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Spatial Attention Shifting and Phonological Processing in Adults with Dyslexia

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According to Hari and Renvall's (2001) sluggish attentional shifting (SAS) hypothesis people with dyslexia have a central deficit in attention shifting. Here we assessed whether a group of adults with dyslexia showed impaired performance on shifting visual spatial attention. Twelve adults with dyslexia and 12 control adult participants took part in a Posner style focused attention orientation task and a shift attention orientation task. The participants also completed standardized measures of single word reading, spelling, IQ, phonological processing, speed of processing and non-word reading. Overall, the dyslexic participants showed the same pattern of performance as the control participants on the attention-orienting task, but completed the tasks at a consistently slower pace. Specifically, participants in both groups found short target presentation intervals more difficult than longer target presentation intervals, and participants in both groups were more impaired when cue-to-target information was invalid 20% of the time (shift task) than when it was valid all of the time (focused task). However, the group with dyslexia was significantly more impaired across the board. While this is indicative of slower attentional processing in this group, attention shifting was not a significant unique predictor of non-word reading performance after age, general ability, and speed of processing had been controlled for. Accordingly, we conclude that while a deficit in cognitive processing speed (e.g. sluggish attention) may characterize dyslexia, it is not the central difficulty. Rather, a deficit in cognitive processing speed occurs alongside a core difficulty with phonological awareness. Thus phonological awareness is the central difficulty for individuals with dyslexia who may also present with deficits in cognitive processing speed.

Keywords: dyslexia, phonological processing, sluggish attentional shifting, attention orientation, adult dyslexia

Dyslexia is characterized as a specific learning difficulty disorder that affects word reading accuracy, spelling accuracy, and fluency and can be comorbid with a range of other sensory, motor, and intellectual difficulties that are not related to intellectual capability (Rose, 2009). The phonological deficit hypothesis posits that individuals with dyslexia find mapping phonemes onto graphemes difficult because they have poorly specified phonological representations (see Snowling, 2000 for a review). There is a substantial body of cognitive research to support this theory (Carroll & Snowling, 2004; Georgiewa et al., 2002; Pennington, Van Orden, Smith, Green, & Haith, 1990; Ramus et al., 2003; Scarborough, 1990; Mayringer & Wimmer, 2000), and poor phonological awareness, namely skill in the awareness and manipulation of linguistic units such as words, syllables and rimes, is a largely undisputed feature of dyslexia (Goswami, 2003).

This language-based hypothesis has been strengthened by neurobiological studies. Weak phonological (feature) sound and orthographic (written) skills seen in dyslexia are associated with reduced activation in several areas of the left hemisphere, including the left middle, inferior, and superior temporal cortex in addition to the middle occipital gyrus (Paulesu et al., 2001; Shastry, 2007; Temple et al., 2001; Wimmer, Hutzler, & Wiener, 2002), all of which are areas highly relevant to language processing. However, the failure of this hypothesis to account for the high incidence of motor and sensori-perceptual deficits experienced by people with dyslexia is considered by some researchers to be a persistent weakness (see Ramus et al., 2003 for discussion).

A contrasting view of the underlying problem in dyslexia is encapsulated by Hari and Renvall's (2001) non-modality specific, sluggish attentional shifting (SAS) hypothesis. According to this hypothesis, people with dyslexia are slow to disengage their attention from a given stimulus as a direct consequence of dysfunction in the right parietal lobe. If the assertion is correct, this impairment should be particularly apparent when dyslexics are presented with rapid stimuli sequences, such as speech stimuli. Hari and Renvall (2001) proposed that individuals with dyslexia have to process larger chunks of phonological input, as they are unable to disengage rapidly from incoming speech stimuli. They argue that these larger units of phonological information would be harder to specify accurately than smaller, more manageable units, leading to poorly formed phonological representations. In addition, difficulty with disengaging rapidly from visual stimuli would lead to slower mapping of graphemes to phonemes, which could further impair the functioning of the sublexical reading route. Thus, the phonological deficit seen in dyslexia is considered to be a consequence of sensory cognitive overload caused by an underlying attentional dysfunction.

Support for the SAS hypothesis comes from neurobiological evidence, which shows that lesions to the right parietal lobe are linked to acquired dyslexia (Brunn & Farah, 1991), and that the right parietal lobe is activated when normal adults read pseudo-words and real words (Mayall, Humphreys, Mechelli, Olson, & Price, 2001). There is also a growing body of research supporting the proposal that people with dyslexia have impaired visual attentional processes on measures such as the attentional blink paradigm and visual search tasks (e.g., Buchholz & Davies, 2005; Buchholz & McKone, 2004; Casco & Prunnetti, 1996; Iles, Walsh, & Richardson, 2000; Hari, Valta, & Uutela, 1999; Roach & Hogben, 2004; Ruddock, 1991; Visser, Boden, & Giaschi, 2004; Williams, Brannan, & Latirgue, 1987). Research indicates that these attentional deficits seem to occur at the sensori-perceptual level, rather than at the level of executive function (Stoet, Markey, & López, 2007).

The present study is particularly concerned with participants' ability to shift the spatial focus of attention, a process that is critical for the operation of the sublexical reading route. Different graphemic units of words are effectively situated in different spatial locations, requiring the ability to shift the focus of spatial attention rapidly and accurately. Typically, spatial attention shifting has been explored using a version of the traditional Posner (1980) cueing task. This involves the presentation of a fixation point, followed by a cue for the location of the target, which can either be valid (where the target subsequently appears in the same location as the cue) or invalid (where the target appears in a different location than the cue).

