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ARTICLE

EEG correlates of personality types

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Abstract Evolutionary interpretation of brain oscillations and empirical evidence link delta oscillations with reward motivation and alpha with anxiety. It is hypothesised that a balance of activity in these two oscillatory systems underlies the dimension of behavioural control. Overcontrollers could be characterised as individuals with a relatively high activity of the alpha oscillatory system, undercontrollers as individuals with excessive activity of the delta oscillatory system, and resilients as individuals with balanced activity of these systems. This hypothesis was tested in a sample of 78 adolescents aged 10-16 years. The predictions were generally confirmed. Relative prevalence of alpha oscillations, particularly in the parietal zone, predicted overcontrolled prototype whereas relative prevalence of delta oscillations, mostly in the frontal region, predicted undercontrolled prototype. Resilients were characterised by balanced activity of alpha and delta oscillations. (*Netherlands Journal of Psychology*, *62*, 81-90.)

Keywords EEG · personality types · alpha oscillations · delta oscillations

In recent years, empirical studies using either Q-factor or cluster analyses have found evidence that three personality types can be replicated across methods, languages and ages. These types, which have been labelled resilients, overcontrollers and undercontrollers, have been characterised in terms of the Block and Block's (1980) constructs of ego resiliency and ego control, the Big Five personality dimensions (Robins, John, Caspi, Moffitt, & Stouthammer-Loeber, 1996) and a variety of psychosocial correlates (Asendorpf & van Aken, 1999). Resilients have been found to be high on all the Big Five characteristics, intelligent, socially and academically competent and well-adjusted. Overcontrollers have been characterised as low on extraversion and emotional stability and vulnerable to internalising problems. Undercontrollers are low on agreeableness and conscientiousness, with academic, behavioural and emotional problems and at greater risk for comorbid internalising and externalising problems.

Recently proposed evolutionary interpretation of brain oscillations suggests that delta, theta and alpha waves reflect activity of three hierarchical philogenetic brain systems. Delta oscillations are associated with motivational reward circuits, theta with contextual memory and emotions and alpha with perception, attention and semantic memory (Knyazev & Slobodskaya, 2003, Knyazev, Savostyanov, & Levin, 2004; Knyazev, Slobodskaya, & Wilson, 2004).

A considerable body of evidence shows that delta activity is enhanced during craving for rewarding stimuli (e.g. Reid, Flammino, Howard, Nilsen, & Prichep, 2005) and decreases when actual reward causes dopamine release in the nucleus accumbens (Ferger, Kropf, & Kuschinsky, 1994; Kropf & Kuschinsky, 1993; Luoh, Kuo, Chan, & Pan, 1994). It has also been shown that administration of testosterone, which is associated with reward motivation in humans (Van Honk, Schutter, Hermans, Putman, Tuiten, & Koppeschaar, 2004), increases delta power (Schutter & van Honk, 2004). Both elevated

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levels of testosterone (e.g. Dabbs & Haregrove, 1997) and relative prevalence of delta oscillations (Knyazev, Slobodskaya, Aftanas, & Savina, 2002; Knyazev, Slobodskaya, Safronova, Sorokin, Goodman, & Wilson, 2003; Knyazev, Slobodskaya, & Wilson, 2004; Scarpa & Raine, 1997) have been associated with violent and antisocial behaviour. This is in line with Gray's theory and empirical findings linking overactive reward system with predisposition to antisocial behaviour (Pickering & Gray, 2001).

