Article ▸ Visual Attentional Deficits in Reading Disability

Vandana Rajaram, OD, PhD, Michigan College of Optometry, Ferris State University, Big Rapids, Michigan
Vasudevan Lakshminarayanan, PhD, University of Waterloo, Ontario, Canada

ABSTRACT

Background: Dyslexia, also referred to as specific reading disability, is a condition where an individual demonstrates a level of reading that is significantly below what may be expected for his age or intelligence. Although the phonological deficit theory of dyslexia is widely accepted, there is accumulating evidence suggesting that at least a subset of dyslexic subjects demonstrate distinct visual attentional deficits. However, it is unclear if the magnitude of visual attention at attended and unattended locations is equivalent in poor and normal readers. The aim of the present study was to examine differences in the magnitude of attentional facilitation (benefits) and inhibition (costs) in response to an abrupt onset spatial cue in children with reading disabilities in comparison to controls.

Methods: A group of impaired readers (n=15), ages nine to 12 years, reading at a level at least 1.5 years below grade level and with average mathematics scores, were included in this study. The control group included an age-matched sample of normal readers (n=20). An adaptation of the covert orienting paradigm was used to investigate differences in magnitude of visual spatial attention between groups.

Results: Poor readers demonstrated smaller costs ($t=2.07$, $p<0.02$) at unattended locations in comparison to their normal counterparts. Additionally, poor readers were significantly slower ($F(1,32) = 14.17$, $p<0.001$) in moving spatial attention in response to an abrupt onset peripheral cue when compared to controls.

Conclusion: The poor readers in the current study were slower in shifting spatial attention in comparison to their normal counterparts. They also demonstrated smaller costs at unattended locations, providing indirect evidence for a diffuse attentional field in this group. Consistent with many studies in the literature, we have presented evidence for spatial attentional deficits in impaired readers, the implications of which are discussed within the context of some of the current models of attention.

Keywords: costs and benefits, dyslexia, spatial attention, specific reading disability

Introduction

Dyslexia, also referred to as *specific reading disability,* is a condition where an individual demonstrates a level of reading that is significantly below what may be expected for his age or intelligence. Additionally, the reading level is also disparate with the individual's cultural, linguistic, and educational experience.[1]

The etiology of dyslexia is widely debated amongst vision scientists as well as educators. One theory that gained widespread popularity early on and that continues to generate strong support amongst researchers is the phonological deficit theory. According to this theory, dyslexia arises from a very specific deficit that selectively impairs the language systems.[2,3] Theorists and experimentalists supporting this idea believe that although other neural systems may contribute to reading disability, the cardinal deficit in dyslexia involves the language systems.[4] Despite considerable support for this theory, there is some scientific evidence to the contrary. For instance, in his review of the magnocellular theory of dyslexia, Stein[5] points out that at least some dyslexic subjects have no apparent difficulty in decoding phonologically regular words but demonstrate a great deal of difficulty when required to name or spell phonologically irregular words (e.g. yacht). According to Stein, in order to read such words, a reader must remember the orthography or visual form of the word. Furthermore, dyslexic subjects have been observed to demonstrate deficits in eye movements, visual search, and visual attention.[5,6] The magnocellular system plays a significant role in all of the aforementioned visual functions. Hence, these observations allude to the visual magnocellular theory of dyslexia. Visual information travels from the retina to the lateral geniculate nucleus (LGN) and then on to the primary visual cortex along two pathways. Although there is considerable crosstalk between these two pathways, each pathway selectively processes specific aspects of vision. The magnocellular or transient pathway specializes in processing visual motion, while the parvocellular or sustained pathway processes high spatial frequency information or object details. Beyond the striate cortex, magnocellular and parvocellular inputs continue to travel along the dorsal and ventral streams, respectively. The dorsal stream, with a predominance of magnocellular input, ends within the posterior parietal cortex.

Many researchers believe that those with dyslexia have a deficiency in the transient pathway which is the fundamental basis for the reading deficiency seen in this group.[5] Support for the magnocellular deficit theory has also come from the works of Lovegrove et al.[7] who demonstrated that the contrast sensitivity function in some dyslexics was reduced, especially at lower spatial frequencies.

