COVERING ONE EYE AFFECTS HOW SOME CHILDREN READ

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It is impressive how effortlessly fluent readers translate strings of visual symbols on a page into meaningful language; often children have learnt this skill before they go to school. Yet as many as 3 to 10 per cent of children at school have particular difficulty in learning to read (Rutter and Yule 1975). Given that reading demands rapid integration of both visual and linguistic information, it is plausible that problems with either visual or language processing could contribute to these children’s difficulties.

As far as language processing is concerned, there is convincing evidence that poor phonological awareness contributes to reading failure (Bradley and Bryant 1978, Lundberg et al. 1980, Wagner and Torgeson 1987). Furthermore, Snowling et al. (1991) have good evidence from their detailed study of J.M. that abnormal speech development may give rise to poor phonological awareness, and hence poor spelling and reading development.

However, the question of whether visual problems might also contribute to children’s reading difficulties is more vexed. Some investigators have failed to discriminate normal readers from disabled readers on the basis of their performance on visual tasks (Benton 1975, Vellutino 1975a, b). On the other hand, many studies that have looked at either the dynamic processing of the retinal image (Breitmeyer 1980, Lovegrove et al. 1986, Geiger and Lettvin 1987, Williams et al. 1989) or at eye-movement control (Stein and Fowler 1982, Bigelow and McKenzie 1985, Rayner and Pirozzolo 1988) have shown correlations between poor reading and poor visual performance.

These opposing conclusions are probably not the result of genuine conflict; the experiments from which the conclusions were drawn were methodologically very different. In the first group of experiments, where no differences were found, poor and normal readers were compared on tasks of static pattern-formation processing; but differences between normal and poor readers do emerge if they are compared on visual tasks which depend on events changing rapidly in time (Williams et al. 1989, see Lovegrove et al. 1986 for review). Similarly, the temporal aspects of auditory perception have been shown to differ between normal and poor readers (Tallal 1976). However, even if good and poor readers can be distinguished on the basis of their performance at a visual task, we are still left with the problem of whether there is any causal relationship between poor visual processing and poor reading.

In a recent paper (Cornelissen et al. 1991), we addressed this issue of causality directly. We suggested that if visual problems contribute to reading difficulty, then
TABLE 1
Characteristics of children who passed and failed the Dunlop test

<table>
<thead>
<tr>
<th>Dunlop Test</th>
<th>Performance IQ* Mean (SD)</th>
<th>Range (yrs:mts)</th>
<th>Range</th>
<th>Reading age* Mean (SD)</th>
<th>Range (yrs:mts)</th>
<th>Range</th>
<th>Spoken vocabulary** Mean (SD)</th>
<th>Range</th>
<th>Rhyme task score† Mean (SD)</th>
<th>Range</th>
<th>Chronological age yrs:mts Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed (N = 32)</td>
<td>106.9 (10.6)</td>
<td>88–133</td>
<td>8:2 (1:7)</td>
<td>6:1–11:7</td>
<td>100.5 (3.0)</td>
<td>63–127</td>
<td>10:9 (3:0)</td>
<td>5–16</td>
<td>9:9 (1:4)</td>
<td>7:7–12:5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failed (N = 32)</td>
<td>106.6 (15.3)</td>
<td>80–130</td>
<td>7:11 (1:1)</td>
<td>6:6–10:10</td>
<td>104.0 (6:6)</td>
<td>75–131</td>
<td>10:7 (3:2)</td>
<td>3–16</td>
<td>9:8 (1:8)</td>
<td>7:2–14:5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*British Ability Scales.
**British Picture Vocabulary Scale.
†Rhyme task score = N correct responses/16 items. No significant differences between children who passed and failed the Dunlop test were found for any of these measures.

affected children may perceive a visually confused version of what is printed on the page, decoding it into a nonsense word, or non-word. To test this, we looked at the effect of unstable binocular control, which is common among young schoolchildren (Stein et al. 1986), on reading performance. Children are said to have unstable binocular control if they fail the Dunlop Test (Stein and Fowler 1982), so in a reading age-matched experiment, we gave children of mixed ability lists of single real words to read. The lists taxed the children's vision increasingly as print size and line-spacing decreased, but linguistic difficulty of the words was kept constant. We found that only children who failed the Dunlop Test made more non-word errors as print size was reduced. Therefore, since the only factor that varied in the experiment was print size, children with unstable binocular control must have experienced some form of visual confusion, leading to the increase in non-word errors.

