PERSONALITY AND THE EEG: AROUSAL AND EMOTIONAL AROUSABILITY

GEORG STENBERG

Department of Clinical Neurophysiology, University of Lund, 221 85 Lund, Sweden

Summary—Eysenck's theory asserts that low cortical arousal accompanies extraversion (or the sub-component impulsivity). In Gray's theory, impulsivity is associated with high sensitivity to signals of reward, and anxiety with high sensitivity to signals of punishment. These hypotheses were tested by recording EEG signs of arousal and phasic arousability in emotional imagery, using 17 EEG channels and frequency analysis by Fourier transform. Three conditions were used: a neutral control task, and two emotional conditions involving imagery about pleasant and unpleasant personal memories. Forty subjects participated (23 men, 17 women; median age 23 years). Orthogonal personality dimensions of impulsivity and anxiety were derived from a joint analysis of the EPI and Karolinska Scales of Personality (KSP) questionnaires. The results showed, as expected, lower arousal, defined by more posterior theta activity, in impulsive subjects than in non-impulsives. These differences extended across all conditions.
   The EEG responses to the emotional conditions, in relation to the neutral one, consisted primarily of a right-lateralized frontal theta increase and changes in temporal beta activity (an increase in the positive condition, and a decrease in the negative one). These responses were expected to be amplified for impulsive subjects in positive emotion, and for anxious subjects in negative emotion. The right-sided frontal theta activity was stronger in high-anxious subjects than in low-anxious ones across all conditions, suggesting higher overall emotionality. For the temporal beta activity, the expected amplification of the response to negative emotion in the high anxiety group was confirmed, but the corresponding prediction for impulsives and positive emotion was not upheld. It is concluded that anxiety is related to EEG signs of heightened emotionality, especially in negative affect, and that impulsivity is associated with lowered arousal.

INTRODUCTION

The related constructs of arousal and arousability loom large in several biologically based personality theories. Although many operationalizations of them are possible, an obvious one is based on the EEG. Known to capture the gross arousal fluctuations of the sleep–wakefulness cycle with reliability, the EEG has shown promise for reflecting the subtler differences of mental activation and individual differences as well.

The tonic aspect of interindividual arousal differences forms the basis of Eysenck's theory of extraversion (Eysenck, 1967). It postulates a higher arousal level in introverts than in extraverts, and derives the behavioural differences between them from this basic assumption. Since the underlying cause is believed to be different levels of activity in a loop connecting the brainstem reticular formation with the cortex, and since this system is known to affect the EEG, most notably in stages of the sleep–wakefulness cycle, predictions about measurable effects on the EEG can be made. Extraverts are expected to show more rhythmic, low-arousal EEG activity, e.g. in the alpha range, than introverts. A number of studies have been performed, inspired by the Eysenckian hypothesis, but the expected results have not always been forthcoming. In a review of studies available in 1984, O'Gorman classified the outcome of 39 relevant studies as favourable for Eysenck's hypothesis in 19 cases, inconclusive in 10, and negative in 10 (O'Gorman, 1984). From reviews of the literature, e.g. (1983), Gale has come to the conclusion that the contradictions in the field can be resolved if some common sources of error are removed, particularly the variation in experimental conditions. These have ranged widely, from rest with closed eyes (Kondo, Bean, Travis & Knott, 1978), to potentially highly arousing tasks, such as mental arithmetic (Broadhurst & Glass, 1969). Gale argues that only conditions inducing intermediate arousal (e.g. repeated opening and closing of the eyes) can bring out the hypothesized differences between personality groups, since conditions either too high or too low in their arousal potential may invoke adaptive countermeasures in *S*s who wish to avoid unpleasant deviations from optimal arousal.

   Instead, O'Gorman (1984) has argued that the variation in methods of personality measurement is responsible for the differences in results. His meta-analysis showed that those studies which used

a version of Eysenck's extraversion scales, or a scale known to correlate highly with it, produced significantly more favourable outcomes. In a later study, O'Gorman and Lloyd (1987) have proposed further specificity in the psychometric measure with which the EEG activity is to be correlated. Extraversion, being a secondary trait, is composed of the primary traits impulsivity and sociability. Several observations (Gray, 1981; Revelle, Humphreys, Simon & Gilliland, 1980) indicate that impulsivity is in fact the trait that correlates most highly with indicators of low arousal. O'Gorman and Lloyd therefore advocated the use of impulsivity measures rather than extraversion, especially if the latter is measured by the EPQ questionnaire, where the impulsivity content has been weakened (Rocklin & Revelle, 1981). They demonstrated this relationship in their sample, in which impulsivity had a significant relationship with alpha activity—in the direction predicted by Eysenck—whereas extraversion had not.

The phasic aspect of interindividual arousal differences concerns arousability in specific situations. The personality theory of J. A. Gray (1972, 1981) posits individual differences in the excitability of brain systems underlying sensitivity to signals of reward and punishment. These threshold differences are not directly linked to the global arousal mechanism referred to by Eysenck. Instead, they entail activity differences in specific brain regions under appropriate conditions.

In the personality sphere, Gray's theory represents an alternative interpretation of the facts on which Eysenck's theory is built. The two-dimensional space of extraversion and neuroticism is better represented by the dimensions of impulsivity and anxiety, since these coincide more closely with the directions of causal influence, according to Gray (1981). Impulsivity is positively correlated with both extraversion and neuroticism, while anxiety correlates negatively with extraversion and positively with neuroticism. Gray's coordinate system can therefore be seen as resulting from a rotation of approx. 45° relative to Eysenck's. In the theory, impulsivity reflects sensitivity to signals of reward, and anxiety reflects sensitivity to signals of punishment (Gray, 1982).

Although the parts of his theory concerned with the neural substrate of anxiety have been extensively investigated in animal experiments by Gray and his associates, relatively few studies have been devoted to the physiological aspects of his personality hypotheses in humans (Fowles, 1988). Several types of difficulties are encountered in this context. First, there is no generally accepted personality questionnaire specifically designed for the measurement of Gray's personality dimensions, although developments are under way in this respect (Wilson, Gray & Barrett, 1990; MacAndrew & Steele, 1991). Second, conditions involving reward and punishment and their emotional effects are notoriously difficult to reproduce in the laboratory. Third, measurement of the activity in the limbic structures specified as the prime movers of these effects is not practically feasible, and physiological assessment of the activation patterns in humans will therefore have to rely on indirect effects, such as global or regional effects on the scalp EEG.

The present study aims to examine the relationship between personality and the EEG in two respects. First, it examines the relationship between impulsivity/extraversion and arousal indices in the EEG. Second, it explores the effects of emotional activation in relation to anxiety and impulsivity in the light of Gray's hypotheses. The measurement conditions used are emotional imagery, of positive and negative hedonic tone, and a neutral control condition. Emotional imagery almost by definition includes the imagined representations of stimuli associated with reward and punishment, and the degree of brain activation accompanying such imagery may be said to reflect the sensitivity which underlies the personality traits in Gray's theory.

The special requirements of generating emotional experience in a laboratory setting are dealt with in two ways. Rather than using emotional stimuli, this experiment enlisted the Ss' own repertory of emotional experiences, to be recollected or imagined at the S's chosen pace. Furthermore, the analysis is restrained to those moments in time, which by self-report were the peaks of emotional involvement.

As regards the objective of assessing tonic arousal differences related to personality, the measurement conditions, positive and negative emotional imagery and their neutral control condition, would probably all be classified as conducive to high arousal according to the criteria used by Gale and O'Gorman. Hence, they do not in themselves allow an assessment of situation by personality interactions over a wide range of induced arousal levels. Additional recordings from the same Ss made during rest and mental arithmetic will therefore be used for reference to extend the range of measurement situations.

The choice of dependent variables to indicate arousal from the range of EEG frequencies and electrode locations is not self-evident, although previous research has largely favoured the alpha rhythm in posterior derivations. The concentration on the alpha band may have been unfortunate, since alpha activity in fact has a non-linear relation to arousal. Alpha is characteristic of a relaxed but wakeful state; changes in the direction of drowsiness will decrease alpha and replace it with slower activity, primarily theta, and changes in the direction of heightened alertness will also decrease it and replace it with faster, mostly non-rhythmic activity. It remains to be determined whether this ambiguity has contributed to the confusion of conflicting results.

The choice of EEG indicators of emotional arousal is even less obvious, although research on emotion and the EEG has tended to center on a few phenomena. One of the first hypotheses in this area was that of Grey Walter, linking the theta rhythm to emotional processes, especially the pursuit of, or deprivation from, "visceral pleasure" (Walter, 1959). Further support for this assumption has been found in observations on infants (Maulsby, 1971). Heath and co-workers, reporting on EEG patterns during emotional states in psychiatric patients with surgically implanted electrodes (Heath, Cox & Lustick, 1974) have found low-frequency, especially delta, increases, relative to a neutral state, in cortical derivations. Similarly, direct high-frequency stimulation of the cingulate gyrus in conscious humans, which elicited subjective feelings of euphoria in many cases, was found to be accompanied by theta activity in scalp recordings (Talairach, Bancaud, Geier, Bordas-Ferrer, Bonis, Szikla & Rusu, 1973). The direction of the hypothesis relating theta to emotion goes against the grain of much EEG research, where rhythmic activity is normally seen as the epiphenomenon of an idling brain, and a reduction of these rhythms is interpreted as a sign of mental activation. Few studies have directly addressed the problem, but incidental observations of heightened low-frequency activity in affective states have accumulated. Among these are increased theta during sexual arousal (Cohen, Rosen & Goldstein, 1976), increased theta and delta during a laboratory stress task (Schwarz, Kielholz, Hobi, Goldberg, Hofstetter & Ladewig, 1982), and increased theta and delta preceding both the responses of healthy Ss in a creativity test and hallucinations in schizophrenics (Whitton, Moldofsky & Lue, 1978). In addition, studies of cognitive tasks have found theta increases to accompany the expected alpha reduction in mental activity such as concept formation (Lang, Lang, Kornhuber, Diekmann & Kornhuber, 1988), verbal and visuospatial tasks (Rugg & Dickens, 1982) and reading (Dolce & Waldeier, 1974). To accommodate such findings with the commonly found theta in drowsiness, Schacter, in a review of the studies available at the time (Schacter, 1977), observed that topography may be important; theta associated with activation being more often found in frontal and central areas.

