Visual Information Processing in Dyslexics

by

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Some percentage of children in most Western countries fail to learn to read and spell at a level expected on the basis of their age and intelligence despite adequate educational opportunities and no obvious brain damage. Such children are commonly referred to as development dyslexics. Extensive research has been conducted in the last thirty years attempting to understand possible causes for such reading failure. In this lecture, I will outline some of this research which has concentrated on how dyslexics and normal readers process visual information. Much of this research has been performed with my colleagues at the University of Tasmania, the University of Wollongong and, now, at Griffith University.

Before discussing the evidence, I will briefly discuss models of word recognition and then go on to ask, "what does the visual system have to do when reading?"

When presented with a word and asked to name it, there are at least two routes which may be followed in our brain. This may be demonstrated by asking, "how do you pronounce a word such as 'yacht' (an irregular or exception word)?" If you pronounced it correctly, you must have been able to access a visual representation of the word in your brain as you would be unable to access the representation ('yot') by sounding out the letters and determining the name. If you had tried that route, you would not have reached the correct pronunciation. If instead you are asked to pronounce regular non-words such as 'borp' or 'framp', most of you will be able to do so correctly. You will not, however, have done this via a visual route because you would not have a stored visual representation of regular non-words in your brain. Without any real conscious awareness you will have converted the letters to sounds (grapheme-to-phoneme conversion) and accessed the name via a phonological route. Thus we may access the name (and the meaning) of words via a visual or phonological route.

This is relevant to dyslexia as evidence shows that there are different types of dyslexia defined by the types of errors made and these types reflect a weakness in one or both of these routes. Boder and Jarrico (1982) classified dyslexics into three subtypes: dysphonetics, dyseidetics and mixed dysphoneidetics. Dysphonetic dyslexics have difficulties with grapheme-to-phoneme translation and have to rely on their sight vocabulary for word recognition. Therefore, they have difficulties with reading non-words but not with irregular words. Dyseidetic dyslexics have problems building a sight vocabulary, and tend to use the grapheme to phoneme conversion route. Therefore, they have difficulties reading irregular words but not non-words. Mixed dysphoneidetic dyslexics have problems in both reading strategies and hence, they have difficulties reading both types of words. I will return to this issue later.

The second major question to consider is, "what does the visual system have to do in reading?" The answer to this question may be seen in the first panel in Figure 1. This shows that, in reading, our eyes stay still for short periods of about a quarter of a second in skilled readers. These periods are known as fixations. In between fixations our eyes move rapidly from one position to another via what are known as saccadic eye movements. Therefore the visual system needs to extract detail from fixations and also integrate or combine information gained from successive fixations. In skilled readers this is an automatic process and we are not aware of the discrete nature of the successive inputs.

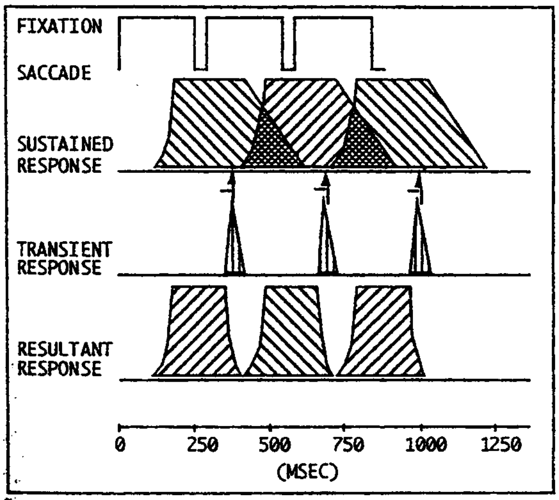

Figure 1. A hypothetical response sequence of sustained and transient channels during three 250ms fixation intervals separated by 25 ms saccades (top panel). Panel 2 illustrates persistence of sustained channels acting as a forward mask from preceding to succeeding fixation intervals. Panel 3 shows the activation of transient channels shortly after each saccade which exerts inhibition (arrows with minus signs) on the trailing, persisting sustained activity generated in prior fixation intervals. Panel 4 shoes the resultant sustained inhibition have been taken into account (adapted from B.G. Breitmeyer, (1980). Unmasking visual masking: A look at the 'why' behind the veil of the 'how'. *Psychological Association.* Permission to reprint granted.).

