ANALYSIS OF INDEPENDENT COMPONENTS OF COGNITIVE EVENT RELATED POTENTIALS IN A GROUP OF ADHD ADULTS

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Abstract
In the last decade, many studies have tried to define the neural correlates of attention deficit hyperactivity disorder (ADHD). The main aim of this study is the comparison of the ERPs independent components in the four QEEG subtypes in a group of ADHD adults as a basis for defining the corresponding endophenotypes among ADHD population.

Sixty-seven adults diagnosed as ADHD according to the DSM-IV criteria and 50 age-matched control subjects participated in the study. The brain activity of the subjects was recorded by 19 channel quantitative electroencephalography (QEEG) system in two neuropsychological tasks (visual and emotional continuous performance tests). The ICA method was applied for separation of the independent ERPs components. The components were associated with distinct psychological operations, such as engagement operations (P3bP component), comparison (vcomTL and vcom TR), motor inhibition (P3supF) and monitoring (P4monCC) operations.

The ERPs results point out that there is disturbance in executive functioning in investigated ADHD group obtained by the significantly lower amplitude and longer latency for the engagement (P3bP), motor inhibition (P3supF) and monitoring (P4monCC) components. Particularly, the QEEG subtype IV was with the most significant ERPs differences comparing to the other subtypes.

In particular, the most prominent difference in the ERPs independent components for the QEEG subtype IV in comparison to other three subtypes, rise many questions and becomes the subject for future research.

This study aims to advance and facilitate the use of neurophysiological procedures (QEEG and ERPs) in clinical practice as objective measures of ADHD for better assessment, subtyping and treatment of ADHD.

Keywords: ERP independent components, ADHD, adults, executive functions

Introduction
In the last decade, the aim of many studies was to define the neural correlates of attention deficit hyperactivity disorder (ADHD). In this context, Event Related Potentials (ERPs) have been investigated in a large number by many researchers and a substantial number of ERP correlates of ADHD have been identified (Barry et al., 2003).

Cognitive ERPs are among the most important characteristics of the function of the brain. Using the independent component analysis (ICA) method, ERPs can be decomposed into functionally different components which have been shown to provide features that could be used for characterizing clinical populations (Kropotov, 2009; Müller et al., 2010; Müller et al., 2011). Thus, the use of ICA substantially improves the traditional method of the separation of signals of ERPs (Kropotov, 2009). These independent components (ICs) have different latencies, different topographies and dif-
ferent functional meanings (Kropotov et al., 2011).

The components were associated with distinct psychological operations, such as engagement operations (P3bP component), motor inhibition (P3supF), monitoring (P4monCC) and comparison components (vcomTL and vcomTR). Amplitude and latency of these components at Pz, Fz, Cz, T5 and T6 leads were measured and analyzed in each test subject.

Activation (engagement) component – P3bP (P3bParietal component) is generated in the parietal cortex and is associated with an operation of action engagement i.e. activation of the cortex. This feature from neurophysiological perspective is associated with activation of cortical and subcortical structures in the frontal-parietal cortex involved in performing of the selected action. From a psychological and functional point of view it is associated with combining all brain resources to implement the action. Previous experiments with the use of this modification of the test have shown that the ERPs in the interval of 200–300 ms have a positive component distributed in the parietal central areas and are related to the mental process of the initiation of action (the component of action engagement) (Pronina et al., 2011). It was confirmed that ADHD children exhibit lower amplitudes of GO and NOGO P300 components in comparison to normal groups (Kropotov et al., 1999; Overtoom et al., 1998; van Leeuwen et al., 1998; Ponomarev et al., 2000).

Inhibition component (inhibition of preparatory activity) – P3supF (P3 suppression Frontal): From a neurophysiological aspect, inhibition of the response includes a special circle in the right ventral prefrontal cortex, basal ganglia and thalamus axis. Ventral prefrontal cortex receives information from the sensory systems that detect the mismatch between the expected and actual sensory stimuli. For example, when the information comes from the visual parts, the cortex receives additionally information from the anterior cingulate, where executive action is compared to the planned (prepared) action. The ventral prefrontal cortex is active when we need to stop or inhibit commenced behavioral pattern. The damage to the inhibition of reaction is conceptualized as the core symptom of ADHD by many authors including Barkley (1997). However, attempts to test his hypothesis experimentally proved quite controversial. The team of Banaschewski et al., (2004) failed to find any deviation of inhibition component in Go/NoGo paradigm. Unlike them Satterfield (1988, 1990, 1994) and his associates have shown a significant reduction of inhibition component in the stop signal task with ADHD group compared with the control group.

