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Research Article

The Effect of Saccades to Distractions on the Reaction Time in ADHD-Inattentive Subtype and Normal Children

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Abstract

The negative effect of distractions on the individuals' attention performance and the possible relation between the performance of the attention system and the pattern of saccadic eye movements has been investigated in different studies. It has been shown that distraction can lead to a delayed saccade toward a target and consequently the increment of the reaction time. The abnormal distractibility of subjects with attention deficit hyperactivity disorder has also been reported in previous studies. In the current study, we investigated the relationship between the saccadic eye movement to the distractions and speed of the response in children with attention deficit disorder (ADD) and normal ones.

All children participated in a visual attention experiment. Subjects were requested to respond to a target when a target and a distraction were presented. Saccadic eye movements and RTs were recorded during the test. Paired samples t-test was used to compare the RT in trials with and without unwanted eye movements (saccade to distraction).

Statistical analysis showed that unwanted saccades led to a significant increase of the RT in normal children ($p<.01$), but not in children with ADD ($p>.05$). It was also shown that the normal group had lower RTs than children with ADD in both trials with and without saccades to the distractions ($p< 0.001$).

The outcomes of this study provided some suggestions about the difference between overt and covert attention to the distractions in normal and ADD children and new diagnostic methods have been proposed for future works.

ABBREVIATIONS

ADHD: Attention Deficit Hyperactivity Disorder; ADD: Attention Deficit Disorder; EEG: Electroencephalography; MMN: Mismatch Negativity; ERP: Event-Related Potential; RON: Re-Orientation of Negativity; RT: Reaction Time; RDE: Remote Distractor Effect

INTRODUCTION

In neurocognitive science, distraction refers to any things that are not related to the goals of a target task and can divert the individuals' mind from the goals. Distractions compete with the target stimuli to use the limited neurocognitive processing resources [1]. The neurocognitive system compares the incoming stimuli with the predefined goals to dissociate distractions from target stimuli. Earlier perception of a stimulus and detection of its features takes about 150 ms after its presentation, and its comparison with the predefined target stimulus finishes after about 250 ms [2].

Behavioral analyses have shown that distractions can reduce the speed and the accuracy of responses. It has been believed that the speed reduction is not due to the slower processing of target stimuli. In other words, the distraction does not interfere with the processing of the target stimuli. The reason for the speed reduction is attributed to the time required to orient the processing resources from the target to the distraction and the initiation of involuntary procedures. Brain electrical activities (i.e., electroencephalography (EEG)) demonstrate that by the presentation of an unexpected distraction, attention control system detects it and as a result of this detection the mismatch negativity (MMN) wave is usually produced in the event-related potential (ERP) signal [3,4]. Then, processing resources are usually involuntary oriented towards the unexpected distraction to process in further that leads to the increment of the P300 amplitude. After a while, the processing resources are reoriented towards the previous ongoing target task. This reorientation is accompanied by the production of the Re-orientation of negativity (RON) component in the ERP signals. These events have been observed in both synchronous and asynchronous presentations of target and distraction stimuli [4].

If the attention control system cannot detect and attenuate distractions timely and correctly, the performance of the individual may decline during the task.

The weakness of the attention control system in inhibiting the distractions has been reported in some of the disorders such as the attention deficit hyperactivity disorder (ADHD), which is one of the neurodevelopmental disorders among children.

This disorder has three inattentive, hyperactive, and combined subtypes. The mentioned weakness is more often reported in the inattentive that is also called attention deficit disorder (ADD). These children are more sensitive to distractions in comparison with normal ones [5-8]. That is, by the presentation of distractions, the performance decline in ADD subjects is higher than the normal group. In ADD subjects, the deficit of the attention control system to the correct and on-time attenuation of distraction is attributed to the weakness of the working memory [9].

The mentioned deviation of the processing resources to the distraction may be followed by the eye movement (e.g., saccade) towards the distractor, which is called overt attention to the distraction. The second possible condition is only accompanied by the deviation of processing resources and no movement towards the distraction is observed, which is called covert attention [10]. The characteristics of eye movements were investigated in ADHD and normal subjects [11-17]. It was shown that ADHD children had problem in gaze fixations. This problem was attributed to the late maturation of the frontal cortex in ADHD children [11]. It was also reported that that people with ADHD had higher saccadic reaction times and errors in anti-saccades than those of normal group [12,13]. In another study, it was demonstrated that ADHD subjects needed more time to inhibit the unexpected eye movements [15]. These problems were attributed to the late maturation of the frontal cortex in ADHD children [11], specifically the dorsolateral prefrontal cortex [14].