In spite of the popularity of the magnocellular theory of dyslexia amongst vision scientists, the question of how a deficient transient pathway could influence the reading task remains to be answered. Although some associations between magnocellular functioning and reading have been established, it has been difficult to establish causation. This is understandable if one considers the fact that written text is comprised of crowded, closely packed, high spatial frequency information. It is the parvocellular pathway that specializes in processing these stimulus attributes. At first glance, it seems that a transient pathway deficit, even if it exists in dyslexics, should not influence the ability to read. However, a number of studies allude to visual spatial attention as the mechanism through which a magnocellular pathway deficit influences reading.[8-11] Visual attention has been defined as a neural process that enhances the processing of visual information from an attended location in the visual field while suppressing information outside of it.[8] One could probably intuitively understand the role a selective mechanism, such as attention, plays in the process of learning to read. Although all words within a text are potential visual inputs, at any given moment the reader is required preferentially to select a very small portion of the text for further processing. Furthermore, he is required sequentially to process the visual form or orthography of the selected text while simultaneously suppressing information from the periphery. Thus, visual attention is plausibly a crucial factor that at least partially determines reading ability.

A widely used method of measuring attentional shifts in the visual domain is the Posner covert orienting paradigm,[12,13] which provides the researcher with a reliable means of measuring the effects of spatial attention at different locations of the visual field without the accompaniment of eye movements. The paradigm requires a subject to respond to a target as quickly as possible while maintaining central fixation. The target usually appears at one of two or more peripheral locations. Prior to the appearance of the target, a cue is flashed that directs the subject's attention to one or more peripheral location(s). On most trials, the cue accurately indicates where the target will subsequently appear. These trials are termed valid. A small percentage of trials mislead the subject in that they direct the subject's attention to an incorrect location. These trials are termed invalid. Valid trials provide information pertaining to the effect of attention on processing of stimuli while invalid trials give the researcher an idea about visual processing at unattended locations. Normal subjects typically demonstrate attentional facilitation or benefits at cued locations and attentional inhibition or costs at non-cued locations.[12] Most versions of the Posner paradigm include two other cue conditions. The first is the neutral cue condition, the purpose of which is to have the subject direct his attention equally to all spatial locations where the target could potentially appear. The next is the catch trial in which the cue appears but the target does not. Catch trials give the examiner an idea about the subject's attentiveness and are used as a reliability index. The Posner paradigm can be used preferentially to activate reflexive or voluntary attention by manipulating the temporal difference between the disappearance of the cue and the subsequent appearance of the target. This temporal lag is referred to as the cue-lead time or the stimulus onset asynchrony (SOA). The attentional effect of the cue remains for approximately 250 ms.[8] Thus, any target presented in the attentional locus within this time is processed faster, and the nature of attention elicited is reflexive.

A number of studies have employed the spatial cueing paradigm to study the relationship between spatial attentional deficits[14-16] and temporal order judgment[17,18] in dyslexia. An early study by Brannan et al.[14] investigated the ability of good and poor readers covertly to allocate attention with the hypothesis that attentional deficits in poor readers would manifest as reduced accuracy in detection of target and/or the utilization of cue information. They employed two conditions of cue validity, 50% (random) and 80%. They demonstrated that good readers and adults showed an increase in detection accuracy as the predictive validity of the cue changed from 50% (random) to 80%, while poor readers did not demonstrate the same improvement. Since poor readers did not demonstrate the same improvement, the researchers concluded that poor readers had a deficit in shifting attention in response to a parafoveal cue. Facoetti et al.[16] also compared the ability of dyslexic and normal children as well as normal adults in orienting and focusing attention. They found that the dyslexic group was selectively impaired in shifting attention in response to a cue presented at a short SOA. Thus, both studies mentioned reported the inability of dyslexic subjects to use cue information when it was presented at short cue lead times. In a more recent study, Facoetti et al.[15] found that dyslexic children demonstrated attentional inhibition which was worse in the left visual field in comparison to the right. However, other studies, using similar covert orienting paradigms, have shown that dyslexic children have longer reaction time (RT) overall, but not specific differences in their ability to use cue information.[19,20]