A number of studies concerning effects of emotion on the EEG have focused on the question of asymmetrical activation of the cerebral hemispheres, and a large proportion of these have used alpha reduction as the measure of activation. Davidson and co-workers have found evidence of valence-specific alpha asymmetries over frontal areas in emotion, indicating greater right-sided activation in negative emotion, and greater left-sided activation in positive emotion (Ahern & Schwartz, 1985; Davidson, Ekman, Saron, Senulis & Friesen, 1990; Davidson & Fox, 1982, 1989; Davidson, Schaffer & Saron, 1985; Davidson, Schwartz, Saron, Bennett & Goleman, 1979).

Lastly, the beta rhythm, especially over temporal areas, has been implicated in emotional phenomena. Ray and Cole found temporal beta to vary as a function of emotion, being more abundant in positive than in negative emotion (Ray & Cole, 1985). Likewise, Matousek, Nüth and Petersén (1983), in a study of diurnal variations in mood and the EEG, found temporal beta to be correlated with ratings of pleasure. When activating the limbic system pharmacologically, Kellner et al. (Kellner, Post, Putnam, Cowdry, Gardner, Kling, Minichiello, Trettau & Coppola, 1987) found affective changes ranging from euphoria to dysphoria, with concurrent selective increases in temporal fast beta (26–45 Hz). Schellberg and associates hypothesized that right temporal fast beta activity would increase in positive relative to negative emotion, and found a tendency, although non-significant, in this direction (Schellberg, Besthorn, Klos & Gasser, 1990).

Whereas earlier work in this field often has surveyed less than the whole range of EEG phenomena, this study includes eight frequency bands, covering a range from 0 to 30 Hz, and a set of 17 electrodes covering all positions of the 10–20 system, except Fp1 and Fp2. Because this approach generates a large number of variables, the indiscriminate examination of which would almost certainly reap chance findings, the statistical treatment was guided by two constraining

principles. Firstly, the large number of dependent variables was reduced by principal components analysis, and as an additional constraint, the replicability of the factors was assessed by applying the same method to a different data set from the same Ss.

It was hypothesized that those EEG features which could, on *a priori* grounds, be associated with low arousal would be more abundant in impulsive Ss. Furthermore, the EEG features found to discriminate the emotional conditions from each other and from the neutral condition are expected to be stronger in positive emotion for impulsives, and stronger in negative emotion for anxious Ss.

METHOD

Subjects

Forty-one students volunteered to participate in experiments on brain waves and mental activity, and were paid for their participation. One S was excluded because of lacking data from one measurement condition. Of the remaining 40 Ss, 23 were male. Median age was 23 years (range: 18–46).

Using scores from the Edinburgh Handedness Inventory, two Ss could be classified as left-handed (laterality quotients < -0.5), six as ambidextrous ($-0.5 < = LQ < = 0.5$) and the other 32 as right-handed. Of the eight non-right-handed Ss, six were male, including the two wholly left-handed.

All Ss but one were university students. Given the fact that students following different degree courses have shown consistent personality differences in a number of studies (Wilson, 1981), an effort was made to avoid bias in the personality composition of the sample by including students from different courses. Thus, 13 studied computer science, 10 psychology, 6 neurobiology, and 10 other subjects, mostly medicine. The group averages for EPI extraversion (13.2 ± 4.0) and neuroticism (7.3 ± 3.4) do not deviate significantly from those of the Swedish standardization group (12.3 ± 3.8, and 7.6 ± 4.3, respectively).

Procedure

On their arrival at the laboratory, Ss were told that the laboratory session would include a measurement during which they were to imagine emotionally laden situations, pleasant and unpleasant ones, while their EEG would be recorded. They were instructed that the situations could be recollections of actual experiences or fantasies, that they would remain private, and that there would be no attempt to inquire into their nature or content. With these instructions, Ss were left to withdraw to a secluded room for the mental preparation of a few (1–5 of each emotional category) situations which they were to use in the subsequent session.

After the preparatory period, Ss were taken to the laboratory, where they were given a brief description of the measurement method and some instructions on how to avoid causing common artifacts, while electrodes were applied to the scalp. The ensuing experimental session included recording of event-related potentials as well as the EEG during several conditions. The measurements reported here occupied the last half hour out of a total session of about 2 hr, including electrode application and recurring impedance checks. They were placed last in the session to allow the greatest possible habituation to the laboratory conditions.

The S sat in a darkened laboratory in a slightly reclining armchair facing away from the experimenter, who was the only other person present. Instructions for the emotional imagery conditions were to imagine an emotional situation with closed eyes, and to press a hand-held button with the right hand when the appropriate mental image had been formed. The instructions were not specific as to the visual, auditory, or other, content of the mental images, but emphasized that the emotional experience be as vivid as possible. For each condition (pleasant/unpleasant) it was indicated that eight to ten button presses would be required. Data collection continued until that number had been attained, which in most cases took about 10 min. An emotionally neutral control condition, also comprising self-paced button presses with closed eyes, was given, where the instruction was to press the button at the end of each subjectively estimated 10 sec period. The button presses were recorded by a computer, and in the case of the neutral condition, a measure of performance was computed as the average absolute deviation from 10 sec of the interval between button presses.

The three conditions (pleasant/neutral/unpleasant) were presented in counterbalanced order, and a few minutes were allowed to elapse between them to dissipate the mood induced by the preceding condition. All measurements took place in the afternoon.

Data acquisition

The EEG was recorded, using a BioLogic Brain Atlas III+ system, with Ag/AgCl-electrodes applied to all 19 electrode positions of the 10/20-system, except Fp1 and Fp2. One electrode was applied immediately above the right eye brow to monitor blinks and eye movements, and another channel was used to record the event markers produced by Ss button presses. All electrodes were referred to linked earlobes, and a ground electrode was applied to the forehead. Impedances were kept below 6 kΩ. The EEG signals were filtered with a bandpass of 0.3–30 Hz and digitized with a sampling frequency of 128 Hz.

Data analysis

Using the digitized and disk stored EEG data, the periods preceding button presses were visually screened for artifacts, and if found to be uncontaminated, an epoch starting 2.6 sec before the button press and ending 0.6 sec before it was extracted, a Hanning windowing procedure was applied and the result was Fourier transformed, yielding power spectra for all channels. The 600 msec immediately before each button press were not included because of possible movement-related potentials. Data from the 6–10 epochs of each run were averaged, producing one data set, containing 18 power spectra (17 EEG channels plus one EOG channel) for each S by condition combination. The spectra covered the range from 0 to 31.5 Hz with a 0.5 Hz-resolution.

Power values were summed and log transformed for normality within eight frequency bands: delta 1: 0.5–1.5 Hz; delta 2: 2.0–3.5 Hz; theta 1: 4.0–5.5 Hz; theta 2: 6.0–7.5 Hz; alpha 1: 8.0–9.5 Hz; alpha 2: 10.0–12.5 Hz; beta 1: 13.0–19.5 Hz and beta 2: 20.0–30.0 Hz. This gave rise to 136 EEG (17×8) variables. To reduce the number of variables, they were subjected to a Principal Component Analysis, from which all components with eigenvalues exceeding unity were retained for a subsequent Varimax rotation. The resulting 15 factors together accounted for 89.5% of the variance in the original data space (see Table 1).

Factor scores were used in repeated measures ANOVAs to test for effects of condition. Because of the risk of falsely significant results in repeated measures ANOVAs if the sphericity assumption has been violated (Vasey & Thayer, 1987), MANOVAs were used to test for overall significance of all effects involving more than one degree of freedom in the numerator, and single degree-of-freedom trend contrasts were assessed only if the overall MANOVA had proven significant. In the trend contrasts, the conditions were ordered positive–neutral–negative, which means that an effect which separates the conditions in accordance with emotional valence will show up as a linear trend. Effects which separate the two emotional conditions jointly from the neutral one will emerge as a quadratic trend.

Comparison data set

During the measurements taking place earlier in the laboratory session, recordings were made of the EEG during rest and mental arithmetic. In the former condition, instructions were to relax with closed eyes, and in the latter to perform repeated subtractions (starting with 1000 and subtracting 7 repeatedly), also with closed eyes. The EEG epochs of these measurements were not time-locked to specific responses from the Ss, but the data acquisition was otherwise comparable. Automatic artefact rejection was enabled, but since epochs were Fourier transformed and averaged on-line, individual epochs were not screened for artifacts. This data set was subjected to the same type of PCA–Varimax analysis. It also yielded 15 factors, accounting for 92.99% of the variance. To check for replicability of factor structure, the vectors of factor loadings were correlated between the two data sets (Barrett, 1986). Table 1 reports, for each factor in the emotional imagery set, its factor similarity correlation with the factor most similar to it in the other data set.