The possible relation between the performance of the attention system (usually assessed by measuring the reaction time (RT) and the pattern of saccadic eye movements has been investigated in different studies [18,19]. It has been shown that distraction may lead to a delayed saccade to the target [20,21]. Problems in the inhibition of saccadic eye movements to distractions were also reported in the previous studies [16,17].

The main goal of the current study is to find out whether saccadic eye movements to the distractions have a considerable effect on the speed of the response (i.e., reaction time (RT) in both ADHD and normal group, or not?

MATERIALS AND METHODS

Participants

Forty-two normal (25girls; 9 ± 0.6 years old) and seventeen ADD (8 girls; 9.4 ± 0.8 years old) IQ matched (using Goodenouph test) children participated in the experiment. Children with ADD were diagnosed by psychiatrists in the Atieh comprehensive psychiatric center of Iran based on DSM-IV, IVA CPT, and QEEG indices. These children did not use any medication and did not receive any behavioral interventions. The parents of normal children were requested to fill the national institute for children's health quality (NICHQ) Vanderbilt assessment scales to evaluate the mental health of this group. Participants had normal vision.

Before the experiment, children and their parents were informed about the test procedures and the parents signed the informed consent forms. The experiment was done under the approval of Iran University of Medical Sciences (# IR.IUMS. REC.1395 90133916).

Experiment

The experiment was a short time visual attention task. It consisted of 38 trials, which the first six trials were considered as a practice to warm up the participant. In each trial, a target (a star shown in Figure 1 (a)) and a distractor (an image of a colored or black and white fruit shown in Figure 1 (b)) were presented. Subjects were requested to tap on a touchpad as soon as seeing a star (presented for 400ms) in the predefined target locations on a monitor. The images of the distractors were shown in the predetermined non-target locations, 200ms before the presentation of the star. The predefined position of targets and distractors locations is shown in Figure 2 respectively by circles and squares. The height of both target and distraction stimuli was about one inch. That is, participants were informed that in each trial the star is presented in one of the circles and distractors presented in one of the squares and they were requested to pay no attention to the position of the squares. Saccadic eye movements and RTs were recorded during the test.

Participants sat in front of a screen with a distance of about 70 cm. The screen was a 21" LCD screen with the resolution of 1600×900 pixels and the refresh rate of 60 Hz. During the test, a camera (1.2 MP, 30 fps) was placed under the monitor in front of the subject's face. A program in the Visual C# 2008 software running under Microsoft windows 7 controlled the presentation and storage of camera output and subjects responses. This program labeled the data recorded by the camera at the start and end of each trial. The frames of different trials were extracted from the videos recorded by the camera. Comparing the position of eyes in the successive frames, the direction of eye movements was detected. The positions of distractions and targets were known in each trial. Therefore, according to the extracted eye movements' directions, saccades to the distractions were detected. These processes (i.e., eye movement analyses) were done offline (i.e., at the end of the experiment).

Measurements and statistical test

Paired samples t-test was used to compare the RT in trials with and without unwanted eye movements (saccade to distraction).

The reaction times of the participants were recorded during the test. To evaluate the difference between recorded reaction times in trials with a saccade to the distraction and those without the saccade, a paired-t-test was used. The differences between the normal and ADD groups were examined by an unpaired-t-test with a significant level of 0.05.

RESULTS AND DISCUSSION

To find out the effect of saccadic eye movement on the RT, the trials that the participants had a saccade to the location of the distraction was separated from trials with no saccade to the distractor. Then, the average RTs of these two kinds of trials was compared in both normal and ADD groups.

Using unpaired-t-test, a significant difference was found between ADD and normal groups in both trials with ($t(57) = 2.6$, $p = .01$) and without ($t(57) = 4$, $p = .0002$) saccades to the distractions. These results were demonstrated in Figure 3 and were summarized in Table 1.

