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Citation for published version (APA):
Bouma, H., & Legein, C. P. (1977). Foveal and parafoveal recognition of letters and words by dyslexics and by average readers. *Neuropsychologia*, *15*(1), 69-80. https://doi.org/10.1016/0028-3932(77)90116-6

DOI:
10.1016/0028-3932(77)90116-6

Document status and date:
Published: 01/01/1977

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Neuropsychologia, 1977, Vol. 15, pp. 69 to 80. Pergamon Press. Printed in England.

FOVEAL AND PARAFOVEAL RECOGNITION OF LETTERS AND WORDS BY DYSLEXICS AND BY AVERAGE READERS

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(*Received* 7 *November* 1975)

Abstract—In adult readers, parafoveal recognition of words is limited by strong interferences between letters. In the present study subjects were 20 dyslexic children and 20 average readers (9–14 yr). Recognition scores of isolated letters, of embedded letters and of words were compared both in foveal and in parafoveal vision. The groups did equally well on isolated letters whereas the dyslexics generally stayed behind on embedded letters and on words. Individual scores of embedded letters and of words were moderately correlated as were word score and reading level. It is advocated that research on dyslexia is directed at possible deficits in reading processes such as eye control, word recognition, and storage not only as separate factors but rather in their intimate relationships.

INTRODUCTION

READING involves the visual intake of language symbols. The visual processes and the language processes involved can to some degree be studied separately. In a series of studies in our Institute, we have concentrated on a number of visual processes in adult readers [1–7]. Here we set out to explore a few of these processes in the reading of children, for which purpose we compare a group of dyslexics with a group of average readers.

Due to the saccadic nature of eye movements in reading, a distinction may conveniently be made between the following visual reading processes (a) eye pauses, eye saccades, and their control; (b) recognition of text material from a single eye pause; and (c) the integration of information from successive eye pauses. The present paper concentrates on recognition from a single eye pause.

The visual recognition of text material from a single eye pause can be studied by means of tachistoscopic presentation, if presentation time is comparable to the duration of normal eye pauses. During reading, eye saccades leave part of the visual information outside the centre of foveal vision, taken here as one degree visual angle. Therefore both foveal and parafoveal recognition are relevant for reading.

Since visual acuity decreases from the foveal centre outwards, parafoveal recognition is bound to suffer as compared to foveal recognition. For adults, a fair correspondence has indeed been found between recognition scores of isolated single letter stimuli and parafoveal visual acuity [2]. However, an essential difference appears between isolated letters and letters embedded in strings. The parafoveal recognition of embedded letters is severely limited, not by a low visual acuity but by strong lateral interference effects between adjacent stimuli [1, 8, 9]. These interferences operate over rather large retinal distances and cause a narrowing of the horizontal visual field in which embedded letters can be recognized, to about one-fourth of the width for isolated letters [1] (Fig. 1). It is probable that in parafoveal vision the recognition of single words is limited by these interference effects [3].

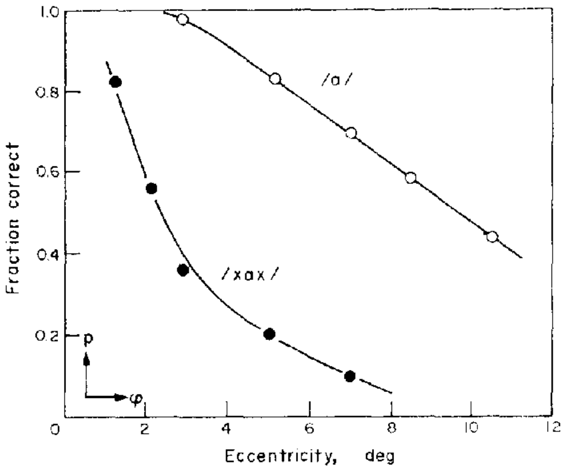

FIG. 1. Correct recognition scores of lower-case letters as a function of retinal eccentricity. In each 200 msec presentation, only one test letter was to be recognized. The test letter was randomly chosen from the alphabet and is symbolically indicated as /a/. The addition of letters x, one at each side, /xax/, makes recognition scores drop sharply, and causes a narrowing of the functional visual field to about one-fourth of the value for isolated letters /a/. The effects are ascribed to adverse processes of lateral visual interference [1].