Personality measurement

The personality measures used were the Eysenck Personality Inventory (EPI), form A, in a Swedish translation, and the Swedish KSP questionnaire (Karolinska Scales of Personality). Ss completed both at home before taking part in the EEG measurement.

Table 1. Characterization of rotated factors: brief description; the eight variables with the highest loadings in absolute value (electrode name followed by abbreviated frequency band: delta 1 ... beta 2); percent variance accounted for in data space; reproducibility, expressed as correlation coefficient for factor loadings as described in text)

	Description	Variables with highest (absolute) loadings	% Var.	Reprod.
1	Low α	P3.α1, PZ.α1, P4.α1, C3.α1, O2.α1, T6.α1, T5.α1, C4.α1	18.99	0.95
2	Posterior δ	P4.δ1, O1.δ1, T6.δ1, T5.δ1, P3.δ1, PZ.δ1, T5.δ2, P3.δ2	17.40	0.74
3	Posterior β	P3.β2, P4.β2, PZ.β2, T5.β2, C3.β2, C4.β2, CZ.β2, O2.β2	12.54	0.81
4	Midfrontal θ and β	FZ.θ1, FZ.δ2, FZ.β1, F3.β1, F4.θ1, FZ.θ2, F3.θ1, FZ.α2	11.44	0.35
5	High α	O2.α2, T6.α2, O1.α2, P4.α2, PZ.α2, T5.α2, C4.α2, CZ.α2	8.47	0.95
6	Frontal δ	F7.δ1, F3.δ1, F8.δ1, F7.δ2, F7.δ1, F8.δ2, F3.δ2, T3.δ1	4.32	0.64
7	Right frontal θ	F8.θ1, F8.θ2, F8.δ2, T4.θ1, F4.δ2, F8.α1, T4.δ2, T4.θ2	3.09	0.59
8	Posterior θ	PZ.θ1, P3.θ1, P4.θ1, C3.θ1, O2.θ1, CZ.θ1, C4.θ1, T6.θ1	2.36	0.63
9	Left temporal θ	T3.θ2, F7.θ2, T3.θ1, C3.θ2, F7.α2, F7.θ1, F7.β1, F7.α1	2.35	0.55
10	Posterior low β	T6.β1, T5.β1, O2.β1, O1.β1, PZ.β1, P3.β1, CZ.β1, C4.β1	1.74	0.67
11	Temporal β	T4.β1, T4.β2, T3.β2, T3.β1, T4.α2, C4.β2, T3.α2, C3.β2	1.74	0.69
12	Posterior high δ	O2.δ2, O1.δ2, T6.δ2, CZ.δ1(−), T5.δ2, P4.δ2, C3.δ1(−), O2.θ1	1.62	0.42
13	L.fr. δ vs. r.fr. β	F4.δ1, F7.β1(−), F7.β2(−), C3.β1(−), F4.δ2, C4.θ2(−), F4.β2, C3.β2(−)	1.24	0.29
14	Right frontal β	F4.β1, F4.β2, F8.β1, C4.β1, F7.θ1(−), T3.β1(−), FZ.β2, T3.β2(−)	1.21	0.39
15	Frontal α	F7.α2, F8.α2, T3.α2, F7.α1, O2.α2(−), CZ.θ2(−), F3.α2, C3.α2	0.96	0.48
	Total variance accounted for		89.45	

Scores for Extraversion, Neuroticism and Lie are derived from the EPI (Eysenck & Eysenck, 1969). The KSP yields scores for 15 scales, selected for their relevance to biologically based personality traits and temperamental vulnerability for psychopathology. Among them are scales related to impulsivity and sensation seeking, anxiety scales, and scales measuring aggression and hostility (Schalling, Edman & Åsberg, 1983). (The complete list of scales is given in Table 2.)

The analysis of the personality scales was guided by the need to find two orthogonal personality variables corresponding as closely as possible to Gray's concepts of impulsivity and anxiety, the former also serving the purpose of testing the impulsivity modification of Eysenck's extraversion–arousal hypothesis. The further need to reduce the number of tests for personality effects in order to keep the Error I rate within limits, suggested a data reduction of the personality scales by factor analysis. Therefore, the three EPI scales and the 15 KSP scales were jointly subjected to a Principal Components Analysis. Factors with eigenvalues greater than 1 were retained and Varimax rotated.

RESULTS

Personality

The 5 personality factors emerging from the factor analysis are presented in Table 2. The first factor, loading highly on Suspicion, Detachment and Irritability, and the second, with high positive loadings on Verbal and Indirect Aggression, and high negative ones on Social Desirability and Lie, both embody important aspects of Eysenck's Psychoticism dimension. The third factor is an impulsivity and sensation-seeking factor, with the highest loadings on Monotony Avoidance (Sensation Seeking), Impulsivity and Extraversion. [Its correlation with the EPI impulsivity subscale, scored as in (Revelle *et al.*, 1980), was 0.64.]

The last two factors both relate to neuroticism and anxiety. Factor 4 has an emphasis on Guilt, Neuroticism and Psychic Anxiety—the latter a scale which incorporates tendencies toward insecurity, worry and low self-esteem. Factor 5 relates most highly to defective Socialization, Psychasthenia, vegetative discomforts (Somatic Anxiety) and Muscular Tension. The separation between internalized, cogitational anxiety, and neurotic distress producing bodily symptoms, parallels earlier findings by Schalling *et al.* (1983).

A factor structure derived from such a small sample can make no claim to replicability, although the results show similarities with earlier findings. Thus factors 2 to 5 correspond to the four factors found with KSP in a male normal population by af Klinteberg, Schalling and Magnusson (1986), but factor 1, accounting for the smallest part of the variance in the present sample, had no counterpart in that study. However, in the present context, the analysis is used as a purely heuristic device to reduce the personality data and derive orthogonal measures of impulsivity and anxiety. For these purposes, only factors 3 and 4 will be considered in further analyses, these two being the ones most clearly related to the theoretical position of Gray. They will henceforth be called Impulsivity and Anxiety (Imp and Anx). A median split was performed on their distributions of factor scores in order to form groups for analyses of variance.

Table 2. Factor loadings of personality variables on factors derived from Principal Components Analysis

|	Factor				
	1	2	3	4	5
EPI variables					
Extraversion	−0.06	0.36	0.68	−0.15	−0.24
Neuroticism	0.22	0.06	−0.03	0.75	0.40
Lie	0.12	−0.68	−0.10	0.30	−0.21
KSP variables					
Somatic Anxiety	0.47	−0.09	−0.19	0.23	0.62
Psychic Anxiety	0.28	−0.21	−0.39	0.52	0.56
Muscular Tension	−0.01	0.04	−0.25	−0.19	0.69
Social Desirability	−0.20	−0.61	0.50	0.16	0.06
Impulsivity	−0.03	0.07	0.79	0.17	−0.11
Monotony Avoidance	0.17	0.06	0.80	−0.27	−0.10
Detachment	0.71	−0.36	−0.29	−0.12	0.20
Psychasthenia	0.16	−0.03	−0.40	0.28	0.73
Socialization	−0.14	0.02	−0.16	−0.16	−0.75
Indirect Aggression	0.03	0.73	0.37	0.15	0.07
Verbal Aggression	−0.09	0.81	0.11	0.11	−0.37
Irritability	0.64	0.46	0.02	0.16	0.15
Suspicion	0.78	−0.02	0.21	0.17	0.11
Guilt	0.02	−0.03	−0.01	0.80	−0.04
Inhibition of Aggression	0.11	−0.44	−0.45	0.40	0.28
Variance explained (%)	11.19	15.34	16.10	11.91	15.80
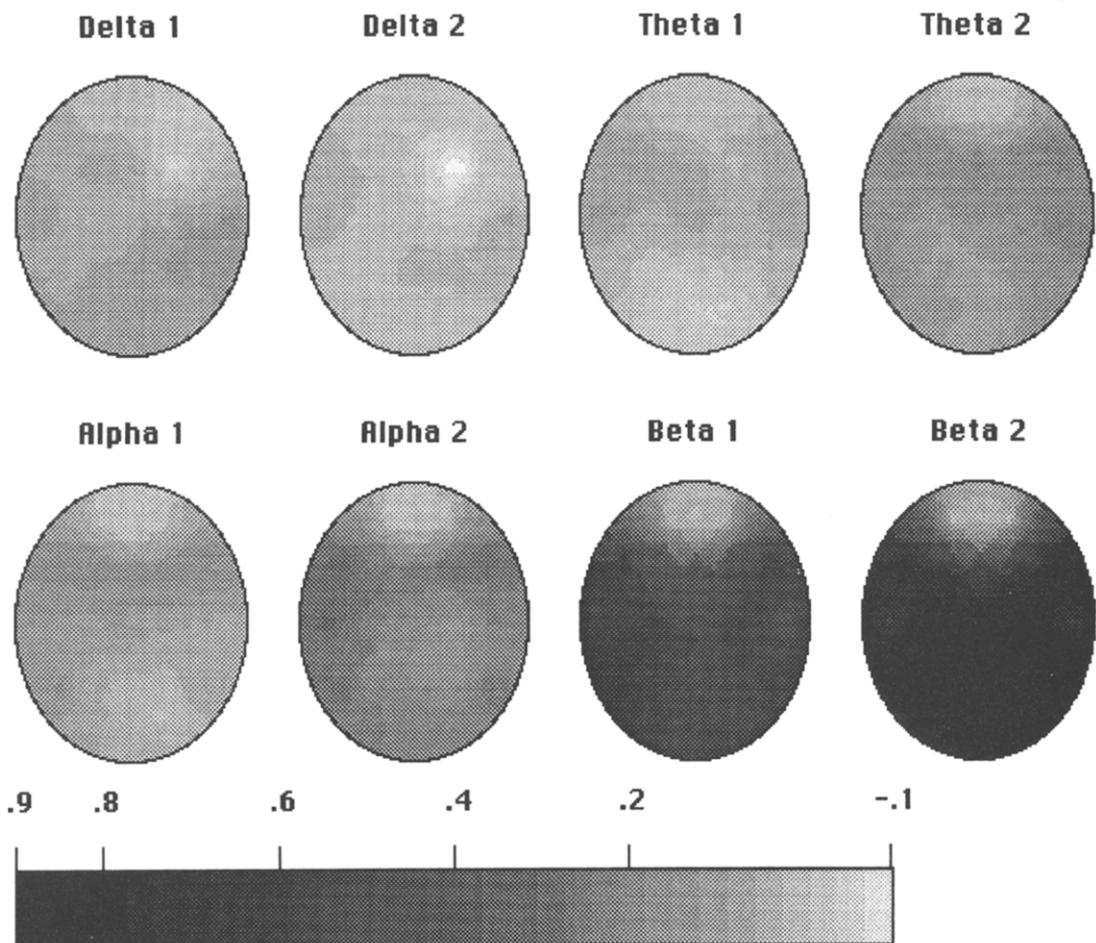
Fig. 1—*legend on p. 1106.*

