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RESTING-STATE EEG SPECTRAL POWER IN CHILDREN WITH EXPERIENCE OF EARLY DEPRIVATION

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Children left without parental care and placed in institutional settings represent a particularly vulnerable group. In the absence of sufficient social interaction, children with experience of early deprivation demonstrate neural, social, and emotional deficits. In the present study, we use electroencephalographic (EEG) techniques to examine the functioning of the central nervous system in a sample of children living in institutions in a large city in Russia. The study involved 11 children with experience of institutional care and 11 matched children from biological families. Participants with experience of early deprivation demonstrated a decrease of spectral power in the theta and alpha bands compared to the comparison group. The decrease of spectral power in the delta, theta and alpha bands, which are closely related to cognitive and emotional processes, may reflect brain developmental patterns associated with early deprivation.

Keywords: early deprivation, institutionalization, cognitive development, EEG, spectral power.

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ИЗМЕНЕНИЕ СПЕКТРАЛЬНОЙ МОЩНОСТИ ЭЭГ В СОСТОЯНИИ ПОКОЯ У ДЕТЕЙ, ПРОЖИВАЮЩИХ В ДОМАХ РЕБЕНКА

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В последние десятилетия было проведено значительное количество исследований, показавших, что опыт институционализации и ранней психосоциальной депривации оказывает негативное влияние на развитие человека. Важным аспектом оценки развития является исследование функционального состояния головного мозга в состоянии покоя. Целью данной работы является выявление изменений распределения спектральной мощности ЭЭГ в состоянии покоя у детей раннего возраста, проживающих в домах ребенка, по сравнению со сверстниками, проживающими в биологических семьях. Регистрация ЭЭГ проводилась при помощи 64 активных электродов. Во время записи испытуемым демонстрировался трехминутный видеофрагмент на мониторе компьютера. В исследовании приняли участие 11 детей из домов ребенка в возрасте от 17 до 43 месяцев и 11 детей из биологических семей в возрасте от 19 до 47 месяцев. Результаты свидетельствуют, что дети из домов ребенка демонстрируют снижение спектральной мощности ЭЭГ в θ-, α- и δ-диапазонах по сравнению с детьми из биологических семей.

Ключевые слова: ранняя депривация, институционализация, когнитивное развитие, ЭЭГ, спектральный анализ.

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Developmental characteristics of children with a history of institutionalization are being actively investigated. In particular, the questions that are being asked are related to differences in the cognitive development of children with a history of institutionalization [5, 15]. It is assumed that such differences can result from atypically functioning neural circuits shaped by suboptimal care settings in early child development in the context of parental deprivation among children residing in special institutions. The impact of the suboptimal care environment on the development and functioning of neural circuits can be studied using noninvasive neuroimaging methods such as the power spectrum analysis of resting-state EEG. The goal of this paper is to identify the features of the EEG spectrum of young children (under 4 years of age) living in baby homes compared to the children raised in their biological families.

Two orphanages in St. Petersburg were selected for participation in the current research study. The group of children with a history of institutionalization consisted of 11 children aged from 17 to 43-month-olds (6 boys and 5 girls, average age 29 ± 9.46 months) raised in baby homes. Conditions in baby homes can be characterized by social and psychological deprivation due to the limited number of social-emotional interactions and the lack of a stable attachment figure. The comparison group was comprised of 11 children raised in biological families, 19 to 47-month-olds (5 boys and 6 girls, average age 32.36 ± 9.81 months). The comparison group was formed on the basis of the child's medical history, complete medical examination of the child at the time of the study, and data from the karyotypic analysis of the genome using the method of G-differential chromosome staining. Only typically developing children, without any significant developmental disorders or genetic syndromes and systemic diseases, were included in the study. The exclusion criteria were the following: mother's complications during the pregnancy and at birth, maternal alcohol abuse and smoking during pregnancy, intrauterine growth restriction, congenital fetal anomalies and CNS abnormalities that are common for the population of children placed in institutions (e.g., encephalopathy, perinatal injury of CNS, cerebral ischemia), and physical and psychological postnatal developmental delay.

Due to the small sample size, we used the Wilcoxon signed-rank test. For detection and correction of the Type I error in multiple comparisons, Benjamini-Hochberg Procedure was used [1]. Groups were matched on sex (χ^2 (1) = 0.18, p = 0.66) and age (W = 49.5, p = 0.42) (statistical analysis was performed in RStudio 1.1.456).

EEG was recorded for 3 minutes at rest. During the recording of EEG, the child watched two muted video clips of slowly moving bubbles on the computer screen. Recording sessions were conducted in the daytime, during waking hours of children. During the recording, the child sat in caregiver's the lap/ The caregivers were instructed to control the attention of a child with a pointing gesture if the child was distracted. All the instances where the child was distracted were recorded by the experimenter in a study journal and, afterwards, were excluded from the study. The research protocol was approved by the Ethics Committee of St. Petersburg University.