The standard finding from research with children and adolescents is that response times (RTs) for the valid trials are faster than RTs for the invalid trials in typically-developing participants (e.g., Schul et al., 2004; Facoetti, Lorusso, Cattaneo, Galli, & Molteni, 2005). The relative delay for the invalid trials is thought to reflect the time required to shift the attentional spotlight from the invalid cue location to the true target location. Accordingly, the further away the target is from the invalid cue location the longer the time lag. However, at cue-to-target intervals greater than 250ms this effect tends to disappear, arguably because the participant's attention starts to focus on novel locations, which reduces the advantage initially provided by a valid cue (Schul et al., 2004).

Facoetti et al. (2005) used this paradigm to compare attention shifting in children with dyslexia to age-matched controls and reading-aged matched controls. When the cue-to-target interval was set at 100ms, both control groups showed the expected faster responses to the target for valid cued trials compared to invalid cued trials. In contrast, the children with dyslexia performed no faster on the valid trials compared to the invalid trials. When the cue-to-target interval was increased to 250ms, the dyslexic participants showed a significant advantage for the valid cued trials, whereas the two control groups performed similarly on trials with valid cues compared to trials with invalid cues. Facoetti et al. (2005) concluded that the children with dyslexia showed a slower attentional capture than controls, supporting Hari and Renvall's (2001) hypothesis that attentional shifting in children with dyslexia is sluggish. Critically, they also concluded that the dyslexic group's attention shifting was slower than younger children of the same reading age. This detrimental performance in comparison to a reading-matched control group led them to conclude that poor spatial attention may be a cause of reading difficulties, rather than a product of poor reading ability.

However, similar studies have produced somewhat different results. Heiervang and Hugdahl (2003) also used the Posner cueing task to compare attention shifting in children with dyslexia (aged 10-12 years) with age-matched controls. They found that the dyslexic participants were generally slower to respond to the target stimuli than the controls across both short (100ms) and long (800ms) cue-to-target intervals. However, in contrast to Facoetti et al. (2005), Heiervang and Hugdahl found that the dyslexic participants showed the same pattern of performance as the typically-developing children. They suggested that dyslexic participants might have difficulty recruiting the necessary cognitive resources to complete the tasks at speed, which would support a general speed of processing deficit rather than a specific problem with shifting attention. Heiervang and Hugdahl also included a no-cue condition in their study, which led to slower RTs in the control group but did not appear to detrimentally affect the RTs of the dyslexic group. This suggests that the cue is of no benefit to the group with dyslexia. Interestingly, they also demonstrated that this group difference masked a considerable amount of variability in the dyslexic groups RTs in comparison with the control group.

It appears then that while several studies have found that people with dyslexia have deficits in engaging, disengaging, and shifting attention, these effects have not been established as consistent either across or within samples. Critically, while group based deficits have on occasion been identified (e.g., Facoetti et al., 2005; Hari et al., 1999), very little attention has been paid to individual participant performance, and it is therefore difficult to determine whether attentional problems characterize a subset or the majority of people with dyslexia (Buchholz & Davies, 2007). Furthermore, there is a need to ascertain more clearly whether attention deficits might play a causal role in the development of phonological deficits.

To this end, Facoetti, Ruffino, Peru, Paganoni and Chelazzi (2008) directly explored whether attentional processing can account for variance in phonological skill. Using the attentional blink paradigm, they demonstrated that 77% of children with dyslexia in their sample had difficulty with attentional engagement, and 54% had difficulty with rapid disengagement from target stimuli. Facoetti et al. (2008) carried out a series of hierarchical regressions with non-word reading as the outcome variable, demonstrating that non-spatial attentional processing accounted for around 24% of the unique variance in non-word reading accuracy, after controlling for age and verbal reasoning. While this may be considered evidence for a significant role of attention in phonological reading processes, this finding should be interpreted with caution. Since the focus of Facoetti et al.'s (2008) study was on non-verbal, visual processes and the role they have to play in phonological processing, it would arguably have been appropriate to control for general nonverbal ability in the regression analyses. Moreover, the attentional blink task is undoubtedly closely linked to speed of information processing (Catts, Gillispie, Leonard & Kail, 2002; Kail & Hall, 1994) and has been previously demonstrated to account for unique variance in reading performance (e.g., Catts, Gillispie, Leonard & Kail, 2002; Kail & Hall, 1994; see Bonifacci & Snowling, 2008 for a different view on this matter). Therefore, to properly assess the amount of variance in non-word reading accounted for by attentional processes, it is necessary to control age, non-verbal ability, and basic speed. Otherwise it is impossible to say that variance is (in some part) attributable to these factors.

Aims and Hypotheses

Following previous research, we sought to investigate whether adults with dyslexia have a deficit in shifting spatial attention. In addition, the study sought to explore whether spatial attention is a unique predictor of non-word reading accuracy when controlling for age, non-verbal ability, and speed of processing. To address these aims, a task was needed that would (a) assess ability to shift attention and (b) assess speed of processing, whilst keeping all other demands on cognitive resources constant. This would enable speed of processing to be effectively controlled in any analyses used to explore the role of attention in predicting non-word reading. To achieve this we have used a modified version of a task, used by Schul et al. (2004), which provides reaction time (RT) data for a focused attention condition (which assesses speed of processing) and a shift attention condition (which assesses attentional shifting).

