Outcome of treatment of visual problems in children with reading difficulties

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Developmental dyslexia is a potent cause of children’s misery and despair, but unfortunately very common: 5-10% of 8-10 yr olds have exceptional difficulty learning to read despite conventional instruction, adequate intelligence and sociocultural opportunity - the definition of dyslexia given by the World Federation of Neurology (Critchley 1970). It is commoner in boys than girls, and there is usually a strong family history. Almost certainly therefore, it has an organic neurological basis. This view has recently received much greater support from results that demonstrate directly that dyslexic brains show neuroanatomical and physiological abnormalities both in language and visual areas (for summary see Demb et al. 1999).

Many people believe that dyslexia is exclusively a phonological problem. Certainly most dyslexics have great difficulty with mentally separating the sounds of words into their constituent phonemes to match with their written alphabetic form (Bradley & Bryant, 1985). But this is not usually their only difficulty. Many dyslexics experience visual problems when reading, often in addition to their phonological ones. These visual symptoms probably result from slight unsteadiness of the eyes when they are trying to fixate on the letters being read. This in turn results from their inheriting a mild impairment of the magnocellular component of the visual system which plays an important role in controlling eye movements because it provides the major input to ocular motor areas of the brain such as the posterior parietal cortex, cerebellum and superior colliculus. This slight magnocellular impairment affects particularly the most vulnerable ocular motor control system, which is the control of the ‘vergence’ eye movements that point the eyes together to focus on near targets as when reading. Hence dyslexics’ binocular vergence control tends to be unstable compared to normal readers. Because their eyes tend to wobble, letters may seem to move around, merge, flip and jump over each other. This is the reason why dyslexics tend to confuse the order of letters when attempting to read (the magnocellular basis of visual dyslexia is summarised in Stein & Walsh, 1997).

Since dyslexics’ visual confusions result from unstable binocular fixation so that the two eyes present competing possible locations of letters and letter features, one obvious treatment is to occlude one eye when reading. Many people have tried patching one eye for reading and close work (see Stein et al. 2000). This has shown that some, but by no means all, dyslexic children can benefit. In our studies we found that the only children who are helped are below the age of 10 and have not yet established stable ocular dominance. When such children read with their right eye only, they made fewer reading errors, suggesting that the occlusion helps to relieve their binocular visual confusion. Paradoxically such a short period of monocular occlusion helps children to overcome their binocular instability permanently without further need for the patch. This is probably because blanking one eye allows the seeing eye to learn to control its own direction without confusion of the other eye’s images; afterwards the other eye follows suit. In all our studies we have found that gaining binocular stability greatly helps initially unstable children to learn to read.

However occluding one eye for reading only helps children up to the age of 10, and only in those who have not established fixed dominance of one eye; this seems to cause unsteady convergent fixation on the words being read. However in older children and adults with poor vergence control, whether they have fixed or unfixed ocular dominance, we have found that vergence exercises can often be very helpful. If the exercises improve the subjects’ vergence control then their reading improves dramatically. Likewise in children with poor eye tracking of moving targets pursuit-tracking exercises can often help to improve their reading.
Even though the magnocellular system does not contribute to colour vision, because it is most sensitive to long wavelengths (red, yellow, green), children’s eye control can also be improved using coloured filters, either in the form of overlays or coloured lenses. We have not found systematic differences between the two. We have concentrated on the primary colours only, studying the effects of red, yellow, green, blue or a neutral density (grey) filter which cuts out the same amount of light, but equally over all wavelengths.

In cases of reduced visual acuity that are not caused by squint or severe refractive error or any other obvious ophthalmological disease, we had found that yellow filters could often correct the problem permanently, probably because yellow filters boost both the red and green cone input to the magnocellular component of the visual system at the expense of the parvo (Fowler et al. 1992). These children were not necessarily dyslexic, but in those that were, the effect on their reading was often dramatic improvement. We have therefore been giving yellow filters to children with reading problems if they report that yellow makes the print clearer, and we have measured their binocular vergence control and reading on referral and 3 months later.