EEG recording was conducted using the actiCHamp (Brain Products GmbH), 64-ch EEG system in combination with PyCorder (Brain Products GmbH), as a programming software. For data preprocessing we used BrainVision Analyzer v. 2.1 software (Brain Products GmbH). Active Ag/AgCl electrodes were mounted on an elastic cap according to the 10—10 montage. Reference electrodes were placed on mastoids. The ground electrode was placed in the Fpz position. The recording was done at the sampling rate of 1000 Hz; the impedance was held below 25 kΩ. During the preprocessing, the channels that contained an excessive number of artifacts were deleted; the deleted channels were then reconstructed with spherical interpolation. After deleting the channels, the signal was re-referenced to the common average reference. Then, an IIR band-pass filter was applied at 0.1 (date time constant — 1.59) and 70 Hz. The recording was then segmented into epochs of 3000 milliseconds without overlap; the segments were tested for the presence of artifacts. Elimination of the artifacts (cardio and muscle artifacts, GSR, eye-movements, etc.) was done in semi-automatic mode: the segments that contained artifacts were automatically marked with the help of the set search algorithm; further, during the visual inspection of each individual segment, the segments were either included into analysis or deleted. The presence of at least 10 artifact free segments (30 seconds of the recording) served as the inclusion criterion for the sample.

Spectral analysis was conducted with the fast Fourier transform (FFT) method (definition 0.244 Hz) alongside the Hann window in the frequency domains that are usually used in pediatric populations [10]: delta (1—4 Hz), theta (4—6 Hz), alpha (6—9 Hz), and beta (10—30 Hz).

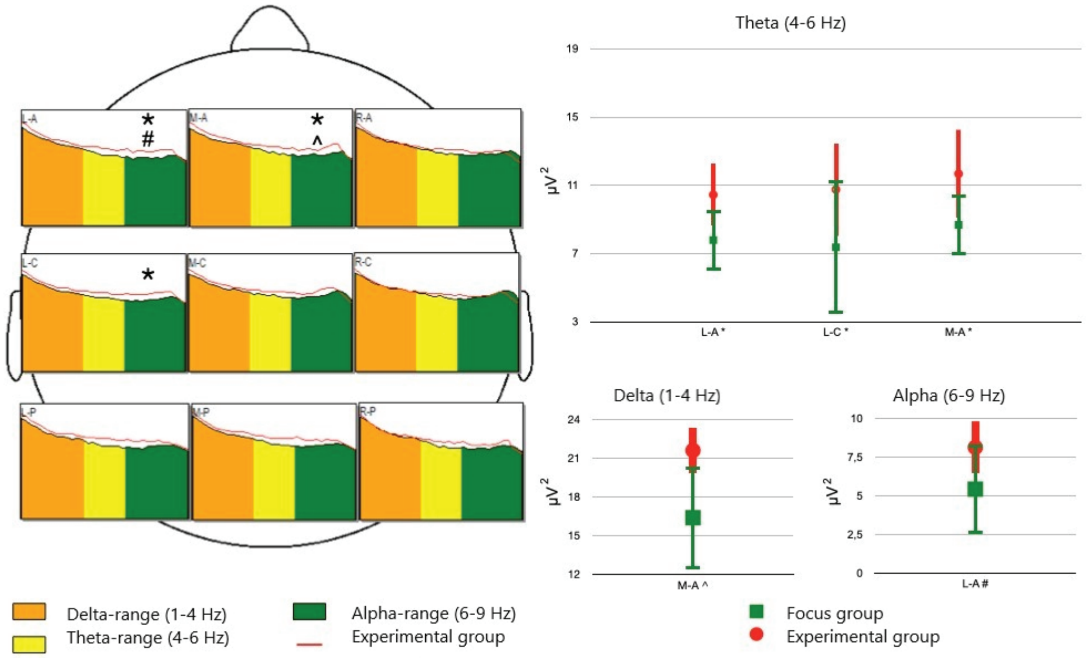
During the comparative data analysis, the electrodes were divided into 9 clusters. Electrodes placed near the participants' eyes (Fp1, Fp2, FT9 and FT10) were not included in the analysis. The L-A cluster included the electrodes AF7, AF3, F7, F5, F3; L-C cluster: FT7, FC5, FC3, T7, C5, C3, TP7, CP5, CP3; L-P: P7, P5, P3, PO7; M-F: AFz, F1, Fz, F2; M-C cluster: FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2; M-P cluster: P1, Pz, P2, PO3, POz, PO4, O1, Oz, O2; R-A cluster: AF8, AF4, F8, F6, F4; R-C cluster: FT8, FC6, FC4, T8, C6, C4, TP8, CP6, CP4; R-P cluster: P8, P6, P4, PO8. Statistical analysis showed the following significant group differences.

