Reading and the ophthalmologist : an introduction into the complex phenomenon of ordinary reading as a guideline for analysis and treatment of disabled readers

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Reading and the ophthalmologist

An introduction into the complex phenomenon of ordinary reading as a guideline for analysis and treatment of disabled readers

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Abstract. Reading problems are a frequent source of complaint in ophthalmological practice. In many cases suitable optical correction is all that is needed. However, difficulties may remain despite adequate optical correction. This paper describes visual reading processes with the aim of making such difficulties understood and, if possible, providing remedies.

Four different types of visual reading processes are distinguished: (a) optical imaging, (b) eye movement control, (c) visual word recognition and (d) integration of information across eye fixations. Next the attempt is made to use our insight to obtain a better understanding of actual reading problems, such as those of elderly readers, low-vision patients, and dyslexics as well as those of the blind. Therapeutic options, including visual aids are given due attention.

0. Introduction

To most ophthalmologists reading problems are in general either a matter of refractive and accommodative disturbances, disorders of motility and of binocular function, or they are linked to defective vision due to corneal disease, lens abnormalities, vitreous clouding or retinal pathology and diseases of the optic pathway. Mostly these problems can – at least partly – be solved by glasses or by more or less sophisticated low vision aids. Nevertheless there are still patients who complain of their reading capacity in spite of adequate optical correction. It appears then that fluent reading involves more factors than just sufficient visual acuity after correction. Advising these patients is a hard job, because the underlying defect is not understood and the advice that can be given is rather aspecific (for example good physical health and adequate illumination).

The purpose of this article is to give an account of the present state of knowledge in the field of visual-reading research which we believe will be of interest and value to the ophthalmologist. For this purpose we will present a framework for analysing various types of reading-problems. There is now a

fairly clear idea of the principles underlying ordinary daily reading, into what separate processes it can be divided and how these processes are linked together. It is our aim to introduce reading-analysis as a tool of ophthalmological clinical practice, for of course the ophthalmologist is the main adviser to be consulted by reading-disabled patients.

This publication will be divided into two distinct chapters. We start with the presentation of a generally accepted model of reading processes (Chapter 1). Clinical aspects of poor reading such as encountered in elderly readers and in patients with low vision are discussed next, including options for reading aids and for a proper illumination. Also, some attention is given to the poor reading which comes with developmental dyslexia or word blindness (Chapter 2). With this information we hope to encourage among ophthalmologists a more analytical attitude to reading problems encountered in their daily practice.

1. Normal reading processes

The concept of 'reading' includes a whole assembly of human activities in which a language code is picked up through the visual system, or sometimes the tactile system, and further processed. We shall look at that complex reading process and try to discern a number of separate sub-processes. The final purpose of such division is to study each of the subprocesses in itself and also the ways in which they are interconnected, so as to arrive at one total description. Since there are more ways than one to make subdivisions, we shall choose one which supplies us with a better insight for our current purposes: the understanding and remedy of reading difficulties. In concentrating on the visual aspects of reading, we shall here distinguish four sub-processes (Figure 1).

A certain text to be read has to be imaged onto the retina for conversion into nerve signals. A description of the *imaging process* (1) should supply us with a specification of the retinal image if we know the text, reading distance and visual axis as well as total eye optics. Whereas text and reading distance are constant during reading, the visual axis rotates because of eye movements, such that it strikes the text at many successive positions (points of fixation).

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imaging by eye optics

control of eye movements

word recognition in a single eye pause

integration across eye pauses
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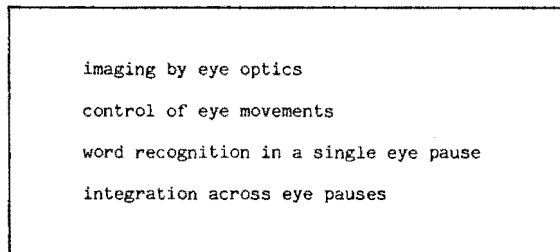
Figure 1. Four consecutive subprocesses of normal reading.

The control of eye movements (2) is our second subprocess. If text and reader are at rest, the eye moves in quick jumps (saccades) separated by longer pauses (eye fixations). This simplifies the description which may now be restricted to the control of timing and extent of such saccades. It has been appreciated for a long time that during the quick saccades, the image of the text moves over the retina so quickly that no useful form information can be picked up. Therefore, visual form information is taken in during reading pauses only. The *intake and analysis of information in a single eye pause* (3) is our third subprocess. In the visual system, analysis of details is sufficient only in a restricted retinal area, namely in the fovea and the parafovea or part of it. Defining this area as the reading field, we can describe the third process as the visual analysis and recognition of print within each momentary reading field. On the retina the text shifts several times each second — nevertheless the true text information in terms of words or meaning is abstracted continuously over longer periods of at least a second for a short sentence. The fourth subprocess is *the integration of text information over consecutive eye pauses* (4). A description of this subprocess requires a specification of short-term storage of the text information. This has two aspects: firstly persistence of purely visual information, and next the persistence of the recognized word of the language in working memory. After this fourth subprocess many other language processes occur which lead to a certain understanding of text content. Since this paper is restricted to visual processes, we shall not deal with these processes here, which lie in the general domain of the psychology of language.

We shall now deal with the four subprocesses separately and include the findings of a number of early and recent papers in the literature.

Eye parameters	pupil size
	lens transparency
	accommodation
	convergence
External factors	illumination
	reading distance
	letter size
	magnification
Effects	quality retinal image
	size retinal image
	retinal adaptation level
	depth of focus

Figure 2. Summary of eye optical reading factors.

1.1 Eye optics (Figure 2)

This is the part of visual reading processes best known to the ophthalmologist and therefore it requires only summary analysis here. Two inner-eye muscles with their feedback systems regulate pupil size and lens power (accommodation). Pupil size influences retinal illumination and, more importantly, depth of focus. At low illumination levels the (un)sharpness of the retinal image may well become the limiting factor for fluent reading.

The optical quality of the retinal image is not critically affected by pupil size at a diameter of 2 mm or more, as long as accommodation is perfect and prevailing wavelengths make chromatic aberrations unimportant.