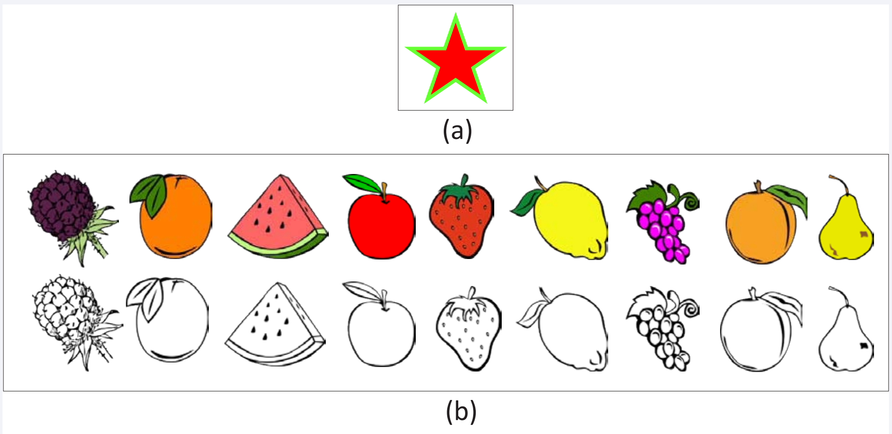

Figure 1 (a) The picture of the target; (b) The pictures of distractors.

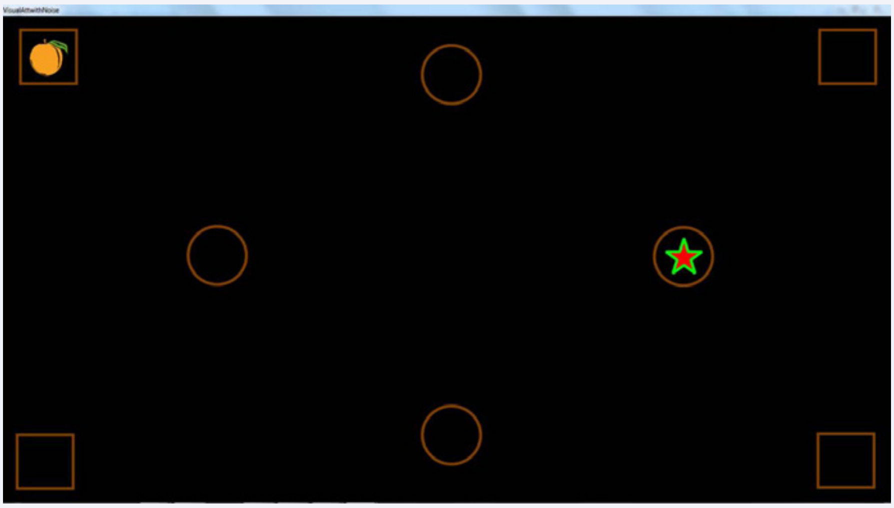

Figure 2 The schematic of one trial of the experiment. Circles are the possible location of the presentation of the target (a star), and squares are the possible location of the presentation of the distractor (a fruit).

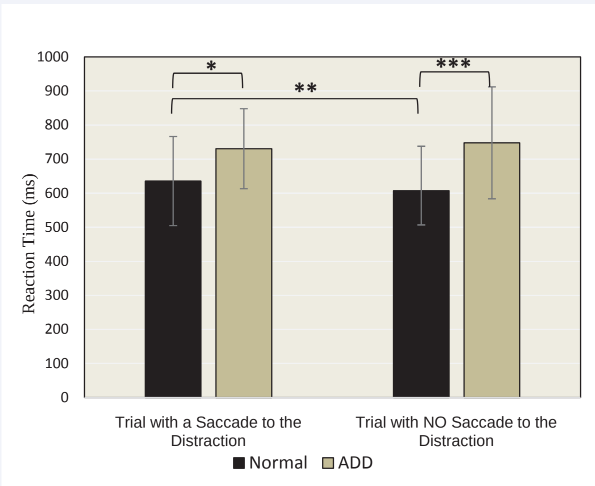

Figure 3 A comparison of the reaction time in trails with and without saccadic eye movement to distractions in normal and ADD children. Error bars indicate between-subjects variability (standard deviation); Bars with star show groups with statistically significant differences. One, two, and three stars mean the difference is significant by a p-value less than 0.05, 0.005, and 0.0005, respectively.

Table 1: Results of statistical comparisons between normal and ADD children in trials with and without saccades to the distraction.