Relation of personality groups to sex and age

Sex distribution was unequal among Imp groups. In the above-median group there were 8 men and 12 women, while the low group held 15 men and 5 women [$\chi^2(1) = 5.01$; $P = 0.025$]. There was no such difference for Anx groups [$\chi^2(1) < 1$]. Nor were there any age differences between personality groups [$F(1,38) < 1$ in both cases].

Principal Components Analysis of the EEG

The 15 factors that emerged from the Principal Components Analysis are briefly characterized in Table 1. Since several of the factors account for relatively small proportions of the total variance, concerns may be raised about their stability and reproducibility. Therefore, only those factors that proved to be reproducible in the comparison data set were accepted for further analysis. The criterion was set at a factor similarity coefficient of 0.6, but an exception was made to this rule. Factor 7, with a factor similarity coefficient of 0.59, was included in the analysis, because it comprises frontal theta, which is expected to be important on the basis of previous research.

Of the remaining 9 factors, three showed significant effects of experimental condition in multivariate analyses of variance: factors 3, 7 and 11. The patterns of factor loadings which defined them are depicted as brain maps in Figs 1–3. The nature of the effects are shown in Fig. 5, where averaged factor scores are plotted as a function of experimental condition.
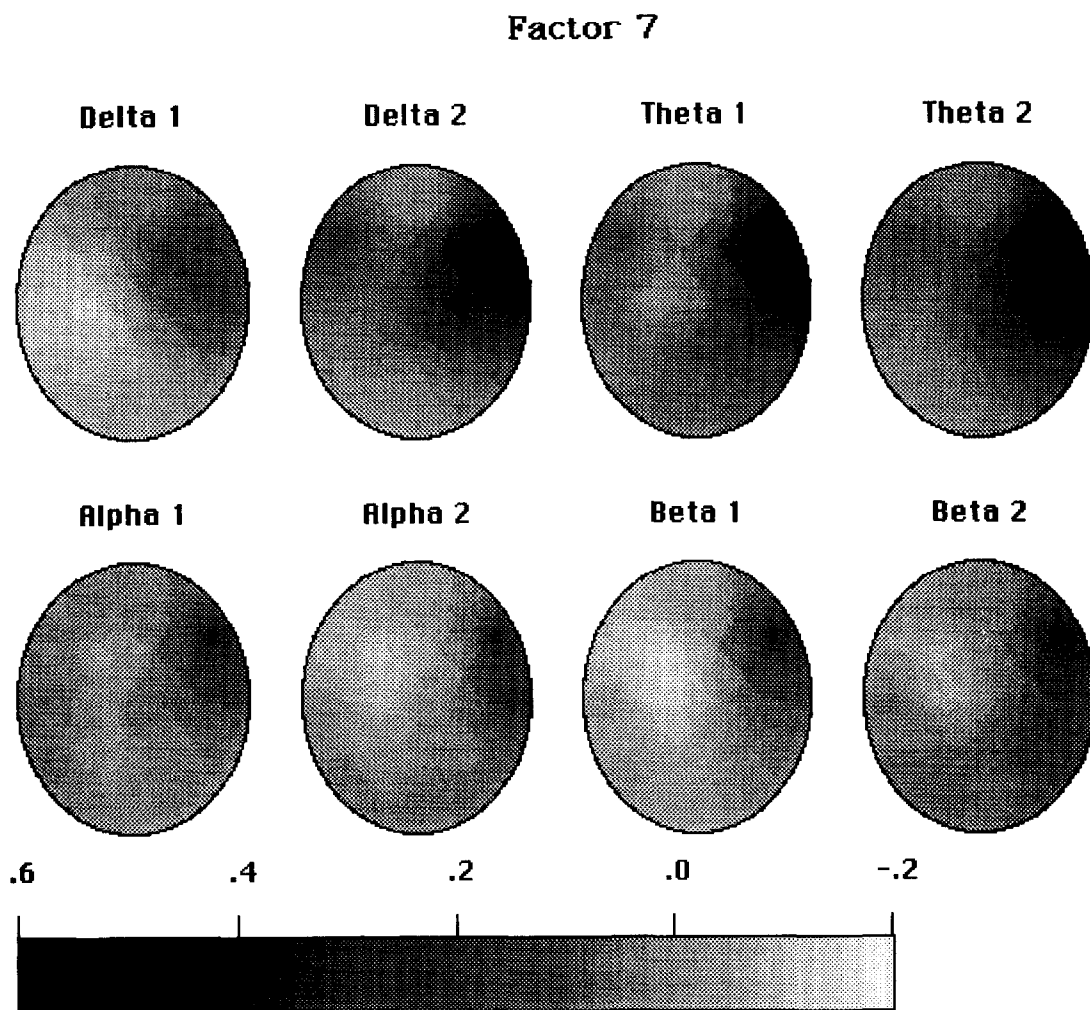
Factor 7

Fig. 2—*legend on p. 1106.*

Parietal beta (factor 3)

Activity in the high beta range increased bilaterally in both emotional conditions, predominantly over parietal areas [MANOVA $F(2,38) = 4.33$; $P = 0.02$; quadratic trend contrast: $F(1,39) = 8.29$; $P = 0.006$]. This was parallelled by a non-significant trend toward a decrease in the low alpha range over posterior areas.

Given that parieto–occipital beta has been found to predict performance in a vigilance task (Belyavin & Wright, 1987), factor 3 could be interpreted as a measure of alertness or sustained attention. It was therefore hypothesized that scores should correlate with the performance measure in the neutral condition, i.e. the accuracy of the time estimation. Indeed, that was found to be the case (Correlation -0.39; $P = 0.012$ between average deviation of time estimate and factor 3 score).

Right frontal theta (factor 7)

Factor 7 was highly asymmetrical, with the highest loadings for theta activity over the right-sided, ventrally placed, frontal electrode F8. Scores increased in the emotional conditions [MANOVA $F(2,38) = 4.09$; $P = 0.02$; quadratic trend contrast $F(1,39) = 7.92$; $P = 0.008$].

To test the possibility that the increase could be caused by eye movements, the low theta activity of the EOG channel was assessed by a MANOVA. The result [$F(2,38) = 0.67$; NS] indicated that this was not the case.
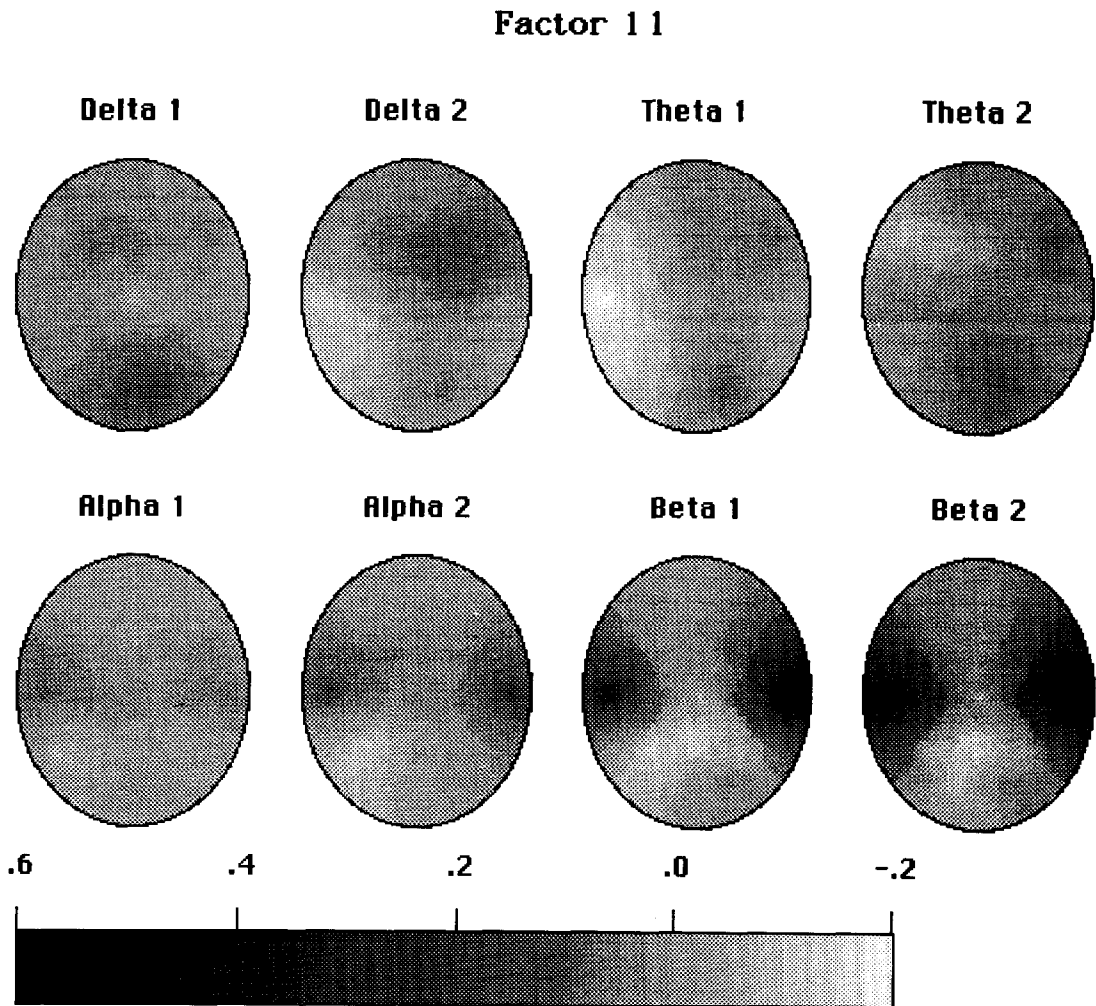
Factor 11

