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Research report

Dyslexia and practice in the attentional blink: Evidence of slower task learning in dyslexia

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ABSTRACT

In this paper we provide an extension to our previous investigation into dyslexia and the attentional blink (AB) (Badcock et al., 2008). The AB is a phenomenon of temporal attention whereby there is a performance cost in reporting a second target when it appears within 500 msec of a first target. We examined performance differences between the first and second 90 trials in a single AB session in a group of adult readers as well as in 6 blocks of 30 trials for T1 only. Overall, there was a significant improvement across the session but most critically, this improvement was greater in magnitude and slower in the phonological dyslexic observers than in control observers. Therefore, group differences were related to rate of improvement. In line with a recent review of the literature, it is suggested that the overall performance difference between the groups relates to general performance factors and not the AB per se. Whether extended practice would entirely attenuate the group difference remains to be seen but it is suggested that the general performance difference relates to development of successful coordination of visual and temporal uncertainties in the distracter and target stimuli.

1. Introduction

Dyslexia is defined as an inability to read as might be expected by an individual's general abilities and experiences. One of the major factors considered to contribute to this difficulty is a deficit in dealing with the phonology of written and spoken language (e.g., Ramus et al., 2003). There is also considerable evidence suggestive of non-phonological deficits (Farmer and Klein, 1995; Valdois et al., 2004; Wolf et al., 2002). This paper is concerned with temporal attention: specifically that measured within a rapid serial visual presentation (RSVP) and a phenomenon known as the attentional blink (AB). In our original investigation (Badcock et al., 2008) we suggested that after controlling for baseline differences between dyslexic and control performance there was no evidence for a differential AB effect in dyslexia. In this paper we examined whether some of the variation in the baseline difference might be due to slower task learning in dyslexia. We provide a comparison of dyslexic and control performance across a dual-target task experimental session.

An RSVP consists of a series of items, commonly letters or numbers, presented one after the other at the same spatial location. A standard presentation rate is one item every 100 msec. Prior and following items provide forward and

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backward masking of a currently displayed item. Asking observers to search for two target items within an RSVP is one way of examining temporal attention and also the temporal cost in processing one target upon another. The AB is a deficit in processing the second of two targets when the second target (T2) is presented within approximately 500 msec of the first target (T1). This effect was initially investigated by requiring observers to identify a white letter (T1) and detect a black letter X (T2) within a series of letter distracters (Raymond et al., 1992). Our understanding of AB has developed with a multitude of investigations but it appears that performance is governed by restricted higher level processing of T2 due to an interaction of attention to T1 and distracter items (Olivers and Meeter, 2008). When T2 immediately follows T1, the cost to T2 performance is more or less absent, an effect known as *lag-1 sparing* (Visser et al., 1999). In fact, observers are capable of processing more than two targets in succession if the series is not disrupted by distracter items (Kawahara et al., 2006). In this sense, the AB effect can be related to the prioritization of T1 processing relative to T2 (capacity sharing, e.g., Tombu and Jolicoeur, 2005) and the speed of temporal recovery from disruptions to an internally driven attentional state required for a reportable representation of T2 (temporary loss of control, e.g., Di Lollo et al., 2005; see also Nieuwenstein et al., 2009).

Quite a few researchers have concerned themselves with the relationship between reading and AB performance (Buchholz and Davies, 2007; Facoetti et al., 2008; Hari et al., 1999; La Rocque and Visser, 2009; Lacroix et al., 2005; Lallier et al., 2010; McLean et al., 2009; McLean et al., 2010; Visser et al., 2004) and whilst it is clear that the two abilities are linked, the exact nature of this link is a point of contention. Initially Hari et al. concluded a prolonged AB effect in dyslexic readers suggesting that the time to AB recovery was longer in this group. This research utilised a traditional white letter identification and black letter X detection paradigm as in the original reports of the AB effect (Raymond et al., 1992) and suggested that dyslexia was associated with sluggish attentional shifting. In our own research attempting to replicate this work, we found differences between the groups suggesting poorer T2 report; however, performance at the longest inter-target intervals (ITIs) remained different between the two groups suggesting a difference in baseline performance (Badcock et al., 2008). When variation in baseline performance was removed, we found no evidence of AB differences between dyslexic and control readers. The current state of the evidence is clearly elucidated by McLean et al. (2010) obviating the necessity of a detailed review here. McLean et al. suggest that dyslexic readers do demonstrate lower overall sensitivity to targets within an RSVP; however, this performance deficit is general and not specific to the AB effect. They found no evidence for a deeper or longer AB effect in dyslexia. McLean et al. also point out that the majority of AB research in dyslexia fails to demonstrate an interaction effect which is critical to demonstrating a specific AB difference. Therefore, the current state of the literature can be summarised as a general difficulty with the RSVP task and not the AB effect per se (see the Discussion for further considerations of the current state of the literature).

