АКТУАЛЬНЫЕ НАПРАВЛЕНИЯ СОВРЕМЕННОЙ ПСИХОФИЗИОЛОГИИ

DIFFERENCES IN EEG OSCILLATIONS DURING VASOACTIVE STRESS REACTIONS IN EXTROVERTS AND INTROVERTS

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Hyperventilation (HV) and breath-holding (BH) are informative psychophysiological tests resulting in rapidly changing cerebral blood flow. The aim of our research was to determine differential EEG spectra of introverts/extroverts with induced HV and BH. Introverts revealed more intensive EEG reaction during HV, which was specifically shown by increased theta and gamma activity in all cortical areas.

Key words: EEG, Brain oscillations, Personality, Extraversion, Hyperventilation.

The study of extroversion is important for understanding the role of personality in various psychophysiological treatment and training systems, such as biofeedback and breath control techniques including holotropic breathing (voluntary hyperventilation) and yoga. According to H.J. Eysenck's (1967) personality theory, the balance between excitatory and inhibitory neural mechanisms is regulated by the Ascending Reticular Activating System (ARAS), and introverts have higher excitability of the reticulo-cortical loop than extroverts [8; 9]. A number of EEG investigations have supported Eysenck's theory [6; 10; 17; 24]. Most studies estimated central nervous system activity on the basis of alpha rhythm measurement, typically finding a negative correlation between alpha spectral power and cortical activation.

However, an exclusive focus on alpha may neglect extraversion effects on other functionally significant EEG indices. Indeed, extraversion has been found to relate to greater slow wave activity in the EEG [21]. Another limitation of much of the existing research is that the traditional EEG bands may be too broadly defined to afford

accurate discrimination of frequency-dependent effects of extraversion on the EEG. Recent work on evoked potentials has shown differing effects of extraversion on upper and lower frequency bands, which may relate to their associations with different cognitive processes [12]. Recent research has also focused on coherence. EEG coherence indicates the extent of synchronization, or desynchronization, of the brain waves from different parts of the brain. Increase in coherence is interpreted as elevation of the functional relations between different cortex regions. Increasing coherence in specific rhythm bands between different parts of the brain could be evidence of prevalent modulation of brain function of the specific pacemakers (depending on frequency or localization). The coherence analysis helps to understand how the brain works as a whole, in relation to modulating rhythms (cortical or subcortical) of the changes in the ongoing EEG.

Differences between extraverts and introverts in cerebral blood flow (CBF) have also been found in PET and fMRI studies [7; 13; 24]. Johnson et al. (1999) concluded that introversion was correlated with rising CBF in frontal lobes and in the anterior thalamus, whereas extraversion was correlated with rising CBF in the anterior cingulate gyrus, the temporal lobes and the posterior thalamus during the cognitive task [13]. Wright at al. (2006) investigated anatomical differences in the whole brain's cortical thickness by using fMRI and found an inverse relationship between specific prefrontal cortex thicknesses and extraversion [24].

Current research on extraversion and EEG has tended to neglect the role of stress factors as moderators of the association. Gale (1983) suggested that stimulating conditions may suppress associations between extraversion and the EEG, but this hypothesis has not been substantiated in subsequent research [10]. In fact, the most straightforward prediction from Eysenck's theory of extraversion, in accord with more recent brain-imaging data, is that environmental stressors may impact introverts more strongly than extraverts [9].

In a recent study we used hyperventilation (HV) and breath-holding (BH) as stress tests. These vasoactive stress tests cause hypercapnia and hypocapnia (increased and decreased CO_2 levels) respectively, which rapidly affect CBF, EEG activity and behaviour. The immediate physiological effect of hyperventilation results in reduced arterial carbon dioxide partial pressure ($PaCO_2$), which, in turn, increases perivascular and intraneuronal pH, and increases glucose consumption and lactate production. A rise in perivascular pH induces notable vasoconstriction, which leads to a rapid reduction in CBF [5; 15; 23]. In EEG, HV leads to synchronization of the cortex, increasing diffused delta activity, arrhythmic delta and theta activity and intermittent rhythmic delta activity (IRDA: high amplitude rhythmic slowing) [11; 20]. It is known that HV results in tachycardia, which leads to light-headedness, visual disturbance, dizziness, tension, anxiety, panic attacks, and weakness or exhaustion. BH triggers a cycle of events that involves several layers, and an inverse pattern to HV that accompanies increasing $PaCO_2$. Hypercapnia results in lower pH, triggering vasodilation which, in turn, produces an increase in CBF, and, in fMRI studies, an increasing BOLD (Blood Oxygen Level Dependent) signal, as well as EEG alpha desynchronization (i. e. decreasing

spectral power density in alpha) [1; 16; 18; 25]. BH and HV have been used in different breathing trainings (for example meditation, holotropic breathing, and Byteiko's breathing as alerting reaction).

