Abstract

The aim of this paper is to study manifestations of temperament in auditory evoked potentials (EP) during the odd-ball paradigm. Three questionnaires were used: Pavlovian Temperament Survey (PTS), Structure of Temperament Questionnaire (STQ), Eysenck Personality Inventory (EPI). All subjects were divided into two groups with high (I) and low (II) concordance between the questionnaires’ data. Amplitudes of N2 wave and of N2-P3 complex were found to be statistically different in the two groups. In group I, a number of significant relations between questionnaires' dimensions and EPs parameters were shown; in group II such relations were much less numerous. The data obtained show that temperament is determined by brain processes of perception and attention, and also hint at the existence of individuals with fundamentally different patterns of psychophysiological manifestations of temperament.

Keywords: attention; temperament; cognitive processes; evoked potentials; N2; P3; psychophysiology.

Introduction

The concept of temperament comprises relatively stable functional dispositions of features that determine general activity of an individual, speed of his or her behavior – and consequently individual peculiarities of a number of cognitive processes (Eysenck, 1982; Rusalov, 2000; Shmelyov, 2002; Strelau et al., 2009). Traditionally temperament is viewed in connection with physiological properties of an individual. One of the first attempts of the physiological study of temperament was undertaken by Pavlov (1951-1952) in the context of his theoretical and experimental paradigm of classical conditioning. Although his theory was positioned as physiological, Pavlov gave only indirect physiological interpretation of temperament types based on behavioral observations. Still it should be admitted that at that time there existed no way of direct physiological study of the brain processes that determine temperament. A similar psychophysiological approach to the study of human mind was developed in the works of Teplov and Nebylitsyn (Golubeva, 2005; Nebylitsyn, 1972). Eysenck (1982) developed a theory based on the analysis of behavioral manifestations of human mind; he also assumed that temperament is based on biological and physiological properties of the brain.

The theories of temperament were implemented in a number of questionnaires designed to classify individuals on the basis of their temperament characteristics. Strelau used Pavlov's theory of types of higher nervous activity (1951-1952) to create Pavlovian Temperament Survey (PTS) that assays 3 basic features of the central nervous system: strength of excitation, strength of inhibition, and mobility of nervous processes (Strelau et al., 1999). Rusalov, relying on the ideas of Nebylitsyn and the theory of functional systems of Anokhin (1968), distinguishes 4 blocks of characteristics of temperament: ergonicity, plasticity, tempo and emotionality, each of them in two aspects – object- and social-related. Accordingly, his Structure of Temperament Questionnaire (STQ) has 8 dimensions (Rusalov, 1990, 2000). Eysenck in his Eysenck Personality Inventory (EPI) describes temperament with two parameters: extraversion and neuroticism (Eysenck, 1982; Shmelyov, 2002).

A number of observations and experiments show that certain combinations of temperament features form standard patterns with cognitive, affective and behavioral peculiarities of an individual. For example a person with higher values of strength and mobility of the central nervous system usually manifests higher activity and endurance, tendency towards extraversion, has relatively high sensory thresholds, stable attention and relatively low emotional reactivity (Eysenck & Eysenck 1985; Rusalov, 1990; Rusalov & Biryukov, 1993; Strelau et al., 1999; Tomas & Chess 1977).

All abovementioned questionnaires are based on similar assumptions and thus are expected to produce highly correlated results (Strelau et al., 1999; Strelau et al., 2009; Rusalov, 1990). But according to our previous research
(Ramendik, 2008) for some individuals strong discordance between the results of questionnaires could be observed. In order to understand the reason of such discordance it is necessary to determine physiological correlates of the fundamental parameters lying in the basis of the structure of temperament. Moreover, it remains unclear which particular physiological processes are responsible for the phenomenon of temperament. Apparently the study of these questions has high theoretical and practical interest.