In this paper we provide an extension to our earlier investigation (Badcock et al., 2008) and examine performance differences across 180 trials of dual-target session. Performance improvement with practice has been investigated within the AB: Maki and Padmanabhan (1994) demonstrated that sensitivity increases with multiple exposure to dual-target RSVPs. Their research was conducted over an extended practice period of multiple RSVP sessions whereas our research considered only a single session. The purpose was to compare changes in performance across the session in the Dyslexic sample compared with our Control group and investigate whether differences in the rate of task learning might account for some of the general difficulties dyslexic readers have with RSVP tasks.

2. Method

2.1. Participants

Participants were recruited through The Dyslexia Project at The University of Western Australia. Recruitment for this project was originally conducted using newspaper and radio advertisements soliciting participation in dyslexia research. The research was approved by the ethics committee of the University of Western Australia and informed consent was obtained prior to participation in the research. Reading ability was based upon a measure of phonemic decoding from the Test of Word Reading Efficiency (TOWRE; Torgesen et al., 1999). This is a speeded measure assessing the rapid reading of non-words in a 45 sec period. Percentile ranks were taken from the manual, with performance for those aged above 24 years being based on the 24-year-old standardisations. Dyslexia was defined as a phonemic decoding score below the 10th percentile (Z-score < -1.29) in conjunction with a reported history of reading difficulties and at least average general ability. The control group was defined as having a phonemic decoding score greater than the 25th percentile (Z-score $> -.67$), no history of reading difficulties, and at least average general ability. The phonemic decoding criteria refer to the Poor or below and Average or above TOWRE descriptions from the manual (Torgesen et al., 1999) for the dyslexic and control criterion respectively.

There were 14 individuals (10 females) in the Dyslexic group, with a mean age of 40.83 (SD = 10.17, minimum = 20, maximum = 65). The 15 individuals (11 females) in the control group had a mean age of 40.42 (SD = 8.40, minimum = 23, maximum = 56). Phonemic decoding percentile ranks were converted to Z-scores. The mean for the Dyslexic group was −1.38 (SD = .07) and for the Control group, .29 (SD = .67). Control phonemic decoding was significantly higher than that of the Dyslexic group; $t(27) = 9.27$, $p < .01$, Cohen's $d = 3.44$. Therefore this group should be considered to have phonological dyslexia.

General ability was assessed using the non-verbal matrices of the Kaufman Brief Intelligence Test (Kaufman and Kaufman, 1990). There was no significant difference between groups: Dyslexic (M = 102.9, SE = 1.96), Control (M = 108.7, SE = 2.13), $t(27) = 2.00$, $p > .05$. All participants were free of neurological conditions which may have affected the interpretation of the results.

2.2. Materials and procedure

The stimuli were displayed on an Liquid Crystal Display (LCD) monitor running at 60 Hz (16.6 msec/frame). The RSVP program was written in Matlab 6.5 (MathWorks, 2003) utilising the Psychtoolbox (Brainard, 1997).

The RSVP included uppercase letter stimuli in Arial font, subtending approximately 1° of visual angle in height and .95° width at a viewing distance of 50 cm. The background was a light green colour (luminance of 20.4 cd/m^2 measured using a Pritchard PR 650 colorimeter). Each trial consisted of a fixation cross presented for 500 msec, followed by 7–18 distracter letters, a first target, 0–11 distracters, a second target (B, F, Y, or X), and 1–12 distracter letters. There were always 13 items following T1, and T2 was always followed by at least one distracter. Each item was presented for 100 msec and there were between 21 and 32 items in each trial. Therefore, T2 could be presented at ITIs from 100 to 1200 msec following the onset of T1. T1 was always a white letter (luminance of 36.6 cd/m^2), randomly selected from the distracters. T2 and the distracters were presented in black (luminance of <.1 cd/m^2). The distracter letters were randomly selected from the alphabet excluding I, O, Q, due to their poor masking properties; B, F, Y, and X as they acted as targets; and T1 which was selected on each trial. B, F, and Y were used as distracter items in the single-target task which is not reported in the current experiment.