Fig. 3—*legend overleaf.*

Temporal beta (factor 11)

Factor 11 loaded almost exclusively on beta activity in the two temporal electrodes T3 and T4, loadings being slightly higher on the right side. It differentiated between conditions according to emotional valence, with the highest factor scores in the positive emotion condition and the lowest in the negative [MANOVA $F(2,38) = 4.55$; $P = 0.01$; linear trend contrast $F(1,39) = 9.22$; $P = 0.004$].

To assess the possible influence of muscle artifacts on the temporal beta activity, a comparison between summed beta activity in the T3/T4 electrode pair with that of the F7/F8 pair and the EOG electrode (applied to the forehead above the right eye) is given in Table 3. Under the hypothesis that emotional thoughts would tend to increase frowning and muscular tension, it could be predicted that myogenic beta would increase in both emotional conditions relative to the neutral one, but especially so in the negative condition. The activity in the forehead electrode and the frontal pair follow this pattern, whereas the temporal beta exhibits a contrasting pattern, with the highest increase in the positive condition and a slight decrease in the negative one.
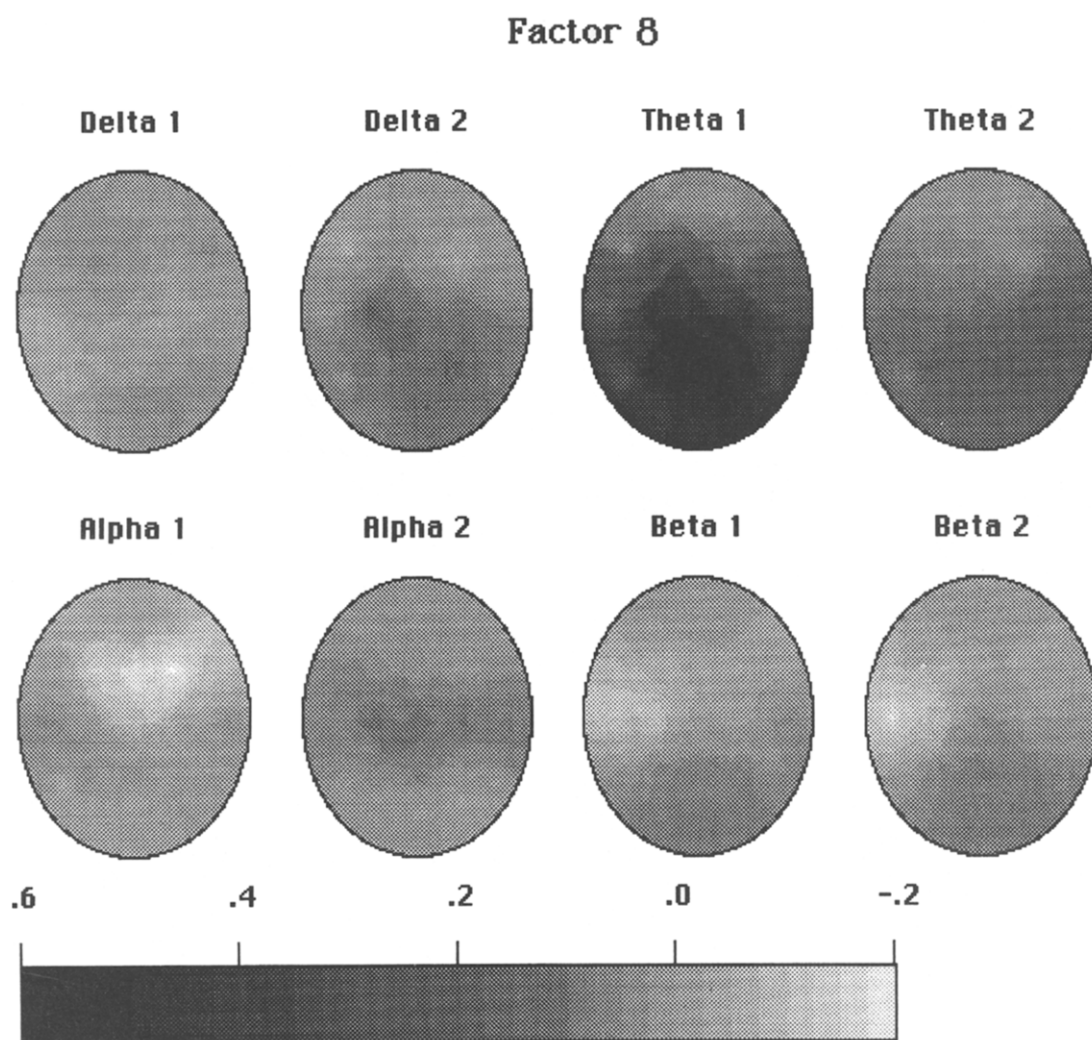

Fig. 4.

Figs 1–4. Loadings of factors 3, 7, 11 and 8 plotted as brain maps with linear interpolation between electrode positions. Values for electrode positions Fp1 and Fp2 were not defined and have been set to zero. For definitions of frequency bands: see text.
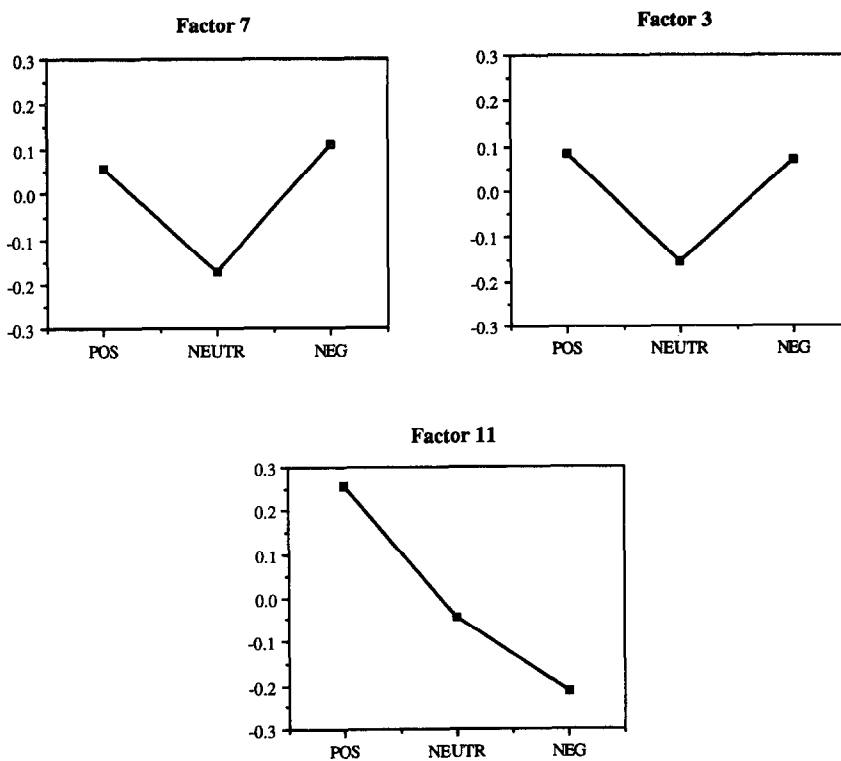
Factor 7

Factor 3

Factor 11

Fig. 5. Average factor scores for factors 3, 7 and 11 as functions of condition: positive (POS), neutral (NEUTR) and negative (NEG) emotional valence.

Arousal indices

Of the nine EEG factors derived in part I, two are of *prima facie* relevance to the hypothesis of arousal differences. They are factors 1 (low alpha) and 8 (posterior theta). They both include rhythmic activity with a broad, posterior distribution i.e. EEG background activity known to be affected by arousal changes. ANOVAs were performed on the scores from each of these, using a 2 (Imp groups) × 2 (Anx groups) × 3 (conditions) model, with repeated measures on the last factor.

