

## EEG SPECTRA IN PEDIATRIC RESEARCH AND PRACTICE

**Pop-Jordanova Nada**

*Pediatric Clinic, Medical Faculty, Ss Cyril and Methodius University,  
Skopje, R. Macedonia*

**Abstract:** After a short review of the developmental characteristics, integrality and complex structure of the EEG spectrum, some original clinical experiences with the diagnosis and treatment of related rhythm abnormalities in children and adolescents are presented. In particular, the approach and results concerning ADHD, OCD and dehydration disorders are discussed. In addition, the environmental effects on neuronal oscillations due to lead pollution and electromagnetic radiation are considered.

**Key words:** neuronal oscillations, children, neurofeedback, ADHD, OCD, dehydration, lead pollution, electromagnetic radiation.

### *1. Introduction*

The major indicators of information processing in the human brain are related to changes in spontaneous neuronal oscillations, event-related potentials, as well as brain metabolic activity. Since the initial report of Berger (1929), the relationship between the EEG and developmental processes from newborn to adult has been extensively studied.

The notion of EEG rhythm presumes regular changes in electric potential measured by electrodes from the scalp. When Fourier or wavelet transforms are applied to EEG recording, the rhythms appear at the corresponding spectra in the form of peaks. The most prominent changes that occur in the EEG with age are related to frequency composition. Normal mechanisms of these rhythms may be changed when some impairment of the brain occurs, becoming slower/higher in frequency, and/or appearing in unusual places. [1, 2, 3]

The use of brain imaging technologies (MRI, PET, SPECT, fMRI, EEG, QEEG, etc.) gives evidence that mental disorders have definite correlates with brain dysfunction. Of all imaging modalities, EEG and QEEG are the most practical, simple, inexpensive and readily applicable in clinical conditions. The conventional EEG detects wave shapes, frequency relationship and transitions of state, and is often used in epilepsy, tumor and brain damage diagnostics, while QEEG enables a precise comparison of the individual record with normative and psychopathological databases. [4, 5]

Normative databases help the clinician to recognize these abnormal patterns and to assess the level of statistical significance of the abnormality. Also, different procedures for automatic spike detection have been invented in practical applications. In addition, low resolution electromagnetic tomography (LORETA) may help to assess the 3D location of generators of EEG rhythms.

## 2. EEG rhythms

### 2.1. Main frequency bands

The slowest brain waves in the human EEG are **delta** oscillations, expressed in healthy adults mainly during the state of deep sleep. In very small babies, delta rhythm can be a normal pattern. At delta frequencies the brain releases many beneficial substances including the growth hormone. The intensity of delta waves in sleep plays a vital role in helping the brain recuperate from the effects of waking activities.

The changes in delta wave activity are shown to begin at about 11 years of age, declining by 25% by age 14. In addition, it is suggested that girls begin brain maturation at least one year earlier than boys. However, once this maturational process begins, it proceeds at the same rate in both sexes. [6, 7]

Generally, we can conclude that delta waves occur mainly in infants, sleeping adults or adults with a brain tumour or impairment.

Related to their generation, there are two types of delta oscillations in human EEG: one of cortical origin, and the other generated in the thalamus.

In the first year of life, a sharp increase of EEG **theta** activity is recorded during internally controlled attention [8, 9, 10]. The age-dependent dynamic of the relationship between frontal theta and attention behaviour reflects the maturational shift in the functioning of the anterior attention system. Also, a positive correlation between current density and glucose metabolism has been revealed [11].

From the clinical point of view, in ADD children the theta peak on the spectra is higher and sharper than normal.

Theta rhythm is generated in the hippocampus and the structures belonging to the limbic system.

Normal **alpha** rhythm begins to appear at three months, and its evolution is not linear with age [12]. The acceleration of alpha is pronounced up to 11–12 years, when the amplitude is highest, then starts to decrease till 20–55 years and increases later. Also, the genetic influence on the maturation of alpha, as well as the hormonal dependence of alpha frequency in females were revealed. The decrease of alpha rhythm during the eyes-open (EO) condition is also age-dependent. [13, 14, 15, 16]

In pathology, alpha rhythm is observed too early in newborn and infants with malformations. In ADD, pathological alpha activity arises in the fronto-temporal channels, together with a theta pick. Abnormal alpha rhythms were found in posterior temporal areas (tinnitus or whiplash), in left parietal areas (dyslexia), as well as the anterior and middle temporal regions (cerebrovascular disorders).