Participants were instructed to identify a white letter and then detect the presence of an X. It was also stated that the X, if present, would appear after the white letter, which would always occur, and that identification of the white letter should be the primary task. Responses were entered by the participants using a standard keyboard when prompted at the end of each trial: for T1, the corresponding letter was used on the keyboard, and T2 responses utilised the '1' and '0' number keys to indicate presence or absence of the letter X. Feedback was given for five practice trials, or until the task was understood.

There were 180 trials in the dual-target condition, presented in six equal blocks. For 120 of these trials T2 was the letter X. The remaining trials acted as letter X absent trials with only T1 being presented: for these, T2 was replaced by a letter randomly selected from the distracter list. The ratio of target to catch trials followed Hari et al. (1999). T2 absent and present trials as well as ITI were randomised within the 180 trials.

As overall performance comparisons have been made elsewhere (Badcock et al., 2008), target performance summarised as a function of ITI is reported in this paper. Raw T1 identification and T2 contingent sensitivity were calculated. T2 contingent sensitivity considers only those trials for which T1 was correctly identified, allowing for an inference of target processing interference. A non-parametric sensitivity index, A′ was used, as this does not make assumptions regarding the distribution of responses (Stanislaw and Todorov, 1999). These summaries were performed for the first and second 90 trials. First half performance was subtracted from second half performance in order to estimate a half difference measure with respect to each target at each ITI.

A further, more sensitive summary was performed with respect to T1. Rather than the half comparison, T1 proportion correct was summarised by six blocks of 30 trials. The summaries were based upon only those trials for which T2 was also presented; that is, T2 absent trials were not included. The block summary was not conducted for T2 due to the large influence of ITI and there being inadequate trials to summarise by ITI within each block. Curve fitting to these data was performed using GraphPad, Prism (Software Makiev, 2007)

It may be important to note that prior to the dual-target RSVP all participants completed 120 trials of a single-target RSVP where they were asked to detect the presence of a black letter which was altered every 40 trials. Pilot research indicated that this did not impact upon overall sensitivity in a subsequent dual-target task.

3. Results

T1 identification and T2 contingent sensitivity are reported for the phonological Dyslexic and Control groups as a function of ITI and task half (first *vs* second 90 trials) in Fig. 1. There is no clear difference between groups with respect to T1; however, accuracy is higher in the second half. With respect to T2, Dyslexic performance is lower than Control performance after 500 msec in the first half but closer to Control performance in the second half. In both groups there is a significant AB pattern, with performance at shorter ITIs lower than later ITIs; and accuracy is higher in both groups in the second half. The half and AB patterns were confirmed via a 2 (Half) by 12 (ITI) repeated measures analysis of variance (see Table 1). For both T1 and T2 accuracy was higher in the second half and the main effect of ITI for T2 reflected significantly lower sensitivity at ITIs less than 600 msec relative to later ITIs (all $p < .01$).

The main concern for this report relates to the between group comparison of the half differences performance. T1 and T2 half differences, that is, second half performance minus first half performance at each ITI, is reported as a function of ITI for Dyslexic and Control groups in Fig. 2. Half difference scores of zero correspond to no difference between the two halves and high values correspond to greater improvement across halves. There is a pattern of greater improvement in the Dyslexic group. This statistical significance of this pattern was tested using a 2 (Group) by 2 (Target) by 12 (ITI) mixed ANOVA. The inferential statistics are reported in Table 2. The only significant effect refers to the group comparison, relating to higher half differences in the Dyslexic group.

To provide a more sensitive comparison of the changes in performance with practice, T1 mean accuracy was calculated for the T2 present trials within blocks of 30 trials. This was not conducted for T2 due to the large impact of ITI. T1 accuracy by trial blocks is presented for the Dyslexic and Control groups in Fig. 3. It is evident that Control performance increases rapidly becoming asymptotic half way through the experimental session, whereas Dyslexic performance shows an initially gradual increase becoming more rapid across the experiment session, showing no sign of asymptote. It is interesting to note that accuracy for both groups is similar in the first and last