The main question of our research was to determine how subjects with different baseline arousal levels (i. e. introverts/extroverts) react to the complementary HV and BH manipulations. The research aimed to examine the effects of HV and BH on EEG spectra in extroverts and introverts. The general expectation was that introverts would react to HV more intensely than extraverts, due to their higher arousal baseline levels, which results in a greater CBF reduction, whereas reaction to BH may have opposite direction. The coherence analysis of the brain oscillations will help to understand the differences in the modulation of the cortex activity.

Methods

Subjects. Fifty three healthy and non-smoking students of Kazakh National University were screened for introversion/extroversion using a Russian translation of the Eysenck Personality Inventory [8]. Participants with strong inclination to introversion or extraversion (no ambivalence, M = 13,86, S.D. = 4,13 for the whole sample; M = 7,4, S.D. = 1,26 for introverts group; M = 19,7, S.D. = 1,83 for extroverts group) were chosen, resulting in 10 introverts (5 men and 5 women) and 10 extroverts (5 men and 5 women). Their age ranged from 18 to 24 years (median age = 21.1 ± 2.4 years).

EEG Measurements. Participants signed the approved consent form and completed the EPI. After familiarizing participants with the EEG procedure and mounting the electrode cap, participants were seated in a comfortable armchair. The subjects were asked to minimize their movements during the EEG recordings. EEG was recorded by using an electroencephalograph "Medicor 8S" (Hungary) monopolarly from symmetrical frontal, central, parietal, and occipital lobes with the indifferent joint ears electrodes (F3, F4, C3, C4, P3, P4, O1, and O2) according to a 10—20% system in the following situations: baseline with closed/open eyes, lasting four minutes (EC, EO), hyperventilation (HV, 120s), after hyperventilation (after HV, 120s), breath holding (BH, 30s), after breath holding (after BH, 120s).

The Spectral Power Densities (SPDs) and inter/introhemispheric coherence of EEG rhythms was analyzed in 11 bands (2—45 Hz.): Delta1, Delta2, Theta1, Theta, Alpha-1, Alpha-2, Alpha-3, Alpha-4, Beta-1, Beta-2, Gamma 1 by using V. Vildavski's program [26]. Analyses tested for extravert-introvert differences at each stage of the experiment, from initial EC baseline to the final BH manipulation.

Results

Baseline level (EC). The results confirmed what Eysenck's theory had predicted in relationship to baseline levels: the introverts showed higher arousal levels, evidenced by significantly ($p < 0,05$) lower SPD in some alpha bands (alpha 1,4 in O1 and alpha 4 in O2).

Alerting reaction (EO). The results of this study were in accord with the typical finding that alerting elicits alpha desynchronization, in both extroverts and introverts.

Additionally, decreasing SPD in theta and beta bands occurred after opening of the eyes in both groups. Furthermore, results indicated increased gamma oscillations in left and right frontal and right occipital lobes and delta oscillations in both frontal and central lobes in introverts, but not in extraverts.

Hyperventilation (HV). The SPD changes following HV were analyzed with respect to the initial baseline (EC). A more widespread EEG reaction to HV was observed in introverts: rising SPD in delta and theta bands, at the majority of sites. Extroverts also showed increasing SPD delta, but no significant changes in theta, as well as increased alpha-4, and beta-2 activity locally (Fig. 1). The higher arousal baseline in introverts may provide for more intensive reactions to HV, and, possibly, a greater induced reduction in CBF. No changes were seen in the middle bands, indicating that alpha-1-2 are not sensitive to HV in either group.

Synchronization in the same bands was seen in coherence data. Also, the coherence data showed an increase in synchronization in delta-1, theta-1, high alpha, and beta bands in both extroverts and introverts.