Alpha rhythm is generated in the thalamus.

**Beta** rhythm in children arises mainly in the frontal area when some stimulus attracts their attention. In some children with high anxiety scores beta waves may arise spontaneously (anorectics, obsessive thoughts, headache, etc.) or as the result of certain drugs. [17, 18] It was shown that stimuli without behavioural significance do not induce the increase of beta activity, and the opposite – meaningful stimuli induce beta activation in frontal cortical areas with a maximum in Fz.

In ADHD children, synchronization of the beta band due to auditory stimuli is lower than in normal children, which confirms the hypofunction of the frontal lobe.

Beta rhythm is generated in the frontal cortex. [19, 20]

## 2.2. EEG complexity and maturation

From the clinical aspect, it is important to mention that real EEG is a complex combination of EEG rhythms. Different oscillations reflect different mechanisms: alpha rhythm reflects the state of thalamo-cortical pathways; frontal midline theta reflects the functioning of the limbic system (hippocampus), while beta rhythms reflect the state of local cortical activation. The clinical decision that some EEG pattern in a patient is not normal must be based on objective criteria (e.g. a statistical comparison with the normative databases).

Research on the origin of rhythmic brain electric activity in various frequency bands indicates that anatomically complex homeostatic systems regulate the EEG power spectrum. Brainstem, thalamic and cortical processes mediate this regulation, whereby deficiency or excess of any of the neurotransmitters may produce remarkable changes in the EEG spectrum.

In childhood, the brain has many synapses related to its activity. During adolescence, the brain reorganizes and eliminates many synaptic connections, a process known as synaptic pruning. This pruning makes the brain's information processing more efficient and powerful while consuming less energy.

In general, in normal children a decrease in slow wave activity and an increase in fast wave activity with increasing age is a typical finding. The elevation in slow wave activity in children with ADHD or learning disabilities is interpreted by the delay in brain maturation as well as by the neurotransmitter dysfunction. The increased low waves activity in ADHD may also reflect a decrease in the dopamine function which is linked to an increase in impulsivity.

Many studies in the development period (childhood) have been aimed at investigating the relationship between the degree of intelligence and spectral EEG parameters. Schmidt *et al.* (2002) obtained a positive correlation of the intelligence test variables with spectral alpha power and significant negative correlation with the spectral power of lower frequency bands. It was supposed that the intelligence quotient is correlated with the degree of EEG maturation and thus reflects the active number of synapses and the degree of differentiation of the neuronal controlling system [21].

### 3. Mental arousal

#### 3.1. Rhythm – arousal – disorder correlation

We consider mental arousal (in the following text arousal) as an important characteristic, relevant to both clinical assessment and treatment.

The interdependence between the brain waves and the level of arousal is quite well established (Tables 1 and 2)

Table 1 – Табела 1

*Textbook classification of EEG activity and the level of arousal [22]*  
*Стандардна класификација на ЕЕГ активноста и ниво на возбуда*

<i>Classification</i>	<i>Frequency (Hz)</i>	<i>Level of Arousal</i>
Beta waves	14–30	Alert, eyes open
Alpha waves	8–14	Quiet waking, eyes closed
Theta waves	4–8	Drowsy, sleep stages 1 and 2
Delta waves	0.5–4	Deep sleep, stages 3 and 4

Table 2 – Табела 2

*Extended classification of EEG activity and the mental states [23]*  
*Проширена класификација на ЕЕГ активноста и ментални состојби*

<i>Brainwaves</i>	<i>Frequency (Hz)</i>	<i>States</i>
Gamma	35	association with peak performance
High Beta	22–35	high correlation with anxiety
Mid Beta	15–20	active, external attention
SMR	12–15	relaxed state, body stillness
Alpha	8–12	relaxed, passive attention
Theta	4–7	very relaxed, inwardly focused
Delta	0.5–3	sleep, deep meditation

On the other hand, the mental arousal level may characterize different mental disorders. So, underarousal (UA) is seen in depression, autism, etc., while the opposite, over-arousal (OA), is present in anxiety, alcoholism, caffeine consumption, etc. “Mixed” state (UA or OA) can be seen in ADHD, OCD, headache, etc., which allows the division these disorders into different subgroups (clusters).