Self-monitoring component – P4monCC (P400 monitoring Cingulate Cortex): Error correction or monitoring of what we have done is very important executive function. From neuropsychological point of view, monitoring is based on neural mechanism of comparison of the expected action compared to the behavioral response. If an action does not meet the expectations, a change in behavior to correct the difference is appearing. Scientists from Ghent University in Belgium (Wiersema et al., 2005) found that children with ADHD have normal monitoring in relation to the detection of the error, but show abnormal and inadequate strategy of adjusting the response.

In the study of Kropotov et al. (2005) which analyzed 150 ADHD children, significantly reduced P400 monitoring component was noted compared to a normative database for appropriate age.

Comparison component – vcomTL (visual comparison temporal left) and vcomTR (visual comparison temporal right): Other indirect indicator of working memory is comparison component, which appears in Go/NoGo task. This component is appearing in response to the second stimulus in NoGo attempts when presented stimulus does not match expectations. In the research of Kropotov et al., 2005 depletion of this component in 36 (25%) of 150 examined ADHD children was found.

According to sLORETA the sensory mismatch component was generated in the left and right temporal areas, the action suppression component was generated in the supplementary motor cortex, and the conflict monitoring component was generated in the anterior cingulate cortex [Kropotov et al., 2011].

The main aim of this study is the comparison of the ERPs independent components in the four QEEG subtypes of ADHD adults as a basis for defining the corresponding endophenotypes among this population. The paper ap-
plies a methodological approach developed in the Institute of Human Brain (St. Petersburg) for assessment of electrophysiological indexes of executive functions of ADHD adults.

Methods

Subjects
Two groups, the ADHD adults and the control group that participated in the study were recruited in the framework of the EU COST Action B27 “Electric Neuronal Oscillations and Cognition – ENOC”. The 67 ADHD adults and 50 normal controls (between the ages 18 and 50 years) were enrolled in the study. The control group was recruited from the local community and matched by sex and age. All subjects gave their informed consent for participation in the study.

A female to males’ ratio was equal for the ADHD (33 females and 34 males) and the control group (25 females and 25 males). The mean age of the ADHD group was 33.4 ± 8.39 years, and for the control group the mean age was 32.8 ± 8.22 years.

In the ADHD group 45 subjects were referred by their psychiatrist (with the previous diagnosis of ADHD) and 22 adults were new patients. Subjects were included in the ADHD group only if they had been diagnosed as ADHD by an independent psychiatrist. The ADHD diagnosis was confirmed according to the DSM-IV criteria with at least 4 symptoms of inattention or at least 4 symptoms of hyperactivity/impulsivity, frequently present during the past 6 months, affected in at least 2 areas of life, with no history of epilepsy and no history of head injury.

It can be noted that the four symptoms of inattention and/or hyperactivity/impulsivity is less than DSM-IV requires for ADHD diagnosis, but according to Barkley this is acceptable for adults. All subjects met the criteria of the Barkley’s Semi-structured Interview for adults with ADHD. In order to ensure diagnostic validity, additional information was collected from parents, partners, relatives and friends. The determination of the presence of adulthood ADHD symptoms during the assessment resulted in 26 ADHD subjects being diagnosed with the inattentive subtype, 4 with hyperactive/impulsive and 37 with combined behavioral subtype. All subjects had normal or corrected to normal vision and were right-handed.

According to Kropotov’s QEEG spectrum classification for ADHD population (Kropotov, 2009), we have made grouping on our subjects according to the following four subtypes: I.) Abnormal increase of delta-theta frequency range centrally or centrally-frontally; II.) Abnormal increase of frontal midline theta rhythm; III.) Abnormal increase of beta activity frontally; IV.) Excess of alpha activities at posterior, central, or frontal leads (Markovska-Simoska and Pop-Jordanova, 2010).

All participants were briefly interviewed before testing to exclude those with a history of head injury with subsequent loss of consciousness, substance abuse, neurological, systemic medical diseases and/or severe psychiatric disturbances. Except for symptoms of psychosis, comorbidities were no reason for subject exclusion.