Spatial attentional shifts in dyslexia have been evaluated in several studies over the years, with many studies indicating that dyslexic subjects demonstrate sluggish attentional shifts.[14,16,19] However, some issues remain unclear. For instance, the observation that dyslexic readers can shift attention in response to a cue does not necessarily imply that the effect or magnitude of attention at attended and non-attended locations is equivalent to that in normal readers.

Additionally, most studies have been limited in their ability to isolate pure attentional effects in dyslexic subjects, and to the best of our knowledge, no study has compared costs and benefits in dyslexic and control groups by directly comparing the magnitude of attentional facilitation and inhibition. We believe that the key to computing the magnitude of the attentional effect is by controlling for the absolute speed at which attention moves across space. By doing so, one can compute how effectively cue information gets utilized relative to that speed. The RT on neutral trials can be used as a measure of the absolute speed at which visual attention moves across space. The purpose of the neutral trial in the covert orienting paradigm is to distribute the subject's attention equally to all possible target locations. A change in RT relative to the RT on neutral trials can therefore be used as a standardized ratio of attentional effect. A ratio of 1.0 can be interpreted as the cue having virtually no effect. A ratio higher than 1.0 would suggest attentional inhibition or cost, and a ratio lower than 1.0 would suggest attentional facilitation or benefit. To the extent that these ratios depart from 1.0, one can get an estimate of the attentional effect of the cue (costs and benefits) which can then be directly compared across groups.

The aim of the present study was to examine differences in the magnitude of attentional facilitation (benefits) and inhibition (costs) in response to an abrupt onset cue in children with reading disabilities in comparison to normal readers. We examined differences in RT as well as differences with respect to costs and benefits across groups.

Subjects and Methodology

Subjects

A group of reading impaired children (n=15), ages nine to 12 years, reading at a level at least 1.5 years below grade level and with average scores in mathematics, were included in our study. Ten children from this sample were recruited from Hoech Middle School from the Ritenour school district in St. Louis, MO. Five subjects in the same age range were recruited from the University of Missouri – St. Louis (UMSL) reading clinic. All subjects had normal or corrected-to-normal visual acuity and binocular vision and no known history of general attentional problems. The control group included a cohort of age-matched normal readers (n=20) also recruited from the Ritenour school district. Informed consent and assent were obtained from the parents and children, respectively. Prior to experimental testing, Snellen visual acuities and gross binocular vision status (cover test and near point of convergence) were measured. This research conformed to the provisions of the University Institutional Review Board (IRB # 030409L).

Apparatus and Stimuli

An adaptation of the covert orienting paradigm used by Facoetti et al.[16] was replicated for its simplicity and ease of use with children. Unlike their paradigm, this study used a complex RT task. Small changes were made to the cue lead times. A program written in JAVA and run on a Dell model desktop computer was used for stimulus presentation and data collection. The fixation target, a cross, subtended a visual angle of 1.5 degrees at the 40 cm viewing distance. The target, a black dot presented on a white background, subtended a visual angle of 0.5 degrees at 40 cm. The cue was an arrow that subtended a visual angle of 1.5 degrees at 40 cm. The monitor had a luminance of 97cd/m^2.