### 3.2. Spectrum-weighted frequency (“brain-rate”) as an integral indicator

By definition arousal is a general, integral characteristic of the mental state. Simultaneously, it is correlated with the integral (polyrhythmic, polychromatic) EEG spectrum. The main characteristic of such a spectrum is its mean frequency weighted over the whole spectrum. We have named it brain-rate ( $f_b$ ). The corresponding formula is [24, 25]

$$f_b = \sum_i f_i P_i = \sum_i f_i \frac{V_i}{V} \quad \text{with} \quad V = \sum_i V_i$$

where the index  $i$  denotes the frequency band (for delta  $i = 1$ , for theta  $i = 2$ , etc.) and  $V_i$  is the corresponding mean amplitude of the electric potential or power. Following the standard five-band classification, one has  $f_i = 2, 6, 10, 14$  and 18 respectively.

Or, in the integral form:

$$f_b = \frac{1}{V} \int f V(f) df \quad V = \int V(f) df$$

One interesting application of this formula is the direct discerning of inner arousal in different mental disorders [25]. Namely, the level of this kind of arousal is directly proportional to the increase of brain-rate from the EO to the EC condition (Table 3).

Table 3 – Табеала 3

*Brain-rate as an indicator of inner arousal*  
*Мозочна брзина како индикатор за внатрешна возбуда*

<i>Disorder</i>	<i>Number of patients</i>	<i>Mean age (years)</i>	<i>EO</i>	<i>EC</i>
Anxiety (adults)	2	45	8.56	10.54
PTSD	1	12	6.27	7.54
OCD	6	14.5	6.82	7.52
Panic attacks	4	13.5	7.58	8.21
Anxiety (children)	8	14.6	7.57	8.19
Stuttering	1	11	8.27	8.50
Autism	5	3.5	5.68	5.86
Tics	3	12.5	8.48	8.47
ADHD	50	8.1	7.86	7.60
Nightmares	2	7.5	8.48	8.13

The patients above the dotted line manifest inner arousal.

Another recent example is the use of the EEG spectrum weighted frequency as a simple indicator of sleep quality [26].

Concerning the application in neurotherapy it should be remembered that the conventional neurofeedback protocols in fact use modulation of discrete frequency bands, assuming these to be associated with frequency-specific mental arousal states. Practically, all neurofeedback interventions can be roughly reduced to the need of mastering flexibility in increasing or decreasing the general mental activation, i.e. mental arousal (which is somehow coupled with metabolic activity). Therefore, the introduced brain-rate  $f_b$  could be employed as a complementary biofeedback parameter, characterizing the whole EEG spectrum (as distinct from e.g. theta/beta ratio). The rationale is that, according to the mentioned empirical results, the EEG frequency shifts are related to mental activation/deactivation, as the main objective of the treatment.

In the light of this approach, some examples from our clinical practice concerning the relevance of neuronal oscillations in paediatric patients will be presented and discussed.

#### 4. Some typical disorders

##### 4.1. Attention Deficit Hyperactivity Disorder

ADHD is one of the most frequent diagnoses during childhood, varying between 2% and 10% depending on country or cultural area, as well as diagnostic criteria or perception. In our country, the incidence of ADHD is about 2%. [27, 28, 29, 30]

The diagnosis of ADHD in our patients ( $N = 50$ , mean age  $8.08 \pm 2.54$  years) was made by diagnostic ICD-10 criteria. We used Conner's rating scales for parents and teachers as well as WICS-R for assessing the cognitive ability. In addition, neurofeedback assessment (eyes open, 30-minute recording) was made with Biograph/Procomp. Version 2.1 in Cz (10/20 international placement). The QEEG for 20 patients (mean age  $10.5 \pm 2.35$ ) was obtained by 21 standard MITSAR EEG recordings with the administration of standardized tests: eyes open, eyes closed, visual continuous performance, auditory continuous performance, reading test and maths test.

