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Monocular occlusion can improve binocular control and reading in dyslexics

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Summary

Developmental dyslexia is a neurodevelopmental condition which causes 5–10% of children to have unexpected difficulty learning to read. Many dyslexics have impaired development of the magnocellular component of the visual system, which is important for timing visual events and controlling eye movements. Poor control of eye movement may lead to unstable binocular fixation, and hence unsteady vision; this could explain why many dyslexics report that letters appear to move around, causing visual confusion. Previous research has suggested that such binocular confusion can be permanently alleviated by temporarily occluding one eye. The aim of the present study was therefore to assess the binocular control and reading progress of dyslexic children with initially unstable binocular control after the left eye was patched. One hundred and forty-three dyslexics were studied. They were selected from children aged 7–11 years referred to a learning disabilities clinic if they were dyslexic and had unstable binocular control. They were randomly assigned to wear yellow spectacles with or without the left lens occluded, and were followed for 9 months. Significantly more of the children who were given occlusion gained stable binocular fixation in the first 3 months (59%) compared with children given the unoccluded glasses (36%). This advantage was independent of IQ or initial reading ability. Furthermore, at all the 3-month follow-ups, children were more likely to have gained stable binocular control if they had been wearing the occluded glasses. Gaining stable binocular control significantly improved reading. The children who did so with the help of occlusion improved their reading by 9.4 months in the first 3 months, compared with 3.9 months in those who were not patched and did not gain stable fixation. Over the whole 9 months, children who received occlusion and gained stable fixation nearly doubled their rate of progress in reading compared with those who remained unstable. At all the follow-ups the reading of those given occlusion was significantly better than that of those not occluded. Thus monocular occlusion helped children with unstable binocular control to gain good binocular fixation. If they gained stability, they made significantly faster reading progress. The progress made by the children who gained stable fixation was much greater than that achieved with other remedial techniques.

Keywords: vision; binocular; dyslexia; reading; neurodevelopment

Abbreviation: BAS = British Abilities Scales

Introduction

Five to ten per cent of primary school children fail to learn to read at the standard expected from their general intelligence, despite adequate cultural opportunity and teaching (Rutter and Yule, 1975). A large body of research has now shown that this is a neurodevelopmental problem and not a result of bad teaching or cultural differences between social classes, as used to be argued. Specific reading disability is part of a wider hereditary neurodevelopmental syndrome that is often known as developmental dyslexia (Galaburda, 1993; Miles, 1993; Fawcett *et al.*, 1996; Fisher *et al.*, 1999). It is generally agreed that the most potent cause of literacy problems is difficulty with parsing word sounds into their constituent phonemes, a phonological defect (Frith 1978; Liberman and Shankweiler, 1978; Bradley and Bryant, 1985; Snowling and Rack, 1991).

However, impaired phonological skill is not usually the only problem that developmental dyslexics face. Several studies have shown that many dyslexics have slightly impaired visual transient/magnocellular function, which is often in addition to their phonological problems (Fowler and Stein, 1978; Lovegrove *et al.*, 1980; Livingstone *et al.*, 1991; Mason *et al.*, 1993; Tallal *et al.*, 1993; Cornelissen *et al.*, 1995; Eden *et al.*, 1996; Stein and Walsh, 1997; Talcott *et al.*, 1998; Witton *et al.*, 1998; Stein and Talcott, 1999). Since the magnocellular system dominates the visual guidance of eye movements by the posterior parietal cortex (Stein, 1992), cerebellum (Rae *et al.*, 1998) and superior colliculus (Sparks, 1986), slight damage may affect only the most vulnerable ocular motor control system, which is the vergence system. Thus dyslexics' binocular vergence control tends to be inferior to that of normal readers (Stein and Fowler, 1980, 1993; Bigelow and McKenzie, 1985; Simons and Grisham, 1987; Stein *et al.*, 1988; Buzzelli, 1991; Evans *et al.*, 1994). Reduced vergence control causes dyslexics' eyes to move around much more when they are trying to fixate on near targets (Eden *et al.*, 1994); hence they are significantly less accurate at localizing (Riddell *et al.*, 1990) or counting (Eden *et al.*, 1995) small dots on a screen than normal readers.