If it is true that, in adult readers, visual interference effects set certain limits to the recognition of words from each single eye pause, one may wonder about beginning readers and in particular about children with reading difficulties. It would be conceivable that part of their reading problems relate to relatively strong interference effects. Following a provisional paper [10], we report here on an experiment in which 20 dyslexic children and 20 children of average reading ability took part as subjects. The stimuli we used were isolated single letters, embedded letters, and single words, which were presented tachistoscopically both in foveal and in parafoveal vision.

METHODS

Subjects

Twenty dyslexic children, among whom 2 girls, were selected by the staff of a remedial teaching school as to specific reading difficulties in the absence of emotional and intellectual deficits. These selection criteria were clearly manifest during the experiments. According to the school's files, W.I.S.C. I.Q. values were between 92 and 135 at an average of 105. Ages were between 10 and 14 yr, at a reading level which was on average 3 yr below that of their age group. Ophthalmological examination by one of us (C.P.L.) as to visual acuity, fundus appearance and binocular coordination revealed that one child had subnormal acuity due to undercorrection and one child had a slight exophoria, without complaints.

The control group of 20 children of the same age among whom 9 girls, were selected from grades 4, 5 and 6 of an ordinary primary school as to average reading level. Ages were between 9 and 13 yr. We chose our control group of the same age group because we were interested in the factors underlying the reading deficit, keeping other factors such as motivation, fixational abilities etc. more or less the same in both groups.

Finally, 5 adult readers from the staff of our Institute also took the battery of tests. They were experienced subjects.

Tachistoscopic stimuli

Stimuli were 23 different lower-case letters (all 26 except x, y, q) and 48 well-known Dutch words. There were three types of stimuli: (1) Letters were presented isolated, to be indicated as /a/, and (2) embedded between two letters x at normal typewriter spacing, to be indicated as /xax/. (3) The 2 × 24 words, /WRD/, were equally distributed over three word lengths, $l = 3, 4, 5$ letters, and for each length over two frequencies of usage g in printed Dutch [11]: very high frequency words, HF, $g \geqslant 10^{-3}$, and less high frequency words, LF, $2 \cdot 10^{-4} \geqslant g \geqslant 10^{-4}$. Twenty-four words served as foveal stimuli and 24 as parafoveal stimuli, 12 left and 12 right of fixation.

The stimuli were typed in lower-case with an IBM ball typewriter through carbon tape on a long sheet of white paper, one stimulus on a line. Type face was Courier-10, which face has pronounced serifs. Height of the short letters (a, c, e . . .) was 1·95 mm, extensions of ascenders and descenders were 0·75 mm. Letter width was between 1·4 mm (j) and 2·5 mm (m, w), at a typewriter spacing of 2·55 mm. This type face was also used in earlier experiments on the recognition of letters and of words by adult readers [1–7].

Tachistoscope

Both for foveal and for parafoveal presentation, a two-channel tachistoscope was used. A blank field of 30 × 30 cm, luminance about 100 cd/m^2 through the half silvered mirror, in which a fixation mark was present, was replaced for 100 msec by a similar field of equal brightness in which one test stimulus was present behind a horizontal window, the edges of which were weakly visible. A transportation mechanism automatically brought each successive stimulus behind the window. The viewing distance was 57 cm, at which distance 10 mm corresponds to 1° visual angle. For foveal test stimuli the fixation mark was a low contrast dot to prevent effects of backward masking.

For foveal stimuli the children initiated each stimulus presentation themselves by pressing a button when looking at the fixation mark. For parafoveal stimuli the experimenter pressed the button immediately after having asked for correct fixation. Correct fixation was checked with an infra-red closed circuit television system. In the video tape recordings, small saccades in the direction of parafoveal stimuli could often be seen, but these occurred after the disappearance of the test stimulus. This is evidence that fixation was usually correctly maintained during stimulus presentation.