Data linking alpha oscillations with perception (Basar, 1998, 1999), attention and semantic memory (Klimesch, 1999) hint at their possible role in recognition of environmental patterns and perceptual awareness. McNaughton and Corr (2004) considered that decision-making in the situation of conflict between fear and reward motivation (the situation which according to these authors gives rise to anxiety) involves heightened attention, external scanning (risk assessment) and internal scanning (memory). As the existing evidence implies, all these functions could be somehow linked with alpha oscillations. Because of that, a particularly active and reactive alpha system should be expected in trait-anxious individuals. Indeed, in high trait-anxiety subjects, enhanced event-related desynchronisation (ERD) to neutral (Knyazev, Savostyanov, & Levin, 2006) and negatively valenced (Aftanas, Koshkarov, Pokrovskaja, Lotova, & Mordvintsev, 1996) stimuli have been observed within the alpha frequency range. Trait-anxiety scores have been found to positively correlate with dominant alpha frequency (Sachs, Anderer, Dantendorfer, & Saletu, 2004) which has been shown to detect both trait and state differences in cognitive preparedness (Angelakis, Lubar, Stathopoulou, & Kounios, 2004). Since higher reactivity (in terms of ERD magnitude) within the alpha band is usually observed against the background of higher amplitude of alpha oscillations (Basar, 1998, 1999; Klimesch, 1999), higher resting or background alpha power in anxious individuals could also be observed. Indeed, it has been shown that alpha power increases during expectation of an event; this general increase is associated with higher event-related desynchronisation (Klimesch, 1999). This evidence implies that higher baseline or inter-stimulus alpha power reflects higher readiness of the alpha system to process information (Knyazev, in press; Knyazev, Savostyanov, & Levin, 2006). Several studies have found a higher resting power for alpha oscillations in anxious individuals (Bell et al., 1998; Knyazev et al., 2002, 2003; Knyazev, Savostyanov, & Levin, 2004; Knyazev, Slobodskaya, & Wilson, 2004). Moreover, in anxious individuals, an anxiogenic situation has been found to increase alpha power (Herrmann & Winterer, 1996; Knyazev, Savostyanov, & Levin, 2004, 2005). Contrariwise, lowering anxiety by means of autogenic training (Jacobs & Lubar, 1989), yogic breathing (Stancak, Kuna, Srinivasan, Dostalek, & Vishnudevananda, 1991), massage therapy (Diego, Field, Sanders, & Hernandez-Reif, 2004; Field, Ironson, Scafidi, et al., 1996) and anxiolitic drugs (Breimer, Hennis, & Burn, 1990; Hotz, Ritz, Linder, Scollo-Lavizzari, & Haefell, 2000) is accompanied by a decrease in alpha power.

Summing up, although the existing evidence mostly links alpha oscillations with cognitive processes, such as attention, perception and semantic memory, these processes seem to be enhanced in an anxiogenic situation, or in trait-anxious individuals who are predisposed to higher vigilance and readiness in unfamiliar environments. All these cognitive processes are externally oriented and subserve the constant scanning of the environment, which is considered to be the main function of the behavioural inhibition system (BIS, Gray, 1982). In a sense, these processes are opposite to motivational drives that regulate behaviour based on internal stimuli. Clearly, to address attention to external stimuli (in order to prepare a relevant response) one needs to temporally suppress internal motivational drives. This suppression is expected to be particularly strong in trait-anxious individuals. Indeed, it has been shown that the strength of the reciprocal relationship between alpha and delta oscillations correlates positively with psychometric measures of behavioural inhibition and negatively with measures of behavioural disinhibition (Knyazev & Slobodskaya, 2003; Knyazev et al., 2003; Knyazev, Slobodskaya, & Wilson, 2004; Robinson, 2001). This strength of reciprocal relationship between alpha and delta oscillations showed trait-like properties to be uniformly higher in high trait-anxiety subjects independently of experimental manipulations (Knyazev, Schutter, & van Honk 2006).

These data prompt an assumption that a brain mechanism which acts to enhance alpha over delta may favour development of cautious and anxious behaviour. Immaturity or underdevelopment of this mechanism may favour appearance of disinhibited behaviour. On the other hand, permanent inhibition of the motivational delta system might be a mechanism leading to development of depression. Indeed, Knyazev, Savostyanov and Levin (2004) showed that a within-subject estimate of anticorrelation between alpha and delta power is most strongly related to the Beck Depression Scale scores. Thus, prevalence of either alpha or delta activity may lead to maladjustment. Balance of the two systems is essential for good social adjustment. Returning to the three personality types, one may hypothesise that overcontrollers should show a prevalence for alpha over delta oscillations, whereas the opposite would apply to undercontrollers. In resilients, activity of the two systems should be balanced. The main objective of the present study was to test these predictions.

Methods

Sample

Previously collected data (Knyazev et al., 2003) including a number of personality, psychopathology and EEG measures collected in a sample of 78 schoolchildren (64% males) aged 11 to 16 years were used in the present study. The subjects were recruited from junior high school grades of ordinary Novosibirsk schools. Data on average monthly income per family member were obtained from the parents. The study was approved by the Institute of Physiology ethics committee. All participants and their parents gave informed consent to participate in the study.

