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Attentional blink differences between adolescent dyslexic and normal readers[☆]

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Abstract

The goal of this study was to evaluate the possibility that dyslexic individuals require more working memory resources than normal readers to shift attention from stimulus to stimulus. To test this hypothesis, normal and dyslexic adolescent participated in a Rapid Serial Visual Presentation experiment (Raymond, Shapiro, & Arnell, 1992). Surprisingly, the result showed that the participants with dyslexia produced a shallower attentional blink than normal controls. This result may be interpreted as showing differences in the way the two groups encode information in episodic memory. They also fit in a cascade-effect perspective of developmental dyslexia.

1. Introduction

An interesting way of understanding developmental dyslexia is in terms of a *cascade-effect* perspective in which small difficulties or deficiencies early in the developmental process snowball into large-scale reading problems later in development and in adulthood. A well-known example is the Matthew effect (Stanovich, 2000). It has been shown that pre-school children who lack exposure to literacy activities usually do not develop phonological awareness which, in turn, reduces their ability to learn spelling-to-sound correspondences. As Stanovich points out, this "...initiate[s] a causal chain of escalating negative side effects (p. 162)" that includes poorer decoding skills, word identification skills, and metacognitive abilities. Thus, these children read less, do not improve from practice, and fall into a pattern of failure that is difficult to stop or to help via remediation.

The cascade-effect idea can also be evoked to explain the impact of small deficiencies in perceptual or cognitive processing on the development of reading. For instance, while theorizing about the relationship between fluency (naming-speed) deficits and reading failure, Wolf and Bowers (1999) suggested that inadequate perceptual and/or cognitive processing could hinder the development of phonemic and orthographic representations in long-term memory. Consequently, children with such processing difficulties would need more practice than their unimpaired peers to reach a comparable level of reading fluency.

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Nicolson and Fawcett (2000) tested this possibility in a series of experiments on automaticity. Dyslexic adolescent readers and controls were asked to participate in a computerized maze navigation task (presented as the classic Pacman arcade game). In the first phase of the experiment, the participants were trained to use four keys to travel in a maze as quickly as possible. The training continued until the participants reached asymptote. In the second phase, participants were required to relearn the maze using different key mappings. Finally, one-year later, participants were once more invited to complete the maze task using the key mappings of the second phase in standard and dual-task conditions. Nicolson and Fawcett found no significant differences between the groups in their capacity to change key mapping, on their skill retention over a year, or on their ability to navigate in the maze under dual-task conditions. However, the dyslexic participants' performances were poorer than those of normal participants in all conditions even after extensive practice. Nicolson and Fawcett concluded that the quality of the dyslexic participants' performances, not their ability to automatize skills per se, were deficient.

A follow-up question is what processes are responsible for this problem. One possibility is that dyslexic individuals need more working memory resources than normal controls to shift their attention from stimulus to stimulus. This makes activities requiring quick processing particularly challenging for them because they lack the resources to keep-up with the stimulus flow and to efficiently encode stimulus-specific information in long-term memory simultaneously. In consequence, we would expect dyslexic individuals to need more practice to reach levels of performance similar to those of normal controls. This account is consistent with Nicolson and Fawcett's (2000) results and with Wolf and Bowers's (1999) model of reading fluency deficits.

The Rapid Serial Visual Presentation (RSVP) paradigm provides a means to evaluate this hypothesis (Raymond, Shapiro, & Arnell, 1992). Typically, a continuous stream of rapidly presented stimuli (often alphanumeric characters) is presented. Two stimuli are marked as targets on some physical dimension (color, font style, etc.,) and the other stimuli are distractors. The participants' task is to report these two targets at the end of each stream. The key result is that when the two targets are shown within approximately 500 ms of each other and the first target is successfully reported, there is a sharp impairment in reporting the second target. This phenomenon is known as the attentional blink.

Although different theories have been proposed, there is sufficient overlap in the accounts to suggest a general explanation of the attentional blink (Shapiro, Arnell, & Raymond, 1997). First, it is assumed that all stimuli in the RSVP stream are processed to a certain extent and that they activate information in long-term memory via priming effects (see Shapiro, Driver, Ward, & Sorensen, 1997). Nevertheless, because of distractor interference, the first target must receive a high degree of attention to be stored in a way to make a subsequent report possible. Thus, while the first target is still being processed, fewer attentional resources are available for the second target, which make it vulnerable to interference or decay. This is the attentional blink.

Chun and Potter (1995) further suggest that this incapacity to successfully consolidate both targets when they are presented within 500 ms of each other reflects the limited-capacity processing of working memory. From this perspective, it may be argued that the RSVP paradigm taxes the control mechanism in working memory (Baddeley, 2000; Baddeley & Hitch, 1974). This control mechanism may also be thought to be responsible for attention shifts. Thus, if dyslexic individuals use more resources to shift their attention from stimulus to stimulus, then they should have even fewer resources available to consolidate the first target in the RSVP paradigm.