Presentation

Eccentricity of presentation φ for the isolated and the embedded test letters was at $\varphi = 0°$ (foveal) or at $|\varphi| = 1°$, either right of fixation ($\varphi > 0°$) or left of fixation ($\varphi < 0°$). A visual angle of 1° corresponded to four letter positions. Parafoveal word stimuli were presented such that the letter closest to the fovea was at $|\varphi| = 1°$, the most outward letter being between $|\varphi| = 1{\cdot}5°$ for $l = 3$ letters and $|\varphi| = 2°$ for $l = 5$ letters. For each stimulus type, parafoveal stimuli were presented randomly right and left of fixation in equal numbers. Letter stimuli were presented once in foveal and once in parafoveal vision. One letter (s) was presented both left and right of fixation so as to equalize the numbers of stimuli left and right of fixation. Word stimuli were presented only once.

The presentation time of 100 msec was chosen lower than average fixation duration in reading (250 msec or so) in order to prevent eye saccades towards the stimulus. Such eye saccades have a latency of at least 150 msec.

In the experiments, foveal stimulus lists preceded parafoveal ones, whereas stimulus lists came in the order: first isolated letters /a/, next embedded letters /xax/, and finally words /WRD/. Each list started with a few extra stimuli to allow the subjects to become acquainted with the task. A pause was inserted half way through the session. The subjects responded orally with either one letter or one word directly after stimulus presentation. These responses were recorded on tape. Two responses were also allowed (e.g. b or k). If the answer was not sufficiently clear (e.g. m vs n) the experimenter asked for clarification. Of the embedded letters /xax/, only the central letter was reported. Responses "illegible", "not seen" etc. were allowed.

Other tests

Lateral dominances for hand, foot, and eye usage were tested using the Harris test [12] and the Miles ABC vision test [13].

All children were given a short oral reading test (Tanghe test) [14] in which words and sentences of a running text became progressively more difficult. Reading level was derived from the number of words read in the first minute. In addition, the subjects read a number of separate words of various complexities.

RESULTS

Reading level

A plot of reading levels of all children as determined from the Tanghe test is given in Fig. 2 as a function of age. Oblique lines delineate an area of average reading ability, which level is seen to be slightly surpassed by 7 children of the control group. The dyslexic children read at a level which average readers reach 0–5 yr earlier. The one boy in the dyslexic group who performed at average level read at a rather high speed, but he made many errors of perseveration.

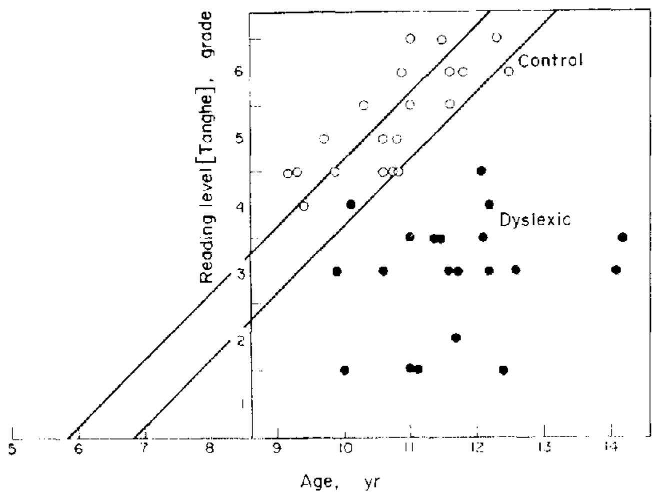

FIG. 2. Grade level of reading (Tanghe test) vs age, of 20 dyslexic and 20 averagely reading subjects. Oblique lines indicate limits of normal reading levels.

Group results

Isolated letters. In recognizing isolated letters the dyslexics and the controls score equally high on average (Fig. 3). Apart from possible ceiling effects, knowledge of letter forms then seems equally developed and is sufficient for the experimental situation. Confused response letters usually showed a visual relation to the stimulus letters, such as l⇄i confusions. As to b–d confusions, the dyslexic group had two foveal and five parafoveal b→d confusions, and one parafoveal d→b confusion, whereas none occurred in the control group. No n–u or b–p confusions occurred. Parafoveal scores were somewhat lower than foveal scores, as should perhaps be expected. Of the 40 children, 9 dyslexics and 9 controls scored higher than 95% at $|\varphi| = 1°$. At this eccentricity, visual acuity is about 50% of the foveal value. For experienced adult subjects this is sufficient for reaching a full score, in accordance with earlier results [2].