Feature	Normal children	ADD children	
Number	42	17	
Sex	25 girls; 17 boys	8 girls; 9 boys	
Age	9 ± 0.6 years old	9.4 ± 0.8 years	
			Stats (*p*=0.05) t(df)=t-stat, *p*=p-value
RT in trials with saccade to the distraction	(mean ± SEM) 635.5 ± 20.21	(mean ± SEM) 730.4 ± 28.12	t(57) = 2.6, *p* = .01
RT in trials with NO saccade to the distraction	606.8 ± 15.79	747.6 ± 38.73	t(57) = 4, *p* = .0002
Stats (*p*=0.05) t(df)=t-stat, p=p-value	t(41) = 3.026, *p* = .004	t(16) = 0.6, *p* = .6	

As mentioned in the introduction, distraction can lead to a delayed response to the target. The underlying causes of this delay are not completely known. However, two possibilities have been suggested for the observed delay: 1-The time of choosing the correct location for attending, and 2-The time required for the processing of distractor properties (called "remote distractor effect" (RDE))[20, 21].

Target locations were predefined in our experiment. Therefore, the increase of the RT cannot be due to the making decision about the target position. For that reason, the increase of the RT can be as a result of the distractor characteristics processing (or RDE). Based on the statistical analysis, it can also be claimed that the difference between ADD and normal children in trials without saccades to the distractors was stronger than situations with a saccade to the distractions. This observation suggests that the differentiation between ADD and normal children in covert attention is more than the overt attention, based on the negative effect of RDE.

Statistical analyses (paired-t-test) also showed that, in the normal group, the values of RTs in trials with a saccade to the distraction was significantly higher than the trials without saccades to the distractions (t(41) = 3.026, *p* = .004). This result is consistent with the claim that for better processing of a target it is required to be in the center of the field of the view [18,19]. When the individuals have a saccade to the distraction, the position of his/her eyes is replaced towards the distraction. As a result, a disturbance and a possible delay may occur in the processing of the target that may lead to the higher RTs.

However, in ADD children, there was no significant difference between the mentioned two kinds of trials (t(16) = 0.6, *p* = .6). This result is inconsistent with all the above interpretations provided for the normal children observations. It means that there was no significant difference between the covert or overt attention to the distraction in ADD children. By a comparison between the results obtained for the normal and ADD groups, it can be suggested that normal children can inhibit their covert attention to the distractions. Therefore, if they have no involuntary saccades to the distraction (i.e., overt attention), they can attenuate the negative effect of distraction. However, in ADD children, even if the involuntary saccades to the distraction (i.e., overt attention) are inhibited, the covert attention to the saccade cannot be controlled correctly due to their weakness of the attention control system. The control of covert distraction is done by the execution and inhibitory systems. The weakness of these systems can lead to the abnormal covert or overt distractions. Overt distraction can be detected by tracking the eye movements. However, the detection of covert distraction is not easily possible. It has been believed that unexpected increment of the reaction time or the decline of the activities of brain regions that involved in the target processing may be due to the covert distraction. Therefore, to investigate the differences between ADD and normal subjects from the aspect of covert and overt attention performance, both eye movement recording and reaction times (or brain activities) are required. This results is consistent with previous studies on the relationship between eye movements' patterns, the deficit of inhibitory system and executive function, and ADHD symptoms [16,17].

CONCLUSION

Our experiment showed that the saccadic eye movements can affect the distractor processing and consequently, the children attention performance. It was also shown that this effect is different in ADD and normal children. The available common clinical computer-based diagnosis methods do not include the presentation of distraction during the task. According to the results of this study and other similar ones, adding several levels of distractions and some criteria to evaluate the distractibility may enhance the accuracy of the diagnostic methods. The current study also showed the difference between the effect of overt and covert attention to the distractions in ADHD and normal children. Therefore, developing new methods that can differentiate the influence of overt and covert attention is suggested for future works to have more accurate and faster diagnosis of ADHD. For example, instead of common diagnostic methods (e.g., test of variables of attention, or integrated visual and auditory test) that usually take a long time and lead to the lack of cooperation between the children and the experimenter, new shorter tests that contain distractions are suggested. According to the results, distractions excite the overt attention involuntary and this effect is different between normal and ADHD children. To develop these methods a system that can track the subjects' saccades to the presented distractions is needed. The relationship between the pattern of these saccades and recorded reaction times can show the performance of overt attention. Comparing this performance in normal and ADHD children can be used as new diagnostic criteria.

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