical arousal.

The hypothesised difference in the brainwave activity of introverts (low amplitude, high frequency) and extraverts (high amplitude, low frequency) supports Eysenck's theory of extraversion (Eysenck, 1967). This assumes that cortical arousal is greater in introverts than extraverts. By the use of other methods to measure brain activity, such as the measurement of cerebral blood flow (CBF), it has been found that higher levels of CBF are found in introverts (Stenberg, Wendt & Risberg, 1993). This supports the arousal hypothesis, where higher CBF levels indicates higher cortical activity. Since the EEG alpha rhythm is known to be prominent in states of relaxation and inhibited by arousing stimuli, it should be more prominent in extraverts than introverts (Savage, 1964).

The equivocal results of previous research in this area may have been due to four factors. The first is the cortical site where the alpha wave is measured. The alpha rhythm (8–13 Hz) has been defined as a sinusoidal wave occurring in the posterior regions of the head, best seen with eyes closed and under conditions of physical relaxation (Niedermeyer, 1987). However, Craig, McIsaac, Tran, Kirkup and Searle (1999) have shown that frontal region 8–13 Hz waves are just as prominent and reactive as alpha waves in posterior regions of the cortex. It may be that personality is not highly associated with EEG (8–13 Hz) waves measured in posterior regions of the brain where visual and auditory processing occurs, but are more likely to be associated in frontal regions. In support of this there have been numerous studies that have found a relationship between emotions and frontal cortical activity (Davidson, Ekman, Saron, Senulis & Friesen 1990; Ekman, Davidson & Friesen, 1990; Hagemann et al., 1999). A study by Davidson et al. (1990) found differences between left and right hemispheric activation during happiness and disgust only in frontal and anterior temporal regions. No EEG differences were found in central, parietal or occipital regions. A study by Hagemann et al. (1999) also found EEG frontal asymmetry in anterior brain regions during dispositional mood, as well as a significant correlation between extraversion and positive affect, and neuroticism and negative affect. Given the above and the importance of the frontal cortex in the development of personality and emotions, it would seem important that the relationship between personality and EEG be explored further in frontal areas.

The second possible source of confounding could be the method chosen for EEG analysis. The properties of the EEG wave suit it to techniques that allow sophisticated analysis of wave characteristics. Spectral or Fast Fourier Transform (FFT) analyses result in reliable and sensitive descriptions of the frequency and amplitude of the wave. In addition, the abundance of alpha waves at any set period, can be determined accurately from this method. Many prior studies did not have access to this technology when analysing the 8–13 Hz wave.

The third factor may be due to the questionnaires used. Some recent studies suggest that it may be the sub-trait, impulsivity, of the broader extraversion trait that may have a greater link to biological under-arousal (O'Gorman & Lloyd, 1987; Stenberg, 1992). In Cattell's 16 Personality Factors questionnaire (16 PF), impulsivity is one of the 11 'primary-order' personality factors used to calculate the extraversion–introversion trait. Therefore it was believed that the 16 PF was the questionnaire of choice for this study, as the association of impulsivity as well as extraversion–introversion was of interest.

The fourth factor is the subjects used in the research. Prior studies have drawn subjects primarily from university student populations and the measure of personality may have been biased due to the narrow and younger age range of the sample. The EEG alpha rhythm has been shown to be constant throughout adult life (Markand, 1990) as well as displaying stable individual differences (Brazier, 1960). However little is known about the stability of this rhythm before adulthood. O'Gorman and Mallise (1984) pointed to the narrow age range (18–35 years) in their participants as a possible reason they failed to confirm Gale's hypothesis.

The purpose of the study reported here was to explore further the possible relationship between personality (specifically extraversion vs introversion) and 8–13 Hz EEG activity. To reduce possible bias, a diverse sample of participants with a broad age range was used; EEG was assessed in frontal areas as well as central and posterior areas; a comprehensive measure of personality was used and EEG was spectrally analysed. Following Gale's hypothesis, only moderately arousing tasks were used during the recording of EEG data.