Embedded letters. Embedded letters are more difficult to recognize (Fig. 4). In foveal presentation, scores for embedded letters were slightly lower than for isolated letters, although 7 dyslexics and 13 controls nevertheless scored above 95% correct. In parafoveal presentation, a rather dramatic influence of the adjacent letters was manifest for both groups of children, the dyslexic group scoring at some 30% correct significantly worse than the control group at some 50%. The experienced adults scored considerably higher at about 85%. Clearly, the visual task of isolating a certain letter from its neighbours is a difficult one, even at an eccentricity as small as 1° visual angle or four letter positions from the centre of fixation. The results indicate slightly higher scores in the right visual field, but since the 12 letters left of fixation were different from the 12 letters right of fixation, no firm conclusions are possible as to intrinsic right–left differences. The incorrect responses in the dyslexic and the control groups were for any one stimulus letter distributed over many response letters, general trends being similar for both groups. Parafoveally, the

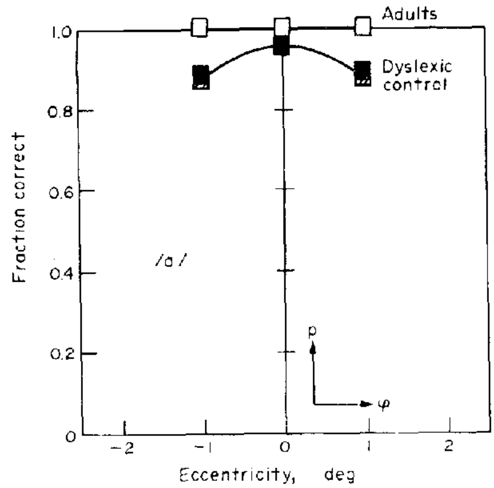

FIG. 3. Group averages of recognition scores of isolated test letters /a/ in foveal and parafoveal presentation. There is no difference between the dyslexic group and the control group.

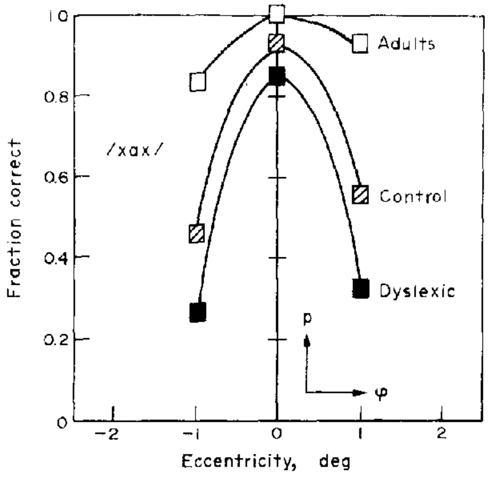

FIG. 4. Group averages of recognition scores of embedded test letters, /xax/, in foveal and parafoveal presentation. As compared to isolated letters (Fig. 3), parafoveal scores in particular are definitely lower, more so for the dyslexic group than for the control group.

dyslexic group had more illegible responses (26%) than the control group (13%). If correct scores of the two groups are correlated for the individual letters, a clearly positive relationship appears ($r = +0{\cdot}69$), indicating that the difficulties concentrated largely on the same letters.

Words. In the recognition of words (Fig. 5) the dyslexic group again experienced more difficulties than the control group, both in foveal and in parafoveal presentation. Foveally, the control group had an almost perfect score (17 children above 95%) as distinguished from the dyslexics (7 above 95%). Parafoveally, the dyslexic group scored an average of about 45% correct as compared with about 70% for the control group. The adult group scored over 90% correct. For all three groups, scores in the right visual field were higher than scores in the left field. We consider the number of 12 word stimuli in the left field and 12 different ones in the right field too small to prove beyond doubt a left–right difference for the present groups.