In the present study we looked at whether the effect of unstable binocular control on reading is due, at least in part, to interference between the images from the two eyes. We asked children to read single words with both eyes open and then with one eye occluded. Any visual confusion from interaction of the images from two eyes should be removed by monocular viewing, and should be reflected in a change in the pattern of reading errors. Therefore we gave children two lists of single words to read, matched for linguistic complexity. We expected that children who failed the Dunlop Test would make fewer non-word reading errors when they read with only one eye.

Method
Subjects
As in the previous report, we drew subjects from a clinical population of children of mixed ability referred for orthoptic assessment at the Royal Berkshire Hospital, Reading. The children had been referred because of suspected reading difficulty. We used the Dunlop Test (DT) to identify 32 (24 male, eight female) children with unstable binocular control. They were compared with 32 (23 male, nine female) children who had normal binocular control, and who were matched for reading age. The children's characteristics are summarized in Table I.

Orthoptic and psychological assessment
Each child was examined to exclude orthoptic and gross opthalmological pathology before performing the DT. This is a subjective test of how reliably retinal information from the two eyes is associated with oculomotor signals about eye position in the head. In order to categorize children as having 'stable' or 'unstable' binocular control, we treated the DT as a pass/fail visual task (see Stein and Fowler 1982 for details of administration): children pass the test if they give the same response in eight or more trials out of 10, i.e. they have a stable response to the test; otherwise they fail the test, and are said to have an unstable response.
The children’s IQ was measured with the British Ability Scales (BAS), calculated from the mean of the matrices and similarities subtest $t$ scores. We used a version of Bradley and Bryant’s (1983) four-word rhyme detection task as a phonological test. We counted the total number of correct responses out of 16 items and assumed that the larger a child’s score, the better the phonological skill. Finally, it is possible that the number of non-word reading errors children make could depend on how extensive their vocabularies are; when reading aloud, a child with a very wide spoken vocabulary might be less likely to utter a response which never occurs in spoken English. For this reason we included the British Picture Vocabulary Scale to ensure that there were no systematic vocabulary differences between children with unstable binocular control and those with normal vision.

**Experimental word list design and administration**

At the beginning of the assessment, each child was given the BAS single-word reading test. Next the child was asked to read two paragraphs from a page on which the entire set of experimental words was printed. We used the same words as those in our earlier paper: each paragraph comprised a list of single words of equal difficulty, selected on the basis of the BAS reading age. The child read one paragraph with both eyes, then the other with only one eye (the right).

The choice of which pair of paragraphs to give was restricted to one of four possibilities, equivalent to four difficulty levels, and each corresponding to a bandwidth of the BAS reading-age score. The two paragraphs of words at each level were matched for word frequency (Thorndike and Lorge 1944), and the midpoint for each bandwidth was adjusted so that children were likely to make 50 per cent errors. This ensured that we would record sufficiently large numbers of reading errors for later analysis.

Other design features of the experimental word lists were as follows: (1) The entire page of experimental words consisted of eight test paragraphs of 45 words each (two paragraphs for each of the four difficulty levels), so each child read 90 words. There were two additional paragraphs of masking words, one at the top of the page and the other at the bottom. This ensured that any line was surrounded by at least three lines above and three lines below. (2) Each paragraph comprised 23 regularly spelt and 22 irregularly spelt words. The maximum number of letters and syllables in each word was 10 and three, respectively. We chose only words with a concreteness value ±1 SD from the mean of 438 (range 158 to 670) (Coltheart 1981). (3) The experimental words were all printed in 12-point Helvetica font, with single-line spacing and one character space between each word.

An example of the appearance of part of the test page is shown in Figure 1.

The sequence in which the pair of paragraphs was read was determined by two factors, balanced according to a double latin square: (a) viewing condition (two levels) and (b) the order in which the paragraphs were read (two levels). This ensured that the 32 children who failed the DT read exactly the same 2880 words as the 32 children who passed, in exactly the same conditions.

We felt that asking children to read with only one eye could have led them to adopt a different reading strategy. To minimize any such effect, children always wore plano spectacles when they were reading; monocular viewing was achieved by placing translucent ‘Blender’ tape over the left lens of the spectacles.