Measures

In his pioneering work, Block (1971) found the three personality types in Q-factor analyses of the California Q-Set (Block & Block, 1980). Asendorpf and van Aken (1999) showed that there is a strong link between Big Five ratings and the California Q-sort. Later Asendorpf, Borkenau, Ostendorf and van Aken (2001) replicated the three personality types in a cluster analysis of questionnaires assessing the Five Factor model of personality. Similar results were obtained by Boehm, Asendorpf and Avia (2002), Schnabel, Asendorpf and Ostendorf (2002), Dubas, Gerris, Janssens and Vermulst (2002) and Rammstedt, Riemann, Angleitner and Borkenau (2004). Therefore, the use of the Big Five measures for extracting the three personality types could by now be considered a well-validated approach.

Most personality researchers now seem to agree that there is a clear correspondence between Eysenck's extraversion and the Big Five extraversion, and between Eysenck's neuroticism and the Big Five neuroticism. There is also growing evidence supporting the claim that there is a correspondence between Eysenck's psychoticism and the Big Five agreeableness and conscientiousness (e.g., Scholte & De Bruyn, 2004). On the other hand, it has been claimed that the three personality types are independent of the type of assessment and method of deriving the types (Mervielde & Asendorpf, 2000).

A close correspondence between the three personality types derived either from the Big Five measures or from Eysenck's and Gray's personality factors has recently been shown (Knyazev, 2004). In this study, Eysenck's and Gray's personality scales along with psychopathology scores were used as input variables for extracting personality types.

Short versions of the Eysenck Personality Questionnaire (EPQ-S, Knyazev, Belopolsky, Bodunov, & Wilson, 2004) and the Gray-Wilson Personality Questionnaire (GWPQ-S, Wilson, Barrett, & Gray, 1989; Slobodskaya, Knyazev, Safronova, & Wilson, 2003) were used as personality measures. Adjustment was assessed with the Strengths and Difficulties Questionnaire (SDQ, Goodman, 1997, 1999), a 25-item behavioural screening questionnaire which is completed by teachers, parents and adolescents providing coverage of adolescents' behaviour, emotions and peer relations. Intellect was measured by a Russian test of verbal IQ (Gurevich, Akimova, Borisova, Zakrin, Kozlova, & Loginov, 1987).

Psychophysiological datarecording and reduction

Physiological measures were obtained during an afternoon visit to the laboratory. EEG was recorded in resting conditions. Each participant was seated comfortably in a quiet, normally lit laboratory room. The participants were asked to minimise their movements during the recording. The procedure consisted of six one-minute recordings (3 with eyes closed and 3 with eyes open) alternating pseudo-randomly, with five one-minute breaks. The EEG was recorded using a PC-based system. A mid-forehead electrode was used as ground. The resistance of the electrodes was maintained below 5 kOhms. The signals were amplified with a multichannel biosignal amplifier with bandpass 0.05 - 30 Hz, -6 dB/octave and continuously digitised at 125 Hz. The number of electrode locations was restricted to six head sites (F3, F4, T3, T4, P3 and P4) placed according to the International 10-20 system and referred to linked-ear electrodes. Artefact-free epochs of 512 samples (i.e. 4.096 secs in duration) were extracted through a Hamming window and submitted to Fast Fourier Transform. For each subject, there were 48 EEG epochs (24 with eyes closed and 24 with eyes open). Following Klimesch (1999), we used alpha gravity frequency averaged over all leads and all epochs as the anchor to adjust frequency bands individually for each subject. We have found previously that individually adjusted EEG measures generally show higher correlations with personality measures. The gravity frequency, f(i), was calculated as the weighted sum of spectral estimates, divided by alpha power: $f(i) = \Sigma(a(f)*f)/\Sigma(a(f)$ (Klimesch, 1999). Power spectral estimates at frequency f are denoted a(f). The index of summation is in the range 7.5 to 12.5 Hz. Then, four frequency bands with a width of 2 Hz were defined in relation to f(i). The frequency bands obtained were termed: theta, f(i)-6 to f (i)-4; alpha1, f(i)-4 to f(i)-2; alpha2, f(i)-2 to f(i); alpha3, f (i) to f(i) + 2. The delta band was defined as approximately 0.2 Hz to f(i)-6. An aggregated measure for broad alpha (hereafter called 'alpha') was obtained by summation of measures for alpha1, alpha2 and alpha3. Relative spectral powers were calculated for every electrode location, every EEG band and each state (eyes closed and eyes open) as a band spectral power divided by total spectral power. Natural logarithms of absolute spectral powers were calculated in addition to relative spectral power measures. EEG variables were aggregated by summing the standardised values. For each frequency band and every cortical area the summation was performed across the two states (eyes closed and eyes open) and two symmetrical electrode locations. Consequently for each subject, relative and absolute power measures for delta, theta and alpha bands were obtained for frontal (F3-F4), temporal (T3-T4) and parietal (P3-P4) cortical zones. Mean absolute and relative spectral powers for each frequency band across the two states and six electrode locations were also obtained.

