

# Eye Movement Performance on the Stroop Test in Adults With ADHD

Journal of Attention Disorders  
2019, Vol. 23(10) 1160–1169  
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DOI: 10.1177/1087054716642904  
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## Abstract

**Objective:** To compare the eye movement patterns of adults with ADHD with those of controls as they perform the Stroop test. **Method:** Thirty individuals with ADHD (ages 18–31), and 30 controls participated in this study. The hypothesis was that under the incongruent condition, the group with ADHD would focus longer on the distracter than the controls. **Results:** Participants with ADHD showed a more pronounced Stroop effect than the controls. Eye movements indicated that more time was spent fixating on the target than on the distracter. The most significant differences between the groups were the overall time spent on the target and the number of fixations on the target, rather than on the distracter. Furthermore, the group with ADHD made more transitions between the target and distracter stimuli. **Conclusion:** These results were interpreted to indicate an inefficient strategy used by the group with ADHD in their attempt to ignore the distracter stimuli. (*J. of Att. Dis.* 2019; 23(10) 1160–1169)

## Keywords

ADHD, eye movement, Stroop test, attention

ADHD is extremely prevalent among the general population. It has an estimated impact on 3% to 7% of school-aged children (American Psychiatric Association, 2000) and on 3% to 3.5% of adults (Barkley, Murphy, & Fischer, 2008). The impacts of ADHD were previously thought not to persist in adults, though studies show that approximately 66% of all children diagnosed with ADHD will continue to suffer from the disorder in adulthood (Weiss & Hechtman, 1993). ADHD is characterized by inattention, hyperactivity, and impulsiveness (Parera, Padmasekara, & Perera, 2007).

Selective attention is the ability to isolate specific relevant stimuli from the overwhelming amount of stimuli that surrounds us (Melara & Algom, 2003). The Stroop task, a tool commonly used to assess selective attention (Assef, Capovilla, & Capovilla, 2007; Milioni et al., 2014; Song, & Hakoda, 2011), was developed by Stroop in 1935. Stroop aggregated two dimensions—one relevant and the other irrelevant—into a single stimulus in the form of a word naming a color but printed in a different color. There are two basic conditions in the Stroop test—congruent and incongruent. In the congruent condition, the color of the word matches the name of the word (e.g., the word “red” written in red ink). In the incongruent condition, these two dimensions do not match (e.g., the word “red” written in blue ink). The increased amount of time and reduced accuracy while naming the color in the incongruent condition compared with the congruent one is referred to as the Stroop effect.

Dyer (1973) used a variation of the Stroop test in his research. He presented the word and the color separately so

that the color (the target) appeared on one side of the fixation point and the word (the distracter) appeared on the other side. The location of the stimuli in relation to the fixation point (left or right) changed at random between experiment repetitions. Participants were instructed to name the color and ignore the word. The results were similar to those produced by the original Stroop test, that is, response time for the incongruent condition was higher than the congruent condition. This indicates that even when separating the two dimensions of the stimulus, the irrelevant dimension will continue to affect the ability to process the relevant one (Dyer, 1973).

Studies that tested performance on the Stroop test on children with ADHD showed that in most cases, a stronger Stroop effect occurred in participants with ADHD than in the controls (Seidman et al., 2004; Sergeant, Geurts, & Oostelaan, 2002). Similar findings were reported for adults (King, Colla, Brass, Heuser, & von Cramon, 2007). A review of studies that used the Stroop test to test performance of

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adult participants with ADHD showed that the results of studies on adults were similar to those conducted on children. This article reviewed 15 studies in which adults with ADHD performed the Stroop test, 11 of which revealed significant differences between the ADHD and control groups (Seidman et al., 2004). Lansbergen, Kenemans, and van Engeland (2007) conducted a meta-analysis study that included previous research conducted on both children and adults. Their results indicate that interference in the ADHD group was greater than in the control group and that the ability to inhibit irrelevant responses, as reflected in the Stroop test, is indeed more impaired in the ADHD group.

Eye movements provide information that cannot be obtained by measuring response time and accuracy alone. In recent years, several studies have used eye trackers to monitor various oculomotor measures in participants diagnosed with ADHD. Munoz, Armstrong, Hampton, and Moore (2003) reported that individuals with ADHD have difficulties suppressing saccades and controlling fixation. Similarly, in a more recent study, Fried et al. (2014) reported that adults with ADHD had difficulties in suppressing micro-saccade rates, blink rates, and pupil dilation while performing continuous performance tasks, which they claim reflect an attentiveness problem.

Olk (2013) was the first to track eye movements while performing the Stroop test. The objective of the study was to determine how Stroop interference is reflected in the attention allocated by participants, by tracking their eye movements while they performed the task. The study used a numeric version of the Stroop test in which arrays of numbers appear on both sides of the screen and the participants must determine which array contains more numbers, regardless of the numeric value of the numbers in each array. The experiment included congruent and incongruent conditions. In the congruent condition, the larger array was comprised of higher numbers than the smaller array. In the incongruent condition, the larger array contained lower numbers than the smaller one. Participants were asked to judge which array was longer, regardless of the numerical value of its components.