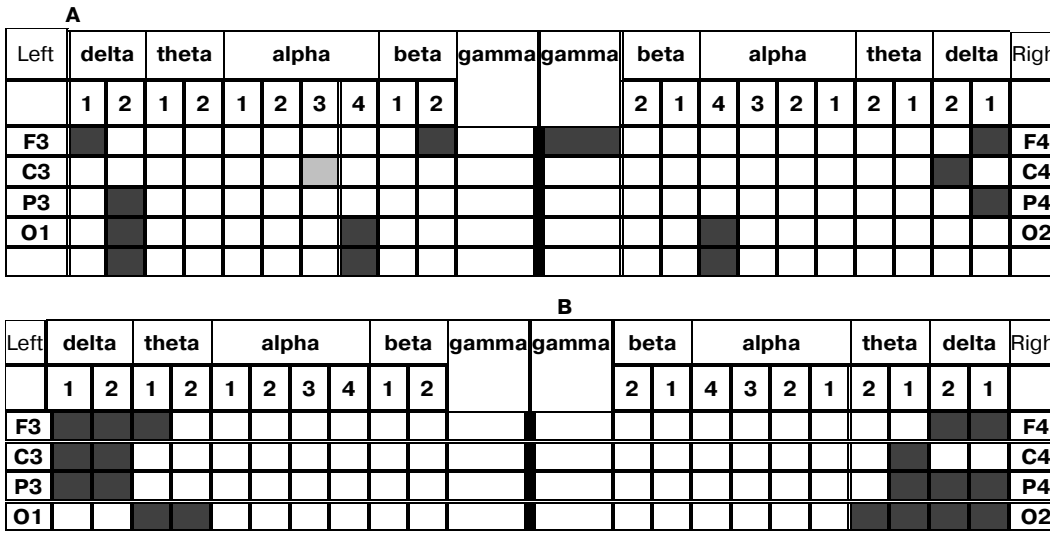

Fig. 1. Changes in PSD of EEG rhythms following HV (HV-EC) in extraverts (A) and introverts (B), as a function of electrode site

— increased PSD ($p < 0,05$)

— decreased PSD ($p < 0,05$)

Breath holding (BH). Our results showed desynchronization in both groups; especially a minimizing alpha SPD trend. At the same time, we observed growth in gamma SPD in all areas for introverts plus localized growth in delta. Extroverts showed a more localized increase in gamma SPD (P3, P4) plus localized RH growth in theta (O2). Furthermore, the extraverted group was also distinguished in that they showed increased beta-2 SPD at C3, C4 and F4 and increasing theta-1 and -2 at O2.

The coherence data suggested that BH in the extroverts influenced higher frequency pacemakers (alpha 4, beta-1, 2) (Fig.2). This can be concluded from observing

the increasing inter-site correlations in higher bands — alpha-4, beta-1, and decreasing correlations in low bands delta-2, theta-1. The increasing theta, gamma correlations in introverts may relate to thalamic-cortical pathway activation, which may be evidence of different way of the mobilization compared to extroverts.

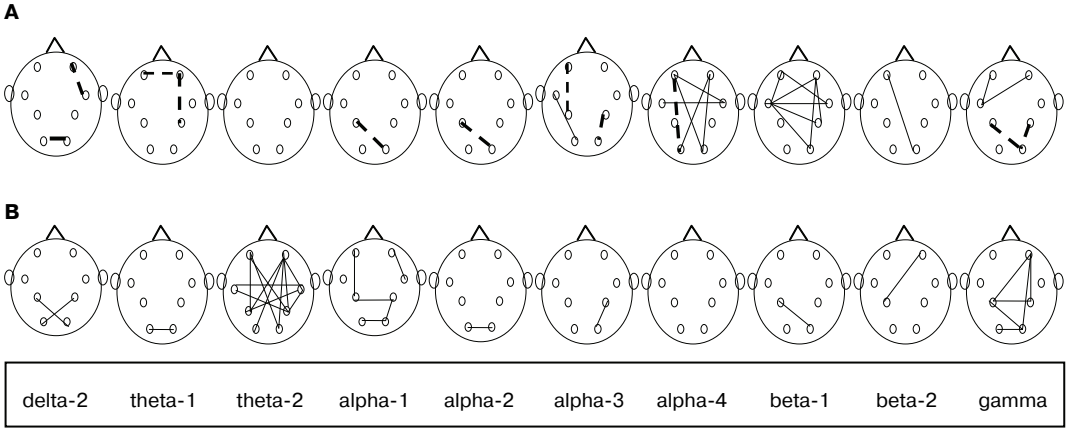

Fig. 2. EEG coherence changes following BH reaction (BH- EC) in extraverts (A) and introverts (B).