In very high illumination, the pupil may become smaller than 2 mm. Now accommodation and depth of focus are not critical, but the optical quality of the retinal image is reduced due to diffraction at the pupil's edge and sometimes also because of cloudiness in the central zone of the eye lens. Both pupil and accommodation vary only slowly, requiring longer than one second to adjust to new circumstances. When the illumination level is relatively low and reading distances vary, this may cause transient unsharp images. The standard situation in which visual acuity is determined in ophthalmologic practice may be not representative: actual reading may well be at a different illumination level than 500 lux, at a substantially shorter viewing distance, with watering eyes, dirty spectacles, and glaring windows or light sources.
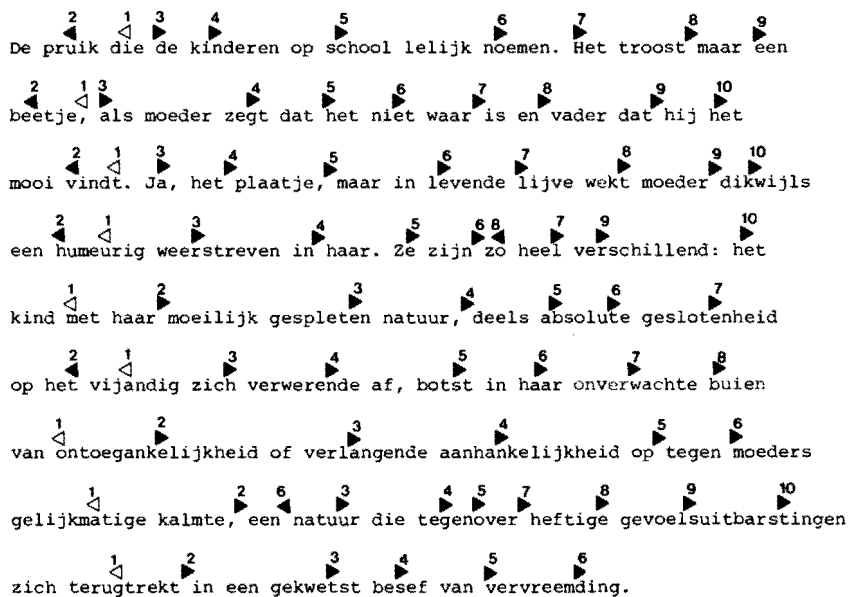
De pruik die de kinderen op school lelijk noemen. Het troost maar een
beetje, als moeder zegt dat het niet waar is en vader dat hij het
mooi vindt. Ja, het plaatje, maar in levende lijve wekt moeder dikwijls
een humeurig weerstreven in haar. Ze zijn zo heel verschillend: het
kind met haar moeilijk gespleten natuur, deels absolute geslotenheid
op het vijandig zich verwerende af, botst in haar onverwachte buien
van ontoegankelijkheid of verlangende aanhankelijkheid op tegen moeders
gelijkmatige kalmte, een natuur die tegenover heftige gevoelsuitbarstingen
zich terugtrekt in een gekwetst besef van vervreemding.

Figure 3. Position of consecutive eye fixations after: reading saccade ▶ , correction saccade ◀ , line saccade ◁ .
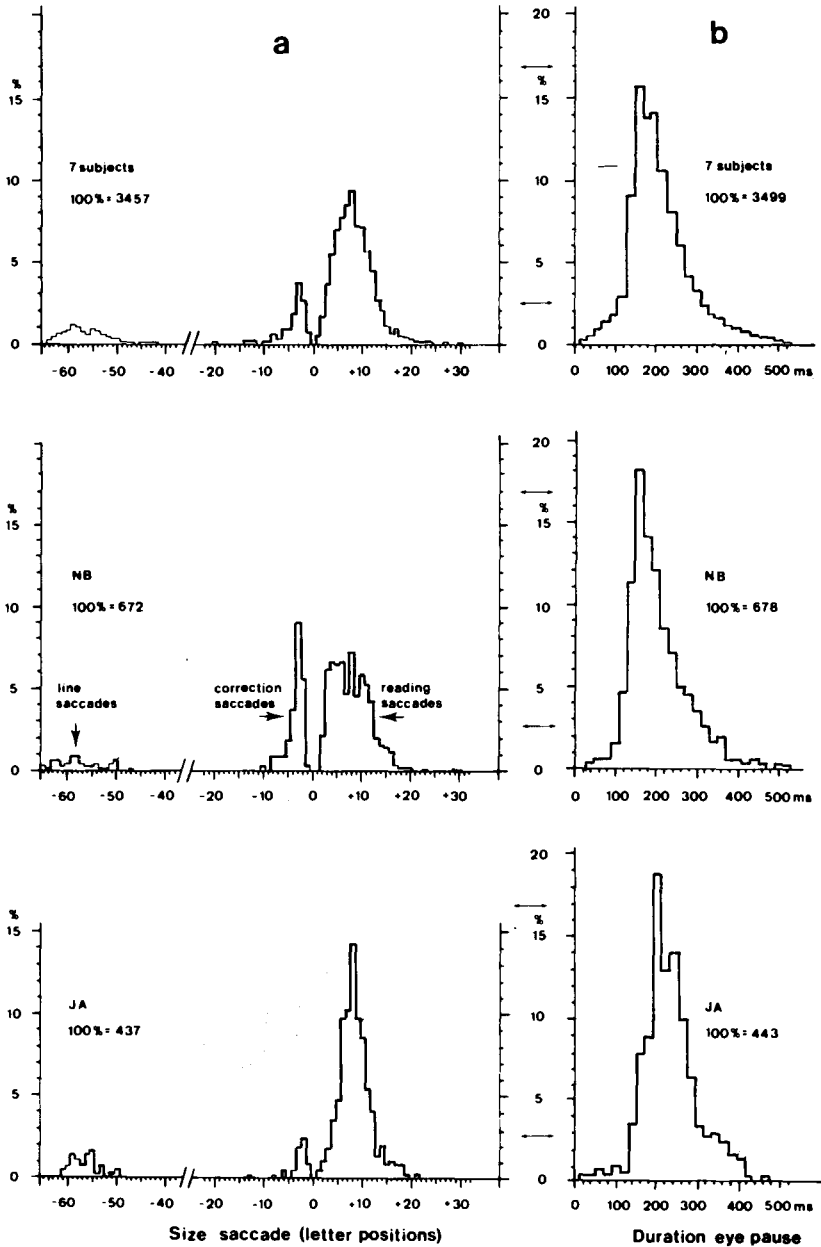
Figure 4. Distribution of eye saccades (a) and fixation durations (b) in reading. Averages of seven normal readers, two of whom are shown individually.

1.2 Eye movement control

Ever since the French ophthalmologist Javal (1878) we know that the eyes when reading move in jumps or saccades rather than smoothly. The jumps have a usual duration of 20—40 milliseconds (msec) and are separated by eye pauses anywhere between 150 and 800 msec. In the reading of running text, three types of saccades may be distinguished (Figures 3 and 4), as already described by Buswell (1920).

Reading saccades, which are forward saccades along the line of print, in Western languages from left to right. Saccade size may vary considerably and is generally smaller in more difficult reading situations such as poor print quality, low illumination, unskilled readers and unfamiliar languages. An average value for reading saccades in normal conditions is 8 letter positions, irrespective of letter size. That the value should be expressed in letter positions rather than in viewing angle indicates that the size of eye saccades is automatically controlled such that they span a constant number of letters.

Correction saccades, which are backward saccades along the line of print. Sizes are usually small — a few letter positions —, but occasionally large correction saccades occur. The name indicates that such saccades apparently reflect recognition difficulties, requiring a second look at certain portions of the text.

Line saccades, from the end of a line of print toward the beginning of the next lower line. These saccades do not quite span the full line length since they start at eye fixations a few letters before the end of the line whereas they finish several letter positions right of the line beginning. Line saccades are frequently followed by a small correction saccade with only a short eye pause in between.

