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A chaotic model of sustaining attention problem in attention deficit disorder

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ABSTRACT

The problem of keeping an attention level is one of the common symptoms of attention deficit disorder. Dopamine deficiency is introduced as one of the causes of this disorder. Based on some physiological facts about the attention control mechanism and chaos intermittency, a behavioral model is presented in this paper. This model represents the problem of undesired alternation of attention level, and can also suggest different valuable predictions about a possible cause of attention deficit disorder. The proposed model reveals that there is a possible interaction between different neurotransmitters which help the individual to adaptively inhibit the attention switching over time. The result of this study can be used to examine and develop a new practical and more appropriate treatment for the problem of sustaining attention.

1. Introduction

Attention deficit disorder (ADD) is one of the most common neurobehavioral disorders. It is usually first diagnosed in childhood, and its symptoms often last into adulthood. A person with ADD often avoids, dislikes, or does not want to do things that take a lot of mental effort for a long period of time. He/she is often easily distracted, usually has trouble keeping attention on tasks or play activities and frequently switches from one activity (mental or physical) to another [1], whereas a person without such a disorder can keep his/her attention for more time in the same situation [2]. Therefore, switching between different activities and inability to maintain attention are not because of sudden changes or noise in the environment. It appears that there is an inherent switching in the attention controlling mechanism of people with attention deficit disorder. This kind of inherent switching is a universal feature of many natural systems, especially neurons [3].

The attention switching symptom of ADD is behaviorally similar to intermittent chaos. Intermittency is a property of a chaotic system in which the dynamics switch back and forth between two qualitatively different behaviors (e.g. periodic to chaotic) even though all control parameters remain constant and no significant external noise is present. Wandering between these behaviors will continue while the system is in the intermittency mode [4]. In other words, in chaotic intermittency, a system cannot preserve its ordered manner and switches repeatedly to chaos. Similarly, people with inattentive type of ADD have difficulty keeping their attention on a task, and they switch between different activities.

The study of chaotic dynamics has received increasing attention and has provided a promising method for studying biological systems and signals [5–9]. The studies conducted so far have shown that chaos plays an essential role in neural

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systems analysis, and brain signals have deterministic chaotic properties [7]. Biological system modeling is another field of study that exploits chaos theory [10–13].

Based on the properties of chaos intermittency and the physiological facts about the human attention system, a novel top–down behavioral model of the attention controlling mechanism in people with ADD is proposed in the current study. Top–down dynamical models start with an analysis of those important aspects of behavior that are robust and reproducible. The top–down approach is a more speculative, big-picture view. The model should predict how the behavior evolves with different changes in the environment [14].

In previous studies, different animal and computational models were presented which show some other problems of ADDs [15–17]. For instance, Balkenius and Björne [15] presented a robot model of attention deficit hyperactivity disorder (ADHD) which can reproduce some of the behaviors of people with ADHD. They show the slow reaction time for people with ADHD and predict the possible working memory impairment in these people. However, no simulation of the sustaining attention problem was done in that study [15]. Brown (2001) developed a model of ADD based on the physiological facts and his experiments with children who have ADD/ADHD. Brown's model describes the complex cognitive functions impaired in ADD Syndrome [16]. There are also some animal models of ADHD in which their goal is to show parts of the brain that are involved in ADHD [17].

In the current study, a new model is proposed whose main goal is the investigation of the frequent attention switching problem in ADDs. Using chaos theory to model an abnormality in people with ADD is one of the novelties of the current study. This model has the ability to show the effect of interaction between attention system components in keeping an individual's attention on a task. It can also predict some possible causes of the attention switching problem.

Section 2 outlines the information about the main parts of the brain that are associated with attention deficit disorders. Section 3 contains details about the proposed model's components. The results and discussion of this study are presented in Section 4 followed by the conclusion in Section 5.

2. The physiological background

The frontal lobe of the brain is a very important part of a complex cognitive processing system. It has many connections to different areas of the brain. Research on the brain function of people with ADD has shown that frontal lobe dysfunction may cause the appearance of ADD symptoms [18]. The frontal cortex has an important role in controlling attention level, focusing, restraint, and patience. When this part of the brain does not work well, signs of distraction, lack of restraint, impatience, and lack of attention to detail are seen in the person [19]. The frontal cortex also plays an important role in the excitation/inhibition balance in information processing [20]. In people with ADD, frontal lobe dysfunction reduces the inhibitory power of the brain, and they have difficulties in inhibiting their attention switching [21–25]. However, there are some recent studies that claimed that the excitatory brain components can also affect ADD [26–29].

It has been reported that a neurotransmitter called dopamine has a considerable effect on frontal lobe function [30]. Several important diseases of the nervous system are associated with dysfunctions of the dopamine system [31,32]. ADD is also believed to be associated with decreased dopamine activity [33]. Dopamine plays a major role in the brain system that is responsible for reward-driven learning [34]. Every type of reward that has been studied and also stressful situations increase the level of dopamine transmission in the brain [35,36].

3. The proposed model

According to the previous discussion, a nonlinear neural network is proposed (Fig. 1) to model the ADD attention switching behavior. Choosing appropriate values for the parameters leads to chaotic behavior.

The model input is composed of two main parts: First, sensory information is received from the subject, on which the person is asked to concentrate. Second, feedback information is extracted from analysis and perception of sensory information. The sensory cortex receives the input information and sends it to the inhibitory and excitatory parts of the brain with an amplification factor of w_i. These parts are attributed to the frontal cortex.

The output of this network can be computed as follows:

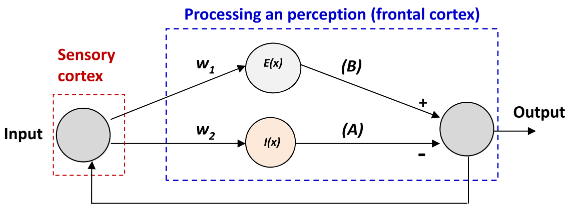

Fig. 1. A behavioral chaotic neural network model of ADD. $E(x)$ and $I(x)$ are the activation functions of two neurons whose outputs are respectively multiplied by (B) and (A). Both $E(x)$ and $I(x)$ are hyperbolic tangent functions. $I(x)*(-A)$ models the inhibitory brain action and $E(x)*(+B)$ models the excitatory brain action. (A), (B), and w_i are values that amplify the output of the neurons.