Measurement procedures

All testing was done in a dimly lit room. Each trial began with the presentation of a fixation cross that appeared at the center of the monitor. This was followed by two boxes appearing approximately nine degrees to the right and left of the fixation cross. Approximately 0.5 seconds later, the cue briefly flashed for approximately 100 msec over one or both boxes. Following cue disappearance, the target appeared in one of the boxes at one of two different cue-lead times, 100ms or 200ms. On valid trials the target appeared in the same box as indicated by the cue. On invalid trials the target appeared within the box opposite to that indicated by the cue. On neutral trials the cue appeared over both boxes and the target appeared randomly in either one of the boxes. On catch trials the target was not presented. All trials had 80% cue validity. Subjects were instructed to maintain fixation on the central cross and avoid eye movements. They were required to respond to the target by pressing on the left mouse button when the target appeared in the left box and the right mouse button when the target appeared in the right. Subjects were encouraged to make prompt responses. RTs were measured and recorded by the computer. If the subject made an inadvertent response to the cue instead of the target, the program indicated this by a default value. These trial responses were discarded prior to data analysis. Each experimental session consisted of 100 trials that were presented in two blocks of 50 trials. Subjects were given a practice run of anywhere between 20 and 30 trials prior to testing. Eye movements were monitored manually.

Results

Mean correct RT data were analyzed using a three-way repeated measures analysis of variance (ANOVA). The two within-subject factors were trial type (valid, invalid, and neutral) and visual field (left or right). The between-subjects factor was group. All RT data greater than three standard deviations from the mean value were discarded.

There was a significant main effect of group ($F(1,32) = 14.17$, $p< 0.001$), indicating that overall poor readers had a significantly larger mean response time (520.57 + 23.31 ms) compared to controls (406.33 + 15.79 ms) (Figure 1). A significant main effect of trial type ($F(2,31) = 49.32$, $p < 0.000$) was found. Invalid trials had the longest RT (507.26 + 16.33 ms), followed by neutral trials (458.11 + 14.81 ms). Valid trials had the shortest RT (425.68 + 16.55 ms) (Figure 2).

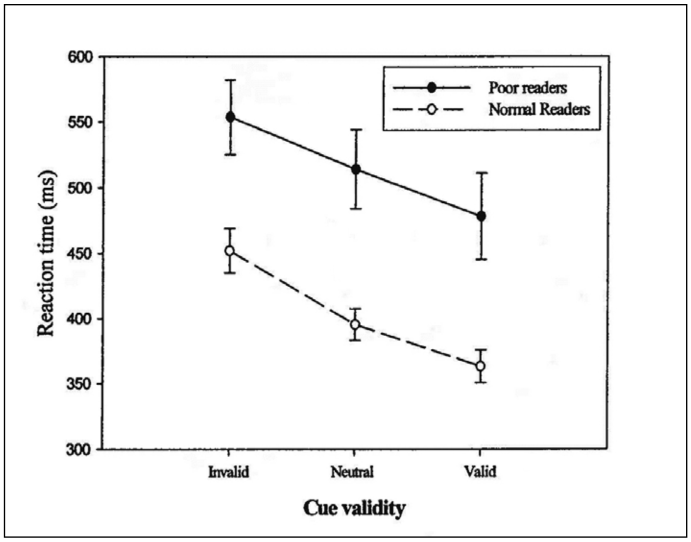

Figure 1: Reaction time is a function of cue-validity. Poor readers demonsrate larger mean response times compared to normal readers on all trial types.

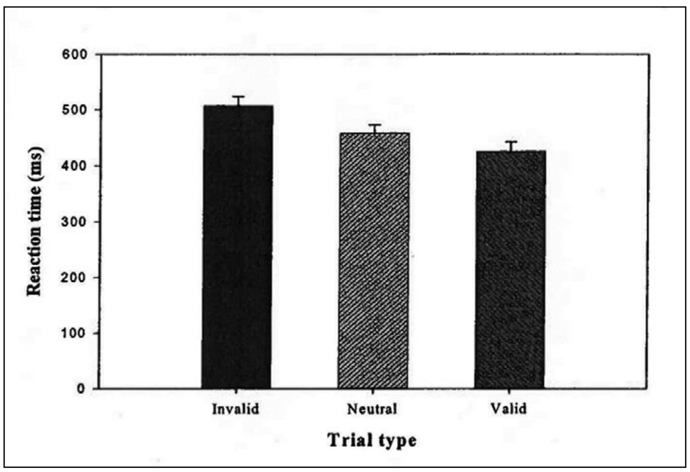

Figure 2: Mean reaction time as a function of cue validity.