This task is a challenge for the visual system, as shown in Panel 2 of Figure 1, which shows that the neural activity triggered by one fixation may outlast the physical duration of that fixation. Theoretically this may lead to the superimposition of input from fixation 1 onto fixation 2 as shown in Figures 1 and 2. Why this does not occur in most readers will be discussed later following a brief introduction to some more detail of visual information processing in humans. Consequently, I will now briefly discuss evidence for two complementary subsystems in the human visual system: the sustained/parvo and the transient/magno systems. In order to do this, I will first discuss the notion of spatial frequency channels in human vision.

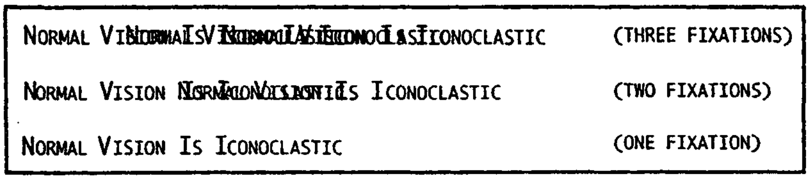

Figure 2. The perceptual masking effects of temporal integration of persisting sustained activity from preceding fixation intervals with sustained activity generated in succeeding ones when the reading of a printed sentence requires one, two or three fixations. Here, as in panel 2 of Figure 1, the effects of transient-on-sustained inhibition have not been taken into account. (Adapted from B.G. Breitmeyer, Unmasking visual masking: A look at the 'Why' behind the veil of the 'How' *Psychological Review*, 1980, 82, 52-69. Copyright 1980 by the American Psychological Association. Permission to reprint granted.)

Spatial Frequency Processing

One approach to vision research (Campbell, 1974; Graham, 1980) indicates that information is transmitted from the eye to the brain via a number of separate parallel pathways. The separate pathways are frequently referred to as channels. Each channel is specialised to process information about particular features of visual stimuli. The properties of channels often have been investigated using patterns composed of black and white bars with fuzzy edges. These patterns are usually called sine-wave gratings. Two properties of sine-wave gratings are important to the research outlined here.

Spatial frequency refers to the number of cycles (one dark plus one light bar) per degree of visual angle (c/deg) in a pattern. High spatial frequency patterns contain narrow bars and stimulate the channels which process detail. Low spatial frequency patterns contain very broad bars and stimulate channels which transmit information about general shape. Contrast refers to the difference between the maximum and minimum luminance of the grating. It is a measure of the ratio of the brightest to the darkest section of the pattern.

Spatial frequency or size-sensitive channels are relevant to reading because when we read we process both general (low spatial frequency) and detailed (high spatial frequency) information in each fixation. We extract detailed information from an area approximately 5-6 letter spaces to the right of fixation. Beyond this, we also extract visual information but only of a general nature such as word shape (Rayner, 1975). These two types of size information must be combined across fixations for fluent reading.

Several studies have shown that these different spatial channels transmit their information at different rates and respond differently to different rates of temporal change. Some channels are sensitive to very rapidly changing stimuli and others to stationary or slowly moving stimuli. In general, channels which are sensitive to low spatial frequencies (general information) are highly sensitive to rapid temporal change while channels sensitive to high spatial frequencies (detail information) are insensitive to rapid temporal change. Such results have led to the proposal of two subsystems within the visual system. This division is believed to be important in combining the two types of size information involved in fluent reading.