A promising and affordable method of studying physiological processes in the brain is the analysis of the electroencephalogram and evoked potentials (EP). A number of studies (Golubeva, 2005; Gurrera et al., 2005; Pavlenko & Konareva, 2000; Righi et al., 2009; Rusalov, 2000) yielded valuable results, but they still do not allow to create an integral psychophysiological theory of temperament and elucidate the mechanisms through which temperament affects cognitive processes. Probably, the main difficulty in psychophysiological study of temperament is that this phenomenon actually represents a reflection of a multidimensional complex of heterogeneous processes, which take place both at brain and mind levels.

We assume that it is possible to advance in this direction by studying EPs in situations of attentional load. Although attention itself is not a simple construct ( Machinskaya, 2003), it is the kind of a cognitive phenomenon that may be deeply rooted in brain physiology including processes of physiological activation (Kahneman, 1973). Thus we expect that individual characteristics of attention strongly depend upon temperament, which is assumed to be essentially a behavioral and psychological manifestation of certain basic physiological features of the nervous system (including physiological activation) (Eysenck & Eysenck 1985). Analysis of discrete EP components, that reflect the crucial stages of stimulus perception and evaluation, allows for quantitative and objective describing of time and strength of underlying brain processes (for details and caveats of such analysis see review: Kok, 2001). Late EP components are most commonly associated with attention and a number of other related cognitive processes (Naatanen, 1992; Donchin, 1988; Polich, 2007).

The present study is devoted to the investigation of relationships between the basic characteristics of temperament and parameters of late cognitive components of EP (N2 and P3) during the odd-ball paradigm used as a simple experimental model of situation, loading attention.

**Methods**

The study was performed in 22 subjects aged 18–20 years. All subjects filled 3 questionnaires: PTS (Strelau et al., 1999), STQ (Rusalov, 1990, 2000) and EPI (Eysenck, 1982; Shmelyov, 2002).

On the basis of questionnaires' results subjects were divided into two groups: group I included subjects with concordant results of the three questionnaires used, while in group II temperament features obtained with three questionnaires disagreed. For this analysis we used mean values of temperament dimensions (M) and their standard deviations (δ) given by the questionnaire's authors (Eysenck, Eysenck, 1985; Rusalov, 1990; Strelau et al., 1999). The value of each subject's temperament dimension obtained in this study (P) was assigned to one of the three levels: low (P<М-δ), medium (М-δ<P<М+δ) and high (P>М+δ). Then each categorized value level was compared pairwise with other dimensions that were described by questionnaire's authors as correlated pairs. If the level of at least one pair of correlated dimensions of a subject did not coincide, then this subject was assigned to group II, otherwise he or she was assigned to group I. Discordance in group II could be related to different temperament dimensions; thus group II might be heterogeneous.

In accordance with the active odd-ball paradigm auditory stimuli were presented in a quasirandom order (with target : nontarget ratio of 1 : 4). Subjects were instructed to press a joystick button after a rare stimulus, which had higher pitch.

Three experimental series were conducted: two easy and one hard. Nontarget stimulus in all series was a 1000 Hz tone. All auditory stimuli were 40 ms in length, with 10 ms rise and fall. In easy series (1st and 3rd) the two sounds could be easily discriminated by all subjects (1050 Hz tone as target stimulus vs. 1000 Hz as nontarget), while for the 2nd hard session the target stimulus was chosen individually for every subject close to but definitely above discrimination threshold (within 1010–1020 Hz range). Subjects committed few errors during both easy and hard series; still, according to their reports, their performance during the hard series required them a much higher concentration of attention and effort.

Electroencephalogram was recorded with NVX-52 encephalograph (Neurobotics, Russia) from 32 leads according to 10-10% system. The analysis reported here was performed on 15 pericentral leads (from F3, Fz and F4 to P3, Pz and P4). Artifacts were removed by visual inspection. EPs were obtained by traditional coherent averaging. Peak amplitudes and latencies were measured for late EP components N2 and P3 (from prestimulus zero line), as well as amplitude and latency of N2-P3 complex (peak-to-peak). Statistical processing of EP parameters, behavioral data and their relation to questionnaire data was performed by general linear model and t-test. Correlations within questionnaire data were determined as Spearman correlation.

