# Dyslexia as a Limitation in the Ability to Process Information

*N. C. Ellis* and *T. R. Miles*
[redacted]

University College of North Wales
Bangor, Wales

Abstract

In an earlier paper (Miles and Wheeler 1975) it was reported that dyslexic subjects, aged over 13, were less able than suitably matched non-dyslexic subjects to respond correctly to arrays of tachistoscopically presented digits. A further experiment is now reported involving a younger age-group: 15 dyslexic subjects, average age twelve and one-half, were matched for spelling age with 15 non-dyslexic subjects, average age eight and one-half; and since the dyslexic subjects were appreciably less successful it is argued that "maturational lag" does not, on its own, fully account for the difference in performance between the two groups. A similar procedure was repeated with 41 dyslexic and 41 non-dyslexic subjects, all aged between 10.4 and 14.4, both with and without the introduction of a visual masking stimulus immediately after the test stimulus. Twenty undergraduate "fast-readers," 20 undergraduate "slow-readers," and four undergraduate dyslexic subjects were also compared both on their responses to tachistoscopically presented digits and on their performance in a visual search task. The results, taken in conjunction, suggest that dyslexia can be regarded as some kind of limitation in the ability to process information, perhaps affecting in particular the "visual code store" postulated by Posner et al. (1969).

## Foreword

We should like to preface this paper by paying tribute to the pioneer work of S. T. Orton. It is a great privilege to have the opportunity of addressing members of the society named after him, and our only regret is that it has not been possible to deliver this paper in person.

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## Introduction

At Bangor, Wales, our research into dyslexia started with informal observation. In particular we studied the mistakes made by children and adults in repeating digits (as in the Wechsler intelligence tests), in reciting arithmetical tables, in saying the months of the year, and in a variety of other tasks. (For further details see Miles 1975). A recognizable pattern of difficulties, often occurring in several members of the same family and inexplicable in terms of lack of intelligence or opportunity, led us to the concept of a constitutionally caused limitation; and it became plain that the difficulties were basically similar to those described by Hinshelwood (1900 and 1917), Orton (1937), Hermann (1959), Critchley (1970), and many others. In what follows, those displaying such difficulties will be described as "dyslexic," those not displaying them as "nondyslexic." We question the use of the question-begging word "normal"; and although all the subjects whom we shall designate as "dyslexic" were in fact weaker at reading and spelling than might have been expected in view of their intellectual level it is not this fact in isolation which justifies the use of the word "dyslexic" but the pattern formed by their difficulties taken in conjunction. The choice of a word implying a constitutional cause is, of course, intentional.

In a first attempt to make sense of our findings one of the present authors made the suggestion that the main feature in dyslexia was "an inability to retain complex information over time" (Miles and Wheeler 1974, p. 9). Since then we have attempted to study the behavior of dyslexic and nondyslexic subjects in more rigorously controlled conditions, with a view to finding out, first, whether the alleged differences genuinely occurred when the conditions were adequately controlled, and, secondly, what in that case were the tasks or combinations of tasks which presented the dyslexic subjects with special difficulty. In general our policy has been to vary the kind and amount of stimulus material presented, the duration of time for which it is available, and the interval between its presentation and the time at which the subject is required to respond.

## Background Research

One of our earliest procedures was to use digits as stimulus material and to present them tachistoscopically at varying time-intervals. An initial experiment along these lines was summarized at the Orton Society meeting at

Rochester, Minnesota, in 1974. (For further details see Miles and Wheeler 1975.) In this experiment the performance of 11 dyslexic subjects, all over the age of 13, was compared with that of 11 nondyslexic subjects of similar age. The differences were staggering: when 5 or 6 digits were presented on the cards the nondyslexic subjects were able most of the time to produce the right answer at exposure times of less than 350 milliseconds (ms.), whereas the dyslexic subjects (who included two undergraduates and several others of university caliber) needed 750 ms. or more. This finding is in line with that reported by Stanley and Hall (1973) who presented six-letter arrays to dyslexic and nondyslexic children for durations of 40–6000 ms. and found that at the higher exposure times the nondyslexic children produced superior recall. More recently Davis (1975), using exposure times of 40 ms. to 6 sec. and with both letters and pictures as stimulus material, has reported a similar difference. These findings, taken in conjunction, seemed to us sufficiently interesting to merit follow-up in further detail.