The sustained (parvo) and transient (magno) subsystems

As mentioned above, it has been shown that spatial frequency channels differ in their responses to changing stimuli. In a typical experiment subjects are shown sine-wave patterns flickering at various rates. Subjects are required to set contrast levels so that they can just see either flicker or pattern. When low spatial frequency gratings (general information) are moving quickly, we see flicker at lower contrasts than we see pattern but we experience the reverse at high spatial frequencies. Separate measures can be taken of our sensitivity to flicker and pattern with a range of different sized stimuli (spatial frequencies) flickering at different speeds. We can then plot sensitivity functions for pattern and flicker thresholds at a range of spatial frequencies. With large stimuli (low spatial frequencies) we are more sensitive to rapidly changing stimuli but with small stimuli (high spatial frequencies) we are more sensitive to stationary or slowly moving stimuli. The two functions obtained from such experiments are believed to measure two subsystems in the visual system, the transient and sustained subsystems, respectively. An extensive discussion of the properties of these systems, and how they are identified, can be found in Breitmeyer (1988). Breitmeyer also discusses the evidence indicating the physiological basis of these two systems. The properties of these two subsystems have been identified and are shown in Table 1.

Table 1

General properties of the sustained/parvo and transient/magno subsystems

Sustained System	Transient System
Less sensitive to contrast	Highly sensitive to contrast
Most sensitive to high spatial frequencies	Most sensitive to low spatial frequencies
Most sensitive to low temporal frequencies	Most sensitive to high temporal frequencies
Slow transmission times	Fast transmission times
Responds throughout stimulus presentation	Responds to stimulus onset and offset
Predominates in central vision	Predominates in peripheral vision
May inhibit the transient system	May inhibit the sustained system

The transient system is predominantly a flicker or motion detecting system transmitting information about stimulus location and general shape. The spatial information it transmits is coarse and thus well suited for transmitting peripheral information. The sustained system is predominantly a detailed pattern system transmitting information about stationary stimuli. The sustained system is most important in extracting information during fixations and the transient system in extracting general information from the periphery. The transient system has also been implicated in the important task of integrating information from successive fixations. These two subsystems and the interactions between them may serve a number of functions essential to reading process.

It has been demonstrated physiologically (Singer & Bedworth,1973) and psychophysically (Breitmeyer & Ganz, 1976) that the two systems may inhibit each other. In particular, if the sustained system is responding when the transient system is stimulated, the transient system will terminate the sustained activity. An example of how this may occur is as follows: if we are fixating on the detail of an object and a stimulus moves into the periphery of our vision, the transient system is likely to inhibit or override the sustained system until we know what is in our peripheral vision. How this may have evolved is easier to imagine if we consider not a human reading but a rabbit eating and a predator appearing to the side. There would be survival value for the rabbit in having the transient system inhibit the sustained system until the level of threat could be determined.

Sustained/parvo and transient/magno subsystems and reading

We can now return to the question left unanswered above: "how does the visual system avoid superimposing inputs from one fixation onto the input from the next fixation?"

The role of transient and sustained subsystems in reading has been considered by Breitmeyer (Breitmeyer & Ganz, 1976; Breitmeyer, 1980; 1983; 1988;). Figure 1 represents the hypothesised activity in the transient and sustained channels over a sequence of three fixations of 250 ms duration separated by two saccades of 25 ms duration each.

The sustained channel response occurs during fixations and may last for several hundred milliseconds. This response provides details of what the eye is seeing. The transient channel response is initiated by eye movements and lasts for much shorter durations. Consequently, both systems are involved in reading. The duration of the sustained response may outlast the physical duration of the stimulus. This is a form of visible persistence, activating the sustained channels. Its duration increases with increasing spatial frequency (Meyer & Maguire, 1977; Bowling, Lovegrove & Mapperson, 1979) and may last longer than a saccade.

Breitmeyer proposes that the problem posed by visible persistence is solved by rapid saccades as shown in the bottom two panels of Figure 1. Saccades not only change visual fixations, they also activate short latency channels (panel 3) which are very sensitive to stimulus movement. This, in turn, inhibits the sustained activity which would persist from a preceding fixation and interfere with the succeeding one (Matin, 1974; Breitmeyer and Ganz, 1976). The result is a series of clear, unmasked and temporally segregated frames of sustained activity, each one representing the pattern information contained in a single fixation as shown in panel 4 of Figure 1.