Olk (2013) showed that response time in the congruent condition was faster than in the incongruent condition. The study also showed that participants responded correctly more often in the congruent condition than in the incongruent one. One index of eye movements that was studied was the direction of the first saccade. Under both conditions, more initial saccades were directed toward the larger array, but the percentage of saccades in that direction was higher in the congruent condition than the incongruent one. In the incongruent condition, more initial saccades were directed toward the smaller array that contained higher numbers, which indicated that the irrelevant dimension (high numeric value) drew the participants' attention in the incongruent condition. Considering the parallel distributing processing

model, this indicates that attention is directed at the information on the irrelevant path as well, though to a lesser degree than at the information on the path that is relevant to the task. This is indicated by the fact that the initial saccades were generally directed toward the larger array. Additional eye movement measures were used, including total duration of fixations and fixation length while responding. These indices showed longer fixations on the larger arrays in both the congruent and incongruent conditions. In other words, despite attention being directed toward both arrays, fixation on the target stimulus was longer, per the instructions given to the participants. Although under the incongruity condition the first saccade was influenced by the numeric value that drew it to the distracter stimulus, the nature of each of the arrays was identified quickly, and attention was shifted to the target stimulus where the participants then focused for longer. This finding coincides with the idea of attention being allocated in accordance with the instructions received and the requirements defined for the task, and that attention supports the relevant information (Cohen, Aston-Jones, & Gilzenrat, 2004; Desimone & Duncan, 1995; Duncan, 2006).

The advantage of the paradigm used in the present study over that of Olk's (2013) is that the target (i.e., color) and distracter (i.e., word) stimuli are presented separately on the computer monitor, counterbalanced between the right and left hemispace. This paradigm enabled us to record eye movements separately for target and distracter stimuli under the congruent and incongruent conditions.

The other two advantages of the paradigm used in this study are that the Stroop test was presented on a computer, which allowed more accurate measures of reaction time compared with the paper-and-pencil version. In addition, this study used a trial-by-trial version of the Stroop test rather than block presentations of the various conditions. These two characteristics were proven to increase sensitivity of the Stroop test over the paper-and-pencil and block versions of the test (King et al., 2007).

Thus, the goal of the present study is to test people with ADHD who struggle to resist distracters whether they are internal or external (Barkley, 1997). The Stroop test is used to assess the interference control process. Participants must restrain their automatic response (reading the word) and prevent it from interfering with the controlled process of naming the color (Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2010; Lansbergen et al., 2007).

Eye movements were recorded while participants performed the Stroop test, which required focusing attention on the target and ignoring the distracters. Eye movements provide information that cannot be obtained by measuring response time and accuracy alone. Eye movement patterns show how attention is allocated and how participants cope with the cognitive conflict presented by the Stroop test. It also provides information about the mechanism that controls the processes performed during the task (Olk, 2013).

Consistent with previous reports in literature, it is predicted that the Stroop effect (i.e., slower and less accurate performance under the incongruent compared with the congruent condition) will be more pronounced in the group with ADHD than in controls. In addition, the eye movements will reflect the attention difficulties experienced by the group with ADHD. It is predicted that the adults with ADHD will display more difficulty in ignoring the distracter information (i.e., words) than the controls.

## Method

### Participants

The study included 60 participants, 30 of whom had been previously diagnosed with ADHD by a neurologist or psychiatrist (average age = 24.4,  $SD = 3.41$  years, 14 men). The control group consisted of 30 healthy participants who had not been diagnosed with ADHD (average age = 23.7,  $SD = 2.25$  years, 8 men). All participants were between 18 and 31 years old and had normal vision (to avoid difficulties while calibrating the eye-tracking device for people with glasses). All were Hebrew speakers with normal intelligence levels and reading skills. The participants responded to ads posted on the university campus and online. All participants in the ADHD group were paid for their participation. The control group consisted of volunteers and psychology students who participated as part of their academic requirements. The experiment was approved by the ethics committee at the Department of Psychology in Bar-Ilan University, and all participants signed an informed consent form before participating. Participants in the ADHD group who normally take medications such as Ritalin were asked not to take medication on the day of the experiment to avoid interfering with the results.

### Tools

**Stimuli display.** SuperLab software (Cedrus Inc., LA, USA) was used to display the stimuli on the computer screen and to link the display duration with the computer that recorded eye movements. The stimuli were presented on an LG 32" 32LG10R screen, and participants were seated 100 cm away from the screen. The room was minimally lit, and the participant's chin rested on a special stand that included a forehead rest as well, to minimize movement as much as possible.

**Recording eye movements.** The participants' eye movements were recorded using the ISCAN Eye Tracking Laboratory (MA, USA, Model ETL-400, which illuminates the pupil using a camera with an infrared beam and measures cornea reflection. The camera was placed near the screen, 45 cm away from the participant. The system uses information

about changes in the location of the pupil to determine the location and movement of the eye. The device samples the spatial location (the point on the  $x$  and  $y$  axes) 120 times per second. During the experiment, the device records the participant's eye movements, and the recorded information is displayed to the person conducting the experiment on a small screen that is not visible to the participant. Another small screen displays the image that the participant is currently viewing on the test computer, with an indicator showing the precise location of the participant's gaze based on the calibration conducted before the experiment began.