2. Method

2.1. Participants

Fifty volunteers, (26 males and 24 females) were randomly selected from a large group of persons working for a large institution as well as from members of the community. The age range of participants was from 22 to 60 years with a mean of 38.3 years (SD = 9.6). They were entered into the study after informed consent. All were overtly free of viral or bacterial disease and reported no prior brain disease or injury.

2.2. EEG procedure

EEG was recorded using the Neurosearch-24 system (Lexicor Medical Technologies), with Ag/AgCl-electrodes applied to all 19 channels of the International 10/20-system. All electrodes were referenced to linked earlobes and impedances were kept below 8 KΩ. EEG data signals were acquired at a sampling rate of 128 Hz and gain set at 16 K to ensure waveform resolution was not lost. All subjects were assessed for their EEG activity for eyes opened (EO) and alert (20 s) followed by eyes closed (EC) and alert (20 s). This was repeated three times. A total of 2 min of EEG activity was recorded or the equivalent of 60 2-s epochs. The 2-s epochs were then used for Fast Fourier Transform (FFT) analysis, with the spectral graph ranging from 0–30 Hz with a 0.5-Hz resolution. To ensure that confounding due to artefact was minimised, a trained technician examined the EEG signal in the epochs for possible noise due to muscle activity or eye movement. Epochs contaminated by noise were removed to ensure that the signals being examined were free of artefact. Less than 10% of data were eliminated by this process.

FFT was applied to the artefact-free data in 2-s epoch samples. Transformation yielded a value representing the magnitude of amplitude, expressed in microvolts (μV). Frequencies in the 8–13 Hz range were extracted and analysed in response to opening and closing the eyes. As we were concerned with capturing the immediate changes in brainwave activity only 2-s epochs were used. During eye closure (10 epochs or 20-s periods) the maximum spectral magnitude of alpha activity (8–13 Hz) and peak frequency was determined from the spectral graphs of the FFT. The 2-s epoch containing the largest spectral alpha peak (μV) was selected from the 10 epochs and this value was used for analysis. This value gives an indication of the levels of alpha activity in the participants. Since there were three periods of eyes closed, an average of the three maximum amplitudes was taken. An experienced technician who was unaware of the personality score of the subjects conducted all EEG measurements.

2.3. General procedure

To ensure that the data recorded from participants were not confounded by circadian rhythm, all participants were asked to attend recording sessions in the morning at 10 am. Participants were prepared for recording and 60 epochs of 2 s/epochs were recorded. Subjects then completed the questionnaires that consisted of the LAQ (Craig, Hancock & Craig, 1996), used to determine their lifestyle patterns and general health. A score of less than 19 on the LAQ suggests reasonable health status (Craig et al., 1996). They also completed the 16 Personality Factors (4th Ed.) (16

PF, Cattell, Eber & Tatsuoka, 1986). The 16PF scale has been shown to have high levels of reliability and validity (Cattell, 1994; Herman & Usita, 1994; Prieto, Gouveia & Fernandez, 1996). The 16 PF measures 16 primary-order factors and from these factors four secondary-order personality traits are derived. The primary factors consisted of warmth, dominance, impulsivity, etc. The secondary-order traits include extraversion–introversion, high anxiety–low anxiety, tough poise–tendermindedness, and independence–subduedness.

2.4. Analysis of data

Subjects were first divided into either an extraversion or introversion group, depending upon the level of extraversion assessed by the 16 PF. The distribution of scores was dichotomised at the mean of the sample, which was a score of 5.7. This was repeated with similar procedures for the other three second-order personality styles measured by the 16 PF. Multivariate analysis of variance (MANOVA) was used to determine whether differences in levels of 8–13 Hz reactivity occurred between the second order personality groups in different regions of the brain.