In these terms, clear vision on each fixation results from interactions between the sustained/parvo and transient/magno channels. Consequently, the nature of transient-sustained channel interaction is important in facilitating normal reading. Any problem either in the transient/magno or the sustained/parvo system or in the way they interact may have harmful consequences for reading.

Transient/magno and sustained/parvo processing in dyslexics and normal readers

The possibility of a visual deficit in dyslexics has been investigated within the theoretical framework of these two subsystems in human vision. The following is not a complete review of all recent research but a selective summary of the research carried out in a few laboratories, including ours. Subjects in the studies by Lovegrove and colleagues have normally been chosen to have at least normal intelligence and a reading accuracy lag of at least two years on the Neale Analysis of Reading Ability (Neale, 1966). In fact many of the children we have worked with have had reading lags of four years.

Visible persistence is one measure of temporal processing in spatial frequency channels and refers to the continued perception of a stimulus after it has been physically removed, as shown in panel 1 in Figure 1. Several studies have compared dyslexics and controls on measures of visible persistence as a function of spatial frequency. It has been shown that dyslexics aged from 8 to 15 years have a significantly smaller increase in persistence duration with increasing spatial frequency than do controls (Lovegrove, Heddle & Slaghuis, 1980; Badcock & Lovegrove, 1981; Slaghuis & Lovegrove, 1985).

When visible persistence is measured in both groups under conditions which reduce transient system activity (using a uniform field flicker mask), persistence differences between the groups essentially disappear (Slaghuis & Lovegrove, 1984). This finding suggests that dyslexics may differ from controls mainly in functioning of their transient systems.

The two groups have also been compared on a task which measures the minimum contrast required to see a pattern. Contrast sensitivity plotted as a function of spatial frequency, is referred as the contrast sensitivity function (CSF). Pattern CSFs have been measured in at least five separate samples of dyslexics and normal readers, with ages ranging from 8 years to 14 years. It has generally been shown that dyslexics are less sensitive than controls at low spatial frequencies (Lovegrove, Bowling, Badcock, & Blackwood, 1980; Lovegrove Martin, Bowling, Badcock & Paxton, 1982; Martin & Lovegrove, 1984). In some studies the two groups do not differ in contrast sensitivity at higher spatial frequencies (Lovegrove et al., 1980) while in other studies dyslexics are slightly more sensitive than controls in the high spatial frequency range (Lovegrove et al., 1982; Martin and Lovegrove, 1984). Once again, attenuation of the transient system by uniform-field masking influenced the dyslexic group less than controls (Martin and Lovegrove, 1988), thus, further supporting the notion of a difference between the groups in the transient system.

A third approach has been to measure transient system functioning more directly than did the previous two measures. It has been argued that flicker thresholds are primarily mediated by the transient system. Consequently, flicker thresholds under a range of conditions have been measured in dyslexics and controls. In these experiments, subjects are shown a sine-wave grating counterphasing, i.e. moving from right to left and back the distance of one cycle at various speeds. Subjects are required to detect the presence of the flicker. In a number of experiments, dyslexics have been shown to be less sensitive than controls to counterphase flicker (Martin & Lovegrove, 1987; 1988; Brannan & Williams, 1988). The differences between the groups sometimes become larger as the temporal frequency increases (Martin & Lovegrove, 1987; 1988) and sometimes do not (Brannan & Williams, 1988). What happens depends on the spatial make-up of the stimuli. This is a direct measure of transient system processing and distinguishes very well between individuals in the two groups (Martin & Lovegrove, 1987).

Lovegrove, Martin, and Slaghuis (1986) have also conducted a series of experiments comparing sustained system processing in controls and dyslexics. Using similar procedures, equipment and subjects as the experiments outlined above, these series of experiments has failed to show any significant differences between the two groups. These data suggest that either there are no differences between the groups in the functioning of their sustained systems or that such differences are smaller than the transient differences demonstrated.

In summary, four converging lines of evidence suggest a transient deficit in dyslexics. The differences between the groups are quite large on some measures and discriminate well between individuals in the different groups, with approximately 75 percent of dyslexics showing reduced transient system sensitivity (Slaghuis & Lovegrove, 1985). At the same time, evidence to date suggests that the two groups do not differ in sustained system functioning.