**Statistical analysis**

The experimental word lists were scored as follows: (1) the total number of errors was counted, an error being defined as a real-word attempt at the target or a non-word error; (2) the total number of non-word errors was counted, these being defined as words which could not be found in a standard English dictionary; and (3) the total number of refusals to attempt a word (non-attempts) was counted.

We used multiple logistic regression to look for a DT×viewing condition interaction to explain changes in the proportion of non-word errors that children made when they read with one as
night hand life head his each must might under hour be last out car who good into talk left find miss week walk help done plan gone finish ending space laboratory
to is with have him or there has know than can long old us much day new why told room never after late mother and face his try see all work did it felt want page give ever children door am saw mean end move finish ending space laboratory ice pack
best true school line seen chance wish pretty paint rest hear garden green touch hot floor person air game speak drop round fool easy feeling aunt top colour bed write deep small rush cover dance tree flower corner wrong roll cream rose glad
trip ground finish ending space laboratory ice pack polar bear inside a jolly roger
letter four child feel happy fight sound chair street wall fine red sense sit blue hat number wear second short story low stop president party both cut nice save high
cup dream bad pull name buy hold farm dog telephone summer beauty slip quiet
send finish ending space laboratory ice pack polar bear inside a jolly roger carton
lift court whisper amount bright view winter system chief safe art sleep design
lunch sight direction quarter accident degree block fortune dozen leap colonel
yellow period member won match nervous contract scheme guard eight flood
product hang brief circle attack prize author waste citizen quick finish ending space
god captain season wrote million meeting square plane edge character scene
wave habit wedding occasion fifteen threw object patient sigh travel cousin permit
straight vote health department taste salary faint speech west strength shop
fashion combine weight trick gas avenue lesson career statement build motion
twist height balance tight science charming wealth running hunter friendship flush
midnight swift profession ache fever echo interview whirl estate stumble religion
bump debt reflection sergeant victim rough payment tourist foothstep wreck banker
weigh copper commercial rusty thunder scent autumn scarlet haul blush rescue
circus finish ending space laboratory ice pack polar bear inside a jolly roger carton
suspect guide laughter crush property display volume tough mortgage raw
quantity temper medicine cruel bunch costume crumb agreement quarrel smell
column slept angel slide calm beginning telegraph navy prayer shriek triumph
charity outfit exhaust atmosphere employment device bargain dip awkward lump
nest chew fatigue bud finish ending space laboratory ice pack inside a jolly roger
parade phase receipt contents trend plug yawn topic sandy numb altitude heir
witch pique refresh exposure aisle rumble freight idle grizzly wrung forbid aerial
wither siege composer vacuum combustion cymbal hoarse perish sphere lunge
junction isle pew dweller wad prosper oblique halve slough newborn fleece finish
champion foreigner nephew flicker dwelling thief punish assault scholar referee
instruct clash outbreak rhyme whoop robber monarch friction squeak cavern
delirium antique hermit iew alter chasm burner courteous offend deficient
performer nymph vocation plumb magnet council hygiene alphabet segment knoll
shopper somersault caste hump plait finish ending space laboratory ice pack polar
bear inside a carton of jolly roger juice probably offer many percent alcohol
because dennis faced three hundred gunslinging coyote wallabies under five beds
with turquoise quilts atop their friendly hides amongst trivial gamesmanship wrestle

Fig. 1. Example of part of test page.

opposed to two eyes. The number of non-word errors as a proportion of total errors
made was entered as the dependent variable. The other variables controlled
for in the model were IQ, chronological age, reading age and phonological ability.
For this analysis we converted continuous explanatory variables (IQ, reading age,
chronological age and rhyme score) to discrete variables by dividing their ranges
into three levels of equal size. Viewing condition and DT were already discrete
variables, with two levels. The regression
model was:

\[ \text{Logit} \left[ \text{non-word error proportion} \right] = \]
\[ \text{IQ} + \text{Age} + \text{Reading age} + \text{Rhyme score} + \]
\[ \frac{\text{DT} \times \text{Viewing condition}}{299} \]

We used a package called GLIM (General
Linear Interactive Modelling) to run the regression analysis. GLIM provides an estimate of the regression coefficient, expressed as a log odds ratio, with its standard error. Thus both the significance and the magnitude of the risk of each independent variable in predicting non-word errors could be calculated. Risk values are expressed as odds ratios: values greater than one represent increased risk; values of less than one represent decreased risk.