First, the largest number of group differences was observed in the theta (θ)-band (Fig. 1). The children with a history of institutionalization demonstrated a decrease in the θ-power spectrum in the left hemisphere and central clusters compared to the children raised in biological families. Significant differences were observed for the left frontal lobe (L-A: $W = 88$, $p = 0.047$, *p*-value was adjusted according to the Benjamini and Hochberg method), left central lobe (L-C: $W = 101$, $p = 0.047$) and middle frontal lobe (M-A: $W = 101$, $p = 0.047$). In the right hemisphere clusters, there were no significant group differences in the θ-band.

The group of children with a history of institutionalization also showed significant decrease in the power spectrum in the alpha (α)-band in the left frontal electrode cluster (L-A: $W = 86$, $p = 0.047$). In the delta (δ)-band the power spectrum in the middle frontal cluster of electrodes was also significantly lower (M-A: $W = 70$, $p = 0.047$). We did not find any statistically significant differences in the beta (β)-band.

In the current study, we detected the differences in the patterns of brain activity of children living in baby homes compared to the children raised in their biological families. A decrease in the power spectrum in the θ-band in children living in baby homes was detected. Previous research in humans and animals showed that θ oscillations could be related to fundamental brain processes such as information processing and neuroplasticity [6]. It was also proposed that there is a connection between θ-activity and the sensory gating mechanisms that are responsible for the selection of task-relevant stimuli and filtering of interfering information [12].

From the literature, it is known that low-frequency EEG oscillations are dominant in the early period of child development and can be related to the development of



Picture 1. EEG power distribution in the studied electrode clusters. On the left, in logarithmic form, the abscissa shows the frequency (1-9 Hz), the ordinate shows the spectral power (μV2). The color code indicates the distribution of spectral power in the target group of children with a history of institutionalization, the red line — in the comparison group; * — statistically significant differences in the θ-range, # — significant differences in the α-range, ^ — significant differences in the δ-range. On the right are the averaged values of the spectral power in the clusters of electrodes, the error bars are 95% confidence intervals

emotional and/or cognitive processes [9]. States connected with positive or negative emotions are accompanied by the increase in θ-range [7]. Moreover, data demonstrate that social stimulation and exploration of new objects by children is accompanied by the presence of θ-rhythm [11]. Furthermore, according to the literature, there is a correlation between the θ-activity and the processes of joint attention [3], and between power in the α-range (6-9 Hz) and behavior focused on social interaction [4].

The results obtained during the current study are in line with the results of the Bucharest Early Intervention Project, BEIP [12], on studying the development of children that were exposed to the global deprivation in Romanian institutions for orphaned children. In particular, the BEIP study showed the decrease of the high-frequency α-rhythm in frontal and temporal lobes of the cortex in children raised in the institutions in comparison with the children from biological families [8].

It is known that the development of cortical structures is connected to the shift of spectral EEG power from low to the high-frequency power bands of EEG [2], with gradual augmentation of the occipital α-rhythm, which is the marker of a more mature brain organization. Typically, from the age of two or three, α-activity in children can be present in all areas, but its intensity is lower in the frontal parts of the cerebral cortex. A number of studies show that the lack of power in the α-band is connected with abnormalities in the development and immaturity of cortical structures. The demonstrated lower spectral power of the α-rhythm in the left frontal and left central clusters in children from baby homes (compared to the control group) can be associated with the significant slowing of the processes of morphofunctional maturation and the development of the above-mentioned cortical regions, related to the negative effects of the depriving environment of institutions.

Moreover, we found that the decrease in the spectral power in the δ-band was only detected in the middle frontal electrode cluster (M-A). Meanwhile, the given result can be defined, firstly, by the limited sample size and, secondly, by the location of the electrodes in the given cluster where the impact of eye-movement artifacts in EEG recording is apparent.

Suboptimal care settings can lead to the abnormalities of morphofunctional maturation such as later differentiation of neuronal cells and myelination of brain pathways [14], [15] that can be seen on a functional level and atypical patterns of power spectrum distribution of EEG.

The results of the current research allow us to assume that morphofunctional transformations that are happening in the crucial periods of CNS maturation (early childhood) are sensitive to the negative impacts of psychosocial deprivation. Therefore, it can negatively affect the developing brain systems and their functional activity, particularly concerning characteristics of different rhythms of EEG.

Our comparative study of spectral characteristics of EEG in a group of children residing in baby homes and a group of children living in their biological families demonstrated several differences in the distribution of the power spectrum of EEG. Thus, children raised in psycho-socially depriving conditions showed decreased power in the θ and α-bands compared to the control group. However, described differences in power in the δ-band in children residing in baby homes need further examination. The observed decrease in power in the given bands associated with cognitive and emotional processes in early childhood can be a marker of abnormal brain development under suboptimal conditions during early child development.

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