### Procedure

The duration of the experiment was approximately 30 min. Detailed anamnesis was recorded for participants in the ADHD group, followed by performance on behavioral tasks in the order described below. The last stage of the experiment was the computerized version of the Stroop test during which eye movements were recorded.

**Attention tests.** Several behavioral tasks frequently used to measure attention were administered to the participants to validate the results of participants with and without ADHD. These include the Trail-Making Test (TMT; Reitan & Davison, 1974), Digit Symbol subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1991), Digit Cancellation Test (Diller et al., 1974; Lezak, Howieson, & Loring, 2004), and Digit Span subtest of the WAIS-R (Wechsler, 1991). These particular tests were chosen because they have Israeli norms and they tap various aspects of attention (i.e., selective attention, divided attention, and sustained attention; Vakil, Blachstein, Sheinman, & Greenstein, 2009).

### Variation of the Stroop Test

The test was comprised of four colors—blue, red, green, and yellow. The words were displayed in Times New Roman, size 144, and the colors themselves appeared in a rectangle that was half of the height and a quarter of the width of the Hebrew word for "red." The words and colors appeared  $10^\circ$  apart, each located  $5^\circ$  away from the center of the screen. The participants were instructed to name the color in the rectangle by pressing the key on the keyboard bearing the corresponding color, while ignoring the word that appeared. The task included a total of 100 trials—50 congruent and 50 incongruent. Color words and the colors themselves did not appear twice in a row in any subsequent trials. The words and colors were displayed horizontally on the right and left sides of the center of the screen. This was counterbalanced between the congruent and incongruent conditions. The inter-trial interval (ITI) ranged from 1 s to 3 s (average 2 s), during which the participant was instructed to

**Table 1.** Performance (*M* and *SD*) of the Control Group and the ADHD Group on Attention Tests.

Attention tests	Control ( <i>n</i> = 30)		ADHD ( <i>n</i> = 30)		<i>p</i>		
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	Group ( <i>G</i> )	Test ( <i>T</i> )	<i>G</i> × <i>T</i>
Trail-Making A	0.30	0.06	0.41	0.24	.02	.001	.35
Trail-Making B	0.78	0.37	0.99	0.46			
Digit Cancellation A	1.06	0.22	1.19	0.27	.08	.001	.25
Digit Cancellation B	1.18	0.12	1.25	0.30			
Digit Span Forward	8.07	1.17	7.30	1.29	.01	.001	.74
Digit Span Backward	6.38	1.26	5.73	1.14			
Digit Symbol	64.33	9.24	54.67	10.44	.001		

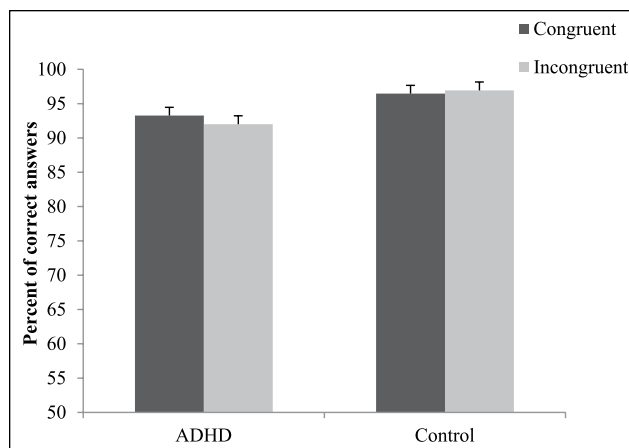
focus on the fixation point at the center of the screen. A keyboard with four keys corresponding to the four colors used in the task was used to select the correct answer and respond to the task.

The first step was to calibrate the device to the participant’s eye movements. The participant was instructed to focus on five different points that appeared on the four corners and center of the screen. All eye movements during the task were recorded and presented in a table that lists the points observed during each sample. Before beginning, participants were given written and oral instructions on how to perform the task. They then practiced the task to memorize the location of each key on the keyboard and avoid movement during the experiment.

## Results

### Attention Tests

As described above, four separate tests were used to assess attention in the control group and in the group with ADHD: *Trail Making A + B*, *Digit Cancellation A + B*, *Digits Forward + Digits Backward*, and *Digit Symbol*. To compare performance times between the groups and between the two parts of the first three tests, mixed-design 2 × 2 ANOVA with repeated measures was performed—Group (control, ADHD) × Test Part (Part A vs. Part B). The first was a between-subject variable and the second was a within-subject variable. For the fourth test (i.e., *Digit Symbol*) *t* test for independent samples was performed. Mean, standard deviation, and significance of each of these tests are presented in Table 1. As can be seen in Table 1, group effect was found for all tests, except for *Digit Cancellation* in which it was just a tendency. These results confirm that members of the group with ADHD have attention deficits.



**Figure 1.** Percentage of correct answers (*M* and *SD*) given by the ADHD and control groups in the congruent and incongruent conditions.