Results
Neither the total number of errors nor the children’s refusals to attempt words varied as a function of viewing condition or performance on the DT (Table II).

The proportion of non-word errors made by children who failed the DT was reduced when they read with one eye as opposed to two (Table III). In contrast, viewing conditions had no effect on the proportion of non-word errors made by those who passed the DT. Multiple regression analysis (Table IV) confirmed a DT x viewing condition interaction ($p<0.01$).

Table IV also shows that the older, better readers, who were probably at the alphabetic stage of reading, made significantly more non-word errors ($p<0.05$ and $p<0.0001$, respectively). Children with better phonological skills tended to make more non-word errors, though this was not statistically significant. Lastly, brighter children made fewer non-word
errors, though again this was not significant.

Discussion
Accurate reading requires rapid integration of visual information across an alternating sequence of binocular fixations and saccades; not only must both eyes be aimed sufficiently accurately at letters on the page, but also the images from the left and right eye must be correctly associated. Children who have unstable binocular control may be poor at integrating both left and right retinal images with each other, as well as with motor information about eye position in the head (Stein et al. 1987). Such a mechanism offers a simple explanation of why children who fail the DT might experience visual confusion when they read. If this is true, we should expect visual confusion to be reduced if the integrating process has to deal with one retinal image rather than two; reading with one eye should change the pattern of children's reading errors. This approach can only implicate a binocular contribution to visual confusion, however, it can not elucidate possible monocular effects such as the perceptual superimposition of sequential retinal frames, as proposed by Breitmeyer (1980).

We did find that monocular viewing reduced the proportion of non-word errors made by children who failed the DT. This strongly supports the idea that unstable binocular control can affect reading because of interference between the images from the two eyes.

We might expect children who fail the DT to make more reading errors over-all than normal children of the same chronological age, but such an effect would be masked in this experiment because we used a reading age-matched design. However, in a survey of 753 primary-school children aged between six and 11 years, Stein et al. (1986) found that those who failed the DT had lower reading ages than normal children, provided they were matched for chronological age. In other words, children with unstable binocular control are more prone to making reading errors.

We might also expect monocular viewing to reduce the total number of errors made by children who failed the DT, but we found that it only altered the pattern of errors they made. Though this may seem contradictory, it suggests that visual confusion of words did not prevent children from recognizing familiar words and therefore reading them correctly. Certainly, there is evidence from adult studies that word recognition is more robust for familiar words, even when presented in a visually mutilated form. Connine et al. (1990) showed a faster reaction time for high-familiarity, high-frequency words presented visually to adults. Furthermore, Pollatsek et al. (1975) asked adults to judge whether pairs of words printed in mixed upper- and lower-case letters were the same or different. These workers found that the accuracy of the subjects' judgements was greater for visually mutilated real words than for pseudowords. Finally, Paap et al. (1984) investigated how efficiently adults could detect letters embedded in real words and pseudowords of both common and rare word shapes. Again, subjects displayed an advantage for real, familiar words.

So, assuming we can equate visual mutilation in these adult studies with visual confusion in the present study, the above findings suggest that unstable binocular control is more likely to prevent children from working out unfamiliar words than reading familiar ones. This means that, during their development, unstable binocular control would reduce the rate at which children add new words to their vocabulary; hence we would expect these children to have lower reading ages than their age-matched peers with normal binocular vision, as reported by Stein et al. (1986).

The kinds of errors that children make are also likely to depend on their stage of reading development. Frith (1985) suggests that during the earliest stages of learning to read, children adopt a logographic strategy, in which 'letter order is largely ignored and phonological factors are entirely secondary': they may recognize words from salient graphic features alone. At this stage, if a word is not familiar, children can either refuse to attempt it or offer something from their lexicon which looks similar. Therefore, whether or not there is visual confusion, children at this stage are most likely to
TABLE V
Change in proportions of non-word errors made by children with unstable binocular control as function of reading age and viewing condition