The goal of this study was to compare normal and dyslexic readers' performances in the RSVP paradigm. We hypothesized that if dyslexic participants generally need more working memory resources than normal controls to shift attention from stimulus to stimulus, then they should find it more difficult to report second targets when first targets are successfully identified in the RSVP task. In other words, they should show a longer attentional blink period.

2. Method

2.1. Participants

Twenty adolescents, from Montréal, Québec, participated in this study. Ten dyslexic adolescents were recruited from specialized schools for students with learning disabilities and special needs (nine males, one female). Ten aged-matched control adolescents were recruited from public and private high schools (nine males, one female). Consent was obtained from the school authorities, the parents and the adolescents. The participants received a five-dollar gift certificate as compensation.

The participants were tested using the Word Identification and Word Attack subtests of the Woodcock Reading Mastery Test-Revised, the four literacy subtests (General Vocabulary, Syntactic Similarities, Paragraph Reading, and Sentence Sequencing) of the Test of Reading Comprehension, 3rd edition (TORC-3), and on non-verbal ability using the age-appropriate Block Design subtest from Wechsler Intelligence Scale for Children-third edition (WISC-III) or the Matrix Reasoning subtest from the Wechsler Adult Intelligence Scale (WAIS-III).

All the participants with dyslexia obtained a standardized score of at least one standard deviation below the norm on (1) TORC-3 Reading Comprehension Quotient (RCQ), Word Identification, and Word Attack; or (2) Word Identification and Word Attack; or (3) RCQ and Word Identification; as well as a normal or above-normal non-verbal ability. Moreover, the normal readers were significantly better than the dyslexic readers on all the reading measures: Word Identification, $t(18) = 2.89$, $p = .01$, for which the means (with standard deviations in parentheses) were 103.80 (10.63) vs. 86.20 (16.07); the Word Attack test, $t(18) = 4.16$, $p = .001$, 103.80 (8.46) vs. 83.40 (12.99); and on the RCQ, $t(18) = 3.79$, $p = .001$, 95.10 (17.12) vs. 68.90 (13.62). However, the groups were equivalent in age, $t(18) = -.19$, $p = .85$, 15.35 (1.54) vs. 15.52 (2.30); and in non-verbal ability, $t(18) = -.31$, $p = .76$, 102.00 (12.95) vs. 104.00 (15.78).

2.2. Materials and design

The stimuli were the digits from 0 to 9. On each trial, a continuous stream of 16 digits was presented on a black background, for 100 ms each. Two non-identical digits were randomly selected to be targets. They were presented in red. The 14 remaining digits were distractors and were presented in white. The first target always appeared in position 3–7 within the stream and the second target always appeared 1–8 positions following the first target. The only constraint was that the same digit was never presented twice in a row. There were eight lags (stimulus onset asynchrony increasing in steps of 100 ms as a function of the number of intervening stimuli) between the first and second target. When the lag was 1, there were no distractors between the targets. Each subject took part in one session that consisted of 400 trials divided into 10 blocks. Within each block, the five target positions by the eight lag combinations were each presented once. The first two blocks were practice and were excluded from the data analysis.

2.3. Procedure

All instructions and stimuli were presented on Pentium IBM-compatible computers. The program MEL Professional v.2.01 provided the experimental instructions, presented the material, and recorded the responses. Participants initiated each trial. First, they saw a fixation point, the "*" character, for 800 ms followed by a blank screen for 200 ms. Next, the 16 digits were presented individually for 100 ms in the center of the screen. Finally, a mask, the " &" character, was presented for 100 ms. At this point, the participants were required to report the two targets, in order, by pressing the corresponding digits on the numeric keyboard. No feedback was provided. The stimuli were in the Mel Professional "Rome20" font and were viewed from a distance of approximately 50 cm. Each stimulus subtended on average $.85 \times 1.43$ degrees of visual angle.

3. Results

First, a 2×8 ANOVA was conducted on the number of correctly identified first targets to ensure that both reading groups were performing the RSVP task at similar levels of ability. The between-group variable was reading Group (Normal vs. Dyslexic) and the within-group variable was experimental Block (1–8). The main effect for Group, $F(1,18) = 1.24$, $p = .28$, the main effect for Block, $F(7,126) = 1.15$, $p = .34$, and the interaction between these factors, $F(7,126) = .17$, $p = .99$, failed to reach significance. Performance averaged over all blocks was 52.2% ($SD = 20.0$) for the Normal group and 60.8% ($SD = 17.8$) for the Dyslexic group. These results suggest that the groups did not differ in their capacity to report the first target. Thus, it is unlikely that the dyslexic group experienced more difficulties with the RSVP procedure than the control group.