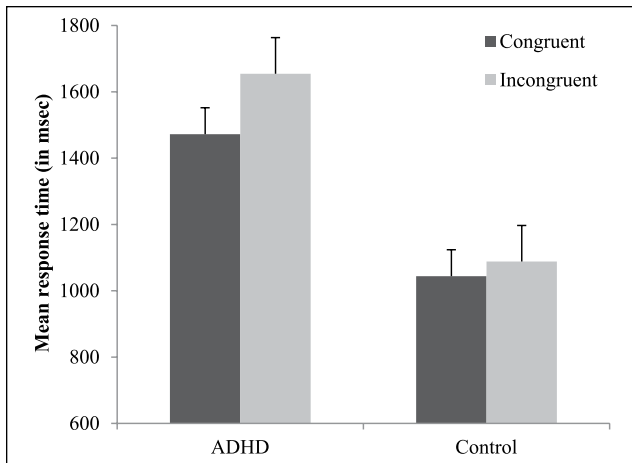
In the tests with two parts, both groups were affected by the more difficult parts to the same extent, as indicated by the non-significant interactions.

### Stroop Test—Behavioral Results

This part of the experiment measured two independent variables: the participants—control and ADHD groups—and the different conditions—congruent, in which the word and color match, and incongruent, in which the two dimensions differ. Two analyses were conducted to measure independent variables. The first was accuracy—the percentage of correct answers, and the second was participants’ response time.

**Accuracy.** The percentages of correct answers in the two groups (control, ADHD) and two different conditions (congruent, incongruent) were compared by performing mixed-design 2 × 2 ANOVA with repeated measures; the first was a between-subject variable, and the second was a within-subject variable. This analysis yielded a significant main effect for the group,  $F(1, 58) = 6.73, p < .05, \eta^2 = 0.10$ , that is, participants in the control group gave more correct answers than members of the ADHD group. The condition main effect did not reach significance,  $F(1, 58) = 0.33, p = .57, \eta^2 = 0.01$ , meaning that congruence or incongruence did not affect accuracy. In addition, the group and condition effects did not significantly interact,  $F(1, 58) = 1.53, p = .22, \eta^2 = 0.03$ , meaning that no significant difference was found between the percentage of correct answers given by the two groups in the congruence condition compared with the incongruence condition (see Figure 1).

**Response time.** To compare average response time in the two groups under the two conditions, mixed-design 2 × 2



**Figure 2.** Response time (*M* and *SD*) for control and ADHD groups in the congruent and incongruent conditions.

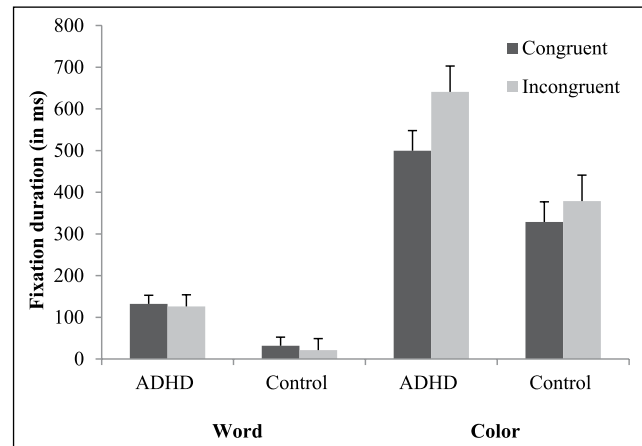
ANOVA with repeated measures was performed—Group (control, ADHD) × Condition (congruent, incongruent). The first was a between-subject variable and the second, a within-subject variable. This analysis yielded a significant main effect for the group,  $F(1, 58) = 14.44, p < .001, \eta^2 = 0.20$ , meaning that the control group responded faster than the ADHD group. In addition, a main effect was found for the condition,  $F(1, 58) = 11.68, p < .01, \eta^2 = 0.17$ , meaning that reaction time in the congruent condition was faster than in the incongruent condition. The interaction between group and condition reached significance as well,  $F(1, 58) = 4.33, p < .05, \eta^2 = 0.07$ .

To determine the source of interaction, *t* tests for dependent samples were performed for each of the groups. The analysis showed a significant difference in response times between the two conditions (congruence and incongruence) in both the control group,  $t(29) = 2.71, p < .05$ , and the ADHD group,  $t(29) = 2.84, p < .01$ . Thus, as can be seen in Figure 3, the source of the interaction is that the group with ADHD was more affected by the test condition (i.e., incongruent > congruent) than the control group (see Figure 2).

### Eye Movements

Three independent variables were analyzed—group (control, ADHD), condition (congruent, incongruent), and stimulus (target—color, distracter—word). Three dependent variables were used to analyze eye movements: fixation duration on the target (color) and on the distracter (word), the number of times the eyes shifted from the target to the distracter, and the number of fixations on the target and the distracter.