Subjects were unmedicated, or they had refrained from taking methylphenidate during 48 hours before testing. Control subjects also did not receive any medication at the time of testing. All participants were asked to refrain from coffee and cigarette intake on the day of the testing. Subjects taking other psychotropic substances were not included in the study.

The study was approved by the local ethics committee. Subjects voluntarily participated in the study and written informed consent was obtained from all participants after having provided an explanation of the procedure.

Procedure
All participants were individually assessed in two sessions with neuropsychological and neurophysiological testing in an environment free from distractions. The testing was carried out in a quiet, air-conditioned room with the experimenter and the recording equipment present. In the first assessment the interview and questionnaires as Current and Childhood Symptoms Scale (Barkley); Brief Symptom Inventory (Derogatis); Health History (Barkley); Trauma questionnaire (Müller & Thomann) and Semi-structured Interview for Adults with ADHD (Barkley) for excluding the ADHD symptoms were applied. The results of
the neuropsychological testing performed with Amsterdam Neuropsychological Testing (ANT) and CogMed test, at the first session, are not relevant to this paper.

EEG data were acquired by the Mitsar 19-channel QEEG 201 system (Mitsar Ltd.), while the subjects were in an eyes-closed and in an eyes-open resting condition, lasting five minutes each (sufficient for 2 minutes artefact-free data EC and EO). Then data was recorded while subjects were performing a visual continuous performance task – VCPT (two-stimulus Go/NoGo paradigm) and emotional continuous performance test – ECPT from Psytask program. The duration of the tasks was approximately 22 minutes for each one.

Separate channels for recording a signal from the button were used for monitoring the accuracy of the test performance and measuring the response trial. The input signals referenced to the linked ears were filtered between 0.5 and 50 Hz and digitized at a sampling rate of 250 Hz. The impedance was kept below 5 kΩ for all electrodes. Electrodes were placed according to the International 10–20 system using an electrode cap with tin electrodes (Electro-cap International Inc.). The quantitative data were obtained using WinEEG software. The linked ears reference montage was changed to average reference montage prior to data processing. In addition, epochs of the filtered electroencephalogram with excessive amplitude (> 100 μV) and/or excessive fast (> 35 μV in 20 to 35 Hz band) and slow (> 50 μV in 0 to 1 Hz band) frequency activities were automatically marked and excluded from further analysis. Finally, the EEG was manually inspected to verify artefact removal.

ERPs were computed off line. The epoch of analysis included 300 ms before the first stimulus and 900 ms after the second stimulus. Trials containing electrooculogram artefacts (exceeding 100 μV threshold) were discarded from further analysis. Trials with omission and commission errors were automatically excluded from averaging. To get reliable ERPs, more than 70 trials for each condition were needed.

Behavioral tasks
The Visual Continuous Performance Task (VCPT) and the Emotional Continuous Performance Task (ECPT), were administered using the standard protocol. During the test, a subject sat in a comfortable armchair with armrests. Pictures were presented in a pseudo-randomized order in the center of a computer monitor placed 1.5 m from the subjects’ eyes. The stimuli were presented on a 17 inch monitor using the Psytask (Mitsar Ltd.) software. Before each session, the test was explained to the subject in detail and 10–20 trials were performed. Accuracy and speed were encouraged. There was a 5-minute rest between the tests. If it was necessary, subjects rested for a few minutes after each 200 trials.

Three categories of visual stimuli were selected for VCPT: 1) 20 different images of animals; 2) 20 different images of plants; 3) 20 different images of humans presented together with an artificial "novel" sound. All visual stimuli were selected to have similar size and luminosity.

For ECPT the three categories of visual stimuli were: 1) 20 different images of angry faces; 2) 20 different images of happy faces; 3) 20 different images of neutral faces presented together with an artificial "novel" sound.

The trials consisted of presentations of paired stimuli with inter-stimulus intervals of 1000 ms and inter-trials intervals of 3000 ms. Duration of stimuli was 100 ms. Four categories of trials were used: Animal-Animal, Animal-Plant, Plant-Plant, and Plant-Plant (Human+Sound) for VCPT and Angry Face–Angry Face, Angry Face–Happy Face, Happy Face–Happy Face, Happy Face–Neutral Face+Sound. The trials were grouped into four blocks with one hundred trials each. In each block a unique set of five animals (angry faces) stimuli, five plants (happy faces) stimuli, and five humans (neutral faces) stimuli were selected accordingly. Each block consisted of a pseudo-random presentation of 100 pairs of stimuli with equal probability for each stimulus category and for each trial category. The task was to press a button as possible in response to all Go trials. A–P (AF-HF) pairs represented the NoGo condition, in which the person should withhold from responding. Thus, after the presentation of the first Go stimulus, the subject was ready to press the button, and presentation of the second stimulus inhibited the prepared motion. For the P–P (HF-HF) and P–H
(HF-NF) it was assumed that the first stimuli would signal that no preparation for action was needed and that the trial could be ignored. It must be stressed here that in pairs A-A (AF-AF) and P-P (HF-HF) the first and the second stimuli were physically the same.