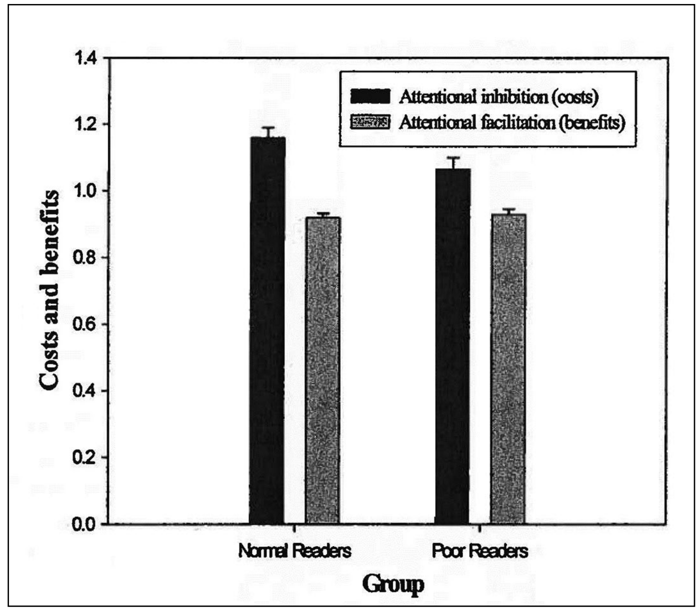

Figure 3: Comparison of costs and benefits in the two groups.

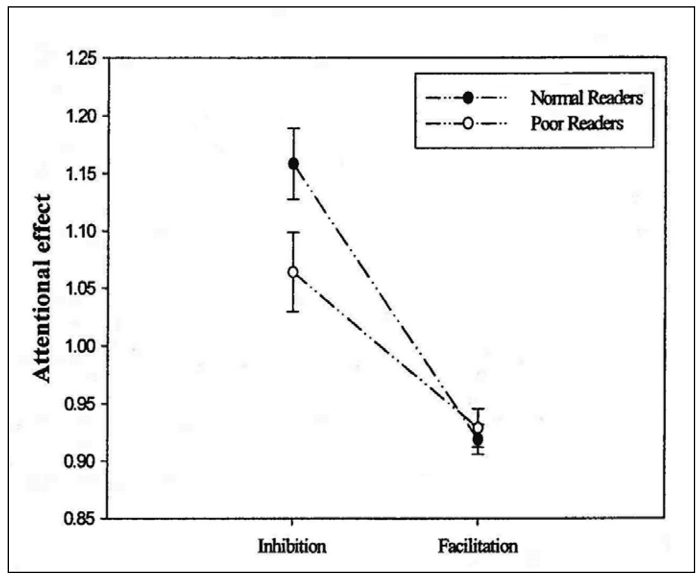

Figure 4: Interaction effect between attentional effect and group.

Comparison of costs and benefits

The main effect of group was not significant ($F(1,32) = 1.90$, $p<0.17$), indicating that both groups demonstrated costs and benefits (Figure 3). The interaction between group and attentional effect was significant ($F(1,32) = 4.21$ $p<0.04$) (Figure 4). A two sample t-test assuming equal variances was run to compare mean differences in costs between the two groups and was significant ($t = 2.07$, $p < 0.02$), indicating that normal readers demonstrate significantly larger costs at non-attended locations in comparison to disabled readers.

Discussion

Our experimental paradigm was designed to investigate whether poor readers differed from controls in their ability to direct visual attention reflexively in response to a spatial cue presented at a short cue lead time. Our first finding was that impaired readers were significantly slower in moving attention spatially in response to an abrupt-onset peripheral cue when compared to controls. A reduction in the speed of moving attention in poor readers has been reported in the literarture.[14-16,19] One possibility that could lead to longer RT in dyslexic readers is the existence of potential deficiencies along one or more cortical structures that may be involved in covert orienting. Early neurophysiological studies suggest that the operation of attentional movement is controlled by the midbrain, and that patients with midbrain lesions demonstrate a reduction in the ability to move attention spatially.[13,21] Posner and Peterson[21] suggest that a lesion in the locus coeruleus, a structure at the level of the brainstem (pons) and a source of the neurotransmitter norepinephrine, may lead to reduced alertness in dyslexics.[19] Reduced alertness is thought to increase RT to an external event, such as an abrupt-onset spatial cue.[19]