In the focused task, participants responded to a target (an arrow pointing in a specific direction: up, down, left or right) by moving a computer mouse and clicking on the arrow. Moving the mouse caused the target to immediately be masked (a multi-arrow mask) and the participants clicked on the arrow in the mask that corresponded with the position and direction of the original target arrow. In this task the target consistently appears in the same location as the cue. By varying the target-to-mask (T-M) time interval, we were able to assess the amount of time needed to process the target effectively. This task also enabled us to measure motor response speed for the dyslexics relative to the typical readers.

The shift task was similar to the focused task except that the cue was only valid 80% of the time. In addition to varying the validity of the cue (and T-M interval), the cue-to-target (C-T) interval was also varied in the shift task. Longer C-T intervals allowed the participants more time to shift their attention. Therefore, if adults with dyslexia have slower attentional orienting than the controls, this should be reflected in less accurate responses to the invalid cues at shorter C-T intervals. In line with the literature (e.g., Catts et al., 2002; Heiervang & Hugdahl, 2003; Kail & Hall, 1994), we further hypothesized that the dyslexic participants would have a speed of processing deficit, demonstrated by slower responses than the control participants, across both the focused and shift tasks. Finally, the study aimed to assess whether attention-shifting ability contributes to non-word reading performance. In order to build on previous research, the analyses assessed the contribution of attention shifting after controlling for age, speed of processing and non-verbal ability. If attention shifting is a key cognitive deficit in developmental dyslexia, then it should contribute towards the variance in non-word reading performance.

Method

Participants

A group of 12 adults with dyslexia and 12 typical adult readers were recruited and matched on age and non-verbal reasoning. Dyslexic readers possessed a diagnosis of dyslexia from either a qualified Educational Psychologist or a Specialist Teacher. Descriptive statistics for the age, general ability and literacy measures for the two participant groups are displayed in Table 1. A series of independent samples *t*-tests confirmed that the dyslexic group were achieving significantly lower spelling raw scores, $t(22) = 2.96$, $p < .05$, and reading scores than the control group, $t(22) = 2.08$, $p < .05$. No significant differences were found between the groups on verbal ability, non-verbal ability, or overall IQ (ps > 0.05).

Measures of Literacy and General Ability

Wechsler Abbreviated Scale of Intelligence. The matrix reasoning and vocabulary subtests of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) were used to assess cognitive ability. For the vocabulary subtest, participants gave verbal descriptions of increasingly sophisticated items; for example, “What is a bird?” or “Tell me what ‘blame’ means.” The matrices subtest involved identifying missing ‘pieces’ of picture patterns or sequences, requiring participants to select the most appropriate fit from five possible responses. The standard assessment procedure for both subtests was carried out in accordance with the manual.

The Wide Range Achievement Test 4 (WRAT 4). The reading and spelling subtests of the WRAT 4 (Wilkinson & Robertson, 2006) were administered. Participants were required to read and spell single words of increasing difficulty and unfamiliarity. Standardized test instructions were adhered to throughout. This test measures word recognition, decoding skills, and single word spelling ability.

The Graded Non-Word Reading Test. To assess phonological decoding we administered the The Graded Non-Word Reading Test (Snowling, Stothard, & McLean, 1996). In this short assessment, participants read aloud five practice items followed by ten phonetically regular non-words of one syllable and ten of two-syllables. Performance was measured in terms of response accuracy.

The Perin False Spoonerism Test. The Perin False Spoonerism Test (Perin, 1983) was administered to assess phonological processing skills. An example of a spoonerism task is the participants being given

Table 1

Mean scores and standard deviations for tests of general ability and literacy.

	Dyslexic group		Control group	
	M	*SD*	*M*	*SD*
Age (years)	34.79	12.56	32.24	15.56
Vocabulary	57.25	15.75	60.33	10.11
Vocabulary (T-score)	50.50	15.98	55.33	10.15
Matrix reasoning	26.41	3.29	26.08	4.17
Matrix reasoning (T-score)	55.00	7.47	54.00	7.84
IQ (standard)	105.25	18.37	108.25	14.09
Reading	56.41	9.60	62.83*	4.76
Reading (standard)	95.08	19.83	105.75*	10.70
Spelling	37.00	10.32	46.67	4.68
Spelling (standard)	90.58	19.38	108.93*	10.71

Note. Data are raw scores unless otherwise stated. Standard refers to standardized test scores with a mean of 100 (*SD* = 15). T-score refers to standardized scores with a mean of 50 (*SD* = 10). $^*p < .05$

(verbally) the name of a famous individual (e.g., David Bowie) and being asked to reverse the initial phonemes to produce (articulate) two new words or non-words (i.e., Bavid Dowie). The participants were familiarized with the concept of spoonerisms if unsure and received three practice items, followed by eighteen test items. A response outside of a five second time limit received no score but feedback and encouragement were given after this time. The participants were scored on the number of correct spoonerisms articulated out of eighteen.