Unexpectedly we also found a group of children who benefited greatly from wearing blue filters when we routinely offered the five filters to them. Because the visual magnocellular system is impaired in many of these children with visual reading difficulties, we had expected that most would benefit from yellow filters boosting the magno input. But in addition about 15% percent of the children we see greatly prefer blue even though in most people the magno system receives only about 10% of its input from blue cones. Perhaps these children have greater than normal amounts of blue cones. Whatever the reason they often benefit dramatically from using blue filters for reading, and also to avoid glare in bright sunshine or for driving at night.

This paper is an audit of these treatments to see whether we have been able to improve the ocular motor control and reading of these children; it does not describe controlled trials of them. Nevertheless we can compare their reading progress in terms of months of reading age gain per month of treatment with those expected for normal readers and untreated children. A consequence of the definition of reading age is that an average child will increase his reading age by 1 month per month of observation. Children whom we have not treated except with placebos because they formed control groups for other studies that we have been carrying out, all tend to progress at a much slower rate than this. However the children whom we have treated in our clinic all improved their eye control together with their reading very considerably more than untreated dyslexics or average children.

Methods. Over 400 children with reading difficulties are referred each year by their GPs, school doctors or nurses to the Learning Disabilities Clinics that we hold in Oxford and Reading. We only follow up the two thirds of the children that we see who have visual symptoms when reading. Thus 31% of the children that we have seen over the last three years were not seen again because they had no visual problems.

We report here the progress of a sample of 297 of those with visual problems. We cannot say from these results how common visual problems are among all children with any kind of reading difficulty because the doctors etc. who referred the children may have been influenced by our well-known interest in visual problems. Nevertheless previous population based studies have shown that approximately two thirds of children with serious reading difficulties do have visual problems, either alone or in combination with phonological or other problems.
All the children were given the matrices, similarities, reading and spelling subtests of the British Abilities Scale (BAS) IQ test. They were also given tests of orthographic and phonological skill, together with a full orthoptic examination. Only the briefest details of this will be given here. Fixation smooth pursuit, vergence and saccadic eye movements were also recorded using an infrared horizontal eye movement recorder. An experienced orthoptist scored these recordings: 3 points if the eye movements were normal, 2 if poor, and 1 if very bad. Visual motion sensitivity was measured using random dot kinematograms, as a measure of their visual magnocellular sensitivity.

The children were then given red, yellow, green, blue and neutral density filters to see if any of these made small print seem clearer. If they chose one of these colours they were asked to use that filter, either as an overlay or tinting their spectacles, for all reading and close work. If no colour helped them, they were under 10 and had unfixed ocular dominance they were given spectacles with a frosted left lens for reading (left monocular occlusion - patching). Other children with unstable fixation were given binocular vergence exercises, and those with poor pursuit tracking were given pursuit-tracking exercises.

**Results**

**Baseline**

The average age of the 297 children was 9 ½ years (114 months). Their IQ was average at 97. But their average reading age was only 7 years, and their spelling age was only 6 1/4 years; thus it was over 3 years behind their chronological age. Likewise their reading and spelling scores were highly significantly worse than expected from their age and IQ. The reading of all the children was more than 1 sd behind that expected from their age and IQ. But only about half (49%) could be classified as dyslexic using the very stringent criterion that their reading had to be as much as 2 sds behind that expected from their IQ.

All these children complained of visual problems when reading. Nevertheless most had good visual acuity in the two eyes for both near and distant targets; so their reading problems were not due simply to low visual acuity. Likewise their depth vision (stereopsis) was normal.

**Eye movements**

The movements of the eyes to the 9 cardinal positions of gaze were clinically normal in all these children. However our eye movement recordings confirmed that most of the children had mild abnormalities of pursuit, fixation or vergence control, although these were not obvious on clinical examination. 71% had poor pursuit (scoring only 1 or 2 on the eye movement recording assessments). 66% had poor vergence. 64% had poor fixation. But their refixating rapid (saccadic) eye movements were good; only 28% had inaccurate saccades.