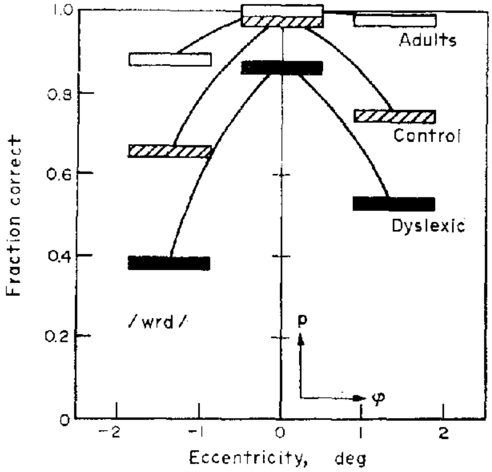

FIG. 5. Group averages of recognition scores for isolated Dutch words in foveal and parafoveal presentation. Word lengths three to five letters. Correct word scores are higher than embedded letter scores (Fig. 4), the dyslexics scoring lower than the controls.

The word stimuli were of three different word lengths and for each word length of two frequencies of usage in the printed language. Figure 6 gives the corresponding scores for the dyslexic and the control groups. Generally, longer words are more difficult to recognize, except in the case of foveal recognition by the control group, where recognition is perfect for all lengths. Here a ceiling effect prevents a possible influence of word length from materialising. For adult subjects, word length has been found to have an influence in the left field, rather than in the right field [3]. As to frequency of occurrence, HF and LF words score equally high in foveal presentation, whereas in parafoveal presentation LF words are somewhat more difficult to recognize than HF words. It may be recalled here that the LF words concerned occur in Dutch at a frequency of about 10^{-4}.

	foveal		parafoveal	
	dysl.	contr.	dysl.	contr.
l=3	96	98	64	84
l=4	87	98	46	72
l=5	75	98	27	54

	foveal		parafoveal	
	dysl.	contr.	dysl.	contr.
HF [van-huis-niets]	87	98	55	75
LF [pad-hout-steen]	85	99	37	65

FIG. 6. Correct recognition scores of words as a function of word length and for two frequencies of usage in printed Dutch (HF frequencies above 10^{-3}; LF frequencies between 10^{-4} and $2 \cdot 10^{-4}$). Scores decrease with word length and are higher for HF than for LF words, as far as ceiling effects are absent. Parafoveal data have been averaged over left and right visual fields.

In general, both groups of children experienced difficulties with the same words. More revealing even for a similar type of process is perhaps the observation that the incorrect word responses, nearly all existing Dutch words, were often the same in the two groups. Incorrect response words generally showed a visual resemblance to the stimulus words concerned, such as (stimulus→response): had→hard, fles→fiets, and maand→mand. In both groups, response words tended to recur as incorrect word responses later in the session. This was true in 10% of the incorrect word responses in the dyslexics and in 9% of the controls.

Word responses "illegible" amounted to 13% of all parafoveal presentations for the dyslexic group and 4% for the control group.

Individual scores. Because of the relatively small number of stimuli, individual scores should be considered with some reserve. Nevertheless they are of value because they may reveal relationships between the scores obtained for different stimuli. For foveal stimuli, a possible general relationship here is hidden because of the high scores (ceiling effect). In parafoveal presentation, scores are generally lower, and Fig. 7 gives word score against embedded letter score for each individual subject. Interestingly, individual values for children of the two groups show an overlap, and a single function seems to obtain for all three groups. The correlation coefficient for the 20 dyslexics is $r = +0{\cdot}50$, for the 20 average readers $r = +0{\cdot}44$, both values differing just significantly from zero. Thus, in parafoveal vision the difficulty of recognizing single words is partly related to the difficulty of recognizing embedded letters. From Fig. 7 it may be observed that word scores are generally higher than embedded letter scores. This clearly indicates that not all letters of a word have to be recognizable for the word to be correctly recognized. The influence of word knowledge is therefore quite manifest, also in the dyslexic group.