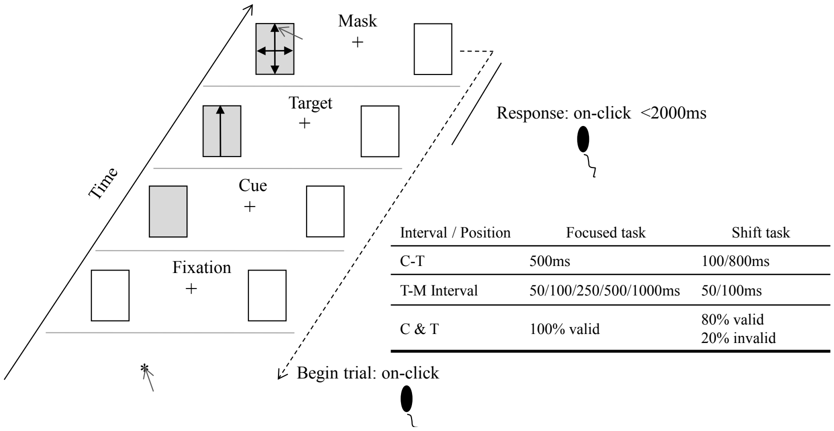
Speed of Processing Tasks

Adult Intelligence Scale. Two standard pen and paper speed of processing tasks were used from the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997): symbol search and digit symbol coding. In the symbol search task, participants sought to match either of two target symbols in an array of five. For the digit symbol-coding task, the numbers 1 to 9 corresponded to individual, non-verbal symbols. Participants inserted the appropriate symbol into a sequence of numbered boxes. For each task, participants worked as quickly as possible until the stimulus set was complete or until two minutes had elapsed. The number of correct items for each task was totaled, a high score reflecting faster speed of processing.

Focused and shift tasks

The focused task and shift tasks, adaptations of Schul et al.'s (2004) attentional orienting experiments, were written using Superlab 4 and were carried out on a Toshiba laptop computer (Windows XP), with a 15" LCD color screen. Participants sat approximately 56cm from the display. The focused task provides an index of perceptual processing speed and motor speed. The shift task provides an indication of attentional orientating speed. Both tasks are illustrated in Figure 1.

Focused task. In the focused task, participants had to respond (indicate location) as quickly as they could to a target arrow that was masked at different time intervals. At the beginning of each trial the participants were presented with an asterisk in the center of the screen, which they had to click using the computer mouse to begin the trial. This ensured that each trial was initiated with the mouse positioned in the middle of the screen. Participants were then presented with a central fixation point (+) and two empty target boxes (measuring 3.8 cm^2) located at an approximately 8.3^o visual angle to the left and right of fixation (the mouse cursor was hidden). One hundred milliseconds later, the participants were cued to either the left or the right box. The cue was an increase in hue (color green) over a period of 500 ms (C-T interval). The target, a black 3.7 cm arrow orientated up, down, left or right, was presented immediately after the cue, in the same box. The target was then masked, using a multi-arrow mask (arrows orientated in all 4 directions), according to a given (variable) target-to-mask (T-M) interval (50, 100, 250, 500, 1000 ms). Upon detecting the target the participant had to move the mouse cursor (now visible in the center of the screen) as quickly as they could and click on the location of the head of the target arrow. Clicking the screen completed the trial, returning the participant to the asterisk screen. In all, the focused task comprised two blocks of 80 trials with a short (self-paced) break between blocks. In one block the cue and target were consistently presented in the left box, in the other



Interval / Position	Focused task	Shift task
C-T	500ms	100/800ms
T-M Interval	50/100/250/500/1000ms	50/100ms
C & T	100% valid	80% valid 20% invalid

Figure 1. Illustration of the Focused task and Shift task procedure.

block they were consistently presented in the right box (order of side counterbalanced). Each participant received a minimum of 6 practice trials, which could be repeated until the participant felt familiar with the task.

Shift task. The shift task was similar to the focused task, but with some important differences. As before, participants began the trials by clicking the asterisk and this was followed by a fixation cross and two boxes. One of the boxes then increased in hue before the target arrow appeared. The target was then masked using the multi-arrow mask. Participants responded as in the focused task, using the mouse. This time however, both the C-T and the T-M intervals were varied. The C-T intervals were 800 (long cue) or 100 ms (short cue) whilst the T-M intervals were 50 or 100 ms. Cue validity was also manipulated. On 80% of the trials the cue and target appeared in the same spatial location (valid: right cue – right target), on the remaining 20% the cue and target appeared in different spatial locations (invalid: right cue – left target). The shift task comprised 6 blocks of 80 trials (480 in total). Half of the blocks had the valid C-T trials appearing on the left and the other half had the valid C-T trails appearing on the right. Participants completed all of the left valid (right invalid) or the right valid (left invalid) blocks before switching over to the opposite blocks (order counterbalanced). Each participant received a minimum of 6 practice trials, which could be repeated until the participant felt familiar with the task.

Procedure

Participants took part in two testing sessions (lasting around 45 minutes each), with a short break between the two sessions. In the first session they were administered the WASI matrix reasoning and vocabulary tests, WRAT 4 reading and spelling subtests, and the phonological tasks. In the second session they completed the WAIS speed of information processing tasks, followed by the focused task and the shift task. Testing was carried out one-to-one, in a quiet, distraction-free room. All procedures were cleared (January 2008) by the University School of Social Sciences Ethics Committee before testing took place. Participants gave signed consent to take part in the research and were aware of the task requirements before testing began. All participants were fully de-briefed following completion of the tasks.

