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ORIGINAL ARTICLE

Attentional blink in children with attention deficit hyperactivity disorder

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Objective: To explore the temporal mechanism of attention in children with attention deficit hyperactivity disorder (ADHD) and controls using a rapid serial visual presentation (RSVP) task in which two letters (T1 and T2) were presented in close temporal proximity among distractors (attentional blink [AB]).
Method: Thirty children aged between 9 and 13 years (12 with ADHD combined type and 18 controls) took part in the study. Both groups performed two kinds of RSVP task. In the single task, participants simply had to identify a target letter (T1), whereas in the dual task, they had to identify a target letter (T1) and a probe letter (T2).
Results: The ADHD and control groups were equivalent in their single-task performance. However, in the dual-task condition, there were significant between-group differences in the rate of detection of the probe letter (T2) at lag + 1 and lag + 4. The ADHD group exhibited a larger overall AB compared with controls.
Conclusion: Our findings provide support for a link between ADHD and attentional blink.

Keywords: Visual attention deficit; attentional disorders; ADHD; attentional blink; visual perception

Introduction

In our daily lives, we are exposed to a vast number of stimuli that must be organized before being processed by the cognitive system. Indeed, attention is a vital mechanism for humans, one which allows us to filter and select relevant information from the environment.[1]

Attentional functions can be impaired in many disorders, notably in attention deficit hyperactivity disorder (ADHD). ADHD is considered the most common neurodevelopmental disorder in children and adolescents, and its prevalence is estimated at around 5% in schoolchildren and 2.5% in adults.[2,3] Characteristic symptoms in children may include hyperactivity, impulsivity, and difficulties sustaining attention in certain activities.[2] Three presentation types have been identified for this disorder: 1) predominantly inattentive presentation (ADHD-I); 2) predominantly hyperactive-impulsive presentation (ADHD-HI); and 3) combined presentation (ADHD-C).[2]

Children with ADHD do not appear to have problems with some automatic attentional processes.[4,5] However, they usually exhibit difficulties in voluntary processes, such as redirecting attention to new stimuli, sustaining their attentional level or, in some tasks, with persevering.[5-8] Many studies have investigated selective visual attention (i.e., the ability to focus on relevant stimuli while ignoring irrelevant distractors) in children, adolescents, and adults with ADHD. Some of this research indicates that, although ADHD children may be distracted by irrelevant stimuli, they are no more affected than are controls.[9-12]

In the study of attentional disorders, the rapid serial visual presentation (RSVP) paradigm has been used to assess selective attention and the temporal aspects of attention.[13-15] In this paradigm, stimuli are presented in rapid temporal succession, and participants must identify the presence of a target (T1) and a probe stimulus (T2). The stimulus can be a letter, a symbol, a word, or a drawing. The experimental procedure is usually divided into two parts. In the first, participants have to identify a T1 (single or control task). In the second, participants must identify a target (T1) and compare it with a probe stimulus (T2). The probe stimulus is presented after T1 with a variable delay.

When participants are instructed to pay attention to the two stimuli (T1 and T2), they usually perform worse when it comes to identifying the second target (T2). This phenomenon is known as attentional blink (AB). In AB, the processing of the first stimulus (T1) interferes with the processing of the second (T2) and impedes its identification. Around 700 ms after the presentation of T1, detection of T2 improves and reaches the rate of

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identification of T1. An important aspect of this model is that AB does not occur when T2 is presented immediately after T1. In this case, it appears that both stimuli are processed together by the visual stream[13-15] (see also Shapiro et al.[16] and Dux & Marois[17] for a review).

The AB paradigm has been used to explore attention deficits and the temporal characteristics of information processing in normal aging and in people with neurological diseases and psychiatric disorders. Different studies have found large and prolonged attentional blinks in normal aging,[18] in patients with Parkinson's[19] and Alzheimer's[20] disease, in people with chronic focal brain lesions,[21-23] and in drug users.[24]

Among people with psychiatric disorders, some studies have found larger AB magnitudes in adults with Tourette syndrome,[25] children with autism spectrum disorders,[5] children and adults with dyslexia,[26-28] and children and adults with ADHD.[29-34] In general, people with mental disorders have a higher AB effect than controls, although statistically significant differences between groups are not always found.

Two studies have examined AB in children. Li et al.[29] found that the effect was greater in an ADHD group compared with controls. Children with ADHD performed worse in the probe detection test (T2) and took longer to recover from the AB effect. Mason et al.[30] assessed 21 children with ADHD (16 with ADHD-C, one with ADHD-I, and four with ADHD-HI) and found no differences between subtypes. However, the ADHD group did show a lower rate in probe detection (T2) compared with controls. Regarding recovery from the AB effect, the groups took a similar amount of time to reach initial levels of recognition.