A second 2×8 ANOVA was conducted on the number of correctly identified second targets that followed correctly identified first targets. The between-group variable was again reading Group (control vs. dyslexic) and the within-group variable was Lag (lag between the first and second target: 1–8). The data are presented in Fig. 1. A significant main effect was found for Lag, $F(7,126) = 9.95$, $p = .001$, and a trend was found for Group, $F(1,18) = 3.89$, $p = .065$. The interaction between these factors was significant, $F(7,126) = 2.86$, $p = .008$. Surprisingly, however, the interaction pattern seen in the Figure shows that the individuals in the Normal group had an

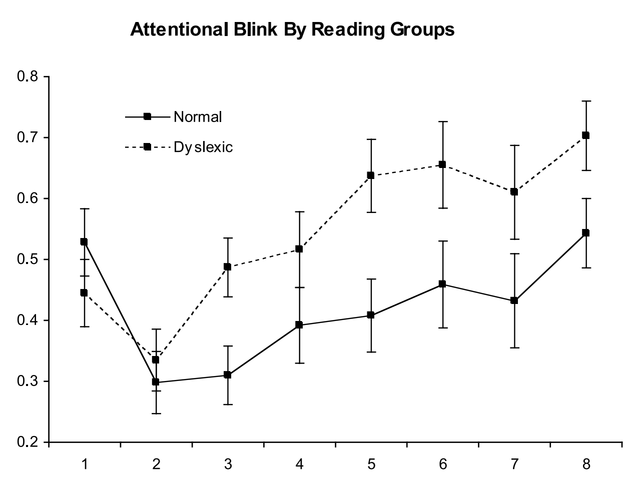

Fig. 1. Response accuracy (with standard error bars) in percentages for second targets (T2) when the first targets (T1) were correctly reported. Chance performance level was 10%.

attentional blink effect persisting over more lags than those in the Dyslexic group, contrary to what we had hypothesized. In a follow-up analysis, the data from lag 1 were removed on the view that temporally contiguous targets are captured in the same perceptual trace, therefore allowing the second target to escape the blink (Shapiro, Arnell et al., 1997). Thus, the resulting Group (Normal vs. Dyslexic) × Lag (2–7) analysis included only the lags that are directly related to the attentional blink phenomenon. In this analysis, both Lag, $F(6,108) = 11.80, p < .001$, and Group, $F(1,18) = 5.49, p = .03$, were significant, but not the Group × Lag interaction, $F(6,108) = 1.06$, $p = .39$. Hence, the data indicate that there was a statistically reliable effect in which the normal readers produced a longer attentional blink period than did the dyslexic readers.

4. Discussion

The goal of this study was to evaluate the possibility that dyslexic individuals would need more working memory resources than normal readers to shift attention from target to target in the RSVP task. Such a need for working memory resources would be revealed in a longer attentional blink effect. Contrary to our expectations, however, the normal readers produced a longer attentional blink period than the dyslexic readers. Furthermore, this result could not be attributed to a general group difference in performing the RSVP procedure because there was no significant difference in reporting the first target. Thus, we are left with an apparent paradox: normal readers performed worse on the RSVP task than dyslexic readers.

One possible way to resolve this paradox is to consider two factors that affect working memory's control mechanism in the RSVP paradigm. The first factor concerns the limitation on resources available for encoding two targets presented within a given time frame because of the need to deal with the interference caused by distractors. This resource limitation is central to the standard interpretation of the attentional blink (Chun & Potter, 1995; Shapiro, Arnell et al., 1997) and explains the presence of the attentional blink in both the normal and dyslexic readers. A second factor concerns a further limitation due the continued processing and integration of the stimuli once they have been encoded in working memory. We can expect that normal, relatively skilled readers will automatically, because of their experience in reading, attempt to continue processing symbolic stimuli, such as numbers and letters, retrieving information about them from long-term memory, creating episodic memory traces (e.g., as posited in the instance based theory of processing; Logan, 1988), and attempting to integrate information across the input. The dyslexic readers, on the other hand, may simply be responding to the immediate task demands of encoding the stimuli for recall at the end of the trial without processing them further. Thus, the dyslexic readers perform "better" in the RSVP paradigm—that is, have a shorter lasting attentional blink—because they do not automatically allocate control mechanism resources to process the stimuli beyond initial encoding. At the same time, however, they allocate similar amounts of resources as normal readers to maintaining the targets in working memory. In terms of Logan's (1988) instance theory of automaticity, we could speculate that dyslexic individuals create fewer retrievable episodic traces in long-term memory when processing stimuli in activities such as reading, arcade games, and the RSVP task that require rapid processing. This would be consistent with our results, with those of Nicolson and Fawcett (2000) on automaticity, and with Wolf and Bowers (1999) model of reading fluency deficits.

Further research is necessary to test this hypothesis about the nature of processing deficits in dyslexia. It will be important to replicate the basic finding that dyslexic individuals have shorter, not longer, attentional blink periods compared to normal readers. Moreover, more direct evidence would be useful to support the hypothesized link between the duration of the attentional blink and the additional processing postulated above for normal but not dyslexic readers. Such research might require a creative adaptation of the RSVP paradigm that would permit one to evaluate the quality of *first* target processing in relation to the length of the attentional blink period. Such a development would take us beyond the usual focus of RSVP research that has, until now, addressed mostly factors influencing the presence, absence, and magnitude of the attentional blink. Finally, from a cascade-effect perspective of developmental dyslexia, this research is promising because it could provide a way to investigate the role of key processing elements in the acquisition of fluent reading skills.

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