Values that indicate blinking were removed from the eye-tracking analysis. Fixations were defined as periods of more than 100 ms without a saccade. Saccades are defined

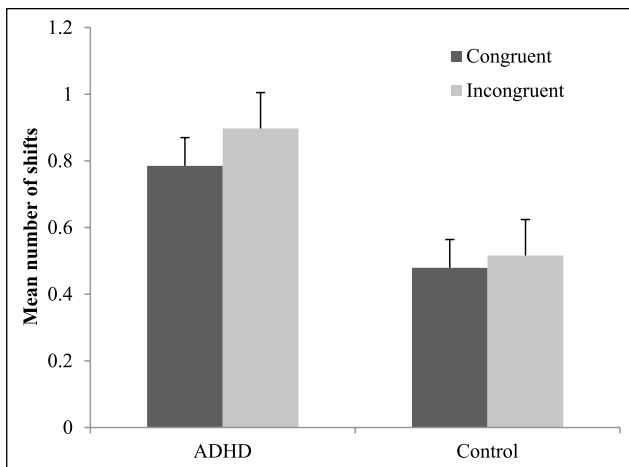


**Figure 3.** Fixation duration on the target and distracter (*M* and *SD*) in the ADHD and control groups in the congruent and incongruent conditions.

as eye movements that exceed  $0.7^\circ$  within 33 ms (C. N. Smith, Hopkins, & Squire, 2006). Target and distracter stimuli appeared alternatively on the left and right side of the screen,  $5^\circ$  from the center of the screen. The stimulus area was defined as the area above and below the stimulus and on the sides extending to the edge of the screen. The most vulnerable area is the one between the two stimuli, in which the stimulus area was defined as approximately 50% of the maximum width of all of the stimuli, reaching the center of the screen.

*Fixation duration on target (color) and distracter (word).* To compare fixation times on each of the stimulus in the two groups and the two conditions, mixed-design  $2 \times 2 \times 2$  ANOVA with repeated measures was performed with the following configuration: Group (control, ADHD) × Condition (congruent, incongruent) × Stimulus (target—color, distracter—word). The former was a between-subject variable, and the latter two were within-subject variables. To eliminate extreme eye movement measures that result from technical problems with the device or incorrect calibration, fixation length was measured using medians rather than mean.

This analysis yielded a significant main effect for group,  $F(1, 58) = 11.56, p < .01, \eta^2 = 0.17$ , meaning that overall fixation time in the ADHD group was longer than in the control group. A main effect was found for the condition as well,  $F(1, 58) = 7.34, p < .01, \eta^2 = 0.11$ , meaning that fixation time was longer in the incongruent than in the congruent condition. A main effect was found for the stimulus as well,  $F(1, 58) = 130.41, p < .001, \eta^2 = 0.69$ , meaning that fixation time on the target was longer than on the distracter. Significant interaction was found between the condition and stimulus,  $F(1, 58) = 25.66, p < .001, \eta^2 = 0.31$ , meaning that although participants focused longer on the target in the incongruent



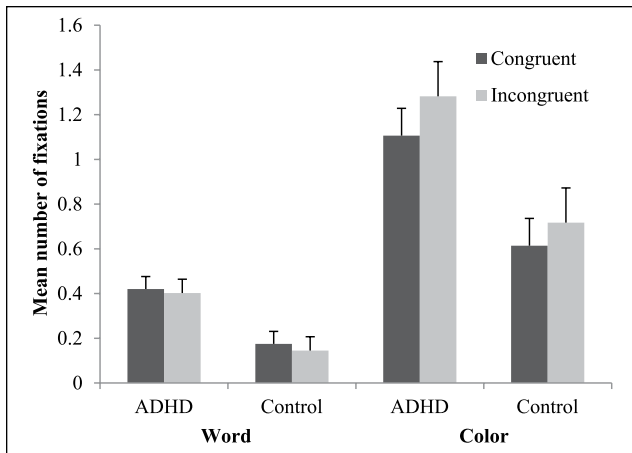
**Figure 4.** Number of shifts between the distracter and target stimuli ( $M$  and  $SD$ ) in the ADHD control groups in the congruent and incongruent conditions.

condition than in the congruent condition, the duration of fixations on the distracter was not significantly different in the congruent and incongruent conditions. The Group  $\times$  Stimulus interaction was marginally significant,  $F(1, 58) = 2.85, p = .10, \eta^2 = 0.05$ , indicating that although both groups fixated longer on the target than on the distracter, the difference was more pronounced in the ADHD group than in the control group. The Group  $\times$  Condition interaction did not reach significance,  $F(1, 58) = 2.18, p = .15, \eta^2 = 0.04$ , meaning that overall, both groups showed the same degree of increase in fixation duration in the congruent condition compared with the incongruent condition. All the above findings should be interpreted cautiously because of the significant triple interaction,  $F(1, 58) = 4.46, p < .05, \eta^2 = 0.07$  (see Figure 4). To detect the source of the triple interaction, two separate analyses for words (i.e., distracters) and color (i.e., target) were conducted. In the words analysis, the group main effect was the only one to reach significance,  $F(1, 58) = 9.89, p < .01, \eta^2 = 0.15$ . That is, the overall fixation duration of the group with ADHD was longer than that of controls. Condition main effect and Group  $\times$  Condition interaction did not reach significance,  $F(1, 58) = 0.50, p = .48, \eta^2 = 0.01$  and  $F(1, 58) = 0.03, p = .86, \eta^2 = 0.01$ , respectively. In the analysis of color, group effect reached significance,  $F(1, 58) = 8.36, p < .01, \eta^2 = 0.13$ . That is, the overall fixation duration of the group with ADHD was longer than that of controls. Main effect for condition reached significance as well,  $F(1, 58) = 15.43, p < .001, \eta^2 = 0.21$ , indicating that overall fixation duration in the incongruent condition was longer than in the congruent condition. The Condition  $\times$  Group interaction was marginally significant,  $F(1, 58) = 3.49, p = .07, \eta^2 = 0.06$ . As can be seen in Figure 3, the increase in fixation duration in the incongruent condition compared with the congruent condition was more