**Results**

Analysis of questionnaire data allowed us to divide the subjects into 2 groups with high (I) and low (II) concordance between the questionnaires' data. Group I comprised 15 subjects (68%) with all four types of temperament; the three questionnaires pointed to the same type of temperament in each of them. Groups II included 7 subjects (32%) in which only the results of PTS and EPI were similar, while STQ pointed to a different type of temperament or gave controversial results.
social-related ergonicity in group I was positively correlated with five STQ dimensions of excitation (STQ 4) was found. The second major center of such correlations was between dimensions of the three questionnaires. The main strength of excitation was also correlated with both dimensions of plasticity and both dimensions of tempo, STQ 2-6) and with strength of excitation (PTS 1). In group II only correlation between extraversion (EPI 1) and social-related plasticity (STQ 4) was found.

The second major center of correlations was strength of excitation (PTS 1), which in group I was positively correlated not only with extraversion, but also with both dimensions of plasticity (STQ 3 and 4) and with social-related tempo (STQ 6). Strength of excitation was also negatively correlated with the latency of the subject’s motor response (pushing the button); i.e. individuals with relatively high strength of excitation responded faster. Latency was also correlated with both tempo dimensions (STQ 5 and 6). In group II only one of these correlations could be found – namely negative correlation of latency with object-related tempo (STQ 5) (which was highly predictable), but other correlations were absent.

In group I neuroticism (EPI 2) was positively correlated with both dimensions of emotionality (STQ 7 and 8) and negatively correlated with social-related ergonicity (STQ 2). It is quite logical that individuals with higher level of neuroticism are more emotional in various spheres and less ready to sustain tension in social contacts. But in groups II only one of these correlations was present – between neuroticism (EPI 2) and social-related emotionality (STQ 8).

As mentioned above, in general group II demonstrated much less correlations between questionnaire dimensions, but it possessed negative correlation between strength of inhibition and object-related plasticity, which was absent in group I.

Behavioral performance during the odd-ball paradigm

In line with the traditional use of odd-ball paradigm the sensory stimuli were sufficiently above discrimination threshold in easy series, and still they were satisfactory discriminated by most subjects even in difficult condition. In the 1st and 3rd series (easy condition) the total percentage of incorrect behavioral responses (false alarms and omissions) was low, and 8 subjects performed at 100% level of accuracy (during the 1st series: mean 0.9%, median 0.4%, range 0.0 – 4.4%, during the 3rd series: mean 0.4%, median 0.0%, range 0.0 – 2.4%). During the 2nd hard series the level of accuracy was generally lower (mean 5.9%, median 3.2%, range 0.0 – 18.8%).

EP Parameters and their Connections with Questionnaire Data

Typical EPs in response to target stimuli in two groups are shown in Figure 2. Comparison of the two groups revealed that they significantly differed in the amplitude of N2 and N2-P3 in both easy series – 1st and 3rd (Figure 3). This difference was most pronounced in the 1st series (T-test, p=0.001 and 0.003 correspondingly). In group II the N2 component had more positive values (grand mean for pericentral leads +3.0 μV, range – -0.5 – +6.4 μV), compared to group I, which displayed typical negative N2 (grand mean for pericentral leads – -1.2 μV, range – -7.1 – +1.5 μV). Interestingly, as shown in Figure 3, N2 amplitude becomes negative in both groups during the hard series. In other words, only group II only in easy condition displayed atypical N2 with positive peak values. It should be also noted that morphology of positive N2 waves as transient negative potential deflections was similar to that of typical negative N2 waves.

Analysis of correlations between questionnaire data and EP parameters revealed that the strongest links exist between EPs and STQ data, but the two groups show quite different patterns of such relationships.