As to the control of saccades, it should first be observed that saccades are the prevailing type of eye movement under any static viewing condition. Therefore they belong to the very normal repertoire of eye movements. There are two different causal factors involved. The first is *control from eccentric vision*: the eyes may jump towards any stimulus in parafoveal or eccentric vision; this type of control is sometimes termed peripheral search guidance. The second is *cognitive control*, i.e. a jump towards a direction in which one expects to find certain visual formation, as for example during driving, one looks in a direction from which traffic may be expected; this is termed cognitive search guidance. Both types of guidance appear to be present in the control of reading saccades. Line saccades require eccentric vision for determining the right line margin near fixation (for initiating the saccade) and the left line margin (for determining saccade size). Even the small correction saccades following line saccades are quite general, since large eye saccades to predetermined positions generally tend to fall short by some small value. Cognitive control is most probably present in correction saccades within the line of print, as it seems plausible that uncertainty in the recognition process causes the eye fixation to return. Reading is such a routine activity that a third type of con-

trol is most probably also present: *routine control* (Bouma and de Voogd, 1974). By this we mean that there is some basic repertoire of forward eye saccades, adjustable only for keeping the speed of eye fixation over the text close to the speed of understanding.

Correction saccades within a line of print would then be indicative of a failure of this routine control to satisfy recognition demands. If the next eye saccade is to be based on recognition from the present eye pause (cognitive control) this can only occur after the recognition has been completed. Therefore only long eye pauses permit this type of cognitive control.

There is evidence that in reading, fixation duration and saccade size are controlled by independent parameters such that, for example, long eye pauses are not generally followed by large reading saccades. For general literature surveys we refer to Rayner (1978) and to Levy-Schoen and O'Regan (1978).

1.3 Word recognition in a single eye pause

Adaptation level
Visual recognition means seeing again what has been seen before and stored in memory. As such it is a high-level or cognitive perceptual activity. However, first an analysis of the retinal image occurs. Retinal processes are dependent on the prevailing illumination (adaptation level). If the adaptation level is sufficiently high, retinal processes are fast and spatial analysis is precise. The lower the adaptation level the slower the retina becomes and the cruder the spatial analysis (Figure 5). Thus there are good reasons for requiring a high
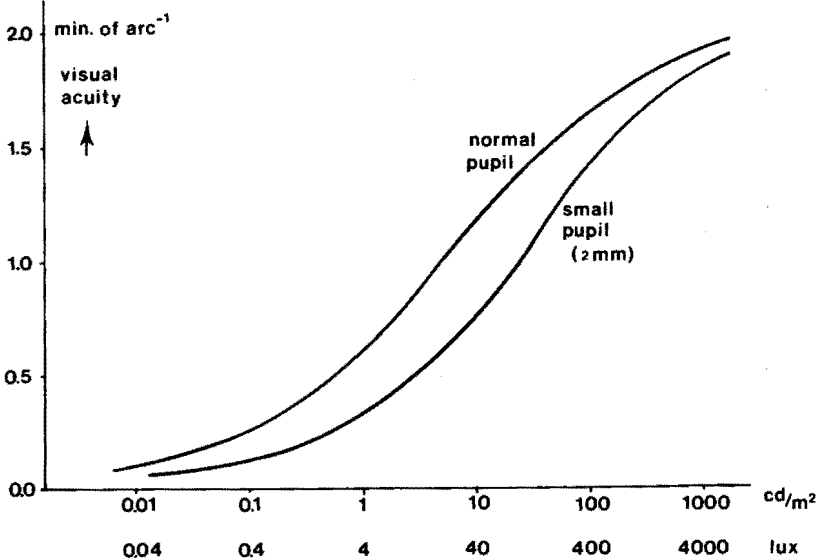

Figure 5. Visual acuity increases with ambient illumination level. The curve depends on pupil size, since the variable proper is retinal rather than text illumination. This is one reason why illumination is more critical for elderly people. Curves adapted from literature data on Landolt-C optotypes.

adaptation level, corresponding to say 400 lux or 100 cd/m^2 at the least. This is probably the main factor why, generally speaking, dark texts on a bright background can be read easier than bright texts on a dark background.

Reading field for single letters

One of the relevant questions is which area of the central retina is functional in the recognition process during reading. It is well known that visual acuity is highest in the foveal centre and decreases toward the retinal periphery. Visual acuity is about inversely related to eccentricity and it reaches a value of about 0.25 at 5° eccentricity. For ease of calculation, we use in experiments type-writer letters (4 per cm) at a reading distance of 57 cm, resulting in 4 letters per degree visual angle. From these values we can roughly calculate how far from fixation visual acuity is still just sufficient for 50% correct recognition of a single letter. This comes out at about 7° or 28 letters from fixation, both right and left of the fovea similar to the symmetry of visual acuity around the fovea. Measurements on recognition of a single letter at various eccentricities confirm these estimates (Bouma, 1970).

Lateral interference or masking

This value of 2 x 28 letters, however true, poses a problem. It would seem plausible that the width of the horizontal visual field in which text recognition occurs is about equal to the size of reading saccades of the eyes. If we really could see about 28 letters right and 28 left of fixation, horizontal eye saccades would seem hardly necessary at all. In actual fact the average reading saccade turns out to be only about 8 letters. The solution of this problem is that the span of about 56 letters is valid only for isolated letters and not for letters in groups, such as in words. Eccentric vision is organized such that adjacent letters hamper each other's recognition by strong effects of lateral masking (Figure 6). If we determine the horizontal span of recognition for embedded letters in experiments we arrive at a value of about 6 letters from fixation (Figure 7), which is of the same order of magnitude as the reading saccades.

In actual fact, the interference is more pronounced left than right of fixation, so that recognition is better in the right visual field, at least for those using Western languages reading from left to right. Initial and final letters of words suffer less from interference than embedded letters, because of the adjacent blank spacing. Also the interference turns out to be mainly directed towards the fovea — leaving initial letters in the left visual field and final letters in the right visual field relatively unaffected.

<div align="center">

fixate
here

12 11 10 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 10 11 12

mask   **mask**

</div>

Figure 6. Demonstration of masking effect for letters. Embedded letters suffer more from masking than initial and final ones. Interestingly, the outward letters (m left, k right) suffer less than the inward letters (k left, m right).
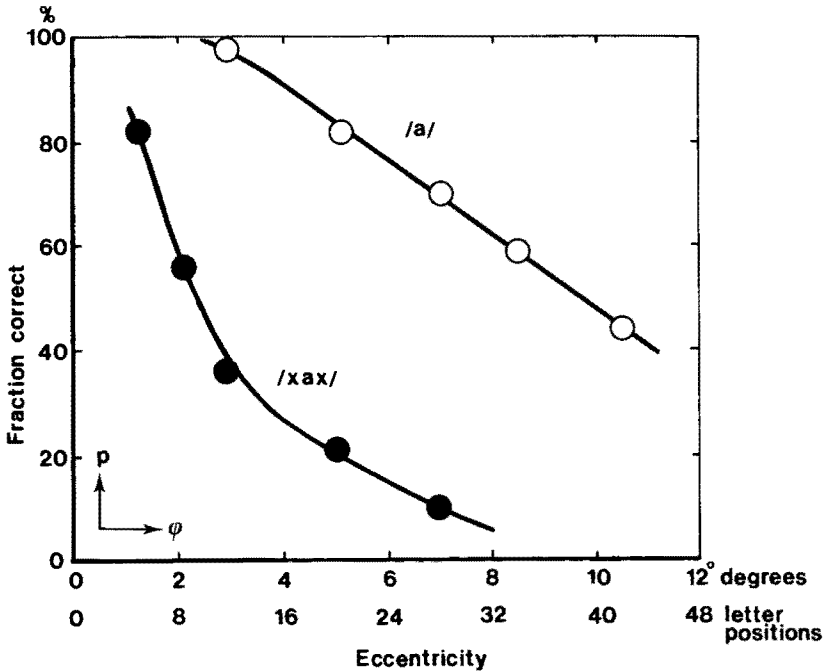
Figure 7. Correct letter recognition for foveal and parafoveal presentation. The curve for isolated letters reflects visual acuity, whereas that for embedded letters shows the strong influence of masking effects between adjacent letters.