Our spectrogram analysis is based on five QEEG subtypes of ADHD. [31] The obtained QEEG showed very slow alpha excess (subtype 5) in 45% of children, high beta activity in the frontal, central or parietal cortex (subtype 2) in 25% of children, while the other 30% children appeared to belong to the first subtype (increased theta amplitude in the frontocentral cortex). One characteristic picture of QEEG (subtype 5) is shown in Fig. 1.

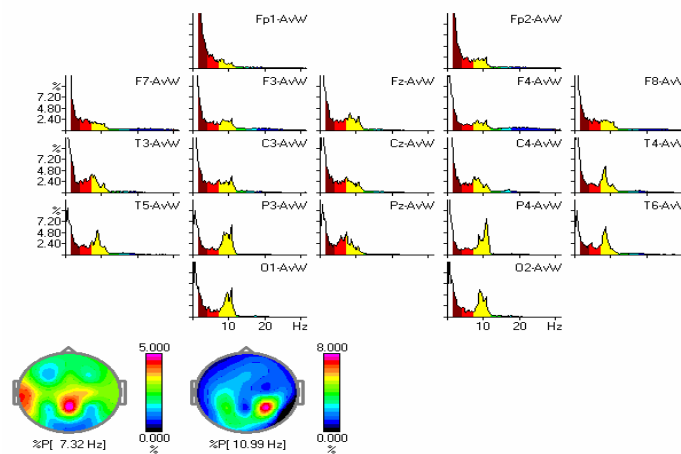


Figure 1 – QEEG subtype 5 for ADHD patient

Слика 1 – QEEG субтип 5 кај ADHD пациент

We followed two neurofeedback treatment protocols. First, training to increase the SMR EEG rhythm (11–13 Hz) and, at the same time, to inhibit

slow activity in the theta range (4–8 Hz); this approach is primarily used for the hyperactive component of ADHD. After that, training to focus attention is performed, aiming at increasing higher beta activity (16–20 Hz); at the same time, training for decreasing the slow activity continued. The training comprised 40 sessions of 60 minutes' duration, one per week.

Table 4 shows the decrease of the amplitude of theta waves, the increase of the amplitude of beta waves, as well as the changes of theta/beta ratio obtained with NF training. In addition, changes in brain-rate as a spectrum shift indicator are displayed.

Table 4 – Табела 4

*Changes of biofeedback parameters before and after training  
Промена на биофидбек параметрите пред и по тренинг*

<i>Parameter</i>	<i>Before NF (<math>\mu V</math>)</i>	<i>After NF (<math>\mu V</math>)</i>	<i>t-test</i>	<i>Significance</i>
Beta brain waves	4.86 $\pm$ 1.6	8.0 $\pm$ 1.38	5.23	P < 0.01
Theta brain waves	20.95 $\pm$ 1.38	15.29 $\pm$ 1.38	8.47	P < 0.01
Theta/beta ratio	4.7 $\pm$ 1.38	2.0 $\pm$ 1.6	4.5	P < 0.01
Brain-rate	7.86 $\pm$ 0.56	8.22 $\pm$ 0.63	6.6	P < 0.01

All children from the sample were tested for intellectual capacities with WISC-R before and after treatment. The finding is shown in Table 5.

Table 5 – Табела 5

*Results obtained for WISC-R  
Резултат од WISC-R*

	<i>Global IQ</i>	<i>Verbal IQ</i>	<i>Manipulative IQ</i>
Pre-treatment	80 $\pm$ 18.3	90 $\pm$ 15.5	73 $\pm$ 18.9
Post-treatment	85 $\pm$ 15.2	100 $\pm$ 12.3	80 $\pm$ 7.2
t-test	1.05 p > 0.05	2.53 p < 0.05	1.73 p > 0.05

Conner's rating scales for children checked by mothers and teachers before treatment amounted 87  $\pm$  2.3 (mean scores), which confirmed attention deficit, impulsivity, social inadaptability and hyperactivity. This figure decreased after the treatment by about 30%.