The unstable binocular control of dyslexics probably explains the unstable visual perceptions that they experience. Many find that letters seem to move around, merge, flip and jump over each other (Orton, 1925; Garzia and Sesma, 1993; Cornelissen *et al.*, 1998). They describe the kind of fluctuating diplopia that might result from unstable binocular fixation. Children with such unsteady eyes tend to confuse and missequence letters when attempting to read, so that they often misread real words as nonsense words (referred to as 'nonwords' by Cornelissen *et al.*, 1991). They probably make these nonword errors because they sound out the visual jumbles with which their mind's eye presents them, and this produces nonsense. In addition, because their visual impressions of words are confused, such children are forced to rely more on the phonological rules that they have learnt. So those with unstable fixation have a characteristic tendency to spell irregular words phonetically, i.e. to make phonological regularization errors (Cornelissen *et al.*, 1994).

The binocular control and accuracy of visual location of dyslexics is not only considerably worse than that of age-matched controls, but it is also worse than that of younger children with the same reading age as the dyslexics (Stein *et al.*, 1987; Riddell *et al.*, 1990). As Bradley and Bryant have pointed out, such a 'reading age match' establishes the direction of causality (Bradley and Bryant, 1985). If poor reading was the cause of poor binocular control, then younger children with the same limited reading ability as older dyslexics should have equally bad eye control. Instead, in our studies the younger children had better eye control. Hence this reading age match strongly suggested that impaired binocular control causes poor reading rather than the other way round. Likewise, Cornelissen and colleagues found that all children with unstable binocular control, whether classified as dyslexic or not, tended to make more visual nonword errors than children of the same reading age with good binocular control (Cornelissen *et al.*, 1991, 1994); again, this suggests that it was their poor binocular control that caused them to make the nonword errors rather than vice versa.

Despite all this evidence, however, there is still a great deal of argument about whether dyslexics' unstable binocular control actually causes reading problems. The best way to convince doubters would be to demonstrate that improving a child's binocular stability improves his ability to learn to read. Clearly this might also have great therapeutic significance.

Since dyslexics' visual confusions fixation may result from unstable binocular fixation causing the two eyes to present competing possible locations of letters and letter features—a kind of fluctuating diplopia—occluding one eye might help these children. We and a number of other groups have tried patching one eye for reading and close work (Benton and McCann, 1969; Dunlop, 1972; Stein and Fowler, 1981, 1985; Masters, 1988). In all these studies some, but by no means all, dyslexic children benefited from this procedure. We found that only children with binocular instability were helped. When such children read with their right eye only, they made fewer nonword reading errors, suggesting that the occlusion helped to relieve their binocular visual confusion (Cornelissen *et al.*, 1992).

Paradoxically, 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 (utrocular control) (Ogle, 1962) 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 (Stein and Fowler, 1981, 1985). However, the design of our studies has been greatly criticized (Bishop, 1989); although the criticisms have been adequately answered (Stein, 1989), we here report a larger trial of occlusion. We aimed to answer two questions: (i) does monocular occlusion treatment help children to gain binocular stability? and (ii) does gaining binocular stability help children to learn to read? Some of these results have been presented to the Association of British Neurologists (October 1997).

Methods

Subjects

Over 300 children with reading problems are referred each year by their general practitioners or school medical officers to our Learning Disabilities Research Clinic situated in the Eye Department of the Royal Berkshire Hospital, Reading. All parents were asked whether they would agree to allow their children to participate in this research project, which had been passed by the ethics committee of the University of Reading. They filled out a questionnaire about whether their children had visual problems, such as visual strain and the blurring, merging, transposing or moving of letters on the page. Only those who complained of one or more of these symptoms were studied further. At their first visit the children were given a full orthoptic examination, including our version of the Dunlop test of binocular stability (Stein and Fowler, 1980, 1993). Any child who had overt ophthalmological problems was seen by an ophthalmologist, but was not included in this study. They were also excluded if they were outside the age range 7–11 years or were found to have stable binocular control in the Dunlop test. The remainder were given the reading, similarities and matrices subtests of the British Abilities Scales (BAS) to determine whether their reading was >2 SD behind that expected from their IQ as assessed from their matrices or similarities scores. If it was, they were classified as dyslexic (Thompson, 1982) and selected for this study. A discrepancy of 2 SD is a very stringent criterion, so that we were sure that these children were truly dyslexic.