The interference is practically absent at the fixation point in foveal presentation. Thus, the fovea is not only the area of maximum acuity, but also of minimum lateral interference. This makes it understandable why foveal vision is better than parafoveal vision even in circumstances where foveal acuity is not clearly superior, such as in dim light or in defective eye optics. Because of the left-right asymmetry of the interference, one might even say that the functional fovea extends somewhat farther into the right visual field than into the left.

However, reading usually involves words rather than letters. Therefore it is of interest to measure how far from fixation single words can be recognized. Just as for letter recognition, one can determine word recognition in eccentric vision by a single brief presentation of 100 msec, too short for an eye saccade which could bring the word in foveal vision. Such tachistoscopic experiments clearly show that the reading field for words indeed extends farther right than left of fixation. Since words cover several letters, one cannot precisely say how far right and left of fixation words can be recognized, but by and large values of 6 letter-positions left and 10 right of fixation yield word scores of about 80% (Figures 8 and 9).

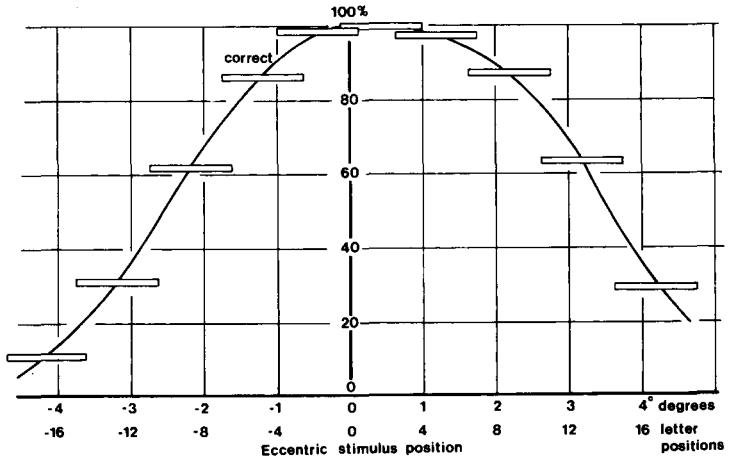This value, which has been derived from recognition experiments of single

Figure 8. Visual word recognition for foveal and parafoveal presentation. Right of fixation, recognition is better than left, which is true for Western languages which read from left to right (Bouma, 1973).

words in eccentric vision, has recently been corroborated for actual reading. By an ingenious technique, eye movements were precisely measured during reading from an electronic display. The letters of the display could be instantaneously changed, synchronously with eye saccades. The experiments were performed such that at any moment only a certain area around momentary fixation displayed actual text whereas the other part of the display was filled with letters not forming existing words. It turned out that reading was unaffected by such presentation if about 5 letters left and 15 letters right of fixation were always correct. The present estimate for the visual reading field
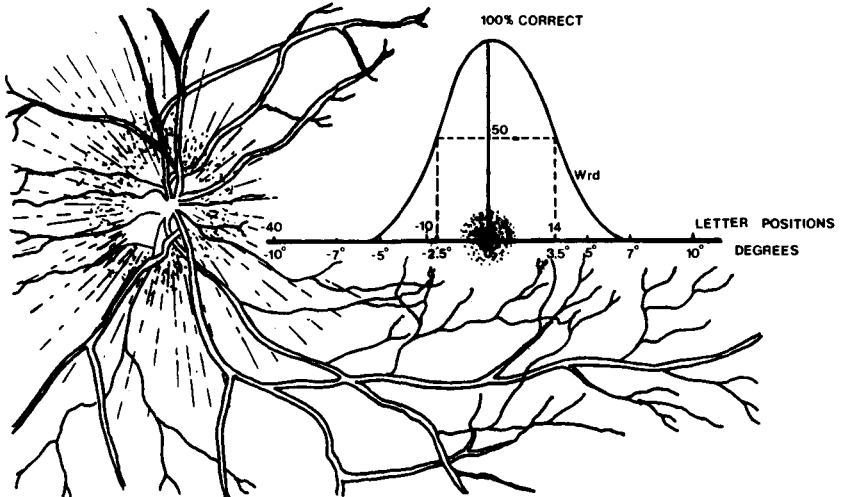

Figure 9. Correct word recognition in foveal and parafoveal vision. Notice the better recognition right as compared to left of fixation.

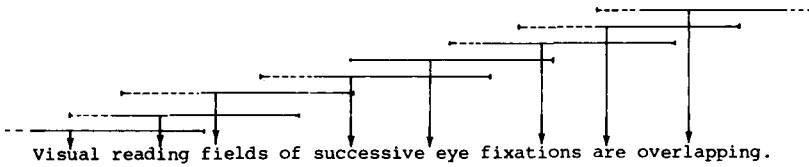Visual reading fields of successive eye fixations are overlapping.

Figure 10. Overlap of consecutive visual reading fields. Arrows indicate points of fixation. Schematic representation; in actual reading the width is dependent on word beginnings and endings as well.

during reading is then from the beginning of the fixated word towards the end of a word 10—15 letters right of fixation (Figure 10; and Rayner, 1980).

What kind of processes determine word recognition? It is an old problem if word recognition is based on letter recognition ('analytic') or on rough outlines, word contours etc ('global'). This question is related to the notion that not all letter combinations are words. Consequently, from an information point of view, words are over-determined for the experienced reader, such that only part of a word has to be seen in order to arrive at a correct recognition. In fact, this is a characteristic of all human recognition. The problem now seems to be approaching its solution through the development of quantitative theories which predict word recognition on the basis of letter recognitions and on the visual vocabulary of the reader (his internal visual lexicon). We shall not deal with these theories in any detail but just state that their analytic aspects take into account perceptual confusions between similar letters and the global aspect is restricted to the relative position of such letters in the word (Bouwhuis and Bouma, 1979).

Speed of recognition (latency)

All recognition processes are to some extent time-consuming. Consequently, word recognition occurs only some time after the word is imaged on the retina. Recognition in foveal vision turns out to be faster than in parafoveal vision, as appears from vocal latency measurements. For each degree of eccentricity, latency increases by some 100 msec. For example, a common latency value for a foveal word response is 400 msec, whereas for 2 degrees (8 letter-positions) parafoveal presentation, latencies of correct word responses are increased to about 600 msec (Figure 11).

1.4 Integration across eye fixations

Because of the reading saccades, the text information is processed in chunks changing 3—5 times each second. As we all know, reading seems to flow as a continuous stream of information. Thus, the incoming bits and pieces are integrated smoothly, and we are now beginning to discover how this is achieved.