Data Analysis

Two dependent variables were calculated for each of the attention tasks: response time (RT) and performance accuracy. Response time scores were calculated by finding the mean RTs in log ms for all target directions on both the left and right side responses (separating out valid and invalid trials in the shift task). Accuracy was a percentage of correct (e.g., left-up-target, left-up-response) responses, collapsed over target direction (up, down, left, right) and side of presentation (left block, right block) for each of the levels of the combined factors.

Response times longer than 2000 ms were terminated, recording a ‘miss’ for that trial. In line with Schul et al. (2004), a response time of 2000 ms was considered sufficient time to allow even participants with slow motor reactions to record their response. Since the participants were responsible for initiating successive trials, the inter-stimulus interval time was governed by them. Miss trials were removed from the RT analysis (as were responses shorter than 200 ms) but were included in the accuracy calculation as an inaccurate response. No erroneous click responses (e.g., left-up-target response for left-down target) were observed.

Table 2

Mean scores and standard deviations for measures of phonological processing, symbol search and digit coding.

	Dyslexic group		Control group		Group difference
	M	*SD*	*M*	*SD*	
Spoonerisms (max = 18)	7.67	6.30	15.58	2.47	*t*(22) = 4.05**
Non-word reading (max = 20)	14.92	5.33	19.17	1.03	*t*(22) = 2.71*
Symbol search (raw score)	32.00	7.59	39.12	5.86	*t*(22) = 2.59*
Digit coding (raw score)	64.67	16.29	89.67	17.52	*t*(22) = 3.62**

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

Table 3

Focused task performance (% correct accuracy) for the control and dyslexic groups.

T-M Interval	50		100		250		500		1000	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	99.20	1.90	99.50	1.20	99.70	.90	99.70	.90	100.00	0.00
Dyslexic	93.50	14.00	96.10	7.20	98.20	4.50	98.20	3.10	98.70	3.10

Table 4

Focused task reaction times (in log ms) for the control and dyslexic groups.

T-M Interval	50		100		250		500		1000	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	2.94	.07	2.93	.06	2.88	.06	2.88	.07	2.89	.07
Dyslexic	3.02	.08	3.00	.07	2.96	.08	2.96	.08	2.97	.10

Results

All data are reported to 2 decimal places. ANOVAS are reported with Generalized Eta Squared (η_G^2) effect sizes in accordance with Olejnik and Algina (2003), and power estimates. Group performance on the measures of spoonerisms, symbol search, digit coding, and non-word reading are presented in Table 2. It can be seen that the dyslexic participants performed significantly poorer than the controls on all of these measures.

Focused Task

Performance accuracy. Informal observations of these data suggest markedly more variability in errors for the dyslexic group compared with the control group. Both groups were near to ceiling in almost all cases (see Table 3). Formal analysis (mixed ANOVA) of the performance accuracy data revealed no significant main effect of group, $F(1, 22) = 2.44$, $MSE = 90.18$, $p > .05$, $\eta_G^2 = .06$, or T-M interval, $F(1.46, 32.05) = 2.53$, $MSE = 14.26$, $p > .05$, $\eta_G^2 = .04$, and no group by T-M interval interaction $F(1.46, 32.05) = 1.49$, $MSE = 14.26$, $p > .05$, $\eta_G^2 = .02$.

Reaction time. Informal observations of the reaction time data suggested greater variability in reaction times for the dyslexic group compared with the control group (see Table 4). This was most pronounced at the shorter latencies. Formal analysis of the reaction time data (mixed ANOVA) revealed a statistically significant main effect of group, $F(1, 22) = 7.44$, $MSE = .03$, $p < .05$, $\eta_G^2 = .24$, with the dyslexic participants being significantly slower than the control participants. There was also a significant main effect of T-M interval, $F(2.77, 61.03) = 33.78$, $MSE = .00$, $p < .05$, $\eta_G^2 = .09$, but no group by T-M

Table 5

Shift task performance (% correct accuracy) for the control and dyslexic groups.

Cue Validity	Invalid							
C-T Interval	Short				Long			
T-M Interval	50		100		50		100	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	98.60	2.10	99.70	1.20	97.60	4.20	99.70	1.30
Dyslexic	90.30	18.20	93.40	11.60	87.50	21.10	89.90	15.50
Cue Validity	Valid							
C-T Interval	Short				Long			
T-M Interval	50		100		50		100	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	99.30	1.30	99.50	.80	99.70	.50	99.90	.30
Dyslexic	96.10	4.90	97.80	2.40	97.00	5.00	99.10	1.60

interval interaction, *F*(2.77, 61.03) = .56, *MSE* = .00, $p > .05$, η^2_G = .00. Holm (1979) corrected, pairwise comparisons of the T-M interval revealed significant differences between the two shortest intervals (50 and 100 ms) and the 250, 500, and 1000 ms intervals, $p < .05$. None of the other comparisons were significant (*p*s > .05).