The Dunlop test

We used a modification of the test introduced by Dunlop to screen children for binocular instability (Dunlop, 1972). The test was performed in the same way as in our previous studies. The child viewed in a synoptophore (a stereoscope with adjustable vergence) two fusion slides of a macular-sized house (subtending 2.5°) with a central front door knob. She or he was asked to keep the eyes fixated on the front door knob. The slide viewed by the right eye had a 'control' post with an arrow on the top of it, positioned to the left of the door, whilst that viewed by the left eye had a post topped with a circle to the right of the door. The child adjusted the vergence angle between the synoptophore tubes until the two slides were fused. Then the tubes were slowly diverged at 1°/s. Most subjects can diverge their eyes under these conditions by up to 5°. Whilst the eyes are moving, but just before fusion breaks down and diplopia intervenes, most subjects see one of the control posts appear to move towards the door knob because the movement of that eye is interpreted as the post moving. The other post appears to remain stationary in relation to the door because that eye's movement is ignored. The child was asked to report which post appeared to move towards the door. In children with good binocular control, even when the test is repeated many times and the cross and circle posts are interchanged, the post which appears to move is always on the same side.

We repeated the test 10 times, interchanging the slides three times. If the child always saw the moving post on the same side, she or he was said to have stable binocular fixation. But if both control posts appeared to move simultaneously, or if the side was not the same on three or more of the 10 trials, the child was classified as having unstable, or 'unfixed', binocular control. The test was carried out in every child, independently of all the other ophthalmological and orthoptic tests, usually as the first test administered. When the research orthoptist (M.S.F.) carried out the tests, she was not aware of the child's history, the results of previous Dunlop tests or of the other tests, or what treatment the child had been receiving.

We used the Dunlop test to assess binocular stability. In children with good binocular control this test identifies the dominant eye in a truly binocular situation. However, the eye that sees the post moving in such children does not necessarily correlate with the dominant eye as measured by standard monocular sighting dominance tests (Riddell *et al.*, 1987), so we did not measure sighting dominance because we were using the Dunlop test only to assess binocular stability. Thus, it was unimportant whether the left or right post appeared to move, so long as it was consistently on the same side (Stein and Fowler, 1980, 1993). Half to two-thirds of the dyslexic children that we see lack stable binocular fixation in this test. But this may be an overestimate because our clinic is based in an eye hospital and we specifically look for children complaining of visual symptoms.

Unfortunately the Dunlop test is not easy to use, especially in inexperienced hands, because it requires children to report the apparent movement of a stimulus which they are asked not to look at directly, in a complex perceptual situation. Nevertheless, many practitioners find it useful for identifying binocular instability (Stein and Fowler, 1993; Bigelow and McKenzie, 1985; Masters, 1988).

Treatment

Because there has been much recent publicity about the possible benefits of coloured filters for dyslexics (Irlen, 1991; Wilkens and Neary, 1991), all the glasses we prescribed were tinted a light yellow. Yellow was chosen because the broadband absorbtion spectrum of the magnocellular system peaks in the yellow range, and we had shown that some children with amblyopia benefit from wearing yellow filters (Fowler *et al.*, 1992). The left lens of half of the spectacles was occluded by covering it with opaque tape. We chose always to occlude the left eye because most of the children wrote with their right hand, and we had shown previously that even most left handers do better with left occlusion (Stein and Fowler, 1980). We told the children and their parents that both kinds of glasses might have a beneficial effect. Very few of the children in the study met each other, so it was most unlikely that they found out that some were occluded and others not; hence they were blind to which glasses might be effective.

Protocol

On first referral, a full orthoptic examination, including the Dunlop test, was carried out on each child, and the BAS similarities, matrices and reading subtests were administered.