Factor 1 (low alpha) exhibited a significant effect of Imp × Anx [$F(1,36) = 6.49$; $P = 0.015$], but the main effects of Imp and Anx alone were not significant (both $F < 1$). Inspection of the group averages showed the highest alpha activity to be in the high Imp and high Anx group (Imp + Anx +), with the ordering of the groups Imp + Anx + > Imp − Anx − > Imp − Anx + > Imp + Anx −. Duncan's multiple range test showed the Imp + Anx + group to be different from the two last groups at the 5% level. Since the sex distribution had proved to be different in Imp groups, sex was entered as a covariate in the model. This enhanced the Imp × Anx effect [$F(1,35) = 7.76$; $P = 0.009$], and showed a main effect for sex as well [with the effects of personality controlled for, women had less alpha than men: $F(1,35) = 4.62$; $P = 0.039$].

A significant main effect of Imp emerged for factor 8, parietal theta [$F(1,36) = 5.92$; $P = 0.020$]. The loading distribution is illustrated as brain maps in Fig. 4. Across conditions, high Imp *S*s had higher scores on this factor than low Imps (Fig. 6). Introducing sex as a covariate did not substantially alter this effect [$F(1,35) = 4.82$; $P = 0.035$].

Table 3. Change in beta activity (13–30 Hz) relative to the neutral condition for different electrodes

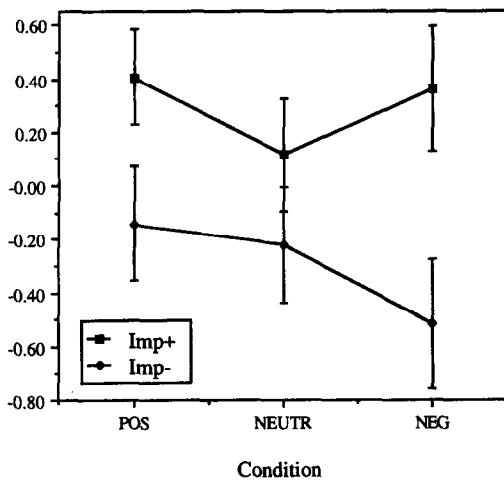|	T3/T4 (%)	F7/F8 (%)	EOG (%)
Positive	11.52	7.59	4.70
Negative	−0.78	10.80	13.72

Fig. 6. Factor scores on factor 8 (posterior theta) for high and low Imp groups. Vertical bars indicate SEM. For abbreviations see legend to Fig. 5.
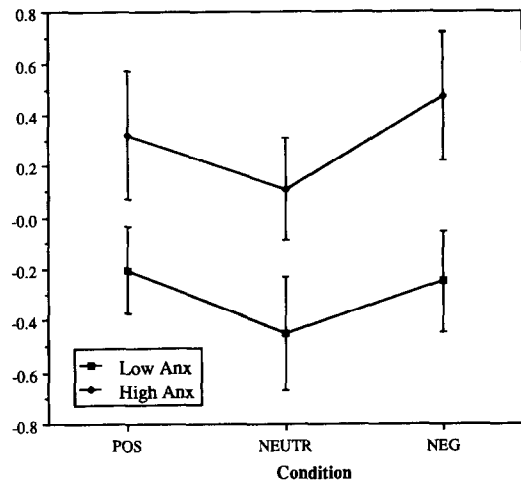
Fig. 7. Factor scores on factor 7 (right frontal theta) for high and low Anx groups. Vertical bars indicate SEM. For abbreviations see legend to Fig. 5.

It was of some interest to see whether the difference between high and low Imp Ss on the theta factor would generalize to the Rest and Mental Arithmetic conditions in the comparison data set, described in the Methods section. Scores on the posterior theta factor corresponding to factor 8 were therefore tested for effects of Imp and Anx. The relationship with personality proved to be essentially the same under these conditions. There was a significant main effect of Imp $[F(1,36) = 6.68; P = 0.014]$. Since the two conditions in this data set differed very much in arousal value, they were also tested separately. The Imp main effect held for both Rest $[F(1,36) = 6.09; P = 0.018]$ and Mental Arithmetic $[F(1,36) = 5.25; P = 0.028]$.

Similarly, the results found for the low alpha factor (factor I, above) were found to generalize to the Rest and Mental Arithmetic conditions. The corresponding factor in this data set also showed an Imp × Anx interaction $[F(1,36) = 6.96; P = 0.012]$, and the ordering of the personality groups proved to be the same: $Imp + Anx + > Imp - Anx - > Imp - Anx + > Imp + Anx -$. There was no personality by condition interaction.

In view of the discussion whether extraversion or impulsivity hold the closest relation to arousal measures, the EPI scales Extraversion and Neuroticism were also used to form groups for ANOVAs on factors 1 and 8 in the emotional imagery data set. No effects of personality were significant in this analysis.

Indices of emotional activation

Three factors demonstrated effects of emotional activation, as shown above. To test the hypothesis of different emotional reactivity for different personality groups, scores on these factors were submitted to ANOVAs as above, the expected results of which were significant Imp × Condition and Anx × Condition interactions, indicating stronger activation for highly impulsive Ss in positive emotion and stronger activation for highly anxious Ss in negative emotion. Furthermore, specificity of these effects would demand that the non-emotional activation of the Rest–Mental Arithmetic measurements, would not show personality by condition interactions.

Factor 3, parietal beta, did not exhibit significant personality effects.

The right-sided frontal theta of factor 7 exhibited a main effect of Anx $[F(1,36) = 4.34; P = 0.044]$, due to higher values for the high Anx Ss in all conditions (Fig. 7).

For the temporal beta factor, nr 11, the predicted Anx × Condition interaction was obtained [MANOVA $F(2,35) = 3.91; P = 0.029$]. A study of simple effects of Anx in different conditions clarified this interaction by showing that the difference between Anx groups was significant only in negative emotion $[F(1,36) = 7.15; P = 0.011]$, as illustrated in Fig. 8. The effects of Imp and Imp × Anx were not significant. Group averages for all personality combinations are shown in Fig. 9.
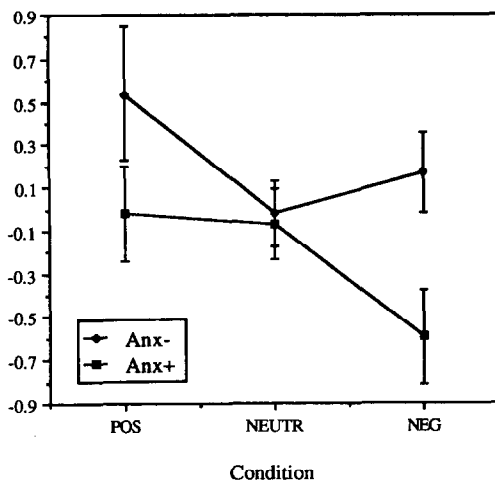
Fig. 8. Factor scores on factor 11 (temporal beta) for high and low Anx groups. Vertical bars indicate SEM. For abbreviations see legend to Fig. 5.
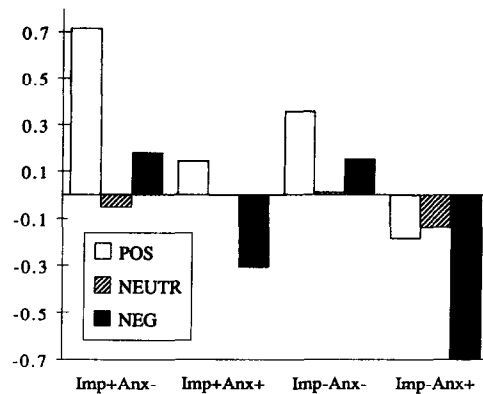

Fig. 9. Scores on the temporal beta factor (factor 11) in the positive, neutral and negative conditions for personality groups formed by combinations of high and low Imp and Anx.

Entering sex as a covariate enhanced some of these personality effects and left the others substantially unaltered. Sex and handedness had no effects in themselves on the factors of interest in emotional reactivity.

Of all 15 factors in the Rest–Mental Arithmetic data set, several showed condition effects, but none showed any personality-by-condition interaction.

DISCUSSION

Arousal and personality

The results of this study support the view that highly impulsive individuals show EEG signs of lower arousal than low impulsives. The main finding in this respect was higher levels of slow activity in the theta band for the impulsive Ss in all measurement conditions. In the alpha band, impulsive Ss showed higher activity only if they combined high impulsivity with high trait anxiety.

A more consistent relationship between impulsivity and arousal in the theta than in the alpha band is not surprising in view of the curvilinear relationship that alpha activity itself holds with arousal. As argued in the introduction, alpha is maximal only in relaxed wakefulness, and decreases will accompany deviations both upwards and downwards, within a range easily reached by an experimental subject in a laboratory.

In a vigilance experiment, Belyavin and Wright (1987) found that theta and beta levels were predictive of errors due to drowsiness, while alpha was highly variable between Ss and did not relate to vigilance performance. Theta activity may, however, bring some interpretative difficulties of its own. As pointed out in the introduction, theta increases may accompany both cognitive and emotional activation. In those cases, however, theta increases are focally localized, often over frontal and central areas (Schacter, 1977). Broadly distributed, posterior theta seems to bear a clearer relationship to low arousal and would therefore justify its place in studies relating personality to arousal.