The changes in the EEG pattern (Table 4) obtained as a result of the training are obvious. In comparison to the considerable change in the theta/beta ratio, the improvement indicated by the brain-rate appeared to be more realistic. It is clear (from Table 5) that verbal and manipulative intelligence scores became higher after NF training and this corresponded to the improvement of school

marks by 10–20 percent. Interview and follow-up Conner's rating scales showed better school performance, lower hyperactivity, better social relationships and improved self-esteem after neurofeedback treatment. In our country stimulant medications for ADHD are not allowed.

Along with QEEG characteristics, for a successful neurotherapy of ADHD children some nutritional, toxic or allergic factors must be taken into account. This multidisciplinary approach at the Crossroad Institute Centre in USA showed a correlation of high delta, or theta or alpha ADD with food allergies, of high beta ADD with both allergies and heavy metals toxicity, as well as of high beta anxiety symptoms with problems in food absorption and the influence of certain chemicals [31]. Some our results related to the toxicity of lead emission and ADHD symptoms are discussed in chapter 6.4.

#### 4.2. Obsessive Compulsive Disorder

Obsessive compulsive disorder (OCD) is related to both cognitive and motor behaviour. Usually, compulsive acts try to neutralize the anxiety connected with obsession thoughts.

Here, we present some of our results for six adolescents with OCD, mean age  $15.17 \pm 2.96$ , five boys, and one girl. The patients were previously treated without success by medication based on inhibitors of selective serotonin reuptake (ISSR).

Psychometric tests (Actual Anxiety Questionnaire, MMPI) showed high scores for anxiety.

The main characteristic of the QEEG spectrum (Fig. 2) is the overactivated frontal cortex (beta range). It is interesting to mention that our results (characterised by beta excess) differ from results shown in Prichep *et al.* [33] which imply two main subtypes of OCD (excess of theta and excess of alpha). The mean brainrate values in Cz were in EO 6.82, while in EC 7.52, indicating inner arousal.

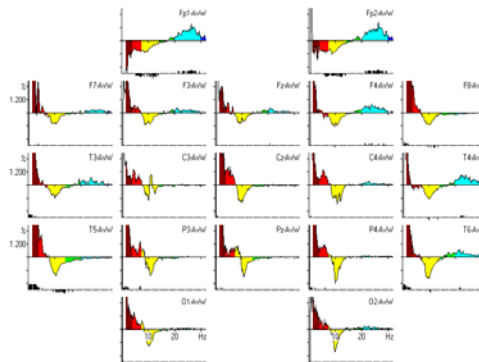


Figure 2 – QEEG spectra (EO) of patient with OCD compared with database  
Слика 2 – QEEG спектри (EO) кај пациент со OCD споредено со базаза

### 4.3. Severe dehydration in infancy

In the standard assessment of long-term consequences of dehydration in children, only clinical follow-up is usually considered. For a deeper insight, the neuronal functioning, including arousal effects, should be investigated. With this aim, we examined 40 children, aged  $8.82 \pm 1.33$  years, with a history of severe dehydration in early infancy caused by diarrhoea. The data from the structured interview, clinical history, as well as pediatric, neuropsychological and EEG examinations were analysed. [34]

The neuropsychological evaluation consisted of Koch's Block-Design Test, Gestalt-Bender Motor Test and Rey's Test. The results showed the persistence of certain neurological disabilities, lower intellectual capacity, slower visual-motor maturation and certain emotional problems, compared with the control group.

As an indicator of prefrontal functioning, the results of Contingent Negative Variability (CNV) showed a decreased amplitude of the expectrogramme as well as delayed reaction time ( $p < 0.05$ ) in comparison with the control group of healthy children of the same age.