Shift Task

Performance accuracy. Informal observations of the performance accuracy data suggest poorer (lower) and more variable performance for the dyslexic group compared with the control group (see Table 5). Formal analysis (mixed ANOVA) of these data showed a main effect for validity (invalid: 94.6%, valid: 98.6%), *F*(1, 22) = 4.38, *MSE* = 173.99, $p < .05$, η^2_G = .05, but no main effect of C-T interval, *F*(1, 22) = 1.19, *MSE* = 11.38, $p > .05$, η^2_G = .00, T-M interval, *F*(1, 22) = 3.67, *MSE* = 34.18, $p > .05$, η^2_G= .01 or group, *F*(1, 22) = 3.90, *MSE* = 352.55, $p > .05$, η^2_G = .08. There was a validity by C-T interval interaction (invalid short: 95.5%; invalid long: 93.7%; valid short: 98.2%; valid long: 98.9%), *F*(1, 22) = 5.54, *MSE* = 14.44, $p < .05$, η^2_G = .01. No other interactions reached statistical significance (*p*s > .05). Holm (1979) corrected, pairwise comparisons of the validity by C-T interval interaction revealed significant differences between the valid and invalid long C-T intervals, $p < .05$. No other comparisons were significant (*p*s > .05).

Reaction time. As with the accuracy data, informal observations suggested greater variability in reaction times for the dyslexic group compared with the control group, being most pronounced at the shorter latencies (see Table 6). Formal analysis of the reaction time data (mixed ANOVA) revealed a statistically significant main effect of group (control: 2.93 log ms; dyslexic: 3.02 log ms), *F*(1, 22) = 7.18, *MSE* = .04, $p < .05$, η^2_G = .18, a main effect of validity (invalid: 3.01 log ms; valid: 2.94 log ms), *F*(1, 22) = 68.49, *MSE* = .00, $p < .05$, η^2_G = .12, and a main effect of T-M interval (50: 2.99 log ms; 100: 2.96 log ms), *F*(1, 22) = 42.60, *MSE* = .00, $p < .05$, η^2_G = .03, but no effect of C-T interval, *F*(1, 22) = .12, *MSE* = .00, $p > .05$, η^2_G = .00. There was also a significant validity by T-M interval interaction (valid 50: 2.98 log ms; valid 100: 2.95 log ms; invalid 50: 3.00 log ms; invalid 100: 3.03 log ms), *F*(1, 22) = 4.85, *MSE* = .00, $p < .05$, η^2_G = .00, a significant group by validity by T-M interval interaction (control valid 50: 2.91 log ms; control valid 100: 2.88 log ms; control invalid 50: 2.99 log ms; control invalid 100: 2.97 log ms; dyslexic valid 50: 3.00 log ms; dyslexic valid 100: 2.98 log ms;

Table 6

Shift task times in log ms for the control and dyslexic groups.

C-T Interval	Short				Long			
T-M Interval	50		100		50		100	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	2.99	.07	2.96	.08	2.99	.07	2.97	.06
Dyslexic	3.06	.07	2.98	.09	3.08	.09	3.02	.09

C-T Interval	Short				Long			
T-M Interval	50		100		50		100	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	2.91	.08	2.88	.07	2.91	.08	2.88	.08
Dyslexic	3.01	.09	2.98	.08	3.00	.08	2.98	.09

dyslexic invalid 50: 3.07 log ms; dyslexic invalid 100 ms: 3.01 log ms), $F(1, 22) = 6.66$, $MSE = .00$, $p < .05$, $\eta^2_G = .00$ and a group by validity by C-T interval by T-M interval interaction, $F(1, 22) = 5.60$, $MSE = .00$, $p < .05$, $\eta^2_G = .00$. No other effects or interactions were significant (*p*s > .05).

In order to explore the group by validity by C-T interval by T-M interval interaction, 95% confidence intervals were calculated and plotted on the means. These data are presented in Figure 2. For clarity of comparison the graphs have been broken down in to 6 smaller displays. Each of the 6 graphs shows RT performance across each C-T interval and T-M interval, for both groups, but differ across validity. The 95% confidence intervals suggest that there are significant differences between control valid response times, and both the dyslexic valid and dyslexic invalid response times for all C-T, T-M intervals ($p < .05$). Significant differences were also observed between control valid and control invalid response times for the 100 ms C-T, 800 ms T-M interval condition, $p < .05$, and dyslexic invalid and control invalid 50 ms C-T, 800 ms T-M interval condition, $p < .05$. No other comparisons were significant (*p*s > .05).

The means, standard deviations and ranges for the three speed indices are presented in Table 7. As indicated by the standard deviations and range scores there is considerable variance in performance, though much of this is carried by one individual. One-sample *t*-tests indicate significantly slower motor speed, $t(11) = 3.47$, $p < .05$, but normal perceptual processing speed and attentional orientating. Correlations also indicated a significant positive correlation between motor speed and perceptual processing speed, $r = .59$, $p < .05$. No other comparisons were significant (*p*s > .05). Removal of the aforementioned individual from the data set ($N = 11$) extinguished this correlation, $r = .33$, $p > .05$ while all other observations (including *t*-tests) remained constant.

Predicting Non-Word Reading Performance

To assess whether attention shifting is a useful predictor of non-word reading performance, a series of hierarchical regressions were carried out. These analyses need to be interpreted with caution considering the relatively small sample size. In contrast to the analyses carried out by Facoetti et al. (2008), the current study assessed the contribution of attention shifting after controlling for speed of processing.