In order to get an understanding of this, some general insight into recognition theory is necessary. Recognition can be taken as perceptual activation of some internal unit, which has been learned earlier in life and consequently
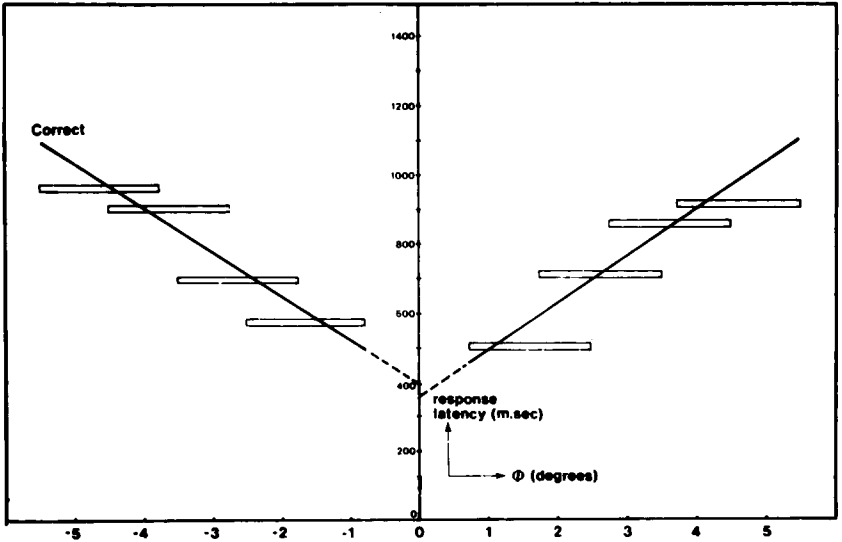
Figure 11. Progressive vocal-latency times for correct word recognition with increasingly parafoveal presentation (Schiepers, 1974).

laid down in long-term memory. For words, such units can be considered as entities in the internal lexicon. The activation can be achieved by two independent means, which usually cooperate closely (Figure 12). The first is by information from the retina, which has been analyzed in its relevant configurational features, after which it reaches the internal units to which it belongs. Each feature usually belongs to a number of units but the combination of features usually determines one unit uniquely. This makes it understandable why certain words resemble each other closely (i.e. if they share many features)
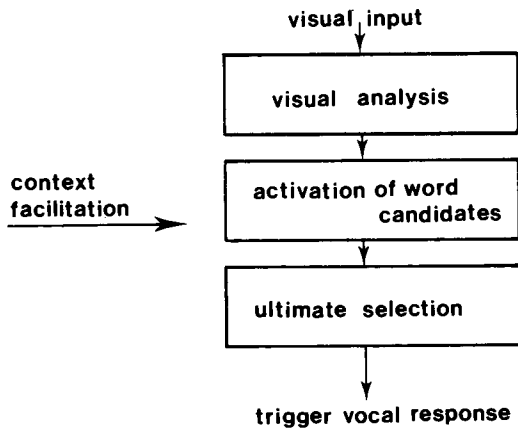

Figure 12. Extended recognition-scheme of words. Compare Figure 13. Visual parafoveal analysis is more time-consuming than foveal processing (see Figure 11).

whereas others are perceptually widely apart (if their features are different). As an example, the words 'eye' and 'age' have visually similar configuration whereas 'eye' and 'gap' are rather dissimilar (Figure 13).

The second way of activation is an indirect one, via the context. The context makes certain units more likely than others. The context is not restricted to sense information but includes for example the contents of the paragraph and sentence to which the word belongs.

Thus the recognition (reading) of a word needs less retinal information as it fits better into the context that the reader can make available by his grasp of the content and by his understanding of the sentences just read. In reading, a certain word is normally *seen* at least twice: first in right parafoveal vision and at the next eye pause in foveal vision. The double retinal information then seems to facilitate activation of the same word unit. In fact, a reader does not even notice if he has recognized the word from parafoveal or foveal information. This can be understood from the fact that parafoveal processing is slower than foveal processing. The slow parafoveal recognition of a word before its central fixation and the fast foveal recognition of the same word one eye pause later then melt together in a single activation of the internal word unit (Figure 14).
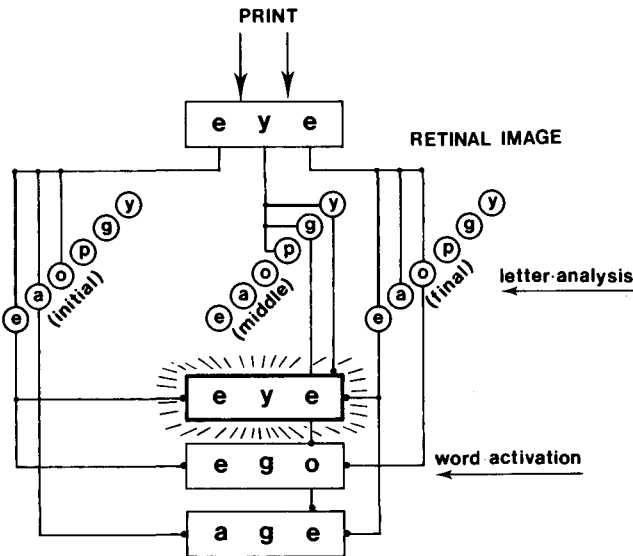

Figure 13. Processes of word recognition in a schematic diagram, according to letter-confusion theory. The letters of the word "eye" projected on the retina each give rise to the activation of a number of internal letter concepts, due to common letter features (letter analysis stage). Next, the activated letter concepts give rise to activation of a number of existing word concepts (word activation stage). The final decision is based on the highest activation among the activated words. In actual reading, the context also facilitates (activates) differentially such that words fitting into the context are more likely to be recognized (not indicated in the diagram).
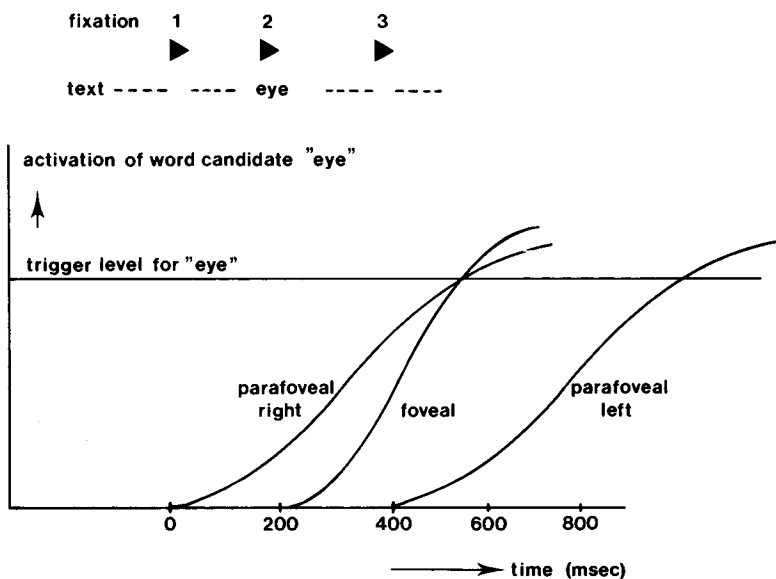
Figure 14. Scheme of the visual recognition (activation) of the word "eye" perceived in three consecutive eye-fixations, explaining single perceptual impression due to differences in processing-time. The information from fixation three is neglected and probably useful for directing correction saccades when necessary.