Mean reaction time (RT) with a standard deviation (SD) of RT was calculated across trials for each participant. Omission- (not pressing the button to Go trials) and commission errors (pressing the button to NoGo trials) were also computed for each participant separately. A response was considered correct if it occurred in relation to the appropriate second stimulus and took place during the time interval from 200 to 1000 ms after the second stimuli presentation.

Decomposition of collection of ERPs into independent components.

The goal of the Independent Component Analysis (ICA) is to utilize the differences in scalp distribution between different generators of ERP activity in order to separate the corresponding activation time courses (Makeig et al., 1996). The components are constructed by optimizing the mutual independence of all activation time curves, leading to a natural and intuitive definition of an ERP component as a stable potential distribution which cannot be further decomposed into independently activated sources. The ICA method used in the present study was implemented in the analysis software described by Kropotov (2009). The 700 ms interval after the second stimulus in the two conditions (Go and NoGo) with sampling rate 250 samples/second was selected.

Statistical analysis

Amplitudes and latencies of the components were computed for each condition and each subject separately. One-way ANOVA was used for assessing statistical significance of the difference between groups (all ADHD, ADHD I, II, III, IV subtype and control) and conditions (EC, EO, VCPT, ECPT). To explain the significant interactions post hoc Bonferroni test was performed. Due to space reasons only the significant effects and interactions between groups and conditions are presented.

Results

Table 1 shows the behavioral performance of participants in VCPT and ECPT. The ADHD group showed a significantly higher number of omission and commission errors and a significantly higher RT and its variance, compared to the control group.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>ADHD group</th>
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<tbody>
<tr>
<td><strong>VCPT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omission errors</td>
<td>1.40 (1.62)</td>
<td>5.89*** (2.98)</td>
</tr>
<tr>
<td>Commission errors</td>
<td>0.69 (1.28)</td>
<td>1.24* (1.46)</td>
</tr>
<tr>
<td>RT (ms) (SD)</td>
<td>364.63 (54.67)</td>
<td>417.52*** (72.26)</td>
</tr>
<tr>
<td>Var&lt;sup&gt;a&lt;/sup&gt; RT (ms) (SD)</td>
<td>7.22 (2.27)</td>
<td>10.82*** (3.20)</td>
</tr>
<tr>
<td><strong>ECPT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omission errors</td>
<td>3.50 (1.77)</td>
<td>14.70*** (3.80)</td>
</tr>
<tr>
<td>Commission errors</td>
<td>1.96 (1.78)</td>
<td>2.33 (1.32)</td>
</tr>
<tr>
<td>RT (ms) (SD)</td>
<td>411.23 (25.6)</td>
<td>456.18** (74.04)</td>
</tr>
<tr>
<td>Var&lt;sup&gt;b&lt;/sup&gt; RT (ms) (SD)</td>
<td>9.80 (3.50)</td>
<td>13.94*** (3.41)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Reaction time; <sup>b</sup> Variability of reaction time – The stars mean the level of significant difference between both groups (***p < 0.001, **p < 0.01, *p < 0.05)

**P3bP (activation component)**

a) Amplitude

When considering the amplitude of the P3bP component in Normal and ADHD groups we have obtained statistically significant difference [F (1,228) = 3.18, p < 0.05, (p = 0.043)], with lower value of the P3bP amplitude in the ADHD group (Figure 1, left).
In terms of the dependence of the P3bP amplitude from the pertaining to the QEEG subtypes of ADHD group, ANOVA showed a statistically significant difference between groups $F(4,225) = 2.7660, p < 0.05, (p = 0.03)$. Specifically, Bonferroni post hoc test localize the lowest value of the P3bP amplitude in ADHD IV subtype with $p < 0.05$ (Figure 2, right). As it can be seen, a linear decreasing of the amplitude depends on the belonging to the subgroup.