Attention shifting in these analyses refers to the z-scores of participants' reaction times to the inconsistent trials on the shift task (i.e., the trials where a shift in attention was required). Speed of processing was indexed by participants overall performance on the focus task, with mean z-scores of reaction time data being taken across all five target-to-mask intervals (50, 100, 250, 500 and 1000 ms).

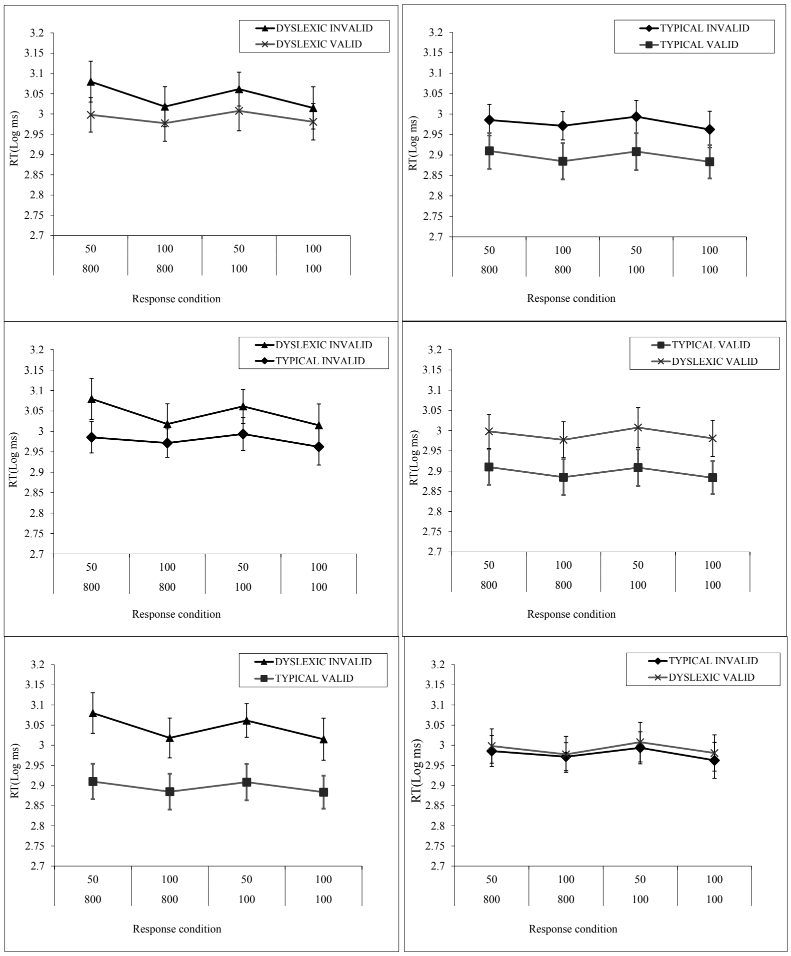


Figure 2. Breakdown of group by validity by C-T interval by T-M interval interaction with 95% confidence intervals.

The first set of regression analyses showed that attention shifting was a significant predictor of non-word reading after controlling for age and nonverbal ability, accounting for around 39% unique variance ($p < .05$). However, attention shifting accounted for only 0.6% after controlling for speed of processing ability (focus task performance), and was no longer a unique predictor of reading performance ($p > .05$).

Similarly, attention shifting accounted for 20% of the unique variance in non-word reading after controlling for age and verbal ability ($p < .05$). However, attention shifting was no longer a unique predictor after controlling for speed of processing, accounting for only 0.4% of the unique variance in non-word reading in this model ($p > .05$).

It should be noted that both speed of processing and attention shifting accounted for additional variance in non-word reading outside of phoneme awareness skills (spoonerisms task) when entered independently at step 3 of the regression analysis ($p < .05$). It is likely that this was because of the speed of processing component shared by both tasks, since when the focus and shift task are entered simultaneously into the regression analysis neither accounts for a significant amount of unique variance ($p > .05$).

Discussion

The aim of this study was to evaluate the proposal that impaired shifting of attention is a core deficit in developmental dyslexia, as suggested by Hari and Renvall's (2001) sluggish attentional shift hypothesis. In order to directly build on previous research (e.g., Facoetti et al., 2008), the current study assessed whether spatial attention was a unique predictor of non-word reading accuracy. The findings indicate that the dyslexics were slower to respond on both the focus and shift tasks than the controls. At first glance this would appear to support a deficit in speed of processing, as suggested by previous literature (e.g., Catts, Gillispie, Leonard & Kail, 2002; Kail & Hall, 1994; Nicolson, 1994). Accordingly, if the dyslexics had difficulty in shifting spatial attention rapidly, this should have been particularly prominent when C-T intervals were very short. However, there was no significant difference in accuracy between the dyslexic and control group at short cue-to-target intervals. Rather the dyslexics appeared to mirror the performance of the control group, albeit doing so at a reduced speed.

The pattern of performance accuracy was straightforward. In the focused task, the dyslexic group was as accurate as the control group across all target–to-mask intervals. In the shift task, no overall differences were observed between the groups.

Table 7

Mean speed indices (in log ms) and correlations for the dyslexic group.