A final remark concerns reading speed. The content of momentary working-memory is of course restricted, and forgetting is and should be the rule rather than the exception. Otherwise an instantaneous "snapshot" of the immediate present would become mixed up with many previous moments. What should be retained is an abstraction of the content (meaning) of what has been read. In order to abstract the meaning from a larger text portion the essential elements of the content should be available simultaneously in working memory. For example, to grasp the content of a full sentence, one should still know at the end of the sentence what the beginning was. The same reasoning applies for larger entities such as paragraphs or chapters. This makes it understandable why generally quick reading may also be good reading, i.e. abstracting from a large passage. On the other hand slow reading provides a more precise impression of the content. The good reader has available a whole repertoire of reading speeds and is flexible to adapt his reading method to his information need and rate of comprehension. One can experience this oneself by comparing ease of reading in one's native language with ease of reading in a less familiar language or by comparing ease of reading when a subject matter is familiar with when it is unfamiliar.

Of course, a full understanding of the reading process has to include the analysis of text in terms of grammar and meaning to the reader. This is now an active area of research in language psychology which is outside the scope of the paper.

1.5 Interrelations between the subprocesses

We will mention here a few ways in which the subprocesses are connected.

Reading distance (1) may be chosen by the reader such that the letters in the retinal image are sufficiently large for *the recognition process* (3). *Eye movement control* (2) and *recognition in a single eye pause* (3) are coupled because eye pauses should be sufficiently long to allow recognition and the size of eye saccades should be compatible with the horizontal size of the visual reading field. Eye movements (2) are also related to visual integration (4) because when reading connected text the eyes should not move faster than the rate of recognition. These are just a few examples to show that these four subprocesses are not independent. Such a subdivision is, however, an indispensable aid for obtaining theoretical and experimental insight into this complex process, and thus for gaining a better understanding of reading difficulties.

What is lacking most at present for a full description is an insight into the time relationships between the processes, such that it can be understood how they can optimally serve one overall reading activity. The visual information reaches the brain in irregular pieces and we are now beginning to understand how these are combined into one fluent stream of information. Such insight is also necessary to advance our understanding of how the reading processes adapt to adverse circumstances such as poor text quality, low visual acuity, tunnel vision, or optical aids. This is a new research area of great practical interest, for which the theory of the reading process has now sufficiently advanced to look forward to a very fruitful period.

1.6 External limiting factors for fluent reading

From the description in section 1 it follows that quality of text, illumination, and reading distance are direct determiners of the reading process. Let us start with illumination. This should be high enough to ensure a good spatial analysis of the print and a quick temporal analysis. For average eyes this will be true at an adaptation level of some 2000 td, corresponding to a luminance of say $100 \, \text{cd/m}^2$ and an illumination level (white paper) of 400 lux. These values are not critical, but it should nevertheless be appreciated that for individual eyes they may be different because of different pupil size, different light absorption, or otherwise. The adaptation level of the retina should be rather constant, to be realized by restricting the luminance difference between paper or letter display and the immediate surround − if not, the saccades will cause just as many adaptation transients (Figure 15). Quality of text is a rather general notion and includes a number of factors. Letter forms should be relatively simple with large openings (such as in 'a, e'). Also letter extensions, such as in 'h, b, g, y', should be at least 40% of the height of the 'small' letters such as 'o, n, x' (to be further called x-height). Stroke width should be about 1/8 of x-height. It is of particular importance that letter configurations that resemble each other visually, such as 'a' and 's' or 'l' and 'i', are designed to
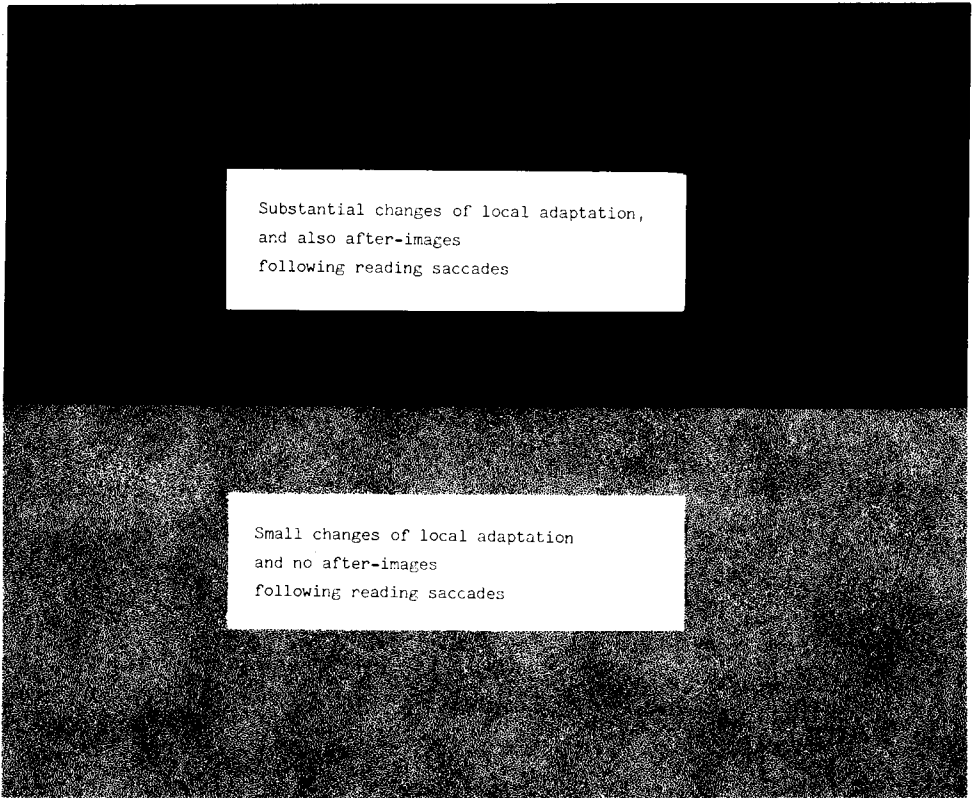
Figure 15. For comfortable reading great fluctuations in adaptation level should be avoided. Due to black (non-reflecting) surrounding, sudden transients in adaptation occur during eye saccades (Figure a (top); this is less the case in Figure b (bottom)).

look sufficiently different. In fact, there are many good type fonts, none of which is absolutely superior, but there are many poorly legible type fonts as well (Figure 16). For running text, lower case letters (a, b, c . . .), are definitely to be preferred to upper case (A, B, C, . . .) because of a pronounced word shape.

X-height size h should be judged in relation to reading distance a — as a rule of thumb h/a should not be less than 1:200, giving x-height a visual angle of at least 15'. In the lay-out very long lines of print (length l) should be avoided unless interline distance d is large — if d/l is less than 1/30 or so line saccades may inadvertently skip one or two lines of print. If a high text density is required, line length should be restricted by using two or more columns, such as in newspapers. If possible, however, an interline distance of at least 4 times x-height is to be preferred. The line beginnings should be in one vertical line such that the proper size of the line eye saccade can be correctly planned — for line endings such 'justifying' is unnecessary.