In addition, repeated measures MANOVA was used to test for hemispheric differences between the second-order personality groups by analysing average values of the left and right hemispheres in the posterior and frontal regions.

In order to determine the relationship between EEG and primary personality scores, the participants were then divided into two groups of 8–13 Hz reactivity, depending upon the average maximum value selected from the alpha wave burst following EC. Subjects were divided based on the mean alpha amplitude increase that was contingent with EC (a value of 5.2 μV). Analyses of variance (ANOVAs) were then conducted on the primary-order factors of personality to determine the scores that were significantly different.

A Chi-square analysis was also conducted followed by an Odds Ratio (Elston & Johnson, 1987) in order to determine the reliability and accuracy of the association between secondary-order personality type and 8–13 Hz amplitude. Also a further Chi-square analysis was conducted in order to determine any associations between the extraversion–introversion personality type and anxiety levels.

3. Results

All subjects were shown to have reasonable health status scores on the LAQ. To test for differences in personality, MANOVAs were conducted. The second-order traits were tested on the left frontal region (FP_1, F_3 and F_7), the right frontal region (FP_2, F_4, and F_8), the left posterior region (T_3, T_5, P_3, C_3 and O_1), the right posterior region (T_4, T_6, P_4, C_4 and O_2) and the central regions (F_z, C_z and P_z). There was a significant difference only for introversion-extraversion groups for both the left and right frontal regions (Wilks lambda = 0.83, df = 3,46, $P < 0.05$ and Wilks lambda = 0.83, df = 3,46, $P < 0.05$ respectively) and the central regions (Wilks lambda = 0.82, df = 3,46, $P < 0.05$). There were no significant differences between left and right hemisphere in any of the other three second-order personality traits. Table 1 shows the mean 8–13 Hz peak amplitudes for all the second-order personality traits from the F_z site (as all frontal sites were similar in reactivity). In order to determine where differences existed, separate analyses

Table 1
Mean 8–13 Hz spectral peak magnitudes for all the second-order personality traits from the F_Z site

	Mean (μV)	SD	Minimum (μV)	Maximum (μV)
Introversion	4.5	1.57	2.0	8.2
Extraversion	6.8	3.17	0.7	15.8
Low anxiety	5.6	2.98	2.0	15.8
High anxiety	5.9	2.64	0.7	11.6
Tender minded	5.4	3.15	0.7	15.8
Tough poise	6.1	2.44	2.0	11.6
Subduedness	6.2	3.26	2.3	15.8
Independent	5.4	2.41	0.7	11.6

of variance (ANOVA) were conducted for all the frontal sites as well as C_z. In these sites the extraverted group was shown to have significantly higher levels of the 8–13 Hz wave amplitudes (see Table 2 for results).

Only the introversion-extraversion construct showed a significant relationship ($\chi^2 = 14.03$, df = 1, $P < 0.01$) between level of extraversion and level of 8–13 Hz amplitude following EC (see Table 3). The Odds Ratio showed a 3.2 times greater chance of having large 8–13 Hz amplitude levels if one was extraverted or conversely, 3.2 times greater chance of having smaller amplitude if one is introverted. There were no significant differences between anxiety levels in the breakdown of the introversion-extraversion group (see Table 4).

For the 16 primary-order traits, significant differences between high and low levels of 8–13 Hz wave activity were found in only five, of which four of these primary-order scores were used to calculate the second-order trait, introversion–extraversion. Table 5 shows these five constructs in the F_z site as all frontal sites were similar in reactivity. A higher primary-order score for dominance, impulsivity and boldness was found with higher 8–13 Hz reactivity, whereas a higher primary-order score for self-sufficiency and self-sentiment was found in lower 8–13 Hz reactivity.