**Treatment**

33 of the children were given neutral density grey spectacles which turned out not to be a very effective treatment. Their reading age advanced by only 1.1 (SE 0.16) months per month of observation. In previous studies completely untreated control groups advanced by only 0.56 - 0.88 months per month. In contrast normal readers advance by 1 month per month by definition. However all the treatments that we now describe produced highly significant gains in the children’s reading. Averaged over all the children that we treated, this amounted to 2.12 months reading gain per month of treatment. This is twice what might be expected of normal readers and over 3 times what might be expected if they had not been treated at all.
These reading gains probably resulted from the improvements in eye control that we observed at the same time. After 3 months of treatment almost half (47%) of those who started with unfixed eye dominance had become fixed. Hence for all the children their average pursuit score on the eye movement recordings improved from 2.19 to 2.68 points; on fixation they improved from 2.23 to 2.62 points and on vergence from 2.29 - 2.77 points. All these improvements were statistically significant. But there was no significant change in their scores for saccadic accuracy (2.72 - 2.90) because it was not very bad in the first place.

Yellow filters

23% of the children chose yellow filters when offered them because they improved the clarity of print. They used these for all reading and close work for 3 months. After this their reading had improved by 5.7 months (1.89 months per month- se 0.18). This was a significant improvement compared with untreated controls.

Their reading improvement probably occurred because the yellow filters helped them to improve their eye control. Their ability to pursue a moving target with their eyes improved from an average score for the eye movement recordings before using the filters of 2.22 to one of 2.59 afterwards. Likewise their vergence control improved from 2.31 to 2.73; fixation from 2.32 to 2.51. All these improvements were statistically significant. However the children’s saccades showed little change (2.79 - 2.81) because they were good in the first place.

Blue filters

13% of the children chose blue filters because these stabilised their visual perceptions. By their next visit after 3 months their reading had dramatically improved by 9.6 months (3.2 months per month). Again this was accompanied by significant improvements in their eye movement scores for pursuit, vergence and fixation.

Green and red filters

7% of the children chose either green or red filters; after 3 months their reading had improved by 7.5 months in the 3 months (2.5 (se 0.55) months per month), and as for the other treatments their pursuit, vergence and fixation scores improved also.

Monocular occlusion

7% of the children were given spectacles with the left lens frosted with opaque material to wear for all reading and close work because they were under 10, had unfixed ocular dominance and were not helped by any of the coloured filters. Their reading age advanced by 1.4 (se 0.16) months per month (4.2 months between the first visit and follow up 3 months later); this was a statistically significant improvement compared with untreated children (t = 2.6; p < 0.05).

Vergence exercises

24% of the children were given exercises to improve their vergence control. Their reading improved by a massively significant 2.5 months per month (an average of 7 1/2 months by the next visit after 3 months); and this also was associated with significant improvements in pursuit, vergence and fixation eye movements.
Tracking exercises

13% of the children were given visual tracking exercises to improve their eye control because their pursuit eye movements were particularly bad. Their pursuit improved greatly from an average score on the eye movement recordings of 1.56 to one of 2.68. As a result their reading improved very significantly - by 1.87 months per month.

Discussion

These results show that our treatments helped children with reading problems very considerably; their rate of increase in reading age tripled compared with what would have happened had they not been treated at all. This compares very favourably with much more time consuming and costly remediation programmes such as those described by Hornsby and Miles (1980) and Thomson (1993) after which reading improvements of 1.8 - 1.9 months per month were seen.

Monocular occlusion, vergence fixation and pursuit tracking exercises are effective because they help these children to improve slight defects in their control of the two eyes when they are trying to fixate on the text. Long wavelength (red, yellow and green) filters probably help because they enhance input to the magnocellular system which plays a major role in ocular motor control, at the expense of the parvocellular system which is normally in competition with the magnocellular system. We speculate that blue filters cutting out long wavelengths may help some children because they have abnormally large numbers of blue cones that are depressed by long wavelength light. We are actively researching these ideas at present.

References

Stein JF & Walsh V (1997) To see but not to read - the magnocellular theory of visual dyslexia, Trends in Neuroscience, 20, 147-152.

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