In a study of adolescents with ADHD, Carr et al.[31] examined the differences between an ADHD-C group and another group that only exhibited inattention (ADD). The authors found that adolescents with ADHD-C were less accurate than controls in identifying the target letter (T1), but there were no differences between the ADHD-C and ADD groups, or between participants with ADD and controls. However, the ADD group was more accurate (67%) than were ADHD-C (53%) and controls (58%) in detecting the probe letter (T2).

In adult samples, Hollinsgsworth et al.[32] used the AB paradigm to assess the performance of high-functioning adults with ADHD relative to controls. They found that the detection rate among individuals with ADHD was significantly lower than that of controls, and that the ADHD group did not recover from the AB effect for any position of the probe detection (T2). The authors suggested that the ADHD group was selectively impaired in allocating and redirecting attentional resources to the targets. Armstrong & Munoz[33] found no differences between participants with ADHD and controls in duration of AB, but the ADHD group did report fewer targets and probes and made more detection errors than did controls. The authors proposed two explanations for their results: 1) poor vigilance and attentional dysfunction among ADHD participants; and 2) gaze instability, leading ADHD participants to look away from the stream of letters. In another study, Carr et al.[34] examined the performance of 159 adults (72 with ADHD, 20 with childhood histories of ADHD in partial recovery, and 67 controls) on an AB task. They found that the mean target accuracy of the control group was better than that of the ADHD group and slightly better than that of the ADHD in partial recovery group.

In summary, studies have found no differences between ADHD and control groups in the detection of the target at baseline or in the detection of probes appearing just after the target. However, findings do indicate significant differences when performing a dual task, with ADHD individuals tending to identify fewer probes[29,30,32-34] and to present a larger AB effect compared with controls.[29-32,34]

Studies carried out with clinical and community samples using a standard dual-target RSVP suggest that all stimuli in the stream are registered by the retina and processed.[17,35,36] Individuals remain unaware of the T2 target probably because they do not allocate sufficient attentional resources to report the second target (T2) at short T1-T2 lags. Therefore, the non-awareness of the stimulus is due not to a lack of perception but, rather, to problems in selective attention. Among the different models proposed to explain AB,[16,17,37] two[16,37] share a common hypothesis: namely, that AB occurs because the resources available for processing the second target are not available until processing of the first target is completed. Thus, the second target is vulnerable to interference from subsequent stimuli in the stream.

The present study used the RSVP paradigm to investigate AB in children with ADHD-C and controls, with the aim of assessing selective attention and the temporal aspects of attention. We expected that compared with controls the ADHD group would exhibit a worse detection rate for T2, as well as a greater AB effect.

Method

Participants

Thirty participants aged 9 to 13 years (mean ± standard deviation = 10.97±1.06 years) were assigned to one of the following groups:

- ADHD group: Comprised 12 participants (mean age = 10.42±0.996 years; nine males). The diagnosis was made by a clinical psychologist with experience in psychological assessment of children and adolescents, in accordance with DSM-IV-TR[38] criteria, by means of an interview (Clinical Interview-Parent Report Form[39]) and on the basis of scores on both an ADHD questionnaire[40] and the Conners' Rating Scales-Revised,[41] which were completed by the participants' parents and teachers. All participants met DSM-IV-TR[38] criteria for ADHD-C. To ensure the quality of assessment data, a PhD clinical psychologist with experience in the assessment and diagnosis of mental disorders (JAAmador-Campos) reviewed the assessment process, the diagnoses, the exclusion criteria, and the assignment of participants to the ADHD and control groups. The experimenter (IB) was blinded to participant allocation.

- Control group: Comprised 18 participants (mean age 11.33±0.97 years; 10 males), all of whom exhibited fewer than six symptoms of inattention and hyperactivity-impulsivity, as assessed by their parents and teachers using the ADHD questionnaire[40]; they also had T scores below 60 on the cognitive problems/inattention scale, the hyperactivity scale, and the ADHD Index of the Conners' scales for parents and teachers.[41]

The ADHD group was recruited from a foundation that provides psychological and psychiatric services to people with ADHD; the control group was recruited through a private school in Barcelona. Participation was voluntary and unpaid. In all cases, an informed consent form was signed by the child's parents or legal guardians. The principles of the 1975 Declaration of Helsinki (revised in Tokyo in 2004) were adhered to throughout the study.