Results

Parent-ratings of adjustment were not used for classification purposes due to the limited number of completed questionnaires. Self-ratings on hyperactivity and teacher-ratings on emotional and peer problems were also excluded due to existing evidence of their low validity. Six personality (i.e. EPQ-S extraversion, neuroticism, psychoticism and lie and GWPQ-S BIS and BAS) and seven psychopathology (i.e. teacher-ratings on SDQ prosocial behaviour, hyperactivity and conduct problems and self-ratings on SDQ prosocial behaviour, conduct problems, emotional symptoms and peer problems) variables were used to identify relatively homogeneous groups of subjects by means of the K-means cluster procedure (Dubas et al., 2002). Initial cluster centres were not specified and the only imposed limitation was the number of clusters, which was set at three. Multivariate analyses of variance with subsequent LSD post-hoc tests were used to examine whether the clusters differed on the personality characteristics. To account for sex differences, gender was entered as the second factor. The effect of type was significant at $p < 0.001$ whereas the effect of gender and gender x type interaction were not. Post-hoc tests revealed that, with the exception of self-ratings of prosocial behaviour, each type was significantly different from the other types on each personality dimension. The first group including 34 adolescents was higher on EPQ extraversion and lie and lower on other personality variables (figure 1) as well as self- and parent-ratings of emotional and peer problems and self- and teacher-ratings of conduct problems. This group was identified as resilients. The second group included 28 adolescents, who scored higher on EPQ neuroticism, GWPQ BIS and self- and parent-ratings of emotional and peer problems. According to the teacher-ratings they were higher on prosocial behaviour and lower on hyperactivity and conduct problems but according to self-ratings they scored lower on prosocial behaviour and higher on conduct problems. This is a frequent observation with anxious adolescents who are predisposed to lower self-esteem and tend to exaggerate their problems (e.g. Knyazev & Slobodskaya, in press). This group was identified as overcontrollers. And finally, the third group including 16 adolescents was higher on psychoticism and BAS as well as self-, parent- and teacher-ratings of conduct problems and hyperactivity and lower on self- and teacher-ratings of prosocial behaviour. This group was identified as undercontrollers. Distribution of boys and girls was significantly different in the three groups with girls prevailing among overcontrollers. The three groups differed significantly on age, with overcontrollers being the youngest group. One-way ANOVA showed that the three groups differed significantly on average monthly income per family member, $F(2, 75) = 4.98$, $p = 0.010$, and verbal IQ, $F(2, 75) = 4.61$, $p = 0.013$ (figure 2). Post-hoc tests showed that average income was significantly lower in overcontrollers than in resilients ($T = -3.03$, $p = 0.004$) and undercontrollers ($T = -2.52$, $p = 0.016$) whereas the last two groups did not differ from each other ($T = 0.07$, $p = 0.948$). Verbal IQ was significantly higher in resilients than in the two other groups ($T = 2.04$, $p = 0.047$ and $T = 3.03$, $p = 0.004$ for overcontrollers and undercontrollers, respectively) with the difference between the latter being non-significant ($T = -0.61$, $p = 0.548$). Thus, it could be concluded that in terms of socioeconomic status and intelligence, as well as personality and psychopathology profiles, the identified groups closely resemble those described in the literature (Robins et al., 1996).

