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Electroencephalogram synchronization analysis for attention deficit hyperactivity disorder children

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Abstract. This study investigated the changes in synchronization of different electroencephalogram (EEG) bands in attention deficit hyperactivity disorder (ADHD) children. EEG data were obtained from 13 children diagnosed with ADHD and 13 normal control children in the resting state. The statistical dependencies between each EEG channel were generated by calculating synchronization likelihood. The differences of synchronization between the ADHD and control groups were statistically evaluated. Overall, the synchronization was significantly higher in the ADHD group in the alpha and beta bands. The present study found that synchronization was significantly altered in the fast EEG bands in patients with ADHD. These findings may enhance our understanding for the relationship between ADHD and cerebral dysfunction.

Keywords: ADHD, EEG, synchronization likelihood

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is one of the most commonly diagnosed childhood behavioral disorders. Children who are diagnosed with ADHD are generally inattentive, impulsive, and hyperactive [1]. It is estimated that about 5–8% of children suffer from ADHD worldwide. ADHD is one of the most common childhood neurobehavioral disorders, and the condition frequently persists into adolescence and adulthood [2].

Electroencephalogram (EEG) is a noninvasive neuroimaging technology that is particularly well suited to pediatric subject groups. Moreover, the high temporal resolution of EEG makes this technique more suitable for examining the synchronization of neuronal activity, in comparison with other imaging methods. Previous studies have found EEG abnormalities in ADHD patients [3, 4]. However, many studies are based on individual-channel EEG analysis.

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Since the multichannel index can integrate the activity of specialized regions into a meaningful whole, it is more useful in reflecting brain functions [5]. Recently, more and more methods have been used to analyze multichannel EEGs to study brain activity, such as global synchronization index (GSI) [6], global dimensional complexity (GDC) [7] and synchronization likelihood (SL) [5]. Synchronization likelihood is suitable for both linear and non-linear systems and can be used to calculate the high temporal resolution and non-stationary time signals. In recent studies, SL has been used to investigate some brain diseases, such as Alzheimer's disease [5, 8] and epilepsy [9].

The aim of the present study is to compare the global functional synchronized brain states by using SL in four EEG frequency bands collected from ADHD and normal control children during the resting state. The differences between the two groups are statistically evaluated.

2. Material and Methods

2.1. Subjects

The study comprised 13 outpatient boys diagnosed with ADHD (age range, 6–13 years; 8.5 ± 3.17 years; right-handed) and 13 age- and gender-matched normal control children (age range, 6–13 years; 7.9 ± 1.98 years; right-handed). The written informed consents were obtained from all parents of the participants, according to the Declaration of Helsinki. The study was approved by the ethics committees of the Xi'an Jiaotong University School of Medicine. All participants had full-scale and verbal IQ scores above 80 (WISC-IV). All participants' parents filled out translated versions of the Conners' Parents ADHD Rating Scales-Revised (CPRS-R) [10] and the DSM-IV ADHD rating scale for current and children ADHD symptoms [11]. An experienced child psychiatrist and health care psychologist made the diagnosis of childhood-onset and current ADHD combined subtype or inattention subtype. The criteria for ADHD included (1) the endorsement of at least 6 of 9 DSM-IV symptoms of inattention and 6 of 9 DSM-IV symptoms of hyperactivity/impulsivity; (2) no history of using stimulant medication, severe brain injury and other neuropsychiatric disorders; (3) no evidence of cognitive deficit, learning disability and communication problems as determined through clinical history and parents' interview. Normal controls were excluded, if they were diagnosed with ADHD and they had the history of using stimulant medication, severe brain injury, other neuropsychiatric disorders, cognitive deficit, learning disability and communication problems.

2.2. EEG recordings

EEGs were recorded from 19 electrodes at the following scalp locations of the 10-20 system: FP1, FP2, F3, F4, F7, F8, Fz, T3, T4, T7, T8, C3, C4, Cz, P3, P4, Pz, O1, and O2. Electrode impedance was below 5 kΩ. The reference electrode was placed at the left mastoid and the ground electrode was placed between FPz and Fz. Vertical electrooculogram (VEOG) was recorded from electrodes attached above and below the left eye, and horizontal electrooculogram (HEOG) was recorded from the outer canthi of both eyes. EEG was sampled with 32 bits of accuracy and the A/D sampling rate was 1000 Hz. All participants were seated inside an acoustically and electromagnetically shielded room. Participants were asked to minimize all movement during the experiments. EOG was used to correct the EEG for eye movement artifacts with procedures of Gratton. The zero phase shift band-pass analog filter was set at 0.5–30 Hz. EEG data were manually edited to remove with incompletely corrected ocular and muscular artifacts. 30 s (30,000 samples) of artifact-free data were selected off-line from each subject. Wavelet packet analysis [12] was performed on each EEG data segment. Daubechies of order 4 was adopted as the mother wavelet, and after eight-octave wavelet packet decomposition, the EEG components of the following four frequency bands was obtained: delta (0.5–3 Hz), theta (4–7 Hz), alpha (8–13 Hz) and beta (14–30 Hz).