	M	*SD*	*Range*	Perceptual processing	Motor speed	Attentional orientating speed
Perceptual processing	2.3	6.22	[-1.74]–[21.56]	-		
Motor speed	1.27	1.27	[-1.11]–[3.47]	.59*	-	
Attention orientating score	-.43	1.94	[-3.88]–[2.33]	.25	.07	-

*$p < .05$

The dyslexic group and the control group were less accurate (and more variable) on the invalid trials than on valid trials, though this was most pronounced between the valid and the invalid cue-to-target (800 ms) intervals (as evidenced by the C-T interval by validity interaction). In short, although the dyslexic group appeared to be more variable, in terms of accuracy their performance mirrored the control group on both tasks.

Similarly, the RT data for the dyslexic group was effectively a slower and slightly more variable version of the control group's performance. In the focused task both groups tended to be slower for the shorter T-M intervals (50 and 100 ms) than the longer T-M intervals (250, 500, 1000 ms), but the control group was faster overall: there were no interactions. In the shift task, the interactions lead to the conclusion that performance for the control group was significantly faster on the valid trials as compared with the performance of the dyslexic group on the invalid trials.

Critically, our adult data support Heiervang and Hugdahl's (2003) findings for children with dyslexia. That is to say that whilst the dyslexic group performance is slower overall, it is still largely comparable with the control group, and follows the same pattern of costs/benefits at different C-T and T-M intervals.

In addition, analysis of the speed indices and correlations suggest that poorer performance in the dyslexic group may be attributed to slower motor speed and not perceptual or attention processing speed. This finding is consistent with known motor difficulties in some, but not all dyslexic individuals (e.g., Ramus et al., 2003; White et al., 2006). Indeed, the correlation between perceptual and motor processing (and the subsequent finding that this was carried by only one particular participant) is consistent with variability in non-phonological deficits across populations with dyslexia (e.g., see Valdois et al., 2003). The impaired scores of the dyslexic group on the WAIS speed of processing tasks could also be a consequence of slower motor skills, since both of these tasks are pencil and paper based and reflect cognitive processing speed alongside motor performance.

Interestingly, the findings seem to emphasize the potential role of speed of processing in non-word reading, as opposed to the ability to shift spatial attention. The shift task accounted for around 40% of the unique variance in non-word reading when entered after age and non-verbal ability. However, once speed of processing was controlled by entering focus task performance in the analysis, attention shifting was no longer a significant predictor of non-word reading. While the focus task was no longer a significant unique predictor when entered into regression analyses at the same time as the shift task, this finding can be attributed to the two tasks both drawing heavily on speed of processing resources, leaving little unique variance to be accounted for.

The greater variability in the dyslexic group's reaction time and accuracy data is particularly worth noting. Previous research findings have been inconsistent in terms of demonstrating attentional deficits in dyslexia, and it is possible that this may be due to the existence of qualitatively different dyslexia profiles or subgroups. Valdois et al. (2003) used an in-depth case study analysis to highlight that dyslexic individuals can have strikingly different cognitive and behavioral profiles. They found that a deficit in visual attention was associated with a "surface" dyslexia profile rather than the classic "phonological" dyslexic. "Surface" dyslexics are known to have particular difficulty with reading exception words as opposed to non-words, although researchers have argued this is due to a mild phonological deficit alongside limited exposure to print (see Griffiths & Snowling, 2002 for a discussion).

It is plausible to speculate that weaknesses in attention could lead children to engage less with the reading process, leading to lower exposure to print than those children without attention deficits, and a subsequent "surface" dyslexia profile. Detailed case studies like the work carried out by Valdois et al. (2003) may prove invaluable in helping to illuminate the individual differences that are inevitably masked by group based research designs. In addition, the suite of studies that have explored the outcomes of children who are genetically "at risk" for developing dyslexia (Guttorm et al., 2005; Pennington & Lefly, 2003; Snowling, Gallagher & Frith, 2003) provide a template for future work in this field.

Limitations

We are aware that our sample size is small and that our analyses are potentially underpowered. Accordingly, we acknowledge that our findings should be treated with caution since we may not have detected all of the potential and more nuanced effects within and between the groups. However, the issue of appropriate sample size and power is a complex one (Hoenig & Heisey, 2001; Thomas, 1997), being impacted by a number of factors including research aims and general patterns of effects found in the pertinent literature. With this is in mind we would argue that we are confident that our sample size was sufficiently large enough address the broad question of differences in processing speed between dyslexic populations and controls and that finding a difference in processing speed is uncontroversially consistent with the pertinent literature (i.e., Facoetti et al., 2005; Hari & Renvall, 2001). Equally, we feel confident that we have enough power to explore the role of processing deficits alongside phonological skill, since our findings are supported elsewhere in the literature where non-word reading performance was controlled (i.e., Heiervang & Hugdahl, 2003). We would nevertheless hope that future research in this and other labs would involve larger samples where more nuanced effects might be discovered within and between the groups. Though on this note we would add that the greater variability in the dyslexic group's reaction time and accuracy data, seen here, is entirely consistent with individual variation in dyslexic populations (e.g., Valdois et al., 2003) and offers a potentially interesting avenue for future research.

In conclusion, the present study provides no support for the hypothesis that impaired shifting of attention underpins the phonological deficit known to characterize dyslexia. While these findings must be interpreted with caution considering the small sample sizes, they add to a growing body of literature that emphasizes the potential role of processing speed alongside phonological skills in persistent reading difficulties (e.g., Catts et al., 2002; Kail & Hall, 1994).

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