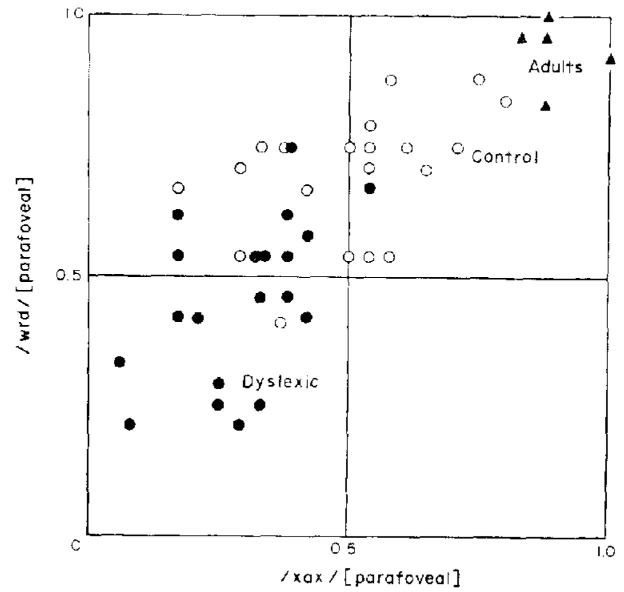

FIG. 7. Scatter diagram, relating for each individual subject the parafoveal word score to the parafoveal score of embedded letters. Data from left and right visual fields have been averaged. Notice the interweaving of dyslexic and control subjects and the general relationship between word score and embedded letter score for all subjects together.

Figure 8 indicates the relation between parafoveal word score and reading level according to the Tanghe reading test. The dyslexics and the average readers are now separated at a reading level of about the fourth grade as was already clear from Fig. 2. Again, a single relationship between the two variables seems indicated. For each of the groups separately only a weak correlation obtains: dyslexics $r = +0{\cdot}33$ (not significant, n.s.) and average readers $r = +0{\cdot}18$ (n.s.).

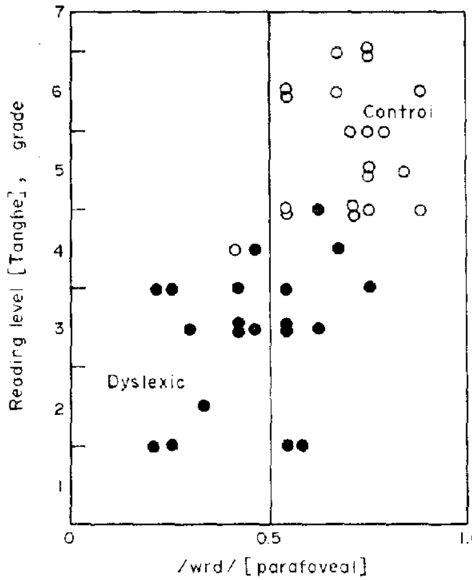

FIG. 8. Grade level of reading vs parafoveal word score for 20 dyslexic and 20 control subjects.

Corresponding correlation coefficients between reading level and parafoveal score of embedded letters are +0·40 (dysl.) and −0·14 (n.s.; controls).

We wish to stress again that because of the small number of stimuli, the correlations are only of indicative value.

Lateral dominance. Ten children of the dyslexic group and one of the control group had a crossed lateral dominance of eye vs hand and foot. However, for 6 children of the control group eye dominance was weak in that it was not equal in all trials. As to recognition scores, the group of children with crossed or weak dominance could not be distinguished from the group of children with unilateral dominance.

DISCUSSION

Complex and simple stimuli

The present results reveal a contrast between isolated letters and embedded letters just aside of fixation. At only four letter positions or 1° from the centre, the embedding of single letters by the addition of one letter x on each side makes recognition scores drop from 90 to 30% in the dyslexic group and from 90 to 50% in the control group (Figs. 3, 4). In the centre of fixation there is only a slight drop from 96 to 85% for the dyslexic group and from 96 to 92% for the control group. Clearly, correct recognition of letters embedded in strings is restricted to quite a narrow field around the point of fixation. In this respect there is a correspondence with adult readers [1, 3].

