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The ADHD effect on the actions obtained from the EEG signals

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ABSTRACT

Attention-deficit/hyperactivity disorder (ADHD) is an important challenge in studies of children's ethology that unbalances the opposite behaviors for creating inattention along with or without hyperactivity. Nevertheless, most studies on the ADHD children, which employed the EEG signals for analyzing the ADHD influence on the brain activities, considered the EEG signals as a random or chaotic process without considering the role of these opposites in the brain activities. In this study, we considered the EEG signals as a biotic process according to these opposites and examined the ADHD effect on the brain activity by defining the dual sets of transitions between states in the complement plots of quantized EEG segments. The results of this study generally indicated that the complement plots of quantized EEG signal have a surprising regularity similar to the Mandala patterns compared to the chaotic processes. These results also indicated that the probability of occurrence of dual sets in the complement plots of ADHD children was averagely different ($p < 0.01$) from that of healthy children, so that the SVM classifier developed by these probabilities could significantly separate the ADHD from healthy children (99.37% and 98.25% for training and testing sets, respectively). Therefore, the complement plots of quantized EEG signals relevant to the ADHD children not only can quantify informational opposition caused from inattention, hyperactivity and impulsivity, but also these plots can provide remarkable information for developing new diagnostic and therapeutic techniques.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a mental disorder of the neurodevelopmental type [1], which leads to the lack of appropriate interaction with the environment [2]. Hence, the symptoms of this disorder are problems paying attention, excessive activity and difficulty controlling behavior [3,4], which usually reduce the children's performance for donning tasks. It is remarkable that 40–60% of children with

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this disorder can naturally reorganize their brain at over time for reducing these symptoms [5,6]. Nevertheless, the reduction of children's performance in the childhood due to the ADHD causes that the children do not get enough skill for the future [1]. Hence, the assessment of children in the childhood for the ADHD diagnosis is a great help to the children, parents, and especially the community health.

Currently, studies, which investigated the ADHD effects on the brain signals, can be generally considered as three groups. First group that examined the influence of ADHD symptoms on the event-related potentials (ERP) using continuous performance tests, and reported a different level of activity on the parietal and frontal lobes [7–9]. Second group that investigated the ADHD effects on the slow cortex potentials (SCP), and expressed that the contingent negative variations (CNV) in the ADHD children were lower than that of healthy children [10,11], and Last group in the data mining [12–14] and neurofeedback [15,16] that used the EEG signals. This group of studies, which employed the EEG frequency analysis for evaluating the ADHD effects on the standard EEG bands, revealed that the hyperactivity and impulsivity in the ADHD children increase the power of δ and θ bands and the inattention decreases the power of α and β bands. These studies in the biofeedback [15–19] also relied on a neurofeedback course for improving the ADHD symptoms, which indicates the self-organizing capability and the creativity of brain networks. Pharmaceutical studies on these children also portrayed a latency at the P200, N200 and P300 waves of event-related potentials [20], which displays the influence of misbehaviors internalized in these children on the attention (alerting, orienting and conflict [21,22]) and sensorimotor networks.

These finding in the behavioral indictors and the indictors obtained from the brain signals, therefore, not only confirm different energy exchanges between internal and external feedbacks in the brain of children with ADHD, but also they indicate that the brain is an open, creative and self-organizing system, which can change the energy exchanges of its feedbacks for amplifying or weakening the ADHD. These finding in the data mining studies also indicate an informational opposition in the influence of hyperactivity, impulsivity and attention on the EEG signals, in which increasing hyperactivity and impulsivity is equivalent to increasing the energy of low frequency components (δ and θ), and increasing attention is equivalent to increasing the energy of high frequency components (α and β).

This informational opposition in the EEG bands, which its origin according to the 1/*f* EEG frequency spectrum is the change of actions generated by the activity of brain opposites (inhibitory and excitatory postsynaptic terminals) [23], and also the brain creativity actually represent that the electrical activities stored in the EEG signals are not random or chaotic processes, rather they are resulted from the activity of complementary opposites (excitatory and inhibitory feedbacks), which the brain as a biotic system usually internalizes them during its interaction with the environment. In other words, any change in the frequency content of EEG signals such as the transient states or the variations relevant to disorders and diseases is dependent on the regularity of actions generated by the activity of brain opposites. In this regard, Sabelli and Kauffman [24–31], which used the complement plot generated by two orthogonal and opposite components (sine and cosine) to quantify the coexistence of opposites in the process equation, reported a surprising regularity in the complement plots of biotic processes obtained by this equation, which are completely dependent on the actions received from the bipolar and complementary feedback of this equation (i.e. $g \times \sin(x_n)$). These researchers in the complement plots obtained from the heartbeat intervals also portrayed regularity similar to the Mandala patterns [24,30–32], which are usually influenced the cardiac disorders and diseases. The complement plots obtained from the rounded EEG signals of children with autism spectrum disorder also indicated a different regularity compared to that of normal children [33], which its reason according to the concepts of bios theory is the change of actions generated by the complementary opposites in the brain {Sabelli, 2005 #10}.

Nevertheless, although this regularity in the complement plots of EEG signals confirms the biotic nature of brain activities, and also indicate that the EEG actions and the informational opposition lies in them are informative to quantify changes resulted from disorders and diseases, most studies on these plots only focused on the visual differences of complement plots, and have actually provided no approach to quantify the regularity of complement plots obtained from the signals. Therefore, the objective of present study is to provide a new approach to quantify the complement plot of EEG signals obtained from children with and without ADHD. The remainder of this paper is organized as follows: Section 2.1 presents data acquisition and noise removal processes. Section 2.2 shows that the EEG is a homeo-biotic process and that the biotic processes can be distinguished from chaotic processes by the complement plot. Section 2.3 quantifies the regularity of complement plot by using the dual sets of transitions occurred between the states of complement plot. Section 3 illustrates experimental results, and finally, Section 4 presents the discussion and conclusion.

2. Materials and methods

2.1. *Subjects*

In this study, we examined 40 children with age range 7–10 years, in which 20 children were with ADHD (50% are healthy). These children were distinguished by helping a professional psychiatrist and information gathered from the detailed history of past and current functioning, and also the Conner's parent rating scales [34]. Fig. 1 shows *T* scores of impulsive-hyperactive extracted from the Conner's parent rating scale for all of the children. As seen in this figure, the *T* scores of impulsive-hyperactive for healthy children were approximately lower than 50, while these scores for the ADHD children were higher than 50.

For each of the children, the EEG signals were recorded from the Fz, Cz, Pz, C3 and C4 positions on the scalp according to 10–20 international system and under eyes-open resting conditions at 250 s. Average of A1 and A2 electrodes was employed as reference value. These electroencephalograms were taken in a psychiatric clinic sponsored by the Islamic Azad

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