As for the dependence of the P3bP amplitude to the test condition (VCPT or ECPT) significant difference was not received between these two tests (although in VCPT amplitude was higher). So, in this case the different stimuli applied in the tests do not affect the amplitude of the P3bP component.

b) Latency

In terms of the latency of P3bP component, a significant difference between the Normal and the ADHD group [$F(1,228) = 3.03, p < 0.05, (p = 0.03)$], expressed through longer P3bP latency in ADHD group (Figure 2, left) was found.

When the ADHD subtypes and the VCPT and ECPT conditions were analyzed as between subject variables, significant differences were not obtained.

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**Figure 1 – Amplitude of P3bP component**

**Figure 2 – Latency of P3bP**
cally significant difference \[ F(1,228) = 11.145, p < 0.01, (p = 0.001) \], with lower amplitude of the component for ADHD group (Figure 3, left).

Additionally, a significant difference was obtained and shown in distribution (Normal, ADHD I, ADHD II, ADHD III, ADHD IV) with \[ F(4,225) = 5.26 \text{ and } p < 0.001 \text{ (} p = 0.000) \] (Figure 3, right). Specifically, Bonferroni post hoc test showed that for \( p < 0.05 \), the amplitude of the P3supF component is with the lowest value in the ADHD IV subtype. Here, as previously found with the P3bP component, the linearly decreasing amplitude depends on the group affiliation (Figure 3, right).

The effect of task is with no significant difference on the amplitude of the P3supF component \([ F (1,228) = 0.004, p > 0.05, (p = 0.95) \].

b) Latency

In terms of latency we have not obtained a significant difference between Normal and ADHD group and the Normal and ADHD subtypes (although ADHD IV subtype as seen in Figure 4, left, is with the longest latency).

However, in terms of the task, the ECPT showed longer latency in comparison to VCPT \([ F (1,228) = 28.54, p < 0.01, (p = 0.000) \] (Figure 4, right).
vcomTL (visual comparison temporal left component)

a) Amplitude

When analyzing the amplitude of vcomTL in groups Normal and ADHD any statistically significant difference \([F(1,228) = 1.98, p > 0.05, (p = 0.16)]\), between the two groups has not been found.

Additionally, no significant difference was obtained in the shown distribution (Normal, ADHD I, ADHD II, ADHD III, ADHD IV) with \([F (4,225) = 0.69 and p > 0.05 (p = 0.60)]\).

While, vcomTL amplitude does not depend on the effect of belonging to a group, the statistical analysis showed that the effect depends on Task condition, with lower amplitude in ECPT compared to VCPT \([F(1,228) = 64.72, p < 0.001, (p = 0.000)]\) (Figure 5).

![Figure 5 – Amplitude of vcomTL in VCPT and ECPT](image)

b) Latency

Concerning the latency, no significant difference between the normal group and the ADHD, as well as between the ADHD subtypes was found \([F (4,225) = 1.54, p > 0.05, p = 0.19]\) (Figure 6).

For the Condition effect there is a significant difference, with a longer latency of vcomTL in ECPT regarding VCPT with \([F(1,228) = 55.05, p < 0.001, (p = 0.000)]\) (Figure 6).

![Figure 6 – Latency of vcomTL in VCPT and ECPT](image)

vcomTR (visual comparison temporal right component)

a) Amplitude

When analyzing the amplitude of vcomTR in groups Normal and ADHD there was no statistically significant difference \([F (1,228) = 0.38, p > 0.05, (p = 0.54)]\), between the two groups. Also, no significant difference was obtained in the shown distribution (Normal, ADHD I, ADHD II, ADHD III, ADHD IV) of \([F (4,225) = 1.35 and p > 0.05 (p = 0.25)]\). For the effect Condition no significant difference between conditions was found \([F (1,228) = 0.07, p > 0.05, (p = 0.78)]\).

b) Latency

Like vcomTL, vcomTR regarding latency showed no significant difference between the normal group and ADHD. Concerning the tasks, there is a longer latency in ECPT \([F (1,228) = 33.29, p < 0.001, (p = 0.000)]\) (Figure 7).

![Figure 7 – Latency of vcomTR in VCPT and ECPT](image)

P4monCC (monitoring component)

a) Amplitude

We obtained statistically significant difference when considering amplitudes of P4monCC component in groups of the Normal and the ADHD adults \([F (1,228) = 10.25, p < 0.01, (p = 0.002)]\), with lower amplitude for the ADHD group (Figure 8, left).