Table 6 – Табела 6

*Results for CNV paradigm*  
*Резултати од CNV парадигма*

	<i>Examined group</i>	<i>Control group</i>
EXP cycles	0.6	3.5
Max. CNV amplitude	8.9 $\mu$ V	13.8 $\mu$ V
Min. Reaction time	303 msec.	245 msec.

## 5. Effects of environmental exposures

### 5.1. Exposure to lead emission

The psychophysiological functions in children exposed to lead emission in a highly polluted part of the Macedonian city of Veles were investigated. [35, 36, 37] Measurement of blood lead levels, multimodal assessment with Thought Technology Ltd. equipment (EEG, EMG, BVP, Skin Conductance, Temperature and Respiration), cognitive psychological tests (Raven matrices) and investigation of graphomotor ability (Bender-Gestalt) on randomly selected children (mean age =  $13.62 \pm 0.6$ ) living near a smelting plant were performed.

The results showed increased lead levels in the tested children (mean blood lead level =  $16.51 \mu\text{g/dl}$ ; norm  $< 10 \mu\text{g/dl}$ ), reflected correspondingly in the values of intelligence scores and grapho-motor ability. Simultaneously, the obtained theta/beta ratios in Cz correspond to increased attention deficit.

The correlations between blood lead level, IQ scores, theta/beta ratio and brain-rate are shown in Figs. 3, 4 and 5.

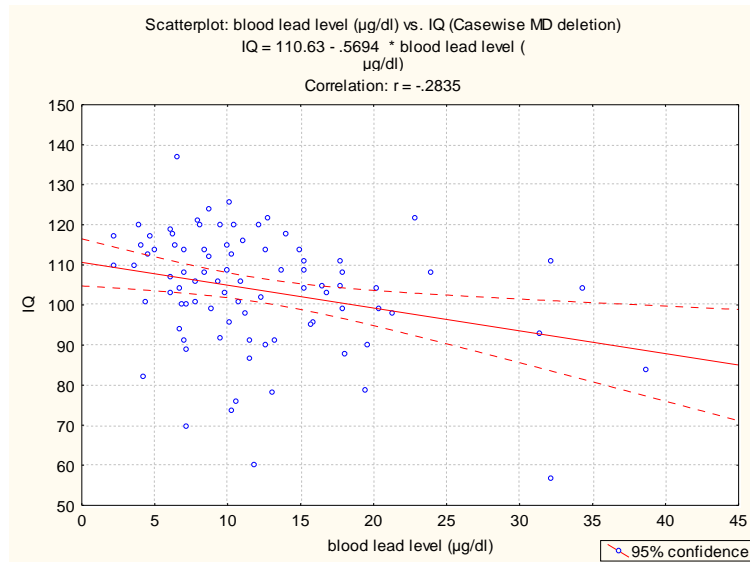


Figure 3 – Correlation of IQ with blood lead level  
 Слика 3 – Корелација на IQ со нивото на олово во крвта

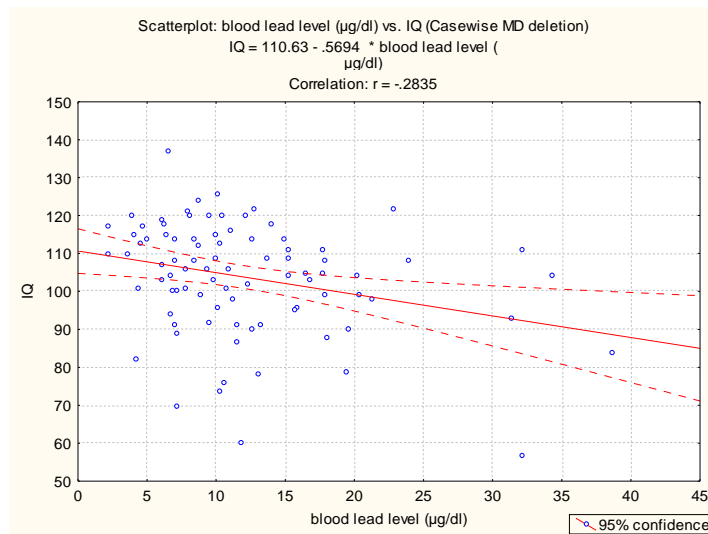


Figure 4 – Correlation of blood lead level with theta/beta ratio  
 Слика 4 – Корелација на нивото на олово во крв со тета/бета односот