Another theory that has been put forth in an effort to explain generalized slowness in dyslexic subjects is the cerebellar deficit theory.[22] Since the cerebellum plays a role in the timing of sensory and motor tasks, a cerebellar deficit would lead to impaired performance on a cue target task.[19] The role of the cerebellum in developmental dyslexia has also been studied by Fawcett and coworkers.[23] They suggest that in order to understand dyslexia, one has to study neurological factors affecting the automatization process. This is because reading and phonological awareness happen in an automatic manner with very little conscious awareness. The cerebellum is considered the autopilot of the brain.[5] It plays a role in reading through eye movement control and by mediating 'inner speech' as a subject reads.[5] Despite reasonably strong support for the cerebellar deficit hypothesis, in recent years there has been increasing evidence against this theory, indicating that there may be little to no association between cerebellar function and reading acquisition.[24-26]

Another significant finding of the current study is that although poor readers had longer RT on all trial types, they did in fact demonstrate the ability to direct attention reflexively in response to an abrupt-onset peripheral cue. In this, our findings diverge from some of the previous work in this area,[14,16] but are consistent with others. For instance, Heiervang and Hugdahl[19] suggest that poor readers operate in a mode of divided attention that limits the deployment of cognitive resources required for a complex RT task. However, the most interesting finding of this experiment was revealed when the pure effect of the cue was analyzed. The advantage of analyzing RT data in terms of costs and benefits is evident from Figures 1 and 4. Figure 1 demonstrates a comparison of RT as a function of cue validity between poor and normal readers. It is evident from the figure that poor readers had significantly longer response time on valid, invalid, and neutral trial types. However, differences in costs and benefits at non-attended and attended locations, respectively, between the two groups are not seen in Figure 1 but are most apparent in Figure 4. Although both groups were able to use cue information, one can see from Figure 4 that the magnitude of attentional inhibition or costs was different for the two groups, with the normal group demonstrating higher costs. On invalid trials, costs observed at non-cued locations provide an indirect measure of the extent to which attention is focused at cued locations. A potential explanation is that a focused modality of attention would lead to a larger attentional capture at attended (or cued) locations. If a target appeared at a non-attended location, the subject had to disengage attention from the cued location and refocus to the locus of the target, which manifested as a cost.[27] It follows then that an unfocused (or diffuse) mode of attention would result in smaller costs at (unattended) locations of target appearance. Thus, figure 4 provides indirect evidence for a diffuse attentional mode in impaired readers. There have been various descriptions of spatial attention including those of a Spotlight,[12] Filter Channel,[28] and Zoom lens.[29,30] These descriptions imply that spatial attention can be localized to a particular spatial locus or can be diffusely distributed in space.[30] In an early study, Facoetti et al.[30] used a simple detection task to demonstrate that reading disabled children had a more diffuse or distributed mode of attention in comparison to controls. In a more recent study, they have demonstrated that dyslexic children show sluggish engagement and disengagement of non-spatial attention.[15] Both studies provide evidence for a diffuse or divided mode of attention in dyslexics. Furthermore, recent evidence suggests that dyslexics may have diffuse visual as well as auditory perceptual modes.[31]