Also, a significant difference was obtained and shown in the subtype distribution (Normal, ADHD I, ADHD II, ADHD III, ADHD IV) with \([F (4,225) = 4.16 and p < 0.01 (p = 0.003)]\) (Figure 8, right). More specifically, Bonferroni post hoc test showed that for \(p < 0.01 (p = 0.001)\) the normal group has greater P4monCC amplitude than other subtypes, especially ADHD IV subtype.
Analysis of independent components of cognitive event related...

Regarding the tasks we did not find a significant relationship between VCPT and ECPT, $F (1,228) = 0.01, p > 0.05, (p = 0.90)$.

b) Latency

In terms of the latency there was a significant difference between the normal and the ADHD group, $F (1,228) = 7.85, p < 0.01, (p = 0.005)$ with a longer latency in ADHD (Figure 9, left). Significant subtype group effect was obtained, $F (4,225) = 2.71, p < 0.05, p = 0.031$ (Figure 9, right), specifically for ADHD IV subtype ($p = 0.04$), which has significantly longer latency than the normal group.

Finally, compared to VCPT the latency of P4monCC in ECPT was longer with $F (1,228) = 39.25, p < 0.001 (p = 0.000)$.

The topographies of all components are presented on Figure 10.
Discussion

The ERP results of this study point out that there is a confirmed disturbance in the executive functioning in the investigated ADHD group. Significantly lower amplitude and longer latency for the engagement (P3bP), motor inhibition (P3supF) and monitoring (P4monCC) components were obtained. Particularly, the QEEG subtype IV showed the most significant difference compared to the other subtypes.

The term executive functions refer to the coordination and control of motor and cognitive actions in order to achieve specific objectives. The executive functions are implemented by complex brain system consisting of several cortical and subcortical structures related to each other. Along with the basal ganglia, prefrontal areas are the seat of executive functions associated with activation, deactivation (inhibition), monitoring and working memory. Although the components associated with the executive functions overlap in time and space, recently developed independent components analysis provides a powerful tool for their separation and the detailed study. Using normative HBI database, we were able to separate and analyze the components of these executive event related potentials: P3bP, P3supF, vcomTL, vcom TR and P4monCC.

The P3bP component of evoked potentials is theoretically and clinically the most studied component in the scientific literature. There are several reasons for this: 1) the P3bP component is created in odd ball task, a task that is easily performed in nearly all categories of neurological and psychiatric patients; 2) P3bP is relatively large component and can be easily distinguished as the wavelength difference between the responses of target and nontarget deviant standards; 3) P3bP has a diagnostic power because impairments of this component were found as several executive dysfunctions in several disorders, i.e. schizophrenia and ADHD (Kropotov, 2009). Otherwise, there are several functional meanings of P3bP component. The most significant of these is the concept of recovery working memory proposed by Donchin (1981). P3A and P3bP components are normally considered as an index of attention and for this reason are widely applied in the diagnosis of brain disorders in which there is disturbance of attention systems. Many studies suggest reduced P3bP component in the ADHD population compared to the normal. The latest diagnostic application was confirmed in this study through reduced amplitude and longer latency to P3bP parietal component (as an index of activation processes) in adults with ADHD, compared to the normal control group. This interpretation also matches the received neuropsychological results and indicates reduced working memory in the target group especially in tasks with increased cognitive effort.

The P3supF inhibiting motor component occurs after NoGo attempts and is expressed through the frontally distributed negativity. Weakening of the inhibition of the response is conceptualized by many authors as the core symptoms of ADHD (including Russel Barkley, a leading name in the field of ADHD). However, some controversial experiments which are testing this hypothesis exist. An international team from the University of Gottingen, Germany, and the University of Zurich (Banaschewski et al., 2004), failed to find any deviations of the ADHD group compared to the normal. Unlike them, another study at the University of Texas, demonstrated significant reduction of this component in the ADHD group. Accordingly (somewhere in between), the results of this paper showed that there is a reduced amplitude of the P3supF component in the ADHD group, but there was no significant difference in latency.