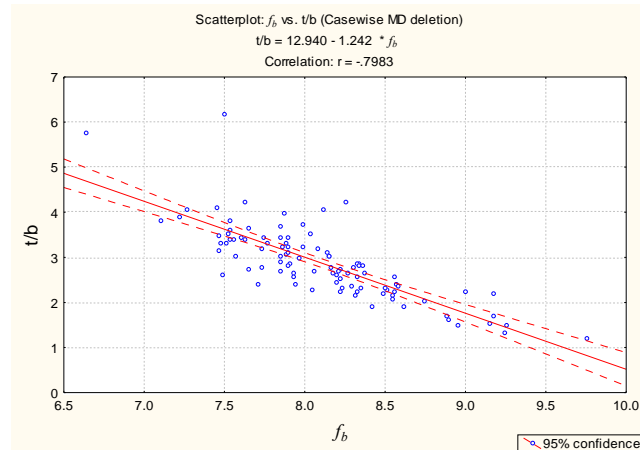


Figure 5 – Correlation of theta/beta ratio with  $f_b$   
 Слика 5 – Корелација на тета/бета односот со  $f_b$

Negative correlations between blood lead level (due to industrial pollution) and IQ (Fig. 3) and attentiveness (Fig. 4) were found in the tested children. Simultaneously, the negative correlation between theta/beta and  $f_b$  was confirmed (Fig. 5).

The publication and media dissemination of our results contributed to the recent governmental decision to close the polluting smelting plant in Veles.

### 5.2. Exposure to electromagnetic fields

We are living in an "all-electric" society, with an exponentially increasing invasion of electromagnetic waves. The corresponding electromagnetic spectrum, including natural and man-made phenomena, is shown in Fig. 6.

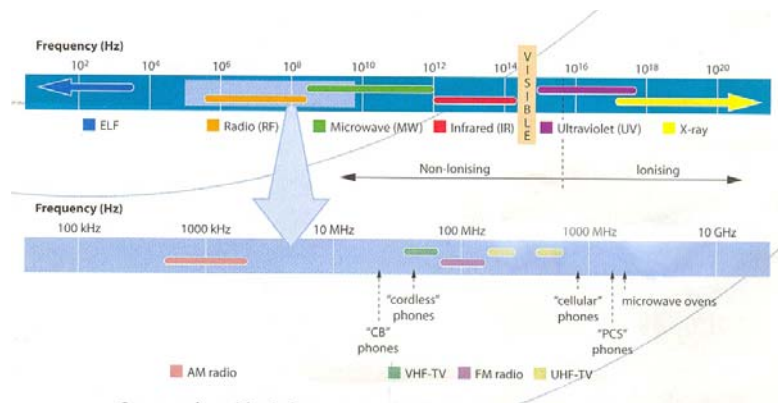


Figure 6 – The electromagnetic spectrum  
 Слика 6 – Електромагнетниот спектар

The health effects of the ionizing part of the spectrum are very well known, which is not the case with non-ionizing radiation: microwave (MW), radio (RF) and extremely low frequencies (ELF).

Recently, some indications of the somatic health effects of non-ionizing radiation have been published. An Oxford University team found a 70% increased risk of leukaemia in children living less than 200 metres from high-voltage lines. Also, a Karolinska Institute team (Stockholm) disclosed a doubling of the risk of acoustic neurinoma (benign tumour of the nerve) among intensive users of mobile phones "for at least ten years duration" [38, 39].

Concerning the possible effects of electromagnetic (EM) radiation on neuronal oscillations, the prevailing official position is that there is no general risk due to non-ionizing radiation. This includes mobile phones as well, arguing that the RF involved (in the range of MHz to GHz) is very much above the EEG frequencies (1–100 Hz).

However, it should be noted that recently some low-frequency components have been identified within the RF mobile communication signals (Table 7).