Greenhouse-Geisser corrected for violation of the sphericity assumption. Repeated measures ANOVAs were used to test the effects of group membership as a between-subject factor, and cortical zone (frontal vs. temporal vs. parietal) and band (delta vs. theta vs. alpha) as within-subject factors on relative spectral power. To account for age differences, age was entered as a covariate. Interaction group membership x band emerged as significant, $F = 3.07$, $df = 3.47$, $p = 0.024$. In undercontrollers, mean relative delta power was higher and mean relative alpha power was lower than in resilients ($p = 0.039$ and 0.033 for delta and alpha power,

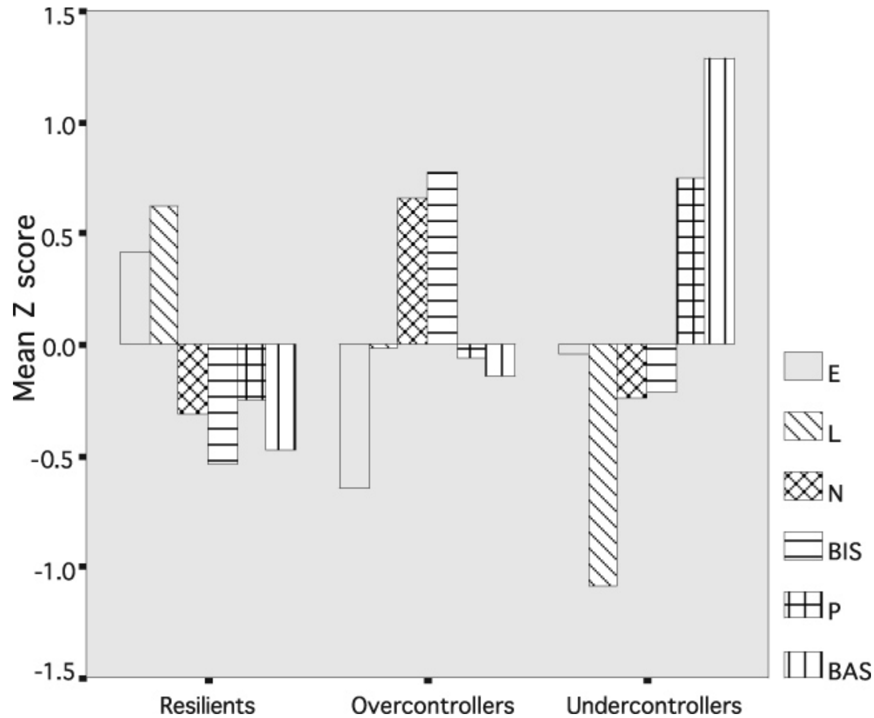

Figure 1 Mean EPQ-S and GWPQ-S scales scores in the three groups identified by means of cluster analysis on personality and psychopathology variables. E = extraversion, L = lie, N = neuroticism, BIS = behavioural inhibition, P = psychoticism, BAS = behavioural activation.

respectively) and overcontrollers ($p = 0.005$ and 0.008 for delta and alpha power, respectively). Overcontrollers did not significantly differ from resilients on mean relative delta ($p = 0.297$) and alpha ($p = 0.453$) power (figure 3).

It is clear that relative power measures contain a proportion of spurious covariance. On the other hand, absolute power measures are contaminated by such influences as electrode resistance, individual differences in skin resistance and skull thickness (Davidson, Jackson, & Larson, 2000). Besides, individual differences in overall spectral power are of lesser importance when reciprocal relations among oscillatory systems are considered. As has been shown previously, when factor analysed,