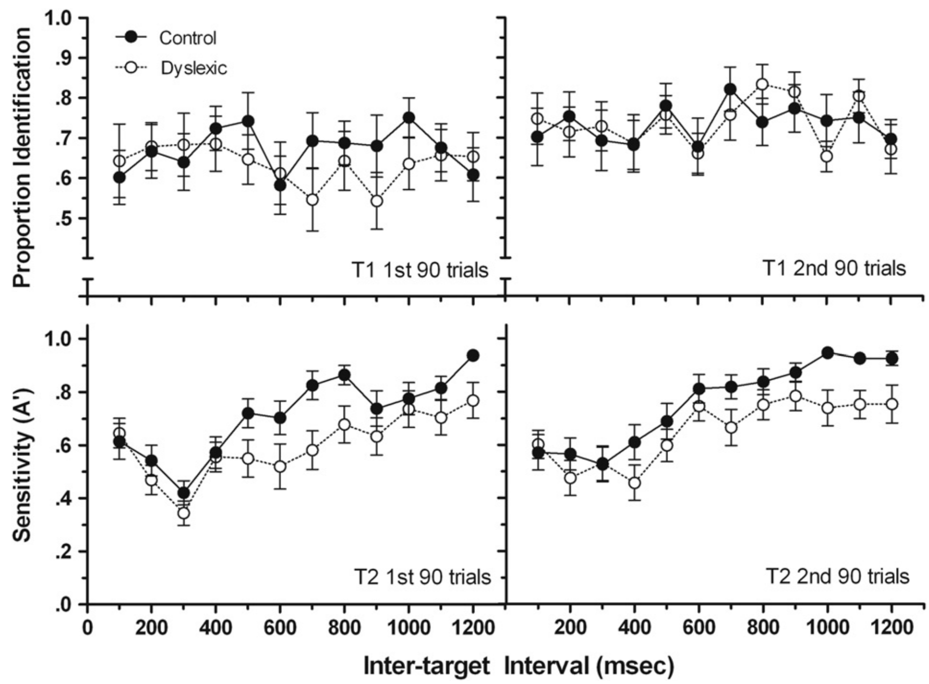

Fig. 1 – T1 identification and T2 contingent sensitivity (A′) for Dyslexic and Control groups as a function of task half (1st *vs* 2nd 90 trials) and ITI (msec). Error bars represent the standard error of the mean.

blocks of trials, the main differentiation occurring in the middle of the session.

To determine whether these patterns of increased accuracy across the session were comparable for the two groups, 3rd order polynomial functions were fitted to the group data. The descriptive statistics are presented in Table 3 and visual plots for each group are overlaid in Fig. 3. A single curve did not provide a suitable fit for both groups, $F(4,4) = 10.42$, $p = .022$, therefore the patterns of performance can be considered different.

4. Discussion

This paper examined performance differences between two halves of a white letter identification: black letter X detection AB task. The findings indicate that both T1 and T2 are higher in the second half of the task and Dyslexic participants demonstrated greater improvement between the halves than Controls. A more sensitive examination of this practice considered T1 accuracy across six trial blocks and suggested differential patterns of improvement between the two groups; Control performance increased quickly, reaching an asymptote at the mid-point of the session whereas Dyslexic performance increased gradually improving more rapidly towards the end of the session and showed no sign of asymptote. Therefore, with practice, Dyslexic performance more closely resembles Control performance. This has important implications for our understanding of RSVP performance in dyslexia which may extend to other paradigms.

It is important to clarify whether the between group differences noted constitute a difference in the AB effect or differences in perceptual learning. The ‘purest’ estimate of AB performance would ideally be made in the absence of any learning. Therefore it might be considered that the first half of the task is the best period over which to estimate the AB. In the current investigation however, there was a significant increase in T1 performance in the control group over the first half which plateaus during the second half. With respect to shared resource models of dual-target tasks (e.g., Tombu and Jolicoeur, 2005), difficulties with one target will result in difficulties with the other target. In this sense, the differences noted in the first half are significantly confounded by differences in learning. Therefore, the findings can be considered consistent with a general difficulty with the RSVP rather than a specific difference in the AB. This is consistent with the current state of the literature.

As introduced earlier, the relationship between reading and AB has received significant attention (Buchholz and Davies, 2007; Facoetti et al., 2008; Hari et al., 1999; La Rocque and Visser, 2009; Lacroix et al., 2005; Lallier et al., 2010; McLean et al., 2009; McLean et al., 2010; Visser et al., 2004).

Table 1 – Inferential statistics for 2 (Half: first *vs* second 90 trials) by 12 (ITI: 100–1200 msec) repeated measure ANOVAs for separate T1 and T2.