Not many studies have used measures of theta activity. Gale, Coles and Blaydon (1969) did, and found significantly higher theta activity in extraverts, a difference that characterized the alpha and the beta bands as well. Gale, Coles, Kline and Penfold (1971) found theta abundance to be related to neuroticism, but again this effect was not specific to the theta band. Rösler (1975), in a study encompassing a wide range of conditions, found an interaction between extraversion and measurement situation for the delta + theta band (1–6 Hz). Group averages reveal that this was due to the development of increasing amounts of slow activity in extraverts during the experiment. The alpha band tended toward a corresponding decline for extraverts, consistent with the present hypothesis that theta reflects arousal better than alpha does.

Gale's hypothesis concerning the importance of experimental task for the revelation of personality differences was not directly tested in this study, since the medium arousal task recommended by him (i.e. repeated opening and closing of the eyes) was not included. Five tasks were observed, of which one was of a low arousal type (rest), while three were relatively high and one high (mental arithmetic) in arousal value. Still, the results indicate that task was not important for the personality differences found here. Instead, they support the position taken by O'Gorman (1984) in ascribing a more important role to the choice of personality measure than to the experimental task. More specifically, in agreement with the results of O'Gorman and Lloyd (1987), impulsivity was shown to be related to measures of arousal, while extraversion was not. In this respect, the results concur with findings from other fields, such as conditioning (Eysenck & Levey, 1972) and cognitive performance under different stressors (Revelle *et al.*, 1980).

Emotional arousability

The main findings concerning EEG signs of emotional activation were increases in right-sided frontal theta and parietal beta, along with valence-specific changes in temporal beta.

When EEG findings are in the beta range, questions can always be raised about possibly myogenic origins. Although all EEG epochs in this study were visually screened for artifacts, subtle effects of muscular tension may be difficult to detect by visual inspection alone. Frontal and temporal electrodes are more subject to muscle artifacts than posterior ones, and from this point of view, the results of factor 11 are more questionable than those of factor 3. The direction of the changes in the temporal beta activity is, however, not readily compatible with the hypothesis of a myogenic origin. The temporal muscles, which underlie the scalp locations of electrodes T3 and T4, have a broad extension, and their influence is likely to affect the anterior location of the F7 and F8 electrodes as well. The effect of these muscles would be to clench the jaws, a manoeuvre not unlikely to accompany the contemplation of unpleasant memories. The beta activity defined by factor 11 instead increases with positive, and decreases with negative emotion. Furthermore, the dissociation of these changes from those of the adjacent F7/F8 pair militate against a common origin in the temporal muscles.

An increase of beta concomitant with increases in positive mood or alleviation of negative mood is in agreement with psychopharmacological effects on the EEG. Both tricyclic antidepressives and anxiolytics of the benzodiazepine type have consistently been observed to increase power in the beta range (Herrmann & Schaerer, 1986). The temporal beta findings in this study closely parallel those of Ray and Cole (Cole & Ray, 1985; Ray & Cole, 1985). In the study by Kellner *et al.* (1987), temporal beta was also found to correlate with emotional valence, but in the reverse direction. The frequency band used in that study (26–45 Hz) had almost no overlap with that of the present study and that of Ray and Cole, and it is quite possible that different bands of the widely defined beta range can be reactive to different conditions.

Evidence from many sources coalesce to implicate the temporal lobes in emotion. The extensive cortical stimulation studies by Penfield and associates produced reports of emotional experience only when the temporal lobes were stimulated (Penfield & Jasper, 1959). O^{15}-PET studies have shown flow increases in the temporal lobes in experimental conditions designed to arouse anxiety (Reiman, Fusselman, Fox & Raichle, 1989). Animal experiments have indicated that the anterior temporal lobes and the functionally connected amygdala are essential for the association of perceived objects with affective value (Jones & Mishkin, 1972). It is therefore not surprising that temporal lobe activity in the EEG should be apt to characterize emotional states. Of all cortical areas, the ones most extensively connected to the limbic system are the temporal lobes and orbitofrontal cortex. The scalp electrode closest to the latter, F7 and F8, were the ones to show marked theta changes with emotion.

To this may be added that the septo-hippocampal system, assumed by Gray to be the neural substrate of anxiety, extends along the medial aspect of the temporal lobes, and may affect EEG activity picked up by temporal electrodes. Furthermore, in a study relating regional cerebral blood flow to personality (Stenberg, Risberg, Warkentin & Rosén, 1990), introverts were found to have significantly higher flow in the temporal lobes than extraverts did. Since the measurement situation for this method in itself may be moderately fear-provoking, the finding could be regarded as a personality by emotion interaction of the same kind as the one found here.

The right-sided fronto-orbital theta increased in both types of emotion. Valence non-specific emotional activations of the right hemisphere have been found with different methods (Bryden & MacRae, 1989). More theta in right than left frontal cortex was also found by Tucker and Dawson (1984) in both positive and negative emotion. Likewise, Ahern and Schwartz (1985) found theta increases in the right frontal lobe during emotion and observe that this "may be more related to the overall arousal level of the particular emotions than to their positive or negative affective valence, *per se*", a conclusion also applicable to the present study.

The generator of the theta response observed in this study is not known, although both orbitofrontal cortex—part of Gray's anxiety system—and limbic structures are possible candidates. Hippocampal theta is a characteristic sign of motivated activation in many mammals, and, although it is a matter of controversy, it has been proposed that hippocampal theta with the same behavioural correlates can be observed in man as well (Steriade, Gloor, Llinas, Lopes da Silva & Mesulam, 1990).

The theta factor revealed tonic personality differences, with higher levels in anxious Ss across all conditions (Fig. 8). Regional cerebral blood flow has been found to be elevated in trait anxious Ss in approximately this right-sided location (Hagstadius, 1989).

Personality and affinity for different types of emotion

Positive and negative affect have been shown to be important dimensions along which the varieties of emotional experience can be ordered (Watson & Tellegen, 1985). Furthermore, the propensities for experiencing the different types of emotion covary with personality traits (Costa & McCrae, 1980). Given the finding that emotional activation could produce measurable effects on the EEG, it was hypothesized that personality traits would interact with the strength, if not the direction, of those effects. The shape to be expected from the interactions was given by Gray's theory (1982).

Most relevant to these hypotheses were the temporal beta effects (factor 11), since they were bidirectional, separating the types of emotion from each other as well as from the neutral state. Of the two expected interaction effects, only the one related to Anx obtained. Anxious Ss proved to react more strongly in the negative emotional condition than non-anxious Ss did, or than they themselves did in the positive condition (Fig. 9). The corresponding hypothesis for Imp and positive emotion did not hold, although the strongest activation by far in the positive condition was produced by the high Imp & low Anx group.

On the whole, support was provided, by purely electroencephalographic indicators, for the view that anxiety as a personality trait is associated with emotionality in general, and particularly with negative emotionality. The case for impulsivity and positive emotion is less clear, and there is at present much more support for the view that impulsivity is associated with low arousal than with facilitation of positive affect. Low arousal could in itself tilt the balance in favour of pleasure-seeking behaviour by biassing the estimated prospects for positive and negative consequences.

The interaction between Imp and Anx deviated from the hypothesized additive type. The unbalanced combinations, Imp + Anx− and Imp − Anx+, behaved according to expectations (Fig. 9). The balanced low group (Imp − Anx−) also conformed to predictions by showing the lowest degree of overall activity by all accounts. The Imp + Anx+ group, however, deviated drastically from the expected pattern by producing a very small emotional activation. This result suggests a different way of reacting to the experimental instructions, especially when considered along with the finding of exceptionally high alpha activity in this group. Since the activations were entirely under voluntary control, the possibility of a protective disemphasis on the affective aspects of the task in highly emotional persons can not be excluded. Only experiments with more direct stimulus control can prove this conjecture right or wrong.

REFERENCES

Ahern, G. L. & Schwartz, G. E. (1985). Differential lateralization for positive and negative emotion in the human brain: EEG spectral analysis. *Neuropsychologia*, *23*(6), 745–755.

Barrett, P. (1986). Factor comparison: an examination of three methods. *Personality and Individual Differences*, 7(3), 327–340.

Belyavin, A. & Wright, N. A. (1987). Changes in electrical activity of the brain with vigilance. *Electroencephalography and Clinical Neurophysiology*, 66, 137–144.

Broadhurst, A. & Glass, A. (1969). Relationship of personality measures to the alpha rhythm of the electroencephalogram. *British Journal of Psychiatry*, 115, 199–204.

Bryden, M. P. & MacRae, L. (1989). Dichotic laterality effects obtained with emotional words. *Neuropsychiatry, Neuropsychology and Behavioural Neuroscience*, 1(3), 71–76.

Cohen, A. S., Rosen, R. C. & Goldstein, L. (1976). Electroencephalographic laterality changes during human sexual orgasm. *Archives of Sexual Behaviour*, 5, 198–199.

Cole, H. W. & Ray, W. J. (1985). EEG correlates of emotional tasks related to attentional demands. *International Journal of Psychophysiology*, 3(1), 33–341.

Costa, P. T. & McCrae, R. R. (1980). Influence of extraversion and neuroticism on subjective well-being: happy and unhappy people. *Journal of Personality and Social Psychology*, 38(4), 668–678.

Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A. & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology. I. *Journal of Personality and Social Psychology*, 58(2), 330–341.

Davidson, R. J. & Fox, N. A. (1982). Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science*, 218, 1235–1236.

Davidson, R. J. & Fox, N. A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology*, 98(2), 127–131.

Davidson, R. J., Schaffer, C. E. & Saron, C. (1985). Effects of lateralized presentations of faces on self-reports of emotion and EEG asymmetry in depressed and non-depressed subjects. *Psychophysiology*, 22(3), 353–364.