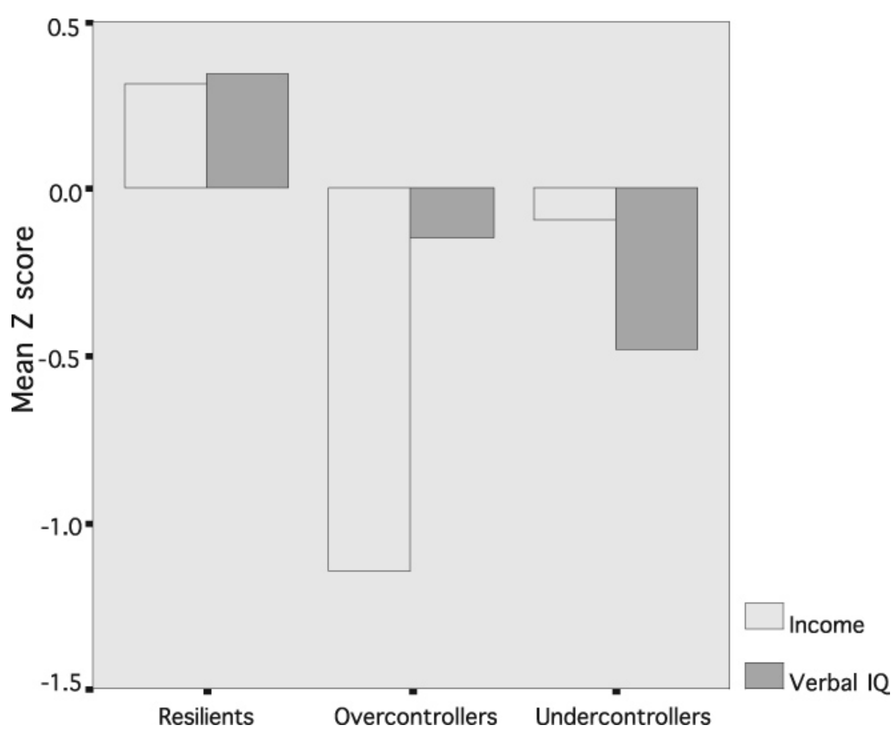

Figure 2 Mean average monthly income per family member and verbal IQ scores in the three groups identified by means of cluster analysis on personality and psychopathology variables.

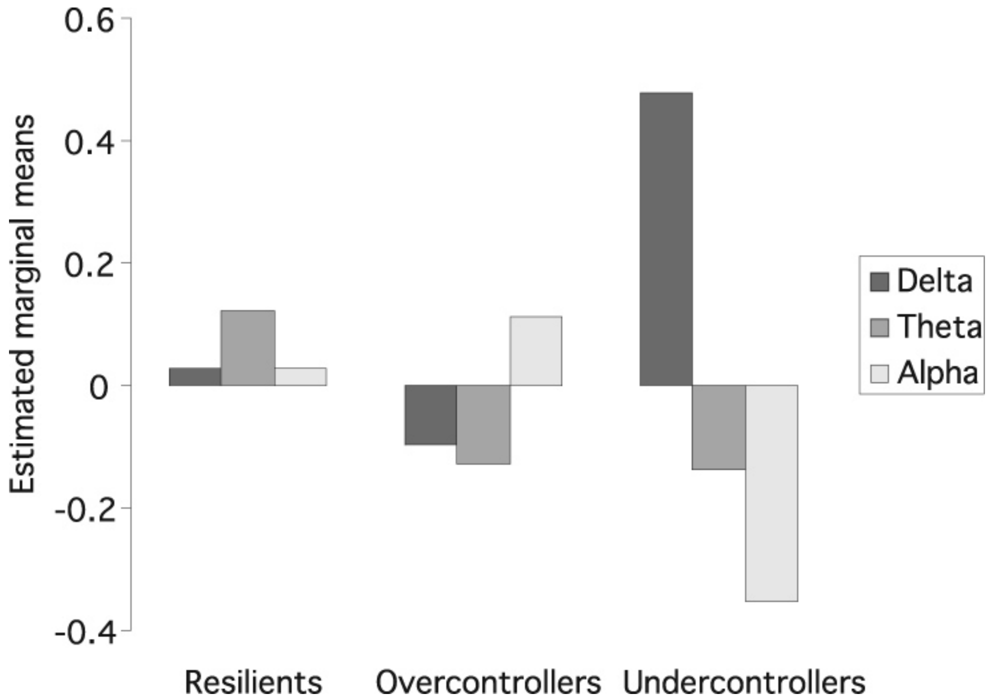

Figure 3 Estimated marginal means of relative delta, theta, and alpha power in the three groups identified by means of cluster analysis on personality and psychopathology variables.

absolute amplitudes or powers of the three EEG bands show positive loadings with the first factor whereas reciprocal relationships emerge in the second and third factors (Robinson, 1999; 2000; Knyazev et al., 2003). Therefore, principal components analyses on the absolute spectral powers correlations matrixes for each cortical zone were performed. As an example, unrotated components for the frontal cortical zone are shown in table 1. Factor scores of the second and the third components were saved as measures of reciprocal relationships of, respectively, delta and theta bands with alpha power (Robinson, 1999; 2000; Knyazev et al., 2003). The third component's scores were inverted so that the higher pole would correspond to more theta and less alpha.