Luminance contrast ration L_l/L_b between letters and background should

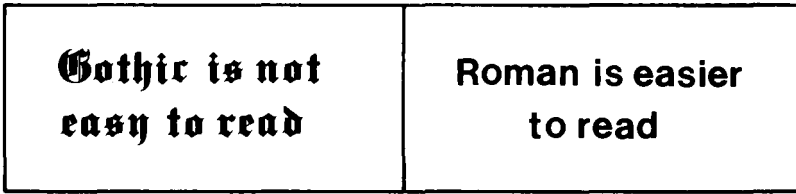| **𝕲𝖔𝖙𝖍𝖎𝖈 𝖎𝖘 𝖓𝖔𝖙 𝖊𝖆𝖘𝖞 𝖙𝖔 𝖗𝖊𝖆𝖉**	**Roman is easier to read**

Figure 16. In these two illustrations it is shown that reading is facilitated by clear-cut letter configurations, as explained in the text.

be better than 1/4. Coloured letters, e.g. on visual display units, are equally legible as black letters if the luminance ratio is sufficient — in other words legibility is not determined by colour contrast but by luminous contrast. Pure colours of extreme wavelengths, however, are to be avoided because of chromatic aberrations of the eye optics and the foveal scarcity of 'blue cones'.

As to reading distance, values less than 30 cm should be avoided just as frequent changes in reading distance should be, the accommodation system being slow and perhaps easily fatigued. This means that paper or text displays should roughly be held perpendicular to the visual axis. To avoid neck muscle complaints the head should be roughly in balance.

1.7 Specific reading situations

We shall now briefly describe some special reading situations in order to indicate critical factors.

Telephone directory (Figure 17)
The required high print density may easily lead to too small a letter type. The minimum reading distance of 30 cm and the required visual angle for each letter leads to a minimum letter size of 1.5 mm (x-height). Since visual search is the rule rather than the exception, the eye should be aided by supplying memory aids once the correct number has been found. Numbers can be found easier when printed in front of rather than behind name and address. The low quality print requires additional illumination.

Electronic text displays
These have been and probably still are a source of many complaints by users. Common difficulties include: (a) bright letters on a dark background, leading to too low an adaptation level; (b) poor letter font and unsharp letter strokes, often only capitals (upper case); (c) illumination from outside, giving less contrast and specular reflection on the display; (d) too high a contrast between screen and surround; (e) too low a contrast between letters and background, in particular for coloured letters; (f) inconsistent use of (too many) colours, not helping the reader in his search problems; (g) if screen and paper (concept) are to be read alternately, contrast ratios between the two may be too high and reading distances too different — also frequent search problems may occur; (h) fatiguing upright head position: the visual axis should be about 10° down-

eindhoven (040)

11 58 60	leeuwen, h c. van, anjelierstr 13	41 21 13	diesveld, h j th	41 07 84	lemmens, g, montferlandstr 1
11 91 15	leeuwen, l. van, anjelierstr 21/a, verfhdl het spectrum		lierop. h j m j. van (04929) 26 51	44 61 44	lemmens, a c m, montgomeryln 414
11 31 14	leeuwen, f p. van, antilopenln 7		*overige woonhuisaansluitingen*	52 09 42	lemmens, j g, nyenrode 54
42 46 42	leeuwen, ds a a. van, baristr 25	41 57 59	dinther, m j. van, verk gooskens, p a, dir (04978) 14 03	51 14 35	lemmens-saassen, a, offenbachln 228
41 29 07	leeuwen, c. van, kl beerpad 103		kaam, p f g. van, proc h	41 56 26	lemmens, m, oostergostr 4
41 91 27	leeuwen, h w m. van, bethelstr 29		(04977) 26 15	42 45 30	lemmens, f, orleanshof 16
12 36 12	leeuwen, h r c. van, biesterwg 51	52 32 08	verheijden, c h a, mag m	52 63 11	lemmens, w g, schootsestr 174
41 76 18	leeuwen-goossens, a. van, boekweitstr 19	41 28 68	verheijden, h m e, adj dir	52 43 58	lemmens, w, schubertln 141
		11 98 36	leferink, g j s, roothaanstr 28	51 11 57	lemmens, p h a, c schuytstr 41
11 13 25	leeuwen, r. van, boerhaaveln 14	52 31 32	legdeur, w h j, p v anrooyln 62	41 74 43	lemmens-broeckx, m th j, venusln 759
42 53 34	leeuwen, g a m. van, bordeauxln 10	43 13 87	lege, j d. de, gen coendersln 63		
43 54 50	leeuwen, j n. van, boschdk 467	39 21 20	legein, dr ch p, michelangeloln 2, oogarts spr u v a	43 12 57	lemmens, l j, verwerstr 98
51 68 82	leeuwen, a j m. van, n brabantln 10		catharina-ziekenh bellen 10.00-12.00 en 14.00-16.00	52 34 52	lemmens, h, vivaldistr 32
				52 73 31	lemmens, a, wenzelwg 29
52 09 54	leeuwen, h j. van, brederoln 106	44 22 70	uitsl privé	52 31 37	lemmens, j, wielantstr 6
44 97 19	leeuwen, b w m. van, cliostr 187	41 65 83	legeland, g h, planetenln 12	51 56 38	lemmens-versteegen, a, zeelsterstr 174
41 50 28	leeuwen, f. van, echternachln 2	42 22 13	legendal, a, grimbeertln 26		
41 05 53	leeuwen, th. van, echternachln 75	43 61 02	leger des heils, pisanostr 47/a	12 19 97	lemmerling, f, kl bleekstr 2/a
		44 95 91	afd kledingd, hemelrijken 104	81 54 11	lemmerlijn, t m j, urkhovensewg 492
12 12 48	leeuwen, p a. van, edelweisstr 89	43 37 04	idem reclass, boschdk 159		
11 17 92	leeuwen, p. van, j v eyckgr 87	41 17 24	léger, a m j, venetiestr 4	42 51 82	lemmers, m m e, bourgognein 11
42 16 68	leeuwen, m a. van, fakkelln 71	44 52 73	legierse, e, a derkinderenstr 9	44 53 46	lemmers, t, kromhoutstr 57
45 13 32	leeuwen, c. van, ds t fliednerstr 5/k502	43 85 06	legius, gerrie, nassaustr 19	52 54 67	lemmers, w th, zeelsterstr 123
		44 93 64	legius, m j m, outshoornstr 43	41 30 11	lemmert, f, tholenstr 14
11 16 17	leeuwen-kuijpers, a. van, gasthuisstr 433	51 81 20	legius, th m, struyckenstr 83	43 43 99	lemon, boetiek, marche 2
		52 51 71	legranse, g m j, ruurlostr 7	81 39 10	lemouchi, a, elmt 5
12 15 22	leeuwen, p j m m l. van, gentiaanwg 17	51 67 81	lehagas bv, rooyakkersstr 12	51 00 87	lemrabt, l b a, offenbachln 658
		52 19 02	idem inbouw autogasapp verk na 18.00 u (04977) 14 20	11 45 34	lems, h, h gorterln 391
51 87 17	leeuwen, d. van, gestelsestr 81			81 38 75	lems, t, heerkensveld 10
51 67 10	leeuwen, g a. van, goudestein 88	86 41 66	techn d na 18.00 u	43 69 67	lemstra, j j, blokln 36, bouwk hfd opz
41 63 09	leeuwen, l l l. van, grenobleln 2	11 02 50	lehane, f m j j h, v wassenhovestr 43		
11 93 51	leeuwen, j. van, g grootestr 83			51 58 14	lemstra, w, n brabantln 50/a
51 87 70	leeuwen, g. van, k de groteln 151	43 84 89	lehmann, a, aurorastr 24	11 37 17	lenaers, j m, rect baptistln 40
11 22 82	leeuwen, c. van, hertensprong 2	11 18 61	leibbrandt-stagger, j r, h gorterln 227	52 23 84	lenaers, m j c, nyenrode 35
44 32 16	leeuwen, a j a, p huyssenswg 48			41 04 62	lenaers-van vliet, c, sonsewg 38
		51 79 44	leibbrandt, j w, huygensln 6	11 97 66	lenaerts, g a p, roostenln 95