pronounced in the group with ADHD than in controls. The fact that this differential effect occurred only with the color stimuli and not with the words is the source of the triple interaction.

**Number of shifts between target and distracter.** This stage of analysis compared the number of shifts between the target and the distracter in the two groups and two conditions. A shift was defined as eye movements between the target and distracter stimuli, without fixating on the neutral area (center of the screen). Mixed-design  $2 \times 2$  ANOVA with repeated measures was performed: Group (control, ADHD)  $\times$  Condition (congruent, incongruent). The first was a between-subject variable, and the second was a within-subject variable. This analysis showed a significant main effect for group,  $F(1, 58) = 6.51, p < .05, \eta^2 = 0.10$ , indicating more shifts between stimuli in the ADHD than in the control group. A main effect was found for condition as well,  $F(1, 58) = 7.11, p < .01, \eta^2 = 0.11$ , meaning that the number of shifts in the congruent condition was smaller than the number of shifts in the incongruent condition. The Group  $\times$  Condition interaction did not reach significance,  $F(1, 58) = 1.83, p = .18, \eta^2 = 0.03$ , indicating that the effect of condition in terms of number of shifts (i.e., congruent  $>$  incongruent) was the same for both groups (see Figure 4).

**Number of fixations on the target (color) and the distracter (word).** This stage compared the number of fixations on each of the stimuli in both groups and under both conditions. Mixed-design  $2 \times 2 \times 2$  ANOVA with repeated measures was performed: Group (control, ADHD)  $\times$  Condition (congruent, incongruent)  $\times$  Stimulus (target—color, distracter—word). The former was a between-subject variable, and the latter two are within-subject variables. This analysis yielded a significant main effect for the group,  $F(1, 58) = 9.81, p < .005, \eta^2 = 0.15$ , meaning that the number of fixations in the ADHD group was higher than the number of fixations in the control group. In addition, a tendency toward a main effect was shown for condition,  $F(1, 58) = 3.67, p = .06, \eta^2 = 0.06$ , that is, the number of fixations in the congruent condition was lower than in the incongruent condition. Stimulus main effect reached significance as well,  $F(1, 58) = 72.06, p < .001, \eta^2 = 0.55$ , indicating that the participants fixated on the target more times than on the distracter. Significant interaction was found between condition and stimulus,  $F(1, 58) = 7.72, p < .01, \eta^2 = 0.12$ , meaning more fixations on the target in the incongruent condition than in the congruent condition, although the number of fixations on the distracter was similar in both conditions. A tendency toward significant interaction was revealed between group and stimulus as well,  $F(1, 58) = 3.35, p = .07, \eta^2 = 0.06$ , meaning that the difference between the number of fixations on the target and the distracter in the ADHD group was greater than the difference in the control group. The group and condition did not significantly interact,  $F(1, 58) = 0.47,$



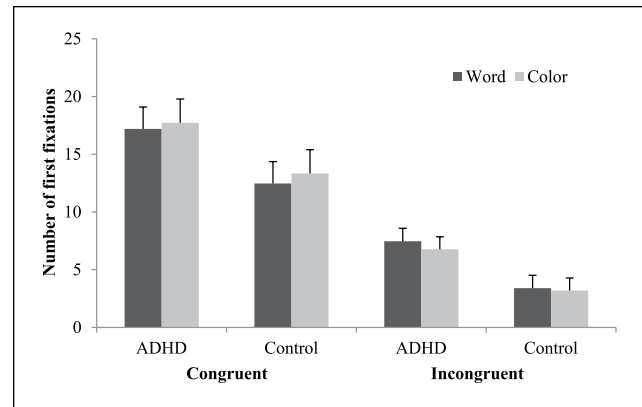
**Figure 5.** Number of fixations on the target and distracter ( $M$  and  $SD$ ) in the control and ADHD groups in the congruent and incongruent conditions.

$p = .50$ ,  $\eta^2 = 0.01$ , meaning that no significant differences were found between the groups regarding the difference between the number of fixations in the incongruent compared with the congruent conditions. The triple interaction did not reach significance,  $F(1, 58) = 0.28$ ,  $p = .60$ ,  $\eta^2 = 0.01$ , indicating that the number of fixations on the distracter in the ADHD and control groups was similar in both the congruent and incongruent conditions, as were the number of fixations on the target in the two conditions (see Figure 5).