Davidson, R. J., Schwartz, G. E., Saron, C., Bennett, J. & Goleman, D. J. (1979). Frontal versus parietal EEG asymmetry during positive and negative affect. *Psychophysiology*, 16, 202–203.

Dolce, G. & Waldeier, H. (1974). Spectral and multivariate analysis of EEG changes during mental activity in man. *Electroencephalography and Clinical Neurophysiology*, 36, 577–584.

Eysenck, H. J. (1967). *The biological basis of personality*. Springfield, IL: Thomas.

Eysenck, H. J. & Eysenck, S. B. G. (1969). *Personality structure and measurement*. London: Routledge & Kegan Paul.

Eysenck, H. J. & Levey, A. (1972). Conditioning, introversion-extraversion and the strength of the nervous system. In V. D. Nebylitsyn & J. A. Gray (Eds), *Biological bases of individual behavior*. New York: Academic Press.

Fowles, D. C. (1988). Psychophysiology and psychopathology: a motivational approach. *Psychophysiology*, 25(4), 373–391.

Gale, A. (1983). Electroencephalographic studies of extraversion-introversion: a case study in the psychophysiology of individual differences. *Personality and Individual Differences*, 4, 371–380.

Gale, A., Coles, M. & Blaydon, J. (1969). Extraversion-introversion and the EEG. *British Journal of Psychology*, 60(2), 209–223.

Gale, A., Coles, M., Kline, P. & Penfold, V. (1971). Extraversion-introversion, neuroticism and the EEG: basal and response measures during habituation of the orienting response. *British Journal of Psychology*, 62, 533–543.

Gray, J. A. (1972). The psychophysiological nature of introversion-extraversion: a modification of Eysenck's theory. In V. D. Nebylitsyn & J. A. Gray (Eds), *Biological bases of individual behavior* (pp. 182–205). London: Academic Press.

Gray, J. A. (1981). A critique of Eysenck's theory of personality. In H. J. Eysenck (Ed.), *A model for personality* (pp. 246–276). Berlin: Springer.

Gray, J. A. (1982). *The neuropsychology of anxiety. An enquiry into the functions of the septo-hippocampal system*. Oxford: Oxford University Press.

Hagstadius, S. (1989). Anxiety proneness related to the regional cerebral blood flow during resting and mental activation. In *Brain function and dysfunction: Regional correlates of mental activity studied in healthy subjects and subjects with toxic encephalopathy*. Doctoral dissertation, Lund.

Heath, R. G., Cox, A. W. & Lustick, L. S. (1974). Brain activity during emotional states. *American Journal of Psychiatry*, 131(8), 858–862.

Herrmann, W. M. & Schaerer, E. (1986). Pharmaco-EEG: Computer EEG analysis to describe the projection of drug effects on a functional cerebral level in humans. In F. H. Lopes da Silva, W. Storm van Leeuwen & A. Rémond (Eds), *Handbook of electroencephalography and clinical neurophysiology*. Amsterdam: Elsevier.

Jones, B. & Mishkin, M. (1972). Limbic lesions and the problems of stimulus-reinforcement associations. *Experimental Neurology* 36, 362–377.

Kellner, C. H., Post, R. M., Putnam, F., Cowdry, R., Gardner, D., Kling, M. A., Minichiello, M. D., Trettau, J. R. & Coppola, R. (1987). Intravenous procaine as a probe of limbic system activity in psychiatric patients and normal controls. *Biological Psychiatry*, 22, 1107–1126.

Klinteberg, B., Schalling, D. & Magnusson, D. (1986). Self-report assessment of personality traits. Data from the KSP inventory on a representative sample of normal male and female subjects within a developmental project. Report from the project Individual Development and Adjustment. (64). Department of Psychology, University of Stockholm.

Kondo, C. Y., Bean, J. A., Travis, T. A. & Knott, J. R. (1978). Resting levels of alpha and the Eysenck Personality Inventory. *British Journal of Psychiatry*, 132, 378–380.

Lang, W., Lang, M., Kornhuber, A., Diekmann, V. & Kornhuber, H. H. (1988). Event-related EEG-spectra in a concept formation task. *Human Neurobiology*, 6(4), 295–301.

MacAndrew, C. & Steele, T. (1991). Gray's Behavioural Inhibition System: a psychometric examination. *Personality and Individual Differences*, 12(2), 157–171.

Matousek, M., Nüth, A. L. & Petersén, I. (1983). Spontaneous vigilance fluctuations in the daytime as reflected by EEG and psychological variables. *Advances in Biological Psychiatry*, 13, 13–18.

Maulsby, R. L. (1971). An illustration of emotionally evoked theta rhythm in infancy: hedonic hypersynchrony. *Electroencephalography and Clinical Neurophysiology*, 31, 157–165.

O'Gorman, J. G. (1984). Extraversion and the EEG: I. An evaluation of Gale's hypothesis. *Biological Psychology*, 19(2), 95–112.

O'Gorman, J. G. & Lloyd, J. E. M. (1987). Extraversion, impulsiveness and EEG alpha activity. *Personality and Individual Differences*, 8(2), 169–174.

O'Gorman, J. G. & Mallise, L. R. (1984). Extraversion and the EEG: II. A test of Gale's hypothesis. *Biological Psychology*, *19*, 113–127.

Penfield, W. & Jasper, H. H. (1959). *Epilepsy and the functional anatomy of the human brain*. Boston: Little, Brown.

Ray, W. J. & Cole, H. W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science*, *228*, 750–752.

Reiman, E. M., Fusselman, M. J., Fox, P. T. & Raichle, M. E. (1989). Neuroanatomical correlates of anticipatory anxiety. *Science*, *243*, 1071–1074.

Revelle, W., Humphreys, M. S., Simon, L. & Gilliland, K. (1980). The interactive effect of personality, time of day, and caffeine: a test of the arousal model. *Journal of Experimental Psychology: General*, *109*, 1–31.

Rocklin, T. & Revelle, W. (1981). The measurement of extraversion: a comparison of the Eysenck Personality Inventory and the Eysenck Personality Questionnaire. *British Journal of Social Psychology*, *20*, 279–284.

Rösler, F. (1975). Die Abhängigkeit des Elektroenzephalogramms von den Persönlichkeitsdimensionen E und N sensu Eysenck und unterschiedlich aktivierenden Situationen. *Zeitschrift für experimentelle and angewandt Psychologie*, *22*(4), 630–667.

Rugg, M. D. & Dickens, A. M. J. (1982). Dissociation of alpha and theta activity as a function of verbal and visuospatial tasks. *Electroencephalography and Clinical Neurophysiology*, *53*, 201–207.

Schacter, D. L. (1977). EEG theta waves and psychological phenomena: a review and analysis. *Biological Psychology*, *5*, 47–82.

Schalling, D., Edman, G. & Åsberg, M. (1983). Impulse cognitive style and inability to tolerate boredom: Psychobiological studies of temperamental vulnerability. In M. Zuckerman (Ed.), *Biological bases of sensation seeking, impulsivity and anxiety*. Hillsdale, NJ: Erlbaum.

Schellberg, D., Besthorn, C., Klos, T. & Gasser, T. (1990). EEG power and coherence while male adults watch emotional video films. *International Journal of Psychophysiology*, *9*(3), 279–291.

Schwarz, E., Kielholz, P., Hobi, V., Goldberg, L., Hofstetter, M. & Ladewig, D. (1982). Changes in EEG, blood levels, mood scales and performance scores during long term treatment with diazepam, phenobarbital or placebo in patients. *Progress in Neuropsychopharmacology*, *6*(3), 249–263.

Stenberg, G., Risberg, J., Warkentin, S. & Rosén, I. (1990). Regional patterns of cortical blood flow distinguish extraverts from introverts. *Personality and Individual Differences*, *11*(7), 663–673.

Steriade, M., Gloor, P., Llinas, R. R., Lopes da Silva, F. H. & Mesulam. M. M. (1990). Basic mechanisms of cerebral rhythmic activities. *Electroencephalography and Clinical Neurophysiology*, *76*, 481–508.

Talairach, J., Bancaud, J., Geier, S., Bordas-Ferrer, M., Bonis, A., Szikla, G. & Rusu, M. (1973). The cingulate gyrus and human behaviour. *Electroencephalography and Clinical Neurophysiology*, *34*, 45–52.

Tucker, D. M. & Dawson, S. L. (1984). Asymmetric EEG changes as method actors generated emotions. *Biological Psychology*, *19*(1), 63–75.

Vasey, M. W. & Thayer, J. F. (1987). The continuing problem of false positives in repeated measures ANOVA in psychophysiology: a multivariate solution. *Psychophysiology*, *24*, 479–486.

Walter, W. G. (1959). Intrinsic rhythms of the brain. In J. Field (Ed.), *Handbook of physiology, section 1* (pp. 279–298). Washington, D.C.: American Physiol. Soc.

Watson, D. & Tellegen, A. (1985). Toward a consensual structure of mood. *Psychological Bulletin*, *98*(2), 219–235.

Whitton, J. L., Moldofsky, H. & Lue, F. (1978). EEG frequency patterns associated with hallucinations in schizophrenia and creativity in normals. *Biological Psychiatry*, *13*(1), 123–133.

Wilson, G. D. (1981). Personality and social behaviour. In H. J. Eysenck (Ed.), *A Model for Personality*. Berlin: Springer.

Wilson, G. D., Gray, J. A. & Barrett, P. T. (1990). A factor analysis of the Gray–Wilson Personality Questionnaire. *Personality and Individual Differences*, *11*(10), 1037–1045.