The ADHD and control groups were equivalent in terms of age ($F_{1,29}$ = 0.880, p = 0.42); a posteriori contrasts (Tukey's honest significant difference) showed no significant differences between the two groups. For all participants, visual acuity (Snellen chart) was normal or corrected to normal (with contact lenses or glasses), and all had normal stereoscopic acuity (Titmus test). The exclusion criteria for both groups were total IQ $<$ 85 according to the Wechsler Intelligence Scale for Children (WISC-IV)[42] and/or presence of any of the following: tic disorders, neurological disorders, pervasive developmental disorders, oppositional defiant disorder, conduct disorder, anxiety and mood disorders, or learning disorders.

Stimuli and apparatus

The task was performed using an ASUS A55V laptop (Intel Core i7). The stimuli, in the form of capital letters, were presented on a 15-inch screen with a spatial resolution of 1280 $\times$ 768 pixels. The letters measured 30 $\times$ 23 mm, such that they subtended a visual angle of 4.3° $\times$ 3.3°. They were all yellow in colour (1 cd/m^2), except for the target (T1), which was green. All the letters were presented against a black background (1 cd/m^2). The stimuli were generated by a software program and consisted of a random sequence of different letters for each trial. This software also controlled the experimental sequence. The participants' responses were recorded by means of a response box and specific software (E-Prime 2.0 Professional, Science Plus Group). A chin rest was used to ensure that subjects were always at a distance of 40 cm from the screen.

Procedure

Each trial involved the presentation in rapid succession of 18 letters at the center of the screen. Each letter was shown for 100 ms, with an interval of 50 ms between stimuli, such that 8.34 letters were presented per second. To prevent the preceding post-image from masking the next letter, a blank image was presented for 50 ms between two successive letters. Thus, the interval between two successive letters (stimulus onset asynchrony, SOA) was 150 ms (100 + 50 ms).

A total of 120 series of 18 capital letters (F, R, P, L, J, A, U, C, E, I, T, H, N, Z, V, S, K, Y) were prepared. Forty of these series were used for the single task, thereby enabling establishment of a baseline (control condition). The remaining 80 series were used for the dual task. The letters appeared in random order within each series. However, depending on the experimental condition (single or dual), either one or two letters could be replaced by the target (T1: X) and the probe (T2: O). Therefore, each series in the single task (control condition) involved 17 distractor letters and one target letter, whereas each of the series used for the dual task involved 16 distractor letters, one target letter (T1: X), and one probe letter (T2: O). In the baseline condition, participants only had to detect the presence of the target letter (T1: X). In half of these single-task trials, the target was not presented (T1: -), i.e., these were negative response trials, whereas in the other half, the target (T1: X) was presented in one of four positions (7, 8, 9 or 10) in the series. In the dual-task condition, participants had to detect the presence of both the target and probe letters (T1: X and T2: O). Furthermore, whereas the target (T1: X) was always presented, the probe (T2: O) was only presented (positive response) in half of the trials, being absent (negative response) in the remainder. The probe letter (T2: O) could appear in positions + 1, + 2, + 3, or + 4 with respect to T1 (lag condition 1-4). Therefore, T1 was followed by a variable period of time: lag + 1 = 150 ms, lag + 2 = 300 ms, lag + 3 = 450 ms, and lag + 4 = 500 ms. Figure 1 shows a graphical depiction of the experimental procedure.

Participants gave their response immediately after presentation of T1 (single task) or T1 + T2 (dual task), with no time limit being imposed. Prior to performing the tasks, participants underwent a training period involving five series, thereby enabling them to practice the keystrokes associated with the possible responses. All the trials were performed in a single experimental session. Each session consisted of a block of 40 single-task trials and another block of 80 dual-task trials. The order of task application was the same for all participants: first the single task and then, after a three-minute rest period, the dual task. Thus, each session began with five practice trials, followed by the 120 experimental trials. The total duration of each session was approximately 15 minutes per participant.

Data analysis

Analysis of hits for single and dual AB tasks was performed by ANOVA.