Two other investigations have encouraged us to look in the general area of "immediate memory" for an increased understanding of dyslexic type difficulties. First, in a study reported by Harzem, Lee, and Miles (1975), 10 dyslexic children aged 9 to 13, and 10 nondyslexic children aged 6 to 7, were required to spell single words by selecting the appropriate letters from an array. Each letter, as it was selected, was either left in front of the subject or moved out of sight; the words to be spelled were presented either visually or aurally, in each case for 10 sec., and the subject responded either immediately or after a delay of 60 sec. during which he sat silently. For the nondyslexic subjects the delay resulted in more spelling errors only in the visual presentation/letters-removed condition; for the dyslexic subjects the delay resulted in more spelling errors (i) in the aural presentation/letters-removed condition, (ii) in the visual-presentation/letters-present condition, and (iii) in the visual-presentation/letters-removed condition; it failed to do so only in the aural-presentation/letters-present condition. Secondly, Blackburn (1976) has used the Bangor files to examine retrospectively the performance of 94 dyslexic subjects (age range 7.6 to 19.9) on the Wechsler "digits forward" and "digits reversed" tests. The Terman and Wechsler norms imply that in the case of nondyslexic subjects—as might be expected—there is improvement with age. Blackburn found, however, that on "digits reversed" the older dyslexic subjects were obtaining only marginally higher scores than the younger ones, and that on "digits forward" the correlation between age and higher score was virtually non-existent. These findings and those of Harzem, Lee, and

Miles (1975) both support the view that dyslexia involves some kind of limitation of immediate memory, though the nature of this limitation is by no means clear.

In what follows we shall describe five further experiments, not in full detail (though further details are available on request) but as an interim report which indicates the areas at present being investigated and our provisional conclusions.

## Some Experimental Findings

The original experiment involving tachistoscopic presentation of digits (Miles and Wheeler 1975) had involved subjects over the age of 13. It therefore seemed desirable to check whether similar differences were still found when the subjects were children. At the same time we wished to take the opportunity of investigating the "maturational lag" hypothesis of dyslexia; in other words, were the mistakes made by dyslexic subjects simply an indication of late development of certain skills or should one think in terms of some inherent defect or specific limitation? We therefore decided to match our dyslexic and nondyslexic subjects not for chronological age but for spelling age. If both groups performed at the same level on the "tachistoscopic presentation of digits" task this would be evidence for maturational lag, whereas if the dyslexic subjects performed less efficiently than the control subjects this would support the hypothesis of some specific limitation.

*Experiment 1.* Fifteen dyslexic subjects (average age 12) and 15 nondyslexic subjects (average age 8.5), suitably matched for spelling age, were presented tachistoscopically with cards containing 4, 5, 6, or 7 digits, with exposure-times between 400 and 1600 ms. When the cards contained 4 digits (with 3 presentations per subject at 400 ms. and 1 presentation per subject at 800 ms.) 6 errors occurred in the 120 cards presented to both groups, all of them being made by the dyslexic subjects. When the cards contained 5, 6, or 7 digits (again with 3 presentations per subject in each condition), the results were as shown in Table 1. These results not only provide additional evidence that dyslexic subjects are distinctively weak at this kind of task; they also suggest that an explanation of dyslexic-type difficulties solely in terms of "maturational lag" is inadequate.

*Experiment 2.* In this experiment, exposure-times between 50 and 1200 ms. were used and each card contained seven digits. The subjects were

Table 1. Mean Number of Digits Correctly Recalled

| *No. Digits per Card* | *Exposure Times* | *Dyslexic Subjects* | *Nondyslexic Subjects* |
|---|---|---|---|
| 5 digits | 400 ms. | 3.44 | 4.37 |
| 5 digits | 800 ms. | 3.95 | 4.87 |
| 6 digits | 400 ms. | 3.88 | 4.97 |
| 6 digits | 800 ms. | 3.94 | 5.24 |
| 6 digits | 1200 ms. | 4.18 | 5.65 |
| 7 digits | 400 ms. | 3.64 | 5.00 |
| 7 digits | 1600 ms. | 4.64 | 6.27 |