Group I Statistical analysis of relations between questionnaires data and EP parameters has shown that in group I during the 1st easy series there was a negative relation between N2 amplitude and several indexes of easiness of switching attention and speed of actions, namely object-related plasticity (STQ 3), social-related plasticity (STQ 4) and social tempo (STQ 6) (i.e. the smaller were these indexes, the more pronounced was negative N2).
Besides, subjects in group I demonstrated negative relation between N2 and P3 latencies and almost the same set of STQ indexes: object-related plasticity (STQ 3) and object-related tempo (STQ 5). Thus in general the greater were plasticity and tempo, the smaller (less negative) was N2 and faster appeared both N2 and P3.

Extraversion was negatively related with amplitude of N2-P3 complex (the more extraverted was a person, the less strength of excitation was observed). Amplitudes of P3 wave and N2-P3 complex were found.

The hard series only negative relations of social-related plasticity (STQ 6) was positively, and social-related tempo (STQ 8) – were also positively related to the length of N2-P3 complex.

In the hard series only negative relations of social-related plasticity (STQ 6) to amplitudes of P3 wave and N2-P3 complex were found.

During the repeated easy condition (3rd series) only the negative relation of object-related tempo (STQ5) to the latency of N2 was preserved from the first easy series, all other abovementioned relations, characteristic of the easy condition, disappeared.

Group II In group II we found much fewer relations which were quite different compared to group I. In easy condition, P3 amplitude was positively related to social-related emotionality (STQ 8). Latency of N2 was negatively related to social-related ergonicity (STQ 2), which characterizes vigor, activity of communication, and this relation was present during both easy and hard conditions. Besides, social-related ergonicity (STQ 2) was positively, and object-related tempo (STQ 5) negatively related to the length of N2-P3 complex.

During hard conditions (2nd series) in subjects of the group II no relations could be detected except for highly significant negative relation between social-related ergonicity (STQ 2) and latency of N2, which was preserved from the easy condition.

When the easy condition was repeated (3rd series), quite different picture appeared: strength of excitation (PTS 1) became positively related to amplitudes of P3 and N2-P3 complex, and strength of inhibition (PTS 2) became negatively related to the length of N2-P3 complex and also negatively to P3 amplitude. Besides, positive relations of object-related emotionality to the latencies of N2 and P3 appeared.

**Discussion**

**Questionnaire Data**

We analyzed data of three similar questionnaires, aimed for diagnostics of typological characteristics of human temperament, together with parameters of late cognitive components of EP in response to target stimuli during the odd-ball paradigm. Comparison of the results of the three questionnaires for each subject allowed us to divide the subjects into two groups. In most subjects (15, 68%) data of all three questionnaires coincided, and multiple correlations were found between various similar dimensions of different questionnaires; this result generally replicates reports of the very creators of these questionnaires and other authors (Rusalov, 2000; Shmelyov, 2002; Strelau, 2009; and other reports). At the same time, in approximately 1/3 of the subjects (7, 32%), comprising group II, the questionnaires produced discordant data: different questionnaires pointed at different types of temperament. In our previous work we had also found out a group of individuals with discordant questionnaire data (Ramendik, 2008).

According to our results, manifestation of temperament as a system of individual traits proved to be more important than separate characteristics of temperaments. Subjects of group I displayed a clear picture of temperament with stable relations between separate traits. For example, subjects with higher strength of excitation manifested higher degree of extraversion, plasticity in action and communication, higher tempo and displayed faster responses to target stimuli (shorter latency of pushing the button); subjects with higher level of neuroticism displayed higher emotionality, etc. Absence of such relations in group II can point to a different composition of their temperament as a system. The reason of this fact may lie in some deep mechanisms of brain function, that cause different cognitive strategies of perception and decision making, and manifest themselves as clearly different pattern of EPs.
EP Parameters and their Connections with Questionnaire Data in Group I

Analysis of relations between questionnaire data and EP parameters in group I allows us to speculate on physiological nature of the phenomena observed.