Results

Data analysis will be presented in two parts. The first concerns the mean proportion of correct responses in the single AB task, while the second considers the mean

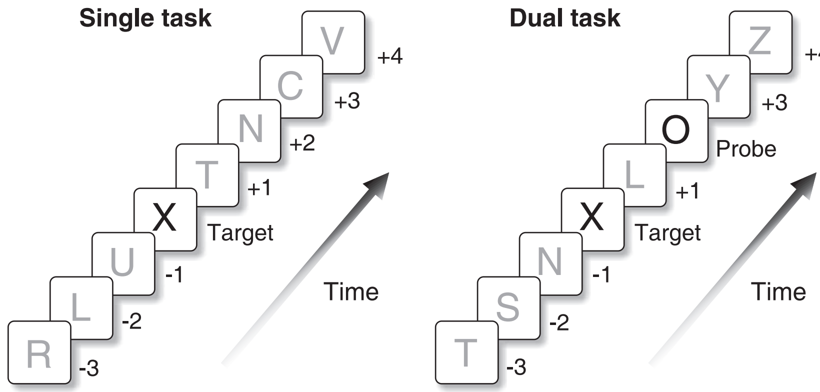

Figure 1 Example of a dual-task trial, using the rapid serial visual presentation (RSVP) stream with a target letter X (T1) and a probe letter O (T2) in position + 2 (lag + 2 condition).

proportion of correct responses in the positive-response trials of the dual task. In the latter case, correct responses were computed only if T2 followed T1 (positive trials), with negative responses being computed as a control.

Single AB task

For each participant, the mean number of T1 detections was calculated by dividing the total number of correct targets (hits) by the total number of trials (40 trials). A between-within 2 (Groups) x 2 (Trial type) ANOVA was then run to compare the proportion of hits in the ADHD and control groups. The repeated measures variable was trial type (positive or negative response), whereas group was the between factor. The ANOVA revealed no significant differences for the single effect of group ($F_{1,28}$ = 0.927; p = 0.344), nor for the single effect of trial type ($F_{1,28}$ = 2.607; p = 0.118), nor for the group vs. trial type interaction ($F_{1,28}$ = 0.163; p = 0.690). This meant that the two groups were equivalent in their single-task performance.

A second 2 (groups) x 4 (position of T1) ANOVA was then run to compare the proportion of hits in the ADHD and control groups. The repeated measures variable was position of T1, while group was the between factor. The ANOVA revealed no significant differences for the main effect of group ($F_{1,28}$ = 3.171; p = 0.086), nor for the main effect of position of T1 ($F_{3,84}$ = 0.119; p = 0.949), nor for the group vs. trial type interaction ($F_{3,84}$ = 1.760; p = 0.161). Figure 2 shows the detection rate for the ADHD and control groups on the single and dual tasks.

Dual AB task

The proportion of correct probe detection (T2) following a T1 detection was calculated for each participant according to the position of the T2 (lag). Thus, we have a null lag (lag 0 = 0 ms) for those trials in which T2 was not presented (negative responses), and four additional lags corresponding to the four positions used in trials where T2 was presented with a delay (lags), that is, positive responses.

ANOVA showed no significant effect of group ($F_{1,28}$ = 3.171; $p < 0.086$; η^2p = 0.096), but there was a significant effect of lag ($F_{4,112}$ = 4.064; p = 0.004; η^2p = 0.186). This latter effect is what characterizes the AB. Finally, a significant effect for the group vs. lag interaction was also observed ($F_{4,112}$ = 3.405; p = 0.011; η^2p = 0.028). Although both groups showed the AB effect, they differed significantly in their detection rate for T2

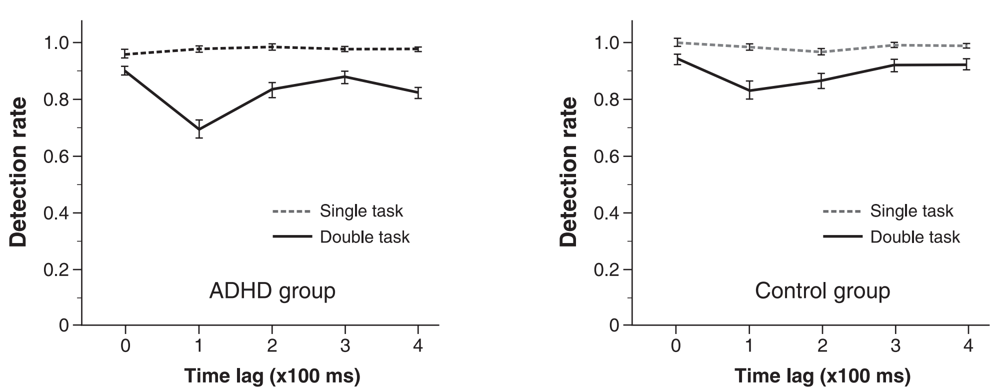

Figure 2 Proportion of correct detections (detection rate) in the attention deficit hyperactivity disorder (ADHD) and control groups on the single and dual tasks. Error bars show the standard error.

at lag + 1 (t_{28} = 2.24; p = 0.033) and for T2 at lag + 4 (t_{28} = 2.62; p = 0.014) (Figure 2).