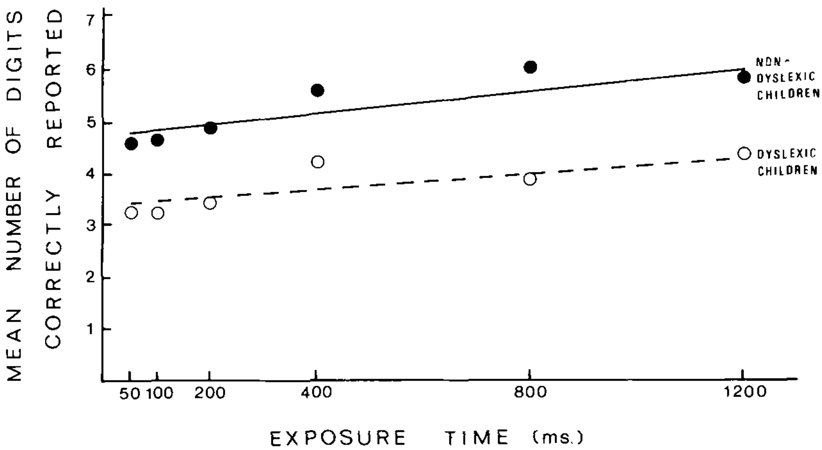
children between ages 10.4 and 14.4 years, with 41 being dyslexic and 41 nondyslexic. Figure 1 gives the results when numbers of digits correctly recalled are plotted against exposure time. The difference between dyslexic subjects and nondyslexic subjects is thus confirmed again; and the graph shows some other interesting features which we shall discuss below.

Sperling (1963) and others have shown convincingly that stimulus information can be "available" in the brain (in what is called the "iconic store") for a short period after the initial source of stimulation has ceased to operate. This period is probably of the order of 100–200 ms. (See Neisser 1967). It follows that in Experiments 1 and 2 the effective exposure time—i.e., the total time available to the subject for processing information—must have involved a combination of tachistoscopic exposure time *plus* iconic storage time. If, however, a visual masking stimulus is added immediately upon the offset of the test stimulus, this will have the effect of introducing "noise" into the iconic store and prevent the further processing of information; and in that case effective exposure time and tachistoscopic exposure time can be equated. (For further theoretical discussion of masking see Kahneman 1968.)

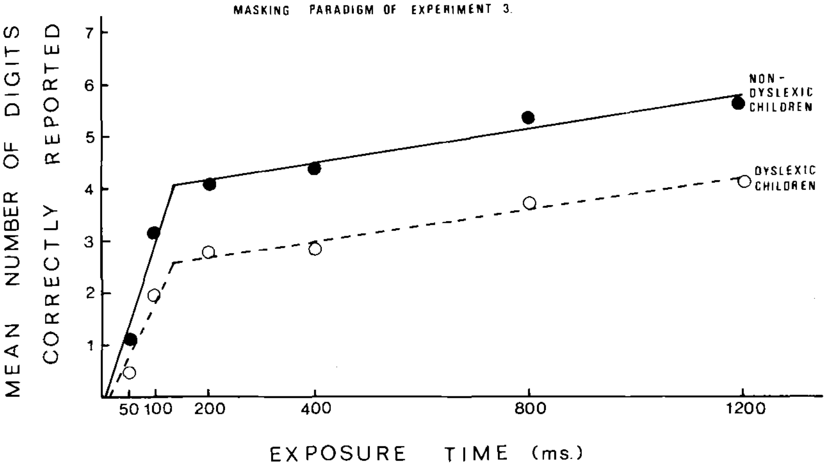
*Experiment 3.* This involved the same subjects and the same procedure as in Experiment 2 except that a visual masking stimulus, in the form of a complex of meaningless shapes, was introduced for 200 ms. immediately after offset of the test stimulus.

Figure 2 gives the results when number of digits correctly recalled is plotted against exposure time.

EFFECT OF EXPOSURE DURATION ON NUMBER OF DIGITS CORRECTLY REPORTED BY THE TWO GROUP OF CHILDREN IN EXPERIMENT 2.




EFFECT OF EXPOSURE DURATION ON NUMBER OF DIGITS CORRECTLY REPORTED BY THE TWO GROUPS OF CHILDREN IN THE BACKWARDS MASKING PARADIGM OF EXPERIMENT 3.



We shall compare below the data of Figure 2 with those of Fig. 1.

Our next task was to follow up our earlier idea (Miles and Wheeler 1974) that the difficulties experienced by dyslexic children and adults in reading, spelling, and arithmetic were manifestations of a more general difficulty, which we now decided to characterise as "slowness in processing information." We therefore conducted an experiment with undergraduates aimed at finding out whether those who were slow at reading were also slower at other tasks which involved information processing. In order to obtain an accurate measure of "digit-processing time" a visual masking stimulus was again introduced.