For binary representation, personality types were converted into dummy variables contrasting each personality type with the two others. For continuous representation, a special procedure has been developed. First, for each personality type, mean values of the six personality and seven psychopathology variables that were used earlier in the cluster analysis were calculated. Second, these values were ascribed to three prototypical 'subjects' ('resilient', 'overcontrolled' and 'undercontrolled') that were added to the sample. Third, for each child in the total sample, two measures of dissimilarity (Euclidian distances and Chebychev) and two measures of similarity (Pearson correlation and cosine) to the three prototypical 'subjects' were calculated. As a result, twelve new variables were developed which measured the closeness of each child to each of the three types by a set of four measures. Finally, four variables representing similarity to each prototype were factor analysed, and the results showed that each set clearly loaded on one 'similarity' factor. Factor scores for these three 'similarity' factors were saved and further used as a continuous measure of closeness to the respective prototypes.

Table 1 Principal components analysis of mean absolute EEG bands' powers at frontal cortical zone.

	1	2	3
Delta	0.76	0.64	0.10
Theta	0.93	-0.14	-0.35
Alpha	0.87	-0.41	0.28

A series of forward conditional binary logistic regressions were then performed with the measures of reciprocal relationships between EEG bands as predictors and personality types converted into dummy variables as outcomes. Matching resilients with all others did not yield any significant predictor. Matching overcontrollers with all others yielded delta-alpha factor at parietal zone as the sole predictor with B = -0.57, p = 0.035, odds ratio = 0.57, and 64% of correctly classified. Matching undercontrollers with all others yielded delta-alpha factor at frontal zone as the sole predictor with B = 0.81, p = 0.007, odds ratio = 2.25, and 78% of correctly classified.

Next, stepwise multiple regressions were used to predict continuous measures of prototipicality from measures of reciprocal relationships between EEG bands. Resilience had no significant predictors. Overcontrol yielded delta-alpha, β = -0.45, T = -4.51, $p < 0.001$, and theta-alpha, $\beta = 0.21$, $T = 2.07$, $p = 0.042$, factors at parietal zone as significant predictors with $R^2 = 0.247$. Undercontrol yielded delta-alpha factor at frontal zone as the sole predictor, $\beta = 0.30$, $T = 2.77$, $p = 0.007$, $R^2 = 0.091$.

Discussion

The hypothesised association of the three personality types with brain oscillatory systems has been confirmed. Relative prevalence of alpha oscillations appeared to be a feature of overcontrollers and relative prevalence of delta oscillations a feature of undercontrollers whereas in resilients the two systems were balanced. From evolutionary perspective, these data indicate that being resilient signifies that the two biological systems underlying biological motivation and cognitive anxiety should be balanced. This seems to be a necessary condition for allowing all the socially desirable properties peculiar to resilients to flourish. It is intuitively understandable since excessive activity of the two systems must inhibit or disturb social adjustment whereas resilience implies a good social adjustment. The regression analysis showed that the EEG variables explained a relatively small proportion of variance in the psychological variables. This is usually the case in most psychophysiological studies. There is no reason to expect that behavioural tendencies that make up the three personality types would strongly correlate with resting EEG measures. One may expect that the association may be stronger in relevant experimental situations but that has yet to be tested.

In addition to the predicted associations, a positive association of overcontrolled prototype with the theta-alpha factor scores at parietal zone was observed, which was not expected. No predictions regarding association of theta oscillations with the three personality types have been made but linking theta oscillations with emotional processing (which evolutionary interpretation implies and ample evidence confirms) makes one assume that this oscillatory system may be more active in neurotic individuals since these individuals are predisposed to strong and changeable emotional reactions (hence the label emotional instability which was attributed to neuroticism). Gray (1982) suggested a special role for theta oscillations in BIS functioning. Evolutionary interpretation suggests higher activity of the theta system in females due to existing evidence of their higher emotional reactivity (Costa, Terracciano, & McCrae, 2001). The analysis of gender differences was not implemented in this study, mostly because it necessitates substantially larger samples; the effect sizes of most gender differences are usually small. Noteworthy, the group of overcontrollers had significantly more females than males. This observation is consistent with the general pattern of gender differences in personality. Numerous studies demonstrate that across different cultures females tend to be higher on neuroticism (the most prominent feature of overcontrollers) than males (Costa et al., 2001). To check whether the observed association of the theta-alpha factor with overcontrolled prototype depended on unequal distribution of genders, an additional regression analysis was performed with entering gender as a covariate in the first step. In this case, the theta-alpha factor disappeared from the list of significant predictors and only delta-alpha factor remained, $\beta = -.43$, $T = -4.23$, $p < 0.001$. That allows suggesting that in overcontrollers, beyond hypothesised overactive negative feedback from alpha to delta system, there could be a gender-specific higher activity of the theta system which is presumably engaged in emotional processing.