Discussion

This study used the RSVP paradigm to analyze the performance of children with ADHD and controls. On the single task, we found no statistically significant differences between the groups in their ability to identify the target (T1). These results are in line with previous reports showing that children (mean age = 10.6±1.6 years[29] and 10.0±1 years[30]), adolescents (aged 13-17),[31] and adults (mean age = 29±12 years[33] or aged 18-35[34]) with ADHD perform similarly to controls on tasks of this kind.

We expected that children with ADHD would show a worse detection rate of the probe letter (T2) compared with controls. Marginally significant differences between groups on the dual task were found ($p < 0.086$), with ADHD participants achieving a lower detection rate for the probe letter (T2). However, the variable group was modulated by the lag factor, as showed in the statistically significant group vs. lag interaction, which reflects the AB effect. Published findings regarding perceptual and attentional deficits in ADHD are controversial. Some studies show a lower rate of probe letter identification in ADHD participants,[29,30,32-34] whereas others have found no differences between ADHD participants and controls.[31]

We also expected a greater AB effect in the ADHD group than in controls. Results confirmed this hypothesis inasmuch as both groups differed significantly in the rate detection of the probe (T2) at lag + 1 and lag + 4. However, these results should be treated with caution, because the size effect found for the lag factor was small (accounting for 18.6% of the total variability in performance score). This probably occurs because, 300 ms after T1, the AB effect begins to vanish. These results agree with other studies[29,32,34] showing that children and adults with ADHD have an increased AB effect.

On a conceptual and theoretical level, Chun & Potter[37] proposed a two-stage model to explain AB. In the first stage, all items are processed in parallel at a superficial level, whereas in the second stage, in-depth processing of stimuli occurs serially. This second stage is necessary for identification of the item. Items in positions T + 1 to T + 6 (i.e., presented 100 ms to 600 ms after T1) can be overwritten by stimuli appearing in the first stage, while the probe is still being processed in the second stage. After approximately 600 ms, stage 2 is completed, and the probe can be transferred from stage 1 to stage 2, enabling the stimulus to be detected. Differences between individuals with ADHD and controls most commonly appear in the second stage, given that this condition requires more attentional resources. Therefore, the lower detection rate in children with ADHD and the longer time to recover from AB may reflect difficulties in processing stimuli quickly and efficiently.

We found no differences between groups in terms of the time needed to recover the initial levels of probe identification in the dual task. However, children with ADHD showed a larger AB effect compared with controls. Studies have generally shown that ADHD participants take longer to recover from AB,[29,32,34] and our results seem to support this view. The slower the recovery from AB, the more prolonged the time to reach the initial levels of probe stimulus (T2) identification.

In summary, the results of this study indicate that children with ADHD and controls perform equivalently when it comes to detecting a stimulus in a single task, thereby suggesting that perceptual processes are functioning correctly in both groups. However, in the dual task, we found that the groups differed in their detection rate for T2 at lag + 1 and for T2 at lag + 4. This finding may indicate that higher-level processes (such as those involved in the assignment of processing resources) are less efficient in children with ADHD than they are in controls. This means that the differences found in terms of the AB effect cannot be attributed to functioning of the visual system, but are probably related to attentional processes.

Previous studies have shown that children with ADHD have no difficulties in attentional processes related to visual discrimination and orientation.[5-8] However, major difficulties appear in tasks that require sustained attention, or attentional control and redirection of attention.[5,8,9,12] Most studies with groups of children, adolescents, and adults with ADHD which used the RSVP paradigm have shown that these participants exhibit a powerful AB effect as compared with controls. Attention, encoding, and retrieval processes can be affected in people with ADHD, leading to difficulties to manage the demands and attentional requirements of the tasks.[17,35,43]

From a clinical and diagnostic approach, these findings are important because cognitive tasks measuring executive functions are often of little use to differentiate subjects with ADHD from controls.[44-46] Therefore, new tasks using the RSVP paradigm or oculomotor markers may be very useful in the differential diagnosis of ADHD.[47-49] One limitation of the present study was the small sample size, which is explained by the fact that we only included ADHD patients without comorbidities and not on medication. Futures studies can include groups of children with ADHD-I and ADHD-HI to assess whether these difficulties occur in all types of ADHD or only in the types involving attention problems (ADHD-C and ADHD-I) or hyperactive-impulsive characteristics (ADHD-C and ADHD-HI). Future studies may also include children with ADHD and other comorbid disorders, especially learning disorders, due to the importance of the attention problems in this condition.

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Disclosure

The authors report no conflicts of interest.

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