2.3. Computing SL

SL was based on the concept of general synchronization [13] between two time series, which took account of both linear and nonlinear synchronization. The time series were reconstructed in a state space according to Taken's theorem by determining two characteristics: the time lag (L) and embedding dimension (M). The co-occurrence of neighboring states (similar patterns) was then quantified, which considered the degree of similarity between the states. The SL ranged between *Pref* (a small number close to 0) and 1, with low SL indicating no synchronization and high SL representative of total synchronization. W_1 and W_2 were windowing parameters, where W_1 was the Theiler correction for autocorrelation and W_2 improved time resolution of synchronization measurement. Time lag (L), embedding dimension (M), *Pref*, W_1 and W_2 were parameters that had to be set; in the present study, $L = 1$, $M = 10$, $Pref = 0.01$, $W_1 = 100$ and $W_2 = 400$.

2.4. Statistical analysis

The Statistical Product and Service Solutions (SPSS, version 13.0; SPSS, Inc., USA) was used for all statistical analyses. The Shapiro-Wilk test was used for testing normal distribution. Statistical significance of SL between the ADHD and control groups was determined by independent samples t-test for each EEG frequency band. A value of $P < 0.05$ was considered to be statistically significant.

3. Results

The results of mean SL of the ADHD and normal control groups in the four EEG bands of interest are shown in Fig. 1. Compared with the normal controls, the ADHD group showed significantly higher SL values in alpha and beta bands ($P < 0.05$). There were no significant differences between the two groups for synchronization in the delta and theta EEG bands.

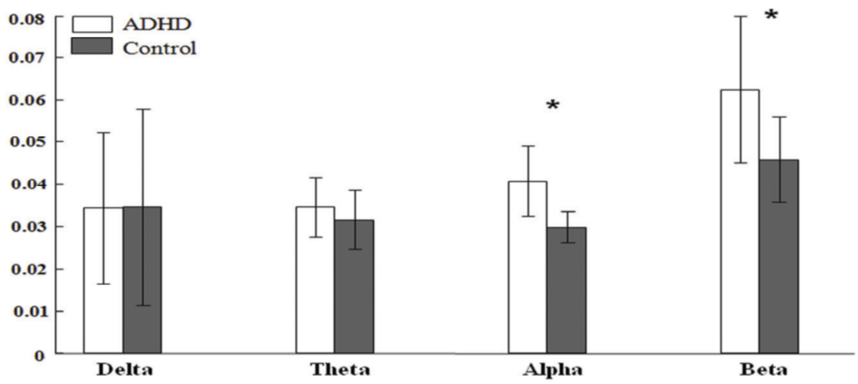

Figure 1. SL values of the ADHD and normal children in each EEG band during the resting state. The asterisks indicate significant differences between the two groups (P < 0.05).

4. Discussion

EEG synchronization is considered to be the performance of brain function region integration. Recently, more and more studies have analyzed brain synchronization activity in ADHD patients. Dockstader [14] had found that the altered patterns of alpha and beta synchronies were associated with ADHD condition using event-related magnetoencephalography (MEG). The research results of Kropotov [15] showed that compared with the pre-training, event-related synchronization of ADHD subjects in alpha frequency band measured at central areas decreased after the whole set of sessions of neurofeedback training. All of them demonstrated ADHD patients had abnormal EEG synchronization in alpha and/or beta bands.

This study investigated the synchronization of different EEG bands during the resting state for both the ADHD and control groups. The SL estimates the dynamical interdependencies between two simultaneously recorded EEG signals and indicates the degree of synchronization between functional processes spatially distributed over different brain regions. In the present study, compared with the control group, the ADHD subjects had significantly higher SL values during the resting state in the alpha and beta bands, which is consistent with previous observations. This result may indicate an excessive increase in cooperation (or synchronization) among different parts of the nervous system and an excessively increased number of dependent neural assemblies in ADHD patients during the resting state in alpha and beta bands.

This study aims to determine the change of brain synchronization status by using EEG signals under the resting state in the ADHD and normal control children. The results suggest that the synchronization is altered in the alpha and beta bands in patients with ADHD. This finding, which is consistent with previous ADHD studies, provides further understanding for the relationship between ADHD and cerebral dysfunction.

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