How might a diffuse mode of attention compromise the ability to read in dyslexics? A wide attentional field can lead to interference from peripheral information, creating problems with foveal reading from an inability to suppress information from the periphery.[30-32] For instance, Geiger and Lettvin[33] presented pairs of letters, one at fixation and the other in the periphery, at various eccentricities to dyslexic and normal readers. While the accuracy of recognition declined sharply with increasing eccentricity in normal subjects, the dyslexic subjects in their study were able to identify letters over a wider area in the periphery in comparison to controls. Accordingly, the researchers suggest that dyslexic subjects undergo a much greater magnitude of lateral masking (visual crowding) at the fixation point than they do farther in the periphery in the direction of reading. Consequently, dyslexics perceive many words within a text simultaneously, unable to isolate one word from the next.[32] Additionally, as mentioned earlier, dyslexic subjects have been shown to have wider and more diffuse perceptual modes in the visual and auditory fields.[31] A subject with a wider visual perceptual mode will be unable to elicit focused attentive selection in the central field and will have greater tolerance for peripheral crowding or clutter, thereby compromising reading performance.[30] Furthermore, in a more recent study, Facoetti et al.[15] demonstrated that dyslexic children with impaired non-word reading showed a selective deficit in attentional inhibition in the right visual field when attention was focused in the left visual field. This finding suggests that a dyslexic subject will plausibly be unable to suppress textual information from the right visual field, which has significant implications for languages such as English in which the direction of text read is from left to right.

The implications of a diffusely spread out attentional focus can also be discussed within the framework of a neural model of attention proposed by Vidyasagar.[9,11] The task of reading involves a series of saccades interspersed by brief fixations. According to this model, during each fixation an attentional spotlight systematically focuses on one or two letters within a word, which are then directed to the ventral stream for processing.[9] When all the letters within a fixation are processed in this manner, the next saccade is executed.[9] The author compares this mechanism to a serial search task operating systematically in experienced readers. Our findings of a spatially diffuse attentional field will theoretically enhance parallel search, i.e. the processing of several stimuli simultaneously, the mechanisms of which are the very opposite of what may be required to accomplish an efficient serial search. If the current results are to be interpreted within the context of Vidyasagar's model, it would imply that a diffuse attentional spotlight unable to narrow effectively will direct many letters simultaneously to the ventral stream for processing. Neurons in the temporal cortex have large receptive fields, receiving parvocellular *and* presumably magnocellular inputs,[9] exhibiting the property of 'position invariance,' implying that objects can be recognized irrespective of their position.[9] Therefore, as per the model, although the letters would be recognized, the word recognition system would nevertheless be confounded without the knowledge of the positions of these letters within the word. This in turn would lead to characteristic letter reversals and word jumbles. Within the context of this model, a diffuse attentional spotlight that also moves with profound slowness might explain why reading is so slow and effortful in impaired readers in comparison to controls.

Despite emphasis on visual attentional deficits in reading disabilities, the authors do not wish to undermine the role that phonological and linguistic ability play in reading acquisition. In fact, a dominant view shared at least by some vision researchers is that the cardinal deficit in dyslexia is phonological and that any attentional deficits that are seen in dyslexics only affect reading ability because they interfere with sublexical mechanisms (such as graphemic parsing), which are considered extremely crucial in the development of reading acquisition.[15,33] There is evidence in the literature in support of this notion.[15,33,34] However, there is also accumulating research evidence which shows that at least a subset of dyslexic subjects demonstrate distinct attentional deficits even on tasks that are clearly non-phonological.[35,36] The latter reinforces the validity of the theory which characterizes dyslexia as a multisystem deficit not limited to the language system.[35,37]

Conclusion

Spatial attentional shifts were investigated in a group of poor readers using the Posner covert orienting paradigm. The results suggest that impaired readers can shift attention in response to a peripheral transient cue, albeit slower than their normal counterparts. Indirect evidence is provided for a diffuse attentional field. Consistent with many studies in the literature, we have presented evidence for visual attentional deficits in impaired readers. However, whether these attentional deficits merely accompany the reading impairment or contribute to it remains an issue of controversy. There are theoretical models which have made predictions about the manner by which attentional deficits could affect reading acquisition, but recent emphasis has been on multifactorial neurocognitive deficits characterizing dyslexia.

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Correspondence regarding this article should be emailed to rajarav@ferris.edu or sent to Vandana Rajaram, OD, PhD, Michigan College of Optometry, Ferris State University, 1124 South State Street, Big Rapids, MI 49307.

Rajaram V. Visual attentional deficits in reading disability. Optom Vis Perf 2013;1(4):141-7.

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