Higher levels of plasticity and tempo (i.e. speed and easiness of thought and action) were accompanied by less negative N2 and shorter latency of N2 and P3. It can be supposed that the faster and the less expensive in terms of brain resources is the process of information processing (especially at the preattentive stage), the greater are subject's plasticity and speed of actions.

The dimensions of emotionality (STQ 7 and 8) and neuroticism revealed similar relations to the length of N2-P3 complex. It should be noted that emotionality was itself correlated with neuroticism. One can suppose that high emotionality and neuroticism are linked to longer duration of processes that start during automated processes of preattentive (including the time of N2 generation) and end with decision making and updating memory context at late attentional stages of perception, including the time of P3 generation (Donchin, 1988; Naatanen, 1992; Polich, 2007; Rutman, 1979).

In hard conditions only negative relations between two STQ dimensions (social-related ergonicity, STQ 2, and social-related tempo, STQ 6) and two amplitudes (P3 and N2-P3 complex) could be detected. Probably, these two social-related STQ dimensions came forward because the motivation for the subjects to perform well in these hard conditions was purely social. Smaller EP amplitude corresponded to higher levels of these STQ dimensions. It can be assumed that in this case higher endurance and speed of activity are ensured by lesser involvement of brain resources in each particular task. Supposedly, lesser involvement of brain resources in each task allows such individuals to perform more mental operations or actions per unit of time and thus creates conditions for greater productivity and lesser fatigability.

It is worth discussing the fact that during the 2nd and 3rd series of the experiments much fewer statistically significant relations were found compared to the 1st series. In other words, when the experiment progresses, much of the regularities disappear or become insignificant. Probably, this can be explained by adaptation of the subjects to the conditions of the experiment and automation of their behaviour (which should be most pronounced by the time of the last experimental series). It can not be excluded that during the 3rd session adaptation and automation allowed the subjects to solve the task without taxing their attentional system. This in turn might have led to reflex-like reacting via some automated strategies developed by the subjects; presumably these strategies did not depend on the subject’s temperament but rather were determined by their previous experience and other unaccountable factors.

The dynamics of relations between temperament and EPs discussed above allows us to suppose that in order to reliably reveal these relations it might be expedient to use an experimental task with maximum uncertainty for the subject and maximum attentional load; moreover, the earliest stage of the experiment with maximum uncertainty for the subject may bring most valuable results.

Peculiarities of EP Parameters and their Connections with Questionnaire Data in Group II

Analysis of relations between questionnaire data and EP parameters in group II (unlike group I) does not give ground for any straightforward interpretations. Two explanations for that can be provided: either the processes of perception in group II have substantially more complex organization
than in group I, or, most likely, group II is itself heterogeneous. The latter supposition is substantiated by the fact that in group II during the 1st easy series 4 subjects displayed atypical positive N2 amplitudes (mean values +3.3 – +6.4 μV), while in three subjects of this group N2 amplitude (-0.5 – +1.3 μV) was close to the values, found in group I (-7.1 – +1.5 μV). It also seems likely that subjects of group II used distinctive cognitive strategies with more effective stages of preattentional and early attentional information processing consuming less brain resources – at least in easy condition (this would explain less negative or even positive N2 peaks in group II).

Conclusions
The results obtained show existence of a certain link between psychological manifestations of individual temperament traits and brain mechanisms of cognitive processes. Group I comprised 2/3 of the subjects, for whom all three questionnaires produced congruous types of temperament. This group manifested a clear unitary system of temperament, based on brain mechanisms of perception and attention. Group II included 1/3 of the subjects with discordant questionnaire data. These subjects displayed a different picture of relations between temperament and its physiological correlates had much less clear organization and manifestation. Difference in EP patterns in groups with concordant and discordant questionnaire data hint that these subjects belonging to the two groups may use different cognitive strategies, leading in group II to inconsistency of questionnaire data. Further studies may show if this hypothesis is true.

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References