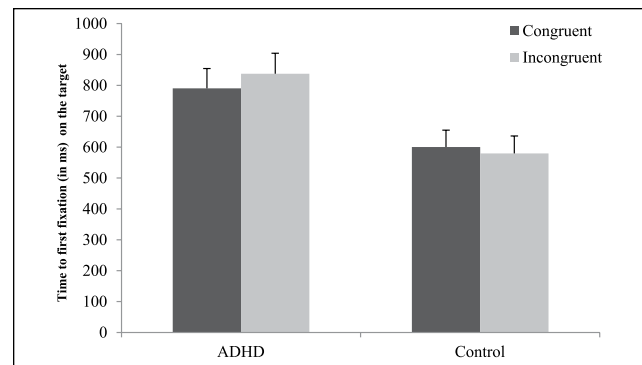
### Eye Movement—Distraction Measures

*Number of trials the target (color) and the distracter (word) fixated on first.* Mixed-design  $2 \times 2 \times 2$  ANOVA with repeated measures was conducted to analyze the effect of Stimulus (the number of times that first fixation was on the color and not the word)  $\times$  Condition (congruent, incongruent)  $\times$  Groups (control, ADHD). The former two are within-subject factors, and the latter is a between-subject factor. It is important to note that to avoid a priori bias as a result of the eyes remaining fixated on the stimulus shown in the previous trial, only fixations that shifted from the central fixation point to one of the stimuli were included in the analysis. In our opinion, these are the only cases that can reflect distraction. This analysis showed a significant main effect for group,  $F(1, 58) = 5.91$ ,  $p < .05$ ,  $\eta^2 = 0.09$ , indicating that overall, the group with ADHD displayed more fixations. Stimulus main effect also reached significance,  $F(1, 58) = 52.28$ ,  $p < .001$ ,  $\eta^2 = 0.47$ , meaning that overall, more fixations were made on the target than on the distracter. All other effects did not reach significance ( $p > .05$ ; see Figure 6).

*Average duration of the first fixation on the word distracter.* Mixed-design  $2 \times 2$  ANOVA with repeated measures was conducted to analyze the effect of Condition (congruent,



**Figure 6.** Number of trials in which participants first fixated on the target (color) and the distracter (word;  $M$  and  $SD$ ) in the control and ADHD groups in the congruent and incongruent conditions.



**Figure 7.** Time to first fixation on the target ( $M$  and  $SD$ ) in the control and ADHD groups in the congruent and incongruent conditions.

incongruent)  $\times$  Groups (control, ADHD). None of the effects reached significance: group,  $F(1, 42) = 2.75$ ,  $p = .11$ ,  $\eta^2 = 0.06$ ; condition,  $F(1, 42) = 0.61$ ,  $p = .44$ ,  $\eta^2 = 0.01$ . The interaction between groups  $\times$  condition,  $F(1, 42) = 0.50$ ,  $p = .48$ ,  $\eta^2 = 0.01$ .

*Time to first fixation on the target.* Here too, we took into account only fixations that started from the central fixation point and shifted either directly to the target or first to the distracter and then to the target. Mixed-design  $2 \times 2$  ANOVA with repeated measures was conducted to analyze the effect of Condition (congruent, incongruent)  $\times$  Groups (control, ADHD). This analysis showed a significant main effect for group,  $F(1, 56) = 7.65$ ,  $p < .01$ ,  $\eta^2 = 0.12$ , indicating that overall, more time elapsed before the group with ADHD first fixated on the target. The condition main effect and the Group  $\times$  Condition interaction did not reach significance,  $F(1, 56) = 0.22$ ,  $p = .64$ ,  $\eta^2 = 0.01$  and  $F(1, 56) = 1.42$ ,  $p = .24$ ,  $\eta^2 = 0.03$ , respectively (see Figure 7).

## Discussion

This research studied eye movement patterns while performing a variation of the Stroop test on adults with ADHD and on a control group. ADHD is characterized by difficulty in response inhibition. This impairment is comprised of three main processes, one of which is interference control, that is, the ability to ignore both internal and external distracters and the ability to restrain automatic responses that compete with the desired response. Previous studies showed that individuals with ADHD struggle to ignore distracters and to inhibit irrelevant responses (Barkley, 1997; Tsal, Shalev, & Mevorach, 2005). The Stroop test assesses the interference control process. Participants are instructed to repress the automatic response of reading the word and prevent it from interfering with the controlled process of naming the color (Boonstra et al., 2010; Lansbergen et al., 2007).

An article that reviewed studies that tested Stroop on adults with ADHD reported significant differences between performance in control and ADHD groups (Seidman et al., 2004). A meta-analysis study included research conducted on Stroop interference in adults and children. The results indicated greater interference in the ADHD group than in the control group (Lansbergen et al., 2007). These results show that the Stroop test can be considered a reliable index to distinguish individuals with ADHD from those without ADHD.

Stimuli in the Stroop test have two dimensions—the color, which is the target and the relevant dimension, and the word, which is the irrelevant dimension and serves as a distracter. In the previous study (Olk, 2013) that tested participants diagnosed with ADHD using a numeric version of the Stroop test while measuring eye movements, targets were not separated from distracters. The critical advantage of the present study is that we used a variation of the Stroop test in which the two dimensions are separated on the screen to enable tracking participants' eye movements toward the target and the distracter separately. Previous studies that separated the word from the color showed that the irrelevant dimension continued to affect the ability to process the relevant dimension and that the Stroop interference effect persisted, though not as powerfully as in the standard configuration (Dyer, 1973; Gatti, & Egeth, 1978).