*Experiment 4.* Cards containing five digits were presented tachistoscopically to 44 undergraduate subjects. By means of a suitable ranging method it was possible to calculate for each subject the minimum time needed for correct reproduction of the 5 digits. On the basis of suitable reading-speed tests the subjects were classified as either "fast readers" (20 subjects) or "slow readers" (20 subjects); and 4 undergraduate subjects known to be dyslexic also took part in the experiment.

*Experiment 4a.* These subjects carried out a visual search task in a further experiment similar to those described by Neisser (1963, 1967), in which they were required to search for target digrams among passages of nonsense letters. Results for Experiments 4 and 4a are given in Table 2.

Table 2. Five-Digit Processing Time and Digram Search Time

| | *Average Reading Speed for 5 Passages (words per minute)* | *5 Digit Processing Time (ms.)* | *Total Digram Search Time (sec.)* |
|---|---|---|---|
| Fast readers (N = 20) | $\bar{x}$ 305.1<br>s.d. 59.8 | $\bar{x}$ 114.1<br>s.d. 57.0 | $\bar{x}$ 167.3<br>s.d. 21.8 |
| Slow readers (N = 20) | $\bar{x}$ 181.1<br>s.d. 25.6 | $\bar{x}$ 219.5<br>s.d. 191.1 | $\bar{x}$ 188.4<br>s.d. 30.3 |
| Dyslexic subjects (N = 4) | $\bar{x}$ 123.8<br>s.d. 39.9 | $\bar{x}$ 450.0<br>s.d. 100.0 | $\bar{x}$ 250.5<br>s.d. 15.8 |

*Experiment 5.* The procedure of Experiment 4 was repeated on the 82 subjects of Experiment 2 (children aged between 10.4 and 14.4, of whom 41 were dyslexic).

It will be noted that the dyslexic children took over four times as long as the control children to process the five-digit test stimuli and that the undergraduate dyslexic adults needed more time than the nondyslexic children.

## Discussion

The evidence put forward above, taken in conjunction with the earlier evidence, both our own and from elsewhere, seems to us to establish that dyslexic subjects are distinctively weak at responding to tachistoscopically presented digits. This claim has "held up" in a variety of different conditions.

In addition, Tables 2 and 3 give some provisional support to the ideas that reading can be regarded as a special case of information processing and that it may be feasible to obtain a stable processing rate for each individual over a limited period. We do not doubt that over the long term the processing rate can be improved (and this has been partially confirmed by informal observations on nondyslexic adult illiterates); but it is interesting that the four dyslexic undergraduates, though their processing time was far faster than that of the dyslexic children, were still taking longer than the nondyslexic children despite the fact that over the years they must have been exposed to far more printed material. It is therefore reasonable to suggest that dyslexia involves some special kind of limitation in the ability to process information, a limitation which can be partly but not fully overcome by suitable practice and training.

Table 3. Five-Digit Processing Time for Subjects between 10.4 and 14.4 Years of Age

| | *5 Digit Processing Time (ms.)* |
|---|---|
| *Dyslexic children* | $\bar{x}$ 1331 |
| (N = 41) | s.d. 585 |
| *Nondyslexic children* | $\bar{x}$ 289 |
| (N = 41) | s.d. 156 |

Many problems remain, of course, as to what kind of limitation it is; but in the light of the above findings we should like to make one further suggestion.

If we compare Figure 2 with Figure 1, an important difference is that the former shows a "two-limber" function similar to that which is typically reported in comparable masking situations (Sperling 1963, 1967; Merickle et al. 1971; Coltheart 1972; Henderson 1972). Various models have been proposed by these authors to explain the presence of the two "limbs"; and possibly it is right to think in terms of two different storage systems which supplement each other—one of these, corresponding to the first "limb," a "visual code store" to which visual material can immediately be transferred (see Posner et al. 1969; Posner 1973), and the other, represented by the second "limb," a name code store where visual and auditory information can be combined. If this is right, then our results suggest that it is the former that functions less effectively in dyslexic subjects. It will be noted that in Figure 2 the slope of the second "limb" is the same for both dyslexic and nondyslexic subjects, the two functions being respectively:

$$\text{dyslexic subjects—} y = 2.38 + 0.0015\,x$$
$$\text{nondyslexic subjects—} y = 3.91 + 0.0015\,x$$

It is possible, therefore, that the differences between the two groups of subjects arise not because of any difficulty on the part of dyslexic subjects in producing the correct names for items in the stimulus array but because of a limitation, which shows itself during the first 150 ms. of processing time, in visual code capacity. While nondyslexic subjects can improve their visual code capacity with practice, it appears that dyslexic subjects even over a period of years fail to show an improvement which is at all comparable.

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