It is particularly interesting that in undercontrollers, prevalence of delta over alpha is most pronounced in the frontal area whereas in overcontrollers the most marked prevalence of alpha over delta was observed in parietal area. Although alpha should be treated as a united system (Basar, 1999), it is obviously polyfunctional and its different parts may participate in different processes. Particularly, according to a number of models, anterior and posterior alpha activity appears to have a different origin (Basar, Yordanova, & Kolev, 1998). Moreover, they seem to develop with different rates. Occipital alpha matures earlier and dominates in young adults whereas frontal alpha increases toward middle adulthood when occipital alpha begins to decline (Yordanova, Kolev, & Basar, 1998). There is much evidence favouring an assumption of alpha system engagement in attention processes (e.g. Klimesch, 1999; Laufs, Krakow, Sterzer, Eger, Beyerle, et al., 2003). It seems tempting to link the two alpha systems with the 'posterior' and 'anterior' attentional systems (Posner & Raichle, 1994). The posterior attentional system is a reactive network involved in orienting or shifting attention from one location to another. It is referred to as 'involuntary' attentional system. The act of orienting arises from three component operations: attention must disengage from the attended location, move to a new location and then engage the new location (Matthews, Derryberry, & Siegle, 2000). Studies of performance in patients suffering from regional brain damage indicate that the disengage, move and engage operations are accomplished through interconnected circuits within the parietal cortex, midbrain and thalamus, respectively. These neuropsychological findings are supported by converging studies using ERP and PET recordings (e.g. Corbetta, Miezin, Shulman, & Petersen, 1993). Studies on attention shift from a threatening cue to a target in the uncued location suggest that the anxiety-related attentional bias may not involve moving toward and engaging sources of threat, but rather, difficulties in disengaging attention and thus shifting away from threat (Matthews et al., 2000). Therefore, relative prevalence of alpha over delta in the parietal zone of high trait-anxious individuals may be interpreted as evidence of enhanced engagement of attention and difficulties with its disengagement and moving. Generally speaking, the alpha system might be referred to as a system dealing with the outer world. Contrary to that, I assume that brain structures associated with delta system mostly promote spontaneous behaviour generated from within. Enhanced attention to a source of potential threat is associated with an increase in alpha production in anxious individuals (Knyazev, Savostyanov, & Levin, 2004). On the other hand, spontaneous behaviour generated from within should cause easy shifts of attention with no relation to outer world. Therefore, balance of the two systems may, above all, reflect balance between attention engagement and move.

The anterior attentional system is referred to as 'voluntary' attentional system because it provides voluntary control of attention. There is a wealth of data linking impulsive, antisocial and psychopathic behaviours along with hyperactivity and attention deficit disorder with deficient inhibitory control executed by prefrontal cortex. (e.g., Miller, 1992; Fuster, 1997). Relative prevalence of the delta system in the frontal area of undercontrollers may reflect failure of the anterior alpha system to provide inhibitory control over delta oscillatory activity in this region. That might be a reason for attention and volition deficit in these individuals. It is well known that voluntary regulation matures relatively slowly and peaks during mid adulthood simultaneously with maturation of the anterior alpha system.

One limitation of this study is that the three personality types were extracted based on other psychometric measures than were used in most of the respective studies. However, it has been shown previously that when extracted in this way, the types are very similar to the ones based on the Big Five measures (Knyazev, 2004). Besides, in terms of psychosocial and psychopathology correlates, the three personality types extracted in this study closely resemble ones described in numerous other studies. Thus, we can be reasonably confident that in this case we have a similar phenomenon. Another limitation concerns variation in ages in this study sample. Analysing 10 and 16 year olds together may seem problematic because of the EEG spectrum and behaviour changes during adolescence. However, splitting the sample into two age groups would not allow a meaningful analysis to be conducted due to the small numbers of subjects in the three groups. Given that alpha power typically increases with age, age differences might actually have diminished the observed effects since overcontrollers, who showed the highest alpha and lowest delta power, happened to be the youngest group. It should also be noted that all main analyses were performed controlling for age.

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