<table>
<thead>
<tr>
<th>Difficulty level</th>
<th>Mean reading age (yrs:mts)</th>
<th>Mean non-word error score*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Binocular viewing</td>
<td>Monocular viewing</td>
</tr>
<tr>
<td>1</td>
<td>6:9</td>
<td>13:0</td>
</tr>
<tr>
<td>2</td>
<td>7:6</td>
<td>30:6</td>
</tr>
<tr>
<td>3</td>
<td>8:0</td>
<td>44:8</td>
</tr>
<tr>
<td>4</td>
<td>9:4</td>
<td>57:5</td>
</tr>
</tbody>
</table>

*Total non-word errors/total errors × 100.

offer real-word responses to unfamiliar words, because that is the only strategy available to them.

Later on in their development, Frith suggests that children move into an alphabetic, and then an orthographic, stage. Children in the alphabetic stage try to work words out using a grapheme-to-phoneme conversion strategy; they probably look separately at each component in an unfamiliar word. At this stage, if a child experiences visual confusion of an unfamiliar word, the consequent visual scramble may well be decoded bit by bit as a non-word. In this case, if visual confusion is reduced by monocular viewing, the child has a better chance of breaking the words up and uttering a real word. However, it must be emphasized that a non-word may still be produced, for phonological reasons.

Evidence in support of this explanation is presented in Table V: the reduction in the proportion of non-word errors with monocular viewing became progressively larger as children’s reading age increased, i.e. as the likelihood of children being in Frith’s alphabetic stage increased.

This study confirmed our previous finding that children with higher reading ages and better phonological skills make more non-word reading errors. This has also been described by Gough et al. (1983) and was discussed in detail in our previous report. However, in the present study the relationship between phonemic awareness and non-word errors was much weaker. Two factors may account for this: first, there are only 128 observations in the present data set, as opposed to 270 in the earlier report; and second, the children in the present study were older and their reading ages were higher, so more would have been in Frith’s orthographic stage of reading development, in which children rely less on explicit grapheme-to-phoneme conversion rules.

In summary, we feel that the present data add further support for the idea that unstable binocular control can interfere with children’s reading.

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SUMMARY
The Dunlop Test was used to identify unstable binocular control in a group of 32 mixed-ability children. They were compared with 32 reading age-matched controls. The children were then asked to read two lists of single real words of equal linguistic difficulty: one with both eyes open and the other with the left eye occluded. Only children who failed the Dunlop Test made fewer non-word errors when they read with one eye. This result provides additional support for the theory that unstable binocular control can directly affect how children read. In addition, these findings suggest that this effect must be due, at least in part, to some interaction between the images from the two eyes.

RÉSUMÉ
L’occlusion d’un oeil affecte la lecture chez certains enfants
Le Dunlop test fut utilisé pour identifier l’instabilité du contrôle binoculaire dans un groupe de 32
enfants de capacités variées. Ils furent comparés à 32 contrôles appariés. On demanda aux enfants de lire deux listes de mots isolés présentant une difficulté linguistique identique, l'une avec les deux yeux ouverts et l'autre avec l'œil gauche fermé. Seuls les enfants ayant échoué au Dunlop test firent moins d'erreurs non-verbales en lisant avec un seul œil. Ces résultats favorisent la théorie selon laquelle l'instabilité binoculaire peut altérer la façon dont un enfant lit. De plus, ces données suggèrent que l'effet peut être lié, au moins pour une part, à une interaction les images de chaque œil.

ZUSAMMENFASSUNG
Die Abdeckung eines Auges wirkt sich auf das Lesen eines Kindes aus

RESUMEN
El tapar un ojo afecta a cómo algunos niños lean
Se utilizó el Test Dunlop para identificar el control binocular inestable en un grupo de 32 niños con habilidad mezclada. Fueron comparados con 32 controles. Se les dijo entonces a los niños que leyeron dos listas de palabras reales solas de dificultad lingüística igual: una con ambos ojos abiertos y la otra con ojo el izquierdo tapado. Sólo los niños que fallaron el Test Dunlop tuvieron menos errores cuando leían con un solo ojo. Este resultado proporciona un nuevo argumento a la teoría de que el control binocular inestable puede afectar directamente a cómo los niños lean. Además estos hallazgos sugieren que este efecto debe deberse, por lo menos en parte, a alguna interacción entre las imágenes de ambos ojos.

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