Of the different possible configurations of the Stroop test, this study tested only the congruent and incongruent conditions. The Stroop effect was defined as the difference in response time in the incongruent and congruent configurations, as defined in a study conducted by Ungar, Nestor, Niznikiewicz, Wible, and Kubicki (2010).

The added value of this study is that eye movements were monitored while participants performed the Stroop test. Eye movements shed additional light on underlying processes and attention allocation while performing the task, in addition to the information that is obtained by

measuring response times and accuracy alone. Olk (2013), who tested healthy control participants, published the only study that tracked eye movements while participants performed the numeric version of the Stroop test. This study showed that the total duration of fixations in the incongruent condition was longer than in the congruent condition. The length of fixations on the target stimulus was longer than fixations on the distracter in both conditions. However, as mentioned above, Olk's study was not designed to track eye movements on target and distracter stimuli separately. The objective of this study was to use eye movements in an attempt to obtain a better understanding of the underlying attention processes that yield a more pronounced Stroop effect in adults with ADHD compared with controls.

The main hypothesis of this study was that the eye movement patterns of participants with ADHD would reflect their difficulty in inhibiting irrelevant information by allocating disproportional attention on the distracter (i.e., words) compared with the target (i.e., color) stimuli. As can be expected based on the behavioral results that showed overall slower response times for the group with ADHD, their overall fixation time (on the distracter and target) was longer than that of controls. This is consistent with previous reports in literature that showed that processing speed is slower in ADHD participants (Mayes & Calhoun, 2007; Shanahan et al., 2006). The slower responses of the participants with ADHD may also be explained by the finding that although both groups made more overall shifts between the target and distracter in the incongruent condition compared with the congruent one, the group with ADHD made more overall shifts than the controls did.

Also coinciding with the behavioral findings, this study found that fixation time in the incongruent condition was longer than in the congruent condition. These findings are consistent with those reported by Olk (2013), who explains that the longer fixations in the incongruent condition may partially reflect the time needed to determine the correct answer when stimuli dimensions conflict, as opposed to when they are congruent. This extra time is required to resolve the conflict between the two dimensions, inhibit the distracter, and activate the target.

The finding that overall, more time was spent fixating on the target than on the distracter was an expected one, as it corresponds with the notion that attention is allocated in accordance with the instructions given and with the task requirements, to support the correct answer (Cohen et al., 2004; Desimone & Duncan, 1995; Duncan, 2006).

An interesting and unexpected finding is that the difference between the groups emerged primarily in duration of fixation and in the overall number of fixations on the target and not on the distracter stimulus. This indicates that the source of the greater Stroop effect in the ADHD group was the longer duration of fixations on the target stimuli in the incongruent condition and not on the distracter as expected.



This indicated that the difficulty experienced by adults with ADHD to ignore distractions stems from a more central process attempting to inhibit the distracter while focusing on the target and not on the distracter. In other words, the fact that the differential effect of congruency (i.e., Stroop effect) of the groups emerged while observing the target and not the distracter is interpreted as an indication that it is not a perceptual process, but rather, a more conceptual one. However, as we hypothesized, individuals with ADHD were generally more visually distracted by the word stimulus than the Control group in both the congruent and incongruent conditions (see Figures 3-5). Thus, consistent with previous studies reported above, participants with ADHD are less efficient in processing the target stimulus when a distracter is present. Additional analyses of more direct measures of the effect of distraction revealed that the group with ADHD was more distracted by the word, as indicated by the fact that their first fixation on the distracter was longer than that of controls. Furthermore, the time to first fixation on the target was longer for individuals with ADHD. It is recommended that in future studies, additional eye-tracking measures (which were not available with our eye tracker) would be analyzed (e.g., saccade/microsaccade rate, velocity, amplitude, and spatial distribution of fixations).

Gualtieri and Johnson (2006) reported that although Stroop test performance of individuals with ADHD improves with age (10-29), their cognitive efficiency does not improve. Similarly, J. L. Smith, Johnstone, and Barry (2004) reported that children with ADHD could reach similar performance rates to those of controls on a Go/No-Go task. Nevertheless, their Event-related potential (ERP) results (N2 Amplitude) indicate that to reach this performance level, they must activate the inhibitory mechanism at an earlier stage than controls. In light of these studies, the results of our study could be interpreted as reflecting an inefficient strategy adopted by the individuals with the ADHD. The eye tracker results indicate that individuals with ADHD focus more on the target than the controls do, possibly in an attempt to look away from the distracter to try to reduce its interference. Apparently, this strategy proves inefficient.

In conclusion, this preliminary study indicates the potential for utilization of the eye tracker as a diagnostic tool for ADHD. The advantage of eye movements over behavioral measures is that the former is automatic and not dependent on the intentional and controlled response of the participant. More research is needed to elucidate the unique eye movement profile characteristic of individuals with ADHD.

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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