Quantitatively, however, there are differences; the useful visual field being on average narrower for our dyslexics than for our average juvenile readers, and narrower for most of the present children than for experienced adults (cf. Fig. 5). Part of the difference may be due to the lack of experience of the children in participating in experiments such as these. It should be observed, however, that they performed quite well with foveal presentation and with parafoveal presentation of isolated letters.

From the literature it is quite clear that in tasks involving relatively simple visual stimuli, dyslexic children score just as high as control children. An example is visual acuity as assessed by means of standard optotypes. However, if the visual stimulus is a rather complex contour configuration, which requires elaborate visual analysis, dyslexic children are often reported to score lower than control children of their age group. Thus dyslexics have difficulties more often than control children in distinguishing properly between figure and ground or in seeing the proper relations between parts and wholes [15, 16]. These tasks include a certain amount of visual search. Now visual search involves both eccentric vision and eye movements. A high degree of visual interference between parts of a complex stimulus would cause a narrow functional visual field during each eye pause, or, in Mackworth's terms, "tunnel vision" [9]. Contrariwise, single isolated stimuli are easily found in parafoveal vision, since they are free from interference effects [17, 18]. Therefore, the notion of an essential difference between simple and complex visual stimuli, as advanced in the literature on dyslexia, is quite close to the present analysis in terms of parafoveal visual interferences.*

Contrary to the above results reported in the literature, VALTIN [21] found hardly any difference in visual test scores of a group of 100 dyslexic readers and 100 carefully matched control children, grades 2–4. In the tests, rather complex visual configurations were involved. It seems then that these results cast doubt on the notion that complex visual stimuli can be considered as a single group. As regards the choice of visual tests, this should be taken as a warning that if relevance for reading is the main issue, the tests should be kept as close to the reading situation as possible, as already stressed in 1958 by MALMQUIST [15].

Word recognition

We find that the group of dyslexics scores lower in parafoveal word recognition than the controls do. This finding is different from the results of MCKEEVER and HULING [22] who found similar parafoveal word scores in poor and in normal readers of grade 7. In the latter study, capital letters were used and descending presentation times, which usually induce effects of sequential bias. For reading, words are more directly relevant than embedded letters. The positive relation between the two (Fig. 7) then suggests that word recognition depends to some degree on the recognition of embedded letters, although, admittedly, positive correlations alone leave room for many interpretations.

In general, visual word recognition will depend on both a sufficient visibility of word attributes, such as letters, and a sufficient knowledge of word forms, i.e. the way in which words are composed of these attributes. Only if knowledge of word forms is adequate, a restricted amount of visual information may directly trigger a word response.

From Fig. 7 it is clear that for most children the fraction of correctly recognized words was higher than the fraction of correctly recognized embedded letters, even if the word

*Characteristically, the foveal centre seems free of this interference, but the ophthalmological literature mentions a similar effect as "crowding" in amblyopic eyes where a foveal centre is functionally absent [19, 20].

stimuli were somewhat farther from the fovea. Since words are composed of a number of letters, it follows that all children scored substantially higher on words than they would have done on just letter strings. This is clear-cut evidence of their knowledge of the forms of these relatively frequent words. The lower correct scores for longer words may be due to a combination of two factors: (a) more influence of interference; (b) an increased need of visual information, in connection with a decreased knowledge of word forms. The first factor seems to be present, although its contribution cannot yet be evaluated quantitatively. As to knowledge of word forms, the lower scores for less frequent words suggest that this knowledge was insufficient. The differences in word scores between certain subjects who score equally high on embedded letters (Fig. 7) may also be indicative of existing differences in knowledge of word forms. However this may be, in our data the dyslexics are only marginally distinguished in this respect from the control children.

VELLUTINO, STEGER and KANDEL [23] presented to children visually 3–5 letter words for 300 msec and, using two different instructions, compared oral word responses to the mere copying of letters. Correct word scores were lower in dyslexics than in control children, suggesting differences in knowledge of word forms. However, the mere copying of letters was also more difficult for the dyslexics, for which a variety of explanations is available.