Effect	T1			T2		
	df	F	η_p^2	df	F	η_p^2
Half	1, 28	14.34**	.34	1, 22	5.71*	.21
ITI	11, 308	1.40	.05	11, 242	23.47**	.52
Half × ITI	11, 308	1.29	.04	11, 242	1.44	.06

** $p < .01$, * $p < .05$.

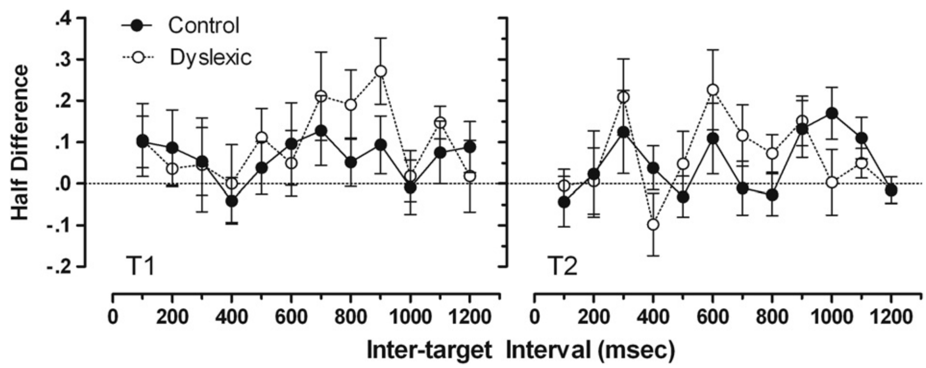

Fig. 2 – T1 and T2 half differences (performance difference between 2nd and 1st 90 trials) for Dyslexic and Control groups as a function of ITI (msec). Error bars represent the standard error of the mean.

A review of these findings suggests that dyslexic performance is associated with generally lower sensitivity to targets within the AB; however, this performance difference does not necessarily relate to the magnitude of inter-target interference (the depth of the AB) or the duration of the AB effect (McLean et al., 2010). Furthermore, AB performance has been related to general capacities and abilities: working memory and intelligence (Colzato et al., 2007; Gillard-Crewther et al., 2007). Therefore, some of the variation in the difference between Dyslexics and Controls may be related to the ability to learn the task-specific parameters which is consistent with predictions made by Ahissar (2007) with respect to 'anchoring'. Ahissar suggests that a wide range of deficits associated with dyslexia can be attributed to a deficit in implicitly utilising previously presented task information in subsequent performance. This suggestion is compatible with the notion of perceptual noise exclusion.

Sperling et al. (2005) considered evidence for a specific visual deficit in dyslexic children (the magnocelluar deficit, see Lovegrove, 1996). Participants were asked to indicate whether a visual grating was present on the left or right of a display and the stimulus contrast required for accurate responding was estimated. The displays were presented either in the presence or absence of visual noise. The critical finding was that contrast thresholds were higher for the Dyslexic children relative to controls in the presence but not in the absence of the visual noise. In this sense, if the extraneous information presented as part of an RSVP can be considered noise, the RSVP is a complicated task.

Table 2 – Inferential statistics of a 2 (Group: Dyslexic and Control) by 2 (Target: T1 and T2) by 12 (ITI: 100–1200 msec) mixed ANOVA.

Effect	df	F	η_p^2
Group	1, 21	3.33*	.14
Target	1, 21	.11	.01
ITI	11, 231	1.05	.05
Group × Target	1, 21	.37	.02
Group × ITI	11, 231	1.01	.05
Group × Target × ITI	11, 231	.95	.04

* $p < .05$ (single-tailed).

The RSVP involves comparing each item within the sequence to some target template and either rejecting or accepting the item as a target (Chun and Potter, 1995). If accepted as a target, the representation must then be made robust enough to be maintained for later report. Increasing the complexity at any point in this series of tasks should lead to increased task difficulty. If, as has been demonstrated (e.g., Rutkowski et al., 2003), dyslexic participants have difficulties with letter stimuli, RSVPs involving letters should be more difficult. If not only temporal but also spatial uncertainty in target positioning is added to the mix, then performance should also be worse as has been noted (Visser et al., 2004). It may be the number of parameters in this series which is critical in explaining dyslexic participants' difficulties with the paradigm. The difficulty a participant has in successfully coordinating the parameters in this series may be indexed by practice effects. In this sense, it can be suggested that dyslexic participants are slower to coordinate these parameters in the current task. It may also be the case that if attention were initially drawn to task-irrelevant features, subsequently shifting attention away from this information may be more difficult for dyslexic readers (Hari and Renvall, 2001).