Table 2
Shows the mean spectral peak magnitudes of 8–13 Hz waves for extraverts and introverts over all sites where extraverts were shown to have significantly higher levels of EEG 8–13 Hz activity (*$P < 0.05$; **$P < 0.01$)

Site	Introverts mean (μV)	SD	Extraverts mean (μV)	SD	*F*	df	*P*
FP1	3.7	1.5	5.3	2.2	8.51	1,48	0.005**
FP2	3.6	1.4	5.3	2.3	8.82	1,48	0.005**
F3	4.2	1.6	6.2	2.9	8.45	1,48	0.005**
F4	4.3	1.6	6.1	2.9	7.57	1,48	0.008**
F7	3.2	1.3	4.4	2.0	5.77	1,48	0.020*
F8	3.1	1.3	4.2	1.9	5.42	1,48	0.024*
FZ	4.5	1.5	6.8	3.2	10.17	1,48	0.002**
CZ	5.5	2.3	7.9	4.5	5.089	1,48	0.028*

Table 3
Shows frequency breakdown of introversion–extraversion with low and high levels of 8–13 Hz activity ($\chi^2 = 14.03$ (df = 1, $P < 0.01$), Odds Ratio = 3.2)

	Low 8–13 Hz levels	High 8–13 Hz levels
Introversion	19	4
Extraversion	8	19

Table 4
Shows frequency breakdown of introversion–extraversion with low and high levels of anxiety ($\chi^2 = 0.35$ (N.S))

	Low anxiety	High anxiety
Introversion	10	13
Extraversion	14	13

Table 5
Shows significant differences between the personality scores for the primary-order personality traits for high 8–13 Hz and low 8–13 Hz groups from the F_z site

Primary factors	Low 8–13 Hz group mean (scores)	SD	High 8–13 Hz group mean (scores)	SD	F (1,48)	P-level
Dominance	5.9	2.1	7.3	1.7	5.7	0.021
Impulsivity	5.8	2.4	7.3	1.5	5.7	0.021
Boldness	5.2	2.1	6.7	2.1	6.0	0.017
Self-sufficiency	6.9	1.7	5.8	1.8	4.5	0.038
Self-sentiment	5.4	2.0	4.3	1.7	4.1	0.047

4. Discussion

The aim of the study was to explore further the relationship between the personality trait introversion–extraversion and EEG 8–13 Hz activity. The results showed strong differences between the introversion and extraversion groups in terms of their frontal 8–13 Hz amplitude reactivity. Extraverted persons in the sample were at least 3 times more likely to have a larger amplitude in the 8–13 Hz frequency spectra. Conversely, introverted persons were more likely to have smaller levels of 8–13 Hz waves.

Since low levels of arousal is hypothesised to be associated with high amplitudes in 8–13 Hz EEG waves and high levels of arousal to be associated with low amplitudes in 8–13 Hz EEG waves, the findings in this study show support for Eysenck's theory of extraversion (1967). His theory (1967) proposes that the accounted differences between introverts and extraverts could be distinguished by different levels of cortical arousal. The differences in cortical arousal between extraversion and introversion is believed to be due to different levels of activity in the ascending reticular activating systems (ARAS). For example, for introversion the activity of the ARAS serves to stimulate the cerebral cortex resulting in higher levels of cortical arousal. Furthermore, Gray (1970) proposes that the physiological basis of introversion should also include a negative feedback loop involving the orbital frontal cortex, the medial septal area and the hippocampus.

The association between extraversion–introversion and 8–13 Hz activity in the study was only found in frontal sites. This perhaps reflects the importance of the frontal regions of the brain in the development of personality. Evidence supporting this comes from neurological studies in which damage to the frontal lobes results in personality disintegration (Stuss & Benson, 1986; Joseph, 1996). There is also evidence that damage to the frontal cortex impairs cortical arousal (Heilman & Van den Abell, 1979; Posner & Petersen, 1990). This supports Gray's (1970) proposal for the involvement of the frontal lobes in the physiological basis of arousal levels in introverts and extraverts.