Either the plain or the monocularly occluding glasses were then given to each child, according to a random rota, by an independent treatment orthoptist who did not reveal who had received which treatment to the investigators. The child was asked to wear them for all reading and writing work. The treatment orthoptist checked whether the children had indeed worn them; all said they had done so. She removed their glasses for all the follow-up examinations, so all investigators remained blind to which treatment the child had been receiving. At each of the three follow-ups the Dunlop test, an abbreviated orthoptic examination and the BAS reading

Table 1 *Numbers of children not occluded or occluded, average ages, IQs derived from their BAS similarities and matrices scores, percentage of fixed Dunlop test responses at each visit (DT1–4) and average reading age at each visit (RA1–4)*

n	Age (months)	IQ	DT1	RA1	DT2	RA2	DT3	RA3	DT4	RA4
Not occluded										
72	107.2 (1.69)	109.3 (1.38)	0%	81.3 (1.41)	36%	86.1 (1.59)	41%	89.1 (1.92)	54%	93.0 (2.08)
Occluded										
71	104.8 (1.73)	112.4 (1.76)	0%	82.9 (1.43)	59%	92.5 (2.47)	46%	94.3 (2.41)	64%	97.7 (2.40)

Numbers in parenthesis are standard errors.

test were repeated, but the investigators were not given the results of previous tests on that child.

Results

Subjects

Over 700 children were considered because they had reading problems, and they also complained of eye strain or visual confusions when trying to read. Twelve per cent had overt ophthalmological or other medical diagnoses, 10% were too young or too old and 45% had stable binocular fixation in the Dunlop test. Of the remainder with unstable binocular fixation, only half were dyslexic by our strict BAS criteria. Finally, therefore, 151 children (20% of the original referrals) were selected for the study. Only eight of these did not complete enough of the follow-ups to be included; four of the eight were occluded and four were not occluded. Six had moved too far away and two had been killed in accidents. The average age of the 143 children described here was 8 years 9 months; their IQ, derived from the BAS similarities and matrices tests, was 111, but their reading age of 6 years 10 months was nearly 2 years behind that expected. Table 1 gives more details.

Monocular occlusion

Seventy-one children with unstable binocular fixation were given the light yellow plano spectacles with occlusion of the left lens; the other 72 received the same yellow lenses but without occlusion. There were no significant differences in age, initial reading age, similarities, matrices or Dunlop test results between the two groups.

By their second visit at 3 months, 42 of those who had received occlusion (59%) had achieved stable binocular control in the Dunlop test, whereas only 26 (36%) converted while wearing the yellow plano spectacles without occlusion. Thus monocular occlusion increased the children's chances of becoming fixed by 23% ($\chi^2 = 7.6$; $P < 0.006$; 95% confidence interval, 7–39%).

In addition, when we compared all the 3-month periods in which children had been wearing occlusion glasses with those when they had not, we found that they were significantly more likely to have gained stable binocular fixation during the periods of occlusion ($\chi^2 = 4.1$; $P < 0.05$).

At the third and fourth examinations a few more occluded children had gained fixation, but others reverted to unstable fixation and some who had been given the plain glasses gained fixed responses spontaneously. Thus, by the fourth visit at 9 months, 64% of those who had been wearing monocular occlusion were fixed, but 54% of those who had the plain spectacles had also gained stable fixation, which was no longer a significant difference. Thus, occlusion hastened the children's acquisition of stable binocular fixation, but perhaps some of these would have fixed spontaneously anyway during the 9 months.

It has been suggested that achieving stable fixation in the Dunlop test is more a function of the intelligence required to understand the test than anything to do with binocular control (Bishop, 1989; but see Stein, 1989). Therefore, we tested whether there were any significant differences in the similarities and matrices IQ scores between those who became stable in any 3-month period and those who did not; we found none. Many of the children whose binocular stability improved stated that their visual symptoms had improved, but we did not explore this systematically.