Is there independent evidence for a transient/magno deficits in dyslexics?

In addition to the primarily psychophysical work presented above, there are also a number of visual evoked potential studies indicating transient/magno pathway deficits (Mecacci, Sechi, & Levi, 1983; Livingstone, Drislane, Rosen, & Galaburda, 1991; May, Lovegrove, Martin & Nelson, 1991; Lehmkuhle, Garzia, Turner, Hash, & Baro, 1993; Kubova, Kuba, Peregrin, & Novakova, 1995).

Further clear evidence has been produced in a brain imaging study using functional MRI techniques of a transient/magno deficit in dyslexics co-existing with an intact sustained/parvo system (Eden, Van Meter, Rumsey, Maisog, Woods & Zeffiro, 1996).

Finally, Galaburda and Livingstone (1993) have been able to analyse cell size and organisation in the transient/magno and the sustained/parvo systems in the brains of former dyslexics. Their results show that dyslexics have fewer larger cells in the magno system, needed for efficient transient system functioning, but do not differ from control brains in the size of small cells underpinning the function of the sustained/parvo system.

What about adult dyslexics?

Recently Elizabeth Conlon and her students at Griffith University have investigated transient/magno functioning in adult dyslexics using coherent motion and dot counting (temporal and spatial) tasks. Their results show that transient/magno deficits are maintained into adulthood. Reading problems are sometimes less extreme in such adults but spelling problems always remain.

What about different types of dyslexics?

Earlier I referred to research showing that there are different types of dyslexia. Some recent studies in the US have shown that mixed dysphonoeidetic and severe dysphonetic dyslexics have transient/magno deficits (eg. Borsting, Ridder, Dudeck, Kelley, Matsui & Motoyama, 1996). This work has recently been extended by Conlon and colleagues using more sensitive measures to show that most dysphonetic and mixed dysphoneidetic dyslexics show such deficits but dyseidetics do not. They also showed a significant correlation between ability to read regular non-words and transient/magno system deficit.

In summary, there is now a large number of studies which have investigated visual information processing in good and poor readers. The results from this wide range of measures confirm the finding of a transient/magno system deficit in certain types of dyslexics.

At least three questions emerge from the demonstration that dyslexics and controls do differ in at least one aspect of visual processing. The first concerns the possible explanations for the conflicting findings reported in the literature. The second addresses the important applied issue of whether any visual manipulations are likely to assist dyslexic children to read. The third question concerns the possible relationship between visual deficits and other documented deficits experienced by dyslexics. These three questions will be discussed in turn.

What about the confusion in the literature?

In the early years of dyslexia research (approximately the first 30 years of this century) it was widely assumed that problems in visual processing were a fundamental component of dyslexia. This view lost favour over the next 40-50 years for two reasons. First, different researchers reported conflicting results with some showing that dyslexics do differ from controls in visual processing and others showing that they do not. Second, much attention was focused on subtle language problems found in many dyslexics. I will return to this later.

An obvious question is whether it is possible to reconcile these different sets of results in terms of the argument presented here. It may be suggested initially that many of the studies which have failed to show differences between dyslexics and normal readers in visual processing have measured sustained processing and those which have shown differences have measured either transient system processing or transient-sustained interactions. Support for this position has been provided by Meca (1985), who conducted a meta-analysis on a large number of studies investigating vision and reading. He plotted effect size as a function of spatial frequency. As would be expected if dyslexics had a transient/magno system problem but not a sustained system problem, effect size was greatest at low spatial frequencies and decreased with increasing spatial frequency (Meca, 1985).

This hypothesis allows us to make predictions about what should be found on a range of different tasks, depending on whether or not transient/magno or sustained/parvo processing is being measured. A study by Solman and May (1990) has investigated spatial localisation in dyslexic and normal readers within this context. They predicted not only conditions where dyslexics should be worse than controls, but also where dyslexics would perform at least as well as or even better than controls. They found that when the targets were close to the fixation points dyslexics performed slightly better than controls. This pattern reversed as the targets moved more into peripheral vision (and were presumably processed more by the transient/magno system). Such an outcome supports the position that some of the confusion in the literature may be explained in terms of which visual subsystem is being measured.