The left and right comparison components (vcomTL and vcom TR) are no significantly different in both examined groups even in terms of amplitude or in terms of latency. But there is a significant difference in terms of the recorded condition that is VCPT vs. ECPT, with lower amplitude and higher latency in ECPT, which shows the dependence of this component of working memory overload with emotional stimulus. This component is an indirect index of working memory, sign for detecting a change in the current stimulus compared with the memory trace stored in working memory. It occurs in response to the second stimulus efforts in NoGo when presented stimulus does not coincide with the expected stimulus. The results of this study did not match the
results of Kropotov et al., 2005, where they have obtained reduced amplitude of the comparison component of 150 ADHD children.

The monitoring P4monCC component is with its highest amplitude and by s-LORETA (Pascual-Marqui et al., 1994) is generated by the medial prefrontal cortex and anterior cingulate cortex with maximum in Cz-Fz. Its functionality includes dynamic adaptation of human behavior through continuous assessment of ongoing activities and their consequences. The ability to monitor and compare current activities with internal standards and objectives is critical for optimal decision making. In this paper, we have obtained a significant reduction in the amplitude of monitoring component in the group with ADHD and significantly longer latencies. Similar results are found in children with ADHD in the above mentioned study of Kropotov et al., 2005. With regard to the recording condition, only significantly longer latencies in ECPT, suggest more difficult nature of the task, which also requires and longer self-processing of the information thus the entity acted properly or not.

In terms of QEEG subtypes the results showed that amplitudes of P3bP, P3supF and P4monCC were significantly generally reduced, with the longest latencies in the fourth QEEG subtype, suggesting impaired activation, inhibition and monitoring components. One possible explanation for this association of ADHD symptoms with QEEG subtype with increased alpha brain activity, may be the fact that the deep state of inactivity (idling) of the brain corresponds to a lack of inhibition, resulting in impulsiveness, hyperactivity and inattention (which was also obtained with the obtained results in the means of reduced amplitudes and longer latencies of evoked potentials in almost all tested components).

These valid subtypes may have different reasons for their occurrence, and therefore can react differently to medication and neurotherapy. These opportunities merit further investigation for future research.

**Conclusion**

From the obtained results, it can be concluded that the applied neurophysiological measures relatively clearly differentiate the ADHD into four subtypes, illustrating the heterogeneous and multifactorial character of this disorder with different clinical expression, related to different underlying neuropsychological and electrophysiological abnormalities, and consequently the different responses to treatment regimes. This study aims to advance and facilitate the pace of using neurophysiological procedures in clinical practice as objective measures of ADHD for better assessment, subtyping and treatment of ADHD. Especially, the most prominent difference for the IV subtype raises many questions and becomes the subject for the future research.

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**Competing interests**

SMS, NPJ report no potential conflicts of interest.

**REFERENCES**


Резиме

АНАЛИЗА НА НЕЗАВИСИМТЕ КОМПОНЕНТИ НА КОГНИТИВНИТЕ ЕВОЦИРАНИ ПОТЕНЦИАЛИ КАЈ ГРУПА ВОЗРАСНИ СО АДХД

Силвана Марковска-Симоска, Нада Поп-Јорданова, Јордан Поп-Јорданов

Македонска академија на науките и уметностите, Скопје, Р. Македонија

Во последната десетина многу студии се обидоа да ги дефинираат нервните корелации на
The deficit of attention and hyperactivity (ADHD). The main goal of this study is the comparison of independent ERP components of four QEEG patterns in the group of adults with ADHD as a basis for defining their endophenotypes.

The study included 30 adults diagnosed with ADHD according to DSM-IV criteria and 50 control group participants of the same age.

The activity of the brain was recorded with a 19-channel QEEG system (quantitative electroencephalography) upon the execution of neurocognitive tasks (visual and emotional continuous test). ICA method was used to divide the ERPs into independent components. These components are associated with different psychological operations, such as engagement (P3bP component), a comparison component (vcomTL and vcom TR), motor inhibition (P3supF) and monitoring (P4monCC) components. ERPs results indicate that there is a disruption of executive functions in the ADHD group, with significantly smaller amplitude and longer latency for the activation component (P3bP), motor inhibition (P3supF) and monitoring (P4monCC) components. Especially, QEEG pattern IV showed the most significant ERP differences compared to the other patterns, which triggered many questions as to why it is such a topic for future studies.

This study aims to advance and simplify the use of neurophysiological methods (QEEG and ERPs) in clinical practice, as objective measures of ADHD to improve diagnosis and treatment of ADHD.

Key words: ERP independent components, ADHD, adult, executive functions.