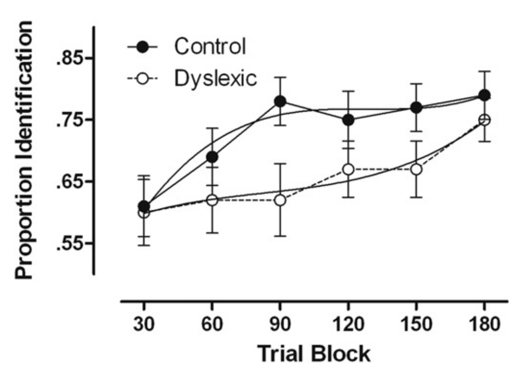

Fig. 3 – T1 proportion correct white letter identification as a function of blocks of 30 trials across the experimental session for the Control and Dyslexic groups.
T1 performance is based upon only those trials for which T2 was presented and error bars represent the standard error of the mean. 3rd order polynomial fits of the data are overlaid for each group.

Table 3 – Inferential statistics for 3rd order polynomial functions fitted to T1 proportion correct summaries within six 30 trial blocks for the Control and Dyslexic groups.

Group	Parameter values				R^2
	B0	B1	B2	B3	
Control	.4	8.53E−03	−6.63E−05	1.71E−07	.94
Dyslexic	.55	2.04E−03	−1.99E−05	8.09E−08	.95

Either through conscious differences or subconscious attention to perceptual regularities in the sequences (Petrov et al., 2005), strategic differences influence AB performance. This is no more evident than in the intriguing event that attention is directed away from the task and performance increases (Olivers and Nieuwenhuis, 2005). Long term practice in the AB improves the ability to ignore distracters and attend to the targets (Maki and Padmanabhan, 1994), attenuating the AB effect. Cues as to the temporal location of targets also reduce the AB (Martens and Johnson, 2005). Therefore, perceptual strategies have been demonstrated in the AB and it may be differences in coordinating uncertainty in distracter and target, as well as temporal position of this information which causes difficulties for dyslexic readers. If this were the case we might expect to see greater improvements in performance with practice as observers become accustomed to the display as was noted in the current investigation. Whether practiced performance can completely attenuate the group differences is an empirical question.

In this sense, an RSVP utilising letters is problematic. For this reason Visser et al. (2004) utilised shape stimuli. A step beyond this would be to remove the need for distracter inhibition by incorporating a minimalist AB design, simply T1, T2, and their respective masks (Ward et al., 1997).[1] Furthermore, target processing efficiency could be titrated in order to equate stimulus processing time commonly suggested to be longer or more difficult to accurate estimate in Dyslexic samples (e.g., Rutkowski et al., 2003). Although the influence of each of these parameters may not be independently significant, it may be a cumulative effect of parameter load.

One final consideration is the conclusion drawn from the original dyslexia AB investigation, that of a prolonged AB (Hari et al., 1999). Hari et al. reported a significant group by ITI interaction, indicative of a specific AB deficit in dyslexia. The procedure as well as the range of ITIs was precisely the same as in the current research in which we did not find a significant interaction. Furthermore, Visser et al. (2004) examined the effect across 1400 msec and also failed to find a significant interaction. Therefore it may be the case that the absence of the interaction effect relates to a failure to establish a suitable estimate of baseline performance. It is conceivable that if a suitable time period were examined, consistent interaction effects could be noted. Husain et al. (1997) report a severely protracted AB effect in patients with visual neglect and as similar deficits have been noted in dyslexia (e.g., Hari et al., 2001) exploring greater ITIs may warrant investigation. It should be noted that dyslexic deficits in single-target RSVP tasks favour a general rather than specific deficit (Buchholz and Davies, 2007; Facoetti et al., 2008; Visser et al., 2004); however, evidence for an interaction at longer ITIs is an empirical question.

[1] It should be noted that a procedure resembling this was adopted by Facoetti et al. (2008) and did not appear to influence the results. It spite of this, the impact of distracter items is likely to be related to task-specific learning and should be minimised wherever possible.

4.1. *Conclusion*

This paper examined performance improvements within an RSVP examining the AB in dyslexic and control readers. Overall, there was significant improvement in T1 identification and sensitivity to T2; however, there was a significantly greater improvement as well as a pattern of slower improvement in the phonological Dyslexic sample. It is possible that the development of strategies to deal with uncertainty in distracter and target identities, as well as the temporal variation in target locations is slower to develop in the Dyslexic sample. Furthermore, differences related to task learning (Ahissar, 2007) and aspects of ignoring task-irrelevant information (Hari and Renvall, 2001; Sperling et al., 2005) should be considered in dyslexic research and might help to explain some of the discrepant findings in the literature.

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