Furthermore, some of the conflicting results almost certainly depend on what "types" of dyslexics have been used in different studies. The results referred to above by Conlon and colleagues show this clearly. This difference between studies is important for a number of reasons including attempts to remediate dyslexics.

REMEDIAL IMPLICATIONS

Two approaches to this question have so far been investigated by our groups or colleagues elsewhere. The first, has manipulated the nature of visual presentation during reading and the second, has attempted to modify the relative balance of the transient/magno and sustained/parvo subsystems.

The one word at a time advantage

Lovegrove and MacFarlane (1990), Hill and Lovegrove (1992) and Pepper and Lovegrove (1999) attempted to predict from Breitmeyer's (1980; 1983; 1988) theory the effects that different types of spatial context may have on reading accuracy in dyslexics and controls. In terms of Breitmeyer's theory outlined earlier a transient deficit should lead to more errors for dyslexics when reading continuous text than when reading isolated words. This is because reading continuous text requires integration of peripheral information from one fixation with central information on the next fixation thus requiring greater transient/magno system involvement. This has been tested by varying the mode of visual presentation (Lovegrove & MacFarlane, 1990; Hill & Lovegrove, 1992). Three conditions of visual presentation on a computer monitor were used while holding the semantic context constant. This was done by presenting stories in three different ways. In the first condition one word at a time was presented in the middle of the screen. Thus, the subjects never had to move their eyes and never had information presented to the right of fixation. In the second condition, one word was presented at a time but its position was moved across the screen so that each successive word appeared to the right of the previous word. Once a word was presented, it remained on the screen so that at the end of the line, a whole line of print was present. Here the subjects were required to move their eyes across the screen but still were never presented with information to the right of fixation. The final condition was a whole line presentation which most closely approximated normal reading. Rate of word presentation was held constant across the three conditions.

The results showed that normal readers were most accurate in the whole line condition and made more errors in the two one word at time conditions (Lovegrove & MacFarlane, 1990; Hill & Lovegrove, 1992; Pepper and Lovegrove, 1999). The reverse was true for the dyslexics; they read significantly more accurately in both one-word conditions than the whole-line condition. We refer to this as the "one word at a time advantage".

There were no differences for the dyslexics between the two one word at a time conditions. This suggests that they did not experience any additional problems when required to move their eyes but did experience difficulties when they had to integrate print to the right of fixation with centrally presented text. It is worth noting that this is quite a large effect and has been found with all dyslexics we have tested. The mode of presentation of written material which maximised reading accuracy in controls, therefore, produced the most errors in dyslexics. Although the exact reason for this effect is still to be determined, these findings may have remedial implications.

The effects of wavelength filtering

If a deficient transient/magno system does play a role in causing reading disabilities, any manipulation which enhances transient/magno system functioning relative to sustained system functioning may assist with reading. Some data from contemporary vision research have provided a means by which to consider this possibility.

Recent psychophysical and physiological data indicate that colour or wavelength differentially affect the response characteristics of the transient/magno and sustained/parvo systems, so that wavelength can affect the relative contributions of transient and sustained channels to the processing of a stimulus. Physiological observations of the primate visual system indicate that there are differences in the colour selectivity of these systems (Livingstone & Hubel, 1987), and that a steady red background light attenuates the response of transient/magno channels (Dreher, Fukuda & Rodieck, 1976; Kruger, 1977; Schiller & Malpeli, 1978). An investigation by Breitmeyer and Williams (1990) provides evidence that variations in wavelength produce similar effects in the human visual system. They found that the magnitude of both metacontrast and stroboscopic motion (transient/magno system functions) were decreased when red, as compared with equiluminant green or white backgrounds, was used. According to transient-sustained theories of metacontrast and stroboscopic motion, these results indicate that the activity of transient channels is attenuated by red backgrounds. Williams, Breitmeyer, Lovegrove and Gutierrez (1991), using a metacontrast paradigm, additionally found that the rate of processing in transient/magno channels increased as wavelength decreases (i.e., towards the blue end of the spectrum), and that red light enhanced the activity of sustained/parvo channels.