Reading progress

Our hypothesis was that the reading progress of children who gained binocular stability in the Dunlop test should be greater than that of those who did not. Figure 1 shows that this was the case; the reading age of the children who received monocular occlusion and thereby gained binocular stability in the first 3 months improved by 9.4 months (3.1 months per month of follow-up) and by 16.1 months over the whole 9 months of follow-up (1.8 months per month), whereas those who did not receive occlusion or gain stability fell even further behind what might be expected for their age. Their reading age advanced by only 3.9 months in the first 3 months of follow-up (1.3 months per month) and 8.0 months over the full 9 months of the study (0.9 months per month). The difference between the two groups was statistically highly significant (3 months, $t_{132} = 2.1$, $P < 0.05$; 9 months, $t_{140} = 3.6$, $P < 0.001$).

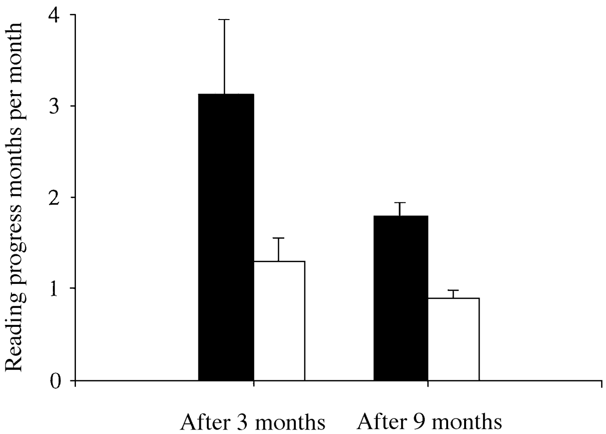

Fig. 1 The effects of gaining stable fixation at 3 and 9 months. Filled columns = stable binocular control; open columns = unstable binocular control.

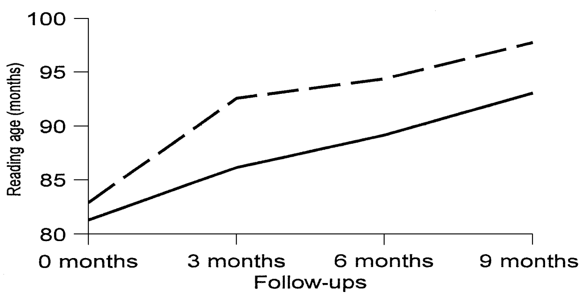

Fig 2 The effects of monocular occlusion on reading age at 3, 6 and 9 months. Continuous line = not occluded; broken line = occluded.

Furthermore, at any of the 3-month follow-ups, when a child had become or remained fixed in the Dunlop test his or her reading showed significantly greater improvement than if he or she was unfixed. Reading age increased by an average of 6.3 months in any 3-month period during which binocular control was stable (2.1 months per month), whereas if a child remained or reverted to being unfixed, reading age advanced by only 3.6 months (1.2 months per month); in other words, fixation nearly doubled the rate of progress in reading ($t_{312} = 2.2$, $P < 0.05$). This is almost exactly what we found in our previous studies (Stein and Fowler, 1980, 1985), in which the rate of progress in reading of children who achieved stable binocular fixation also doubled. This improvement occurs whether stable fixation is gained with the help of monocular occlusion or spontaneously. Many children report that letters no longer seem to move around, as reported in our previous studies (e.g. Cornelissen *et al.*, 1992).

There was also a treatment effect. Even though the age, IQ and reading age of the groups were similar when they were first seen, at all the follow-ups the children who had been given monocular occlusion had advanced faster than those who had not (Fig. 2). At the first follow-up this reading age advantage amounted to 2.3 months per month over those who were not occluded, but since some children who were not occluded nevertheless fixated spontaneously the advantage was reduced to 1.8 months per month, averaged over all three follow-ups (95% confidence interval, 0.8–2.8 months). This treatment effect suggests that monocular occlusion was probably responsible for the significant improvement in reading.

Since it has been suggested that the greater reading progress of children who gain binocular stability in the Dunlop test might be the result of differences in their initial reading age (Bishop, 1989) a repeated measures ANOVA (analysis of variance) of reading ages at the 3-, 6- and 9-month follow-ups was performed, controlling for initial reading age. This confirmed that the occluded children benefited significantly [$F(1,127) = 3.8$, $P < 0.05$].