Maturational lag

As dyslexia has been reported to relate to a lag in maturation of certain perceptual or cognitive functions rather than to a permanent, steady deficiency [16], we have searched our data also for similarities in correct and incorrect responses of the two groups.

Firstly, the relation between embedded letter scores and word scores in parafoveal vision is a continuous one (Fig. 7), and the same is true of the relation between word recognition and reading level (Fig. 8). Secondly, the order of difficulty of the individual embedded letters and of the stimulus words turned out to be rather similar in the two groups. Thirdly, incorrect letter and incorrect word responses were often the same in the two groups. Fourthly, in both groups response words tended to recur as responses later in the test equally often.

We conclude that in our tachistoscopic recognition experiments dyslexic and control groups differed in degree rather than in essence. For substantiating notions of a specific maturational lag for the present visual tasks, a longitudinal study would be required.

Recognition, storage, and eye control

Apart from word recognition, reading requires storage of the recognized items and refreshed retinal images by means of adequate eye saccades. The present experiments concentrate on word recognition only while leaving these other factors and their relationships out of account.

In psychological tests, dyslexics tend to show some backwardness in certain visual, auditory, cognitive, and motor abilities, to mention just a few factors of the many that seem to be involved [15, 16, 21, 24, 25]. In line with this, MORRIS [26] has suggested that it is the number of adverse factors rather than a single outstanding difficulty that determines the severity of dyslexia.

The present experiments then have only a small contribution to make in suggesting just one more contributory factor. For us, the task at hand is to study the various reading factors in their mutual relationship and to concentrate on factors which are likely to contribute to, rather than covary with, reading difficulties.

Acknowledgements—Thanks are due to Mr. A. L. M. VAN RENS for his enthusiastic assistance throughout the investigation and to Mr. A. VAN VROENHOVEN and Mr. J. HUPPERETZ, directors of the schools involved, as well as to their staffs for their interest and their fine cooperation.

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Résumé :

Chez les lecteurs adultes, la reconnaissance parafovéale des mots est limitée par une forte interférence entre les lettres. L'étude présente concerne 20 enfants dyslexiques et 20 lecteurs moyens (9-14 ans). Les scores de reconnaissance des lettres isolées, des lettres incorporées et des mots étaient comparés selon qu'il s'agit de vision fovéale ou parafovéale.

Les performances des 2 groupes étaient également bonnes sur les lettres isolées tandis qu'en général, les dyslexiques étaient inférieurs sur les lettres incorporées et les mots. Les scores individuels pour les lettres incorporées et les mots étaient en corrélation modérée de même que le score pour les mots et le niveau de lecture.

On préconise que les recherches sur la dyslexie soient dirigées vers la mise en évidence dans les processus de lecture de déficits portant sur le contrôle oculaire, la reconnaissance des mots et leur emmagasinement non seulement en tant que facteurs isolés mais plutôt dans leurs inter-relations.

Deutschsprachige Zusammenfassung:

Bei starker Interferenz zwischen Buchstaben ist das parafoveale Erkennen von Wörtern bei erwachsenen Lesern eingeschränkt. In der vorliegenden Studie bestanden die Versuchspersonen aus 20 dyslektischen Kindern und 20 Durchschnittslesern (im Alter von 9 - 14 Jahren). Für isolierte Buchstaben, für eingebettete Buchstaben und für Wörter wurden die Erkennungsleistungen beim fovealen und parafovealen Sehen verglichen.

Die Gruppen erbrachten gleiche Leistungen bei isolierten Buchstaben, während die Dyslektischen im Allgemeinen zurückblieben bei eingebetteten Buchstaben und bei Wörtern. Die individuellen Leistungen bei eingebetteten Buchstaben und bei Wörtern wurden korreliert ebenso wie die Wort-Leistung und das Leseniveau.
Es wird dafür plädiert, daß die Dyslexie-Forschung die möglichen Ausfälle beim Leseprozeß bestimmt wiezz. B. Augenkontrolle, Worterkennen und Speicher, nicht nur als getrennte Faktoren, sondern vielmehr in ihren innigen Verflechtungen.