——— Increased coherence ($p < 0,05$).

– – – – Decreased coherence ($p < 0,05$).

Discussion

The study provides some findings that are in accord with earlier work, as well as some novel results. Consistent with other EEG studies supporting Eysenck's theory [6; 21], introverts had higher baseline cortical arousal, as evidenced by lower alpha-4 SPD in occipital cortex and higher alpha mode frequency. Both subject groups showed the expected EEG response to HV (increased delta) and to BH (decreased alpha). As predicted, introverts appeared to be generally more reactive than extraverts to HV in the lower frequency bands that define the characteristic EEG response and extraverts seem to be more reactive in relation to alpha. By contrast, reactions to BH were in different ways of the mobilization in groups. The coherence data helped to observe where synchronization or desynchronization occurs in whole brain functioning. BH evoked increased alpha–4 and beta coherence in extroverts but not introverts. These data suggested the differentiation of the higher alpha-4 from lower alpha bands in activation process.

We consider that the higher gamma reactivity in stress reactions to BH in introverts is a result of higher cortical reactivity. According to recent studies, gamma oscillations play an important role in selective attention, learning, and memory as modulators of cortical synchronization for mutual cortico-cortical interactions among neuronal populations [14; 22]. Logotheis (2001) found that gamma rhythm during a visual task was accompanied by increasing CBF in the visual cortex [21]. On the other hand, the rising delta activity may serve as evidence of limbic system activation and, on the contrary, decreasing CBF in cortex and increasing in thalamus [4].

Terehin (1996) and Sviderskay & Bikiv (2006) studied HV effects on cortical electrical activity and found individual differences in EEG reaction, with some participants showing faster and more intense reactions than others [2; 3]. Our research suggests that such individual differences might be due to introversion/extroversion. Sviderskay&Bikiv stated that some participants had higher spatial synchronization in frontal lobes and lower spatial desynchronization in parietal-frontal lobes during baseline assessment (as we observed in introverts) [2]. They concluded that response in these participants reflected a more complicated reorganization of the cortico-subcortical and cortico-cortical relations during HV. In our study the introverts showed such reorganization.

By contrast, the increasing CBF during BH engages alpha-1 and 2 desynchronization in both groups that matches decreasing SPD in alpha during hypoxia [1], or the increasing BOLD signal [5; 18; 25]. The rising gamma SPD in all brain areas in introverts and only in P3 in extroverts testifies to the importance of this oscillation in regulation during BH, especially for the former group.

Conclusion. This study has shown differential vasoactive stress reactions of extroverts and introverts: the introverts had more intensive slow-wave EEG reactions to HV than extroverts; and introverts' reactions to BH indicated more intense changes in gamma-delta relations. Therefore, the results of this study testify to the existence of different types of regulation for introverts/extroverts.

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РАЗЛИЧИЯ В ЭЭГ-ОСЦИЛЛЯЦИЯХ ПРИ ВАЗОАКТИВНЫХ СТРЕСС-РЕАКЦИЯХ У ЭКСТРАВЕРТОВ И ИНТРОВЕРТОВ

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Гипервентиляция (HV) и задержка дыхания (BH) — информативные психофизиологические тесты, быстро изменяющие церебральный кровоток в результате гипо-, гиперкапнии и, как следствие, ЭЭГ-активность. Целью данного исследования является выявление различий между ЭЭГ-спектральными характеристиками у интровертов и экстравертов при реагировании на гипервентиляцию и задержку дыхания. Выявлено, что интроверты реагируют на гипервентиляцию и задержку дыхания более интенсивно, в частности увеличением тета- и гамма-активности во всех отведениях.

Ключевые слова: ЭЭГ, осцилляции мозга, индивидуальные различия, экстраверсия, гипервентиляция.