Discussion

These results confirm our 1985 conclusion that monocular occlusion can help 7- to 11-year-old children to achieve stable binocular control. As in our 1985 study, significantly more of those given occlusion gained stable responses in the first 3 months. Over the next 6 months some of those who were not occluded converted spontaneously, as was also expected from our previous results (Stein *et al.*, 1986). In our 1986 study we found that as children grow older the continuing development of the vergence system provides progressively better control. Fifty per cent of unselected primary school children had developed stable binocular control by the age of 5 years, and in each succeeding year ~6% more did so. Thus, by the average age of the unstable dyslexics reported here we would have expected only 30% of normal children to remain unfixed. Of those who are unfixed at age 8 years, we would expect ~20% to become fixed spontaneously within 9 months, as we found in our 1985 study. Instead, 54% did so. Thus, wearing plain yellow glasses without occlusion may by itself have increased the children's chances of gaining stable binocular control (to 54%), compared with our previous studies in which we gave children clear plano spectacles or no treatment at all, when only 20–24% of children gained stable fixation (Stein and Fowler, 1980, 1985). Perhaps this effect of the yellow colour occurred because it boosts the magnocellular system.

In our 1986 study we also found that the reading of children with unstable binocular control was 6 months behind that of those who had achieved stable control. Thus, poor binocular control appears to impede reading in both unselected primary school samples and dyslexics. Monocular occlusion seems to help many such children to gain stability more quickly. But we cannot be sure that they would not have done so spontaneously, though more slowly. Nevertheless, at a time when reading progress should be rapid, an advantage of 3–9 months of binocular stability gained by monocular occlusion is likely to be highly beneficial.

The answer to our second question, whether gaining stable binocular fixation helps children to learn to read, also confirmed our 1985 result. The reading of those who gained fixed responses in the Dunlop test improved almost twice as fast as that of those who did not, probably because they suffered fewer visual confusions. This progress in reading was greater than any that we have found in the literature for more conventional treatment regimes, such as training in phonics, which tends to improve dyslexics' phonological ability but has a much less rewarding effect on reading real words and sentences (Wise and Olson, 1995).

We also observed a direct treatment effect of occlusion on reading, independent of whether the children actually achieved stable fixation, so that although the initial reading age of treated and untreated children was similar, at all follow-ups the reading of those given occlusion treatment was more advanced than that of those not occluded. The advantage remained statistically significant even after we had allowed for the strong influence of the children's initial reading ability on their progress. This effect of occlusion on reading confirms that it was mainly the occlusion that helped them to gain binocular stability, hence faster reading progress, and not some unknown *tertium quid.*

It has been argued that gaining binocular stability in the Dunlop test may be merely a consequence rather than a cause of improved reading (Bishop, 1989). But this is most unlikely because we have shown in a number of studies that children with binocular instability suffer more visual confusions than children with stable control even when their reading ability is the same overall. Hence, the visual errors were probably the result rather than the cause of their poor binocular control, because the children with stable binocular control read at the same level but did not make the visual errors.

In this study we repeated the Dunlop tests blind to previous test results and to any other information about the child; this has confirmed that some children who were temporarily fixed can revert to binocular instability. Whatever its imperfections, however, several studies have demonstrated a clear relationship between instability in the test and reading problems. Nevertheless, some groups have not found the test useful (Newman *et al.*, 1985; Evans *et al.*, 1994; Goulandris *et al.*, 1998). Clearly, a better measure of binocular instability is needed, and we are trying to develop one.

In conclusion, our results suggest that the visual magnocellular deficit found in dyslexics can cause binocular instability and that this can often be circumvented by left monocular occlusion. Seven- to 11-year-old dyslexic children with binocular instability gained stable binocular fixation more quickly than they would have otherwise, and, more importantly, this treatment also helped them to learn to read. Whether the children gained stability with the help of monocular occlusion or spontaneously, their rate of reading progress almost doubled. These results do not imply that binocular instability is the only problem affecting dyslexics' reading. Many also suffer from poor phonological skills. However, since it can be treated relatively easily, we believe that all children of this age with visual reading difficulties should be assessed for binocular instability and offered a brief period of monocular occlusion if appropriate.

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