These results indicate that wavelength would provide a means of modifying the relative functioning of the transient/magno and sustained/parvo systems.

Williams, LeCluyse and Bologna (1990) used a metacontrast paradigm to obtain direct measures of the effects of colour temporal visual processing in normal and disabled readers. They found that the metacontrast functions obtained with dyslexics in blue light were very similar to those obtained with controls in white light in terms of both the magnitude of masking and the onset asynchrony at which maximum masking occurred. In other words, the function produced by the blue mask in dyslexics is similar in time course to the function produced by the white in normal readers. This finding suggests that blue light produces a normal time course of processing in dyslexic readers, and is consistent with the contention that blue light may enhance processing rate in transient/magno channels.

Given the systematic effects of colour on the perceptual performance of the dyslexics and the fact that this manipulation can render their performance comparable to that of normal readers, Williams et al., (1990) investigated the effects of colour on actual reading performance. They did this by measuring reading comprehension in three conditions similar to those used by Lovegrove and MacFarlane (1990) and outlined in the previous section. Their results showed that dyslexics generally comprehended text better when it was presented in blue than in white or red light. While Williams et al. (1990) have yet to determine the long-term effects of wavelength on reading, these results on comprehension are interesting and again suggest a possible remedial direction.

Thus, there is preliminary work on two remedial approaches (one-word presentations and effect of colour) derived from our knowledge of a specific visual deficit in dyslexia. While much work has yet to be done, the results to date are promising and are currently being pursued further.

Possible relationships to other problems manifest in dyslexia

A final question for consideration resulting from the work on vision and dyslexia concerns any possible relationship between the deficits described here and other known deficits in dyslexia. There is extensive evidence that dyslexics perform worse than control readers in a number of other areas, especially in aspects of phonological awareness and working memory (Lovegrove, McNicol, Martin, MacKenzie & Pepper, 1988). It is important to ask what, if any, is the relation between the transient/magno system deficit and these other processing areas.

This issue was considered in a study of approximately 60 dyslexics and 60 controls (Lovegrove et al.,1988). They measured aspects of transient/magno system processing, phonological awareness, phonological recoding and working memory in each child. These data were subjected to a factor analysis which showed that phonological recoding as measured by non-word ability, loaded on the same factor as the measures of transient/magno system processing. This shows some relationship between the two processing areas but does not, of course, reveal the precise nature of that relationship.

Until this relationship is further clarified, it is premature to reject the possibility of a link between visual and phonological processes in reading. The measures of working memory used did not load on the same factor as did the transient system measures and the phonological recoding measures.

It is possible that some of these different deficits are related by virtue of the fact that some dyslexics have a problem in processing rapidly presented stimuli in all sensory modalities. Tallal (1980), for example, has shown that dyslexics have temporal problems in audition which may be auditory analogues of the visual transient/magno system deficits we have studied. This possibility has been speculated on by Livingstone, Rosen, Drislane, and Galaburda (1991), who noted that the auditory and somatosensory systems may also be subdivided into fast and slow components like the visual system. They then speculated that problems in each fast system may occur in dyslexics. If this were so, a rapid temporal processing deficit in dyslexics may contribute to their problems in phonological awareness. Even though this possibility has not yet been directly investigated, it is an exciting prospect which may help to integrate a large amount of apparently discrepant data.

CONCLUSIONS

The data reported in the last fifteen years show that many dyslexics have a particular visual deficit. It has also been shown that it is unlikely that the transient deficit results from being unable to read (Lovegrove, Martin, & Slaghuis, 1986) although it is not yet known how it contributes directly to reading difficulties. This processing problem appears to present only in certain "types" of dyslexics. There is still a lot of work to be done before we know how this difficulty relates to other difficulties but one interesting possibility has been outlined. The results with different modes of visual presentation and with the effects of wavelength on reading in dyslexics and controls are being further investigated in our laboratories and are encouraging.

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