Notwithstanding the above, while this study found no significant differences in alpha levels in the posterior sites, there was a trend towards a greater level of alpha activity in extraverts compared with introverts. As discussed earlier a number of prior studies (Savage, 1964; O'Gorman & Mallise, 1984; Wall et al., 1990) have shown differences in alpha levels between extraverts and introverts in posterior regions. It could be that a higher level of posterior alpha activity occurs all over the scalp of the extraverted persons, but the levels are substantially larger in frontal regions of extraverted persons.

No other 16 PF secondary-factor personality type was shown to be associated to the electrical activity of the brain. Previous studies have found relationships between low alpha rhythm amplitude/high frequency and anxiety proneness (Brazier, Finesinger & Cobb, 1945; Ulett, Glesner, Winokur & Lawler, 1953; Terelak, 1976). This study does not support this finding, as no significant differences were found between anxiety levels and 8–13 Hz activity throughout the scalp. Recently, Stenberg (1992) found that EEG frontal asymmetry was significantly different in high-anxious and low-anxious participants, however, this was in the theta frequency band. Also, despite Gray's (1970) proposal that introverts are more sensitive to punishment and hence are more susceptible to increased levels of anxiety, this study found no significant relationship between the anxiety levels of introverts and extraverts.

Since there were no other significant relationships with other second-order personality traits, a breakdown of the primary-order factors was examined. Extraversion, being a secondary trait is composed of many primary traits. In the 16 PF extraversion is calculated from 11 different primary factors, each with a different weighting. The factors with the stronger weighting include dominance, impulsivity, boldness and self-sufficiency. These four factors showed significant differences with different levels of frontal 8–13 Hz activity. Generally a higher dominance, impulsivity and boldness score (traits typical of extraverts) showed a higher level of 8–13 Hz activity. Self-sufficiency scores showed the opposite of the above, with higher scores in those with lower 8–13 Hz frontal activity. Introverts are therefore more likely to be self-sufficient. This study supports prior research where impulsivity was shown to be associated with activity indicative of lower arousal impulsivity (Gray, 1981; O'Gorman & Lloyd, 1987). Results also showed that several other primary factors of extraversion, including dominance and boldness, have significant relationships with level of 8–13 Hz activity.

The results from this study support the findings of research that showed EEG differences between extraverted and introverted persons. The inconsistencies in the findings of prior research may well have been due to sources of error arising from sample bias, site measurement as well as the personality measures used (Stenberg et al., 1993). Furthermore, according to Cattell and his theory of personality, the traits that are believed to be influenced by heredity are personality factors related to the second-order traits of extraversion and introversion (Ewen, 1993). It is interesting that these personality factors are the ones that show a relationship to the bioelectric activity of the brain. There has been evidence that both the EEG alpha rhythm as well as the personality traits related to extraversion–introversion are genetically influenced (Stenberg, 1992). For instance, studies on twins have revealed greater similarity in the frequency of the alpha wave in monozygotic as compared to dizygotic twins (Vogel, 1970). There have also been reports that showed the associations to introversion-extraversion was twice as high in monozygotic twins than in dizygotic twins (Holden, 1987). This raises the question of whether personality traits and brain wave patterns may be co-inherited or that perhaps certain personality traits may develop in response to a specific type of brain activity (Wall et al., 1990).

Presently the authors are developing 'hands-free' environmental control units for the severely disabled community (Craig et al., 1999; Kirkup, Searle, Craig, McIsaac & Moses, 1997). This technology is dependent upon the level of 8–13 Hz wave reactivity in the disabled. It is therefore important to understand the factors that are related to variations in the 8–13 Hz EEG wave. We have shown that in spinal cord injury, 8–13 Hz reactivity is reduced (Craig et al., 1999). This present research suggests that personality factors such as extraversion–introversion could also have an important influence on the 8–13 Hz amplitude levels, and thus its contribution to 8–13 Hz wave reactivity must be understood for the future development of the 'hands-free technology'.

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