Table 7 – Табела 7

*Low-frequency components within mobile phone signals*  
*Нискофреквентни компоненти содржани во сигналите на мобилните телефони*

<i>Mobile phone signal</i>	<i>Frequency component (Hz)</i>	<i>EEG band</i>
<b>DTX</b> (Discontinuous Transmission)	2	Delta
<b>GSM</b> (Global System for Mobile Communication)	8.3	Theta/alpha
<b>TETRA</b> (Terrestrial Trunked Radio)	0.98 17	Delta Beta
<b>DECT</b> (Digital Enhanced Cordless Telecommunication)	100	High gamma

Consequently, we assume that the exposure of the brain to these frequencies may change the arousal level (according to the correlations from Table 1) and stimulate/destimulate certain disorders (according to the correlations from chapter 3.2).

Thus, the mobile phone could act as some kind of uncontrolled (chaotic) EEG modulator, with individually specific detrimental or beneficial neuropsychological effects [40, 41]. Simultaneously, this ambivalence in outcomes could explain why the existing research results on mobile phone – EEG effects seem to be controversial and indecisive.

In any case, recent recommendations for caution and further investigations should be taken quite seriously, especially in the case of the developing

and sensitive brains of the young. Namely, European FMF-NET experts underline "the need to apply the principle of precaution – as in the excessive use of mobile phones by children, for example" [39]. Also, in the 2006 WHO Research Agenda for Radio Frequency Fields it is stated: "If ethical approval can be obtained, acute effects on cognition and EEGs should also be investigated in children exposed to RF fields in the laboratory".

Some of the ideas presented in this chapter will be investigated within a recently approved EU FP6 project "SAVE EMF" (2007–2010) entitled "Upgrading the research capacities for safety and health effects of human exposure to electromagnetic fields".

The project will be realised at Skopje University (L. Grcev, Faculty of Electrical Engineering and N. Pop-Jordanova, Faculty of Medicine), with partner institutions from France, Netherlands, Slovenia and Switzerland.

### 6. Conclusion

Clinical work differs from pure scientific research based on precisely designed experiments and control studies. The main duty of the clinician is to deal with the actual problem and cure the illness. The investigation tools must be directed to problem solving, including the answers related to diagnostics of the illness based on clinical evaluation, laboratory tests and imaging techniques, as well as the selection of the most efficient therapy.

Paediatric patients are distinguished from others by a continuous developmental process and specific characteristics of each period of childhood. The difference between normal and abnormal is often vague.

The assessment of a child with some mental/behavioral problems needs both psychometrics and neurometrics, whereby QEEG cannot be a substitute for conventional EEG, and even less for clinical competence. The therapy must be multidimensional, implying psychotherapy, pharmacotherapy and neurotherapy (some biofeedback modalities). Support from parents and teachers is essential.

In both diagnostics and therapy, an individual integral approach is important, including the correlation with the arousal states and the corresponding spectrum-weighted frequencies.

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#### Резиме

### ЕЕГ СПЕКТАР ВО ПЕДИЈАТРИСКИТЕ ИСТРАЖУВАЊА И ПРАКТИКА

**Поп-Јорданова Нада**

*Педијатриска клиника, Медицински факултет,  
Универзитет Св. Кирил и Методиј, Скопје, Р. Македонија*

По еден кус вовед за развојните карактеристики, интегралноста и комплексната структура на ЕЕГ спектарот, во овој труд се изнесени некои оригинални искуства околу дијагнозата и третманот на битните ритмички абнормалности кај децата и адолесцентите. Особено се разгледани резултати што се однесуваат на АДХД, ОЦД и дехидрациите. Како додаток, даден е осврт на околински индуцираните ефекти врз невронските осцилации провоцирани од полуцијата со олово и електромагнетната радијација.

**Клучни зборови:** невронски осцилации, деца, неурофидбек, АДХД, ОЦД, дехидрација, полуција со олово, електромагнетна радијација

#### Corresponding Author:

**Pop-Jordanova Nada**  
Pediatric Clinic, Medical Faculty,  
Ss Cyril and Methodius University,  
1000 Skopje, R. Macedonia

**E-mail:** npopjordanova@yahoo.com.mk