Figure 17. Example of the Dutch system used for telephone directories. Advantages: clear separation of columns. minimal distance between number and name; lower case lettering. Disadvantage: print too small for elderly people and lack of contrast due to grey paper.

wards; (j) for glasses of elderly users a correction suited to the reading distance is necessary.

Reading from broadcast TV screens

Text superimposed on TV images often suffers from low contrast and it is not uncommon for contrast to differ even from letter to letter, because of the still visible background. Dark letters on a homogeneous bright background cannot be advised because of the large area flicker which comes with high luminances. Therefore, in this case, bright letters on a dark background are to be preferred. Letters should be at least 2 mm for every 20 cm reading distance and thus be definitely larger than the just mentioned value for perfect quality print, because reading time is usually very limited and the TV screen will often suffer from reflections from other light sources.

Proof correction

This requires a special skill. In normal reading, text content is the important factor whereas in proof reading, content is important only to the extent that no lines or words have been left out. Reading for correct spelling is so different that a special way of reading is required in which the corrector makes smaller eye saccades, and preferably even adopts special reading habits such as reading in the reverse direction to avoid automatic reading for meaning.

Distance reading

There are many situations in which reading distance is essentially long, such as in the reading of traffic signs, train and bus indicators, prices in windows, names of streets, text on slides and overhead projections, blackboards, and TV, to mention just a few. The main rules to be observed are a proper contrast between letters and background, a proper type font, a sufficient size (x-height at least 1/200 of reading distance) and a proper layout in particular if much information is given. In conditions of darkness, contrasts between sign and surround should not exceed a factor of 10:1. Unlike situations with normal print the reader usually has little influence on reading conditions and just has to put up with it if the proper reading conditions are not met.

Browsing and skimming through newspapers and books (visual search)

This may be either for a predetermined purpose or just for general information. Both have in common that eye saccades may be large and irregular, separated by short text portions read normally. The characteristic of visual search is that one reads all the time what one does not want to read — search stops when the required information has been found. In directed visual search it is of importance that one knows where a certain item can be found such that the search area becomes as small as possible. This is not necessary in browsing through newspapers if no special information is sought. In search, the eyes are drawn to conspicuous items of information such as headings, ads or pictures. A feature of conspicuous information is that it can be detected easily in eccentric vision, such that a single eye saccade brings it in foveal vision.

Speed reading

If information density is low or if only a rough impression of content suffices, other reading habits may be helpful. Just a few fixations per page are required for gathering a first idea of text content, and these may be placed strategically at the ends of paragraphs or so. Since information from widely different text portions is taken in within a short period, it is a suitable method for getting the gist of the content of a long piece of text. For a self-teaching course, see de Leeuw and de Leeuw (1965).

1.8 Learning to read

We can take it for granted that during their development, children will learn to understand speech and to talk. This is not to say that we understand the processes involved, we simply notice that practically all children learn these skills at an early age. In learning to read and to write, a different situation prevails. In many countries, part of the adult population has not learned the reading skills at all and in the countries where nowadays most people learn to read, this has been so only for about a hundred years. Furthermore reading, in contrast to speech, develops at a later age and for most children it calls for extensive formal teaching at school. When children are learning to read, they have already developed language skills by way of understanding and producing speech (Figure 18). In this sense, reading and writing skills are usually developed secondary to speech.

Reading is the mapping of visual symbols onto internal concepts of a certain meaning. In the process of learning to read, the visual symbols are still unknown and the concepts of meaning are already present. Two different ways
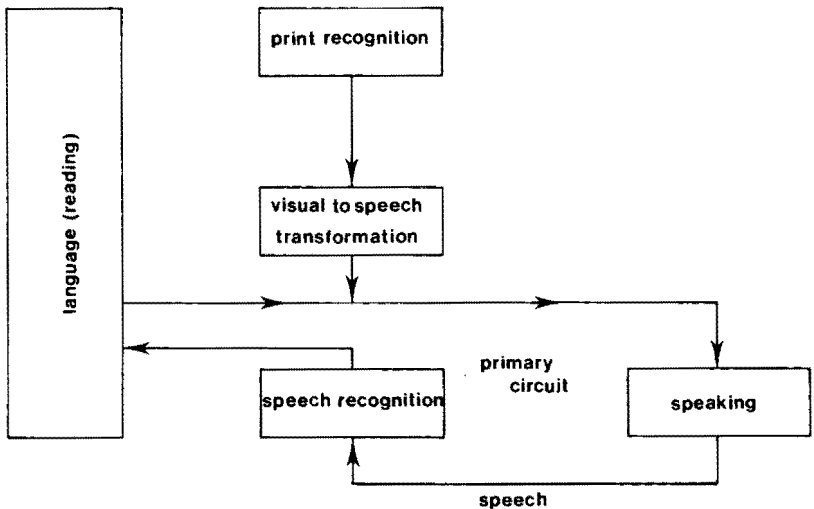

Figure 18. The beginning reader has to acquire his reading skills by converting visual information into a speech signal, thereby gaining access to the primary language-circuit already functioning well. Thus, meaning is accessed by mediation of speech. At this stage silent reading is not possible.

of mapping the unknown visual symbols to the known meaning concepts can be envisaged. One is a direct mapping, comparable to the visual recognition of the drawing of a tree, where the visually recognized picture is sufficient to directly activate the concept of a tree. In the case of a visual similarity between the language symbol and the object itself, such associations will probably develop relatively easily, such as in certain pictograms, but for most concepts there are no such visual symbols which can be directly understood. In that case some help is needed either from more elaborate pictures which represent the meaning and which are to be associated with the visual language symbols (such as in the look-and-say method) or from the spoken name of the object, to be associated with the visual language symbols.

Now a distinction should be made between (a) ideographic scripts, such as Chinese or Japanese Kanji, in which each visual symbol directly represents a certain meaning as such, without any direct relation to its sound, and (b) alphabetical scripts, involving the mapping in some way of a limited number of letter symbols to the sounds such that the name of the object (rather than its meaning) is represented by the string of letter symbols. The reading skill then initially involves the automatic application of spelling-to-sound rules. Without such rules the different visual words resemble each other too much to be discriminated, except perhaps for a limited number of very different words. Therefore, learning to read rests heavily on the mastering of the spelling to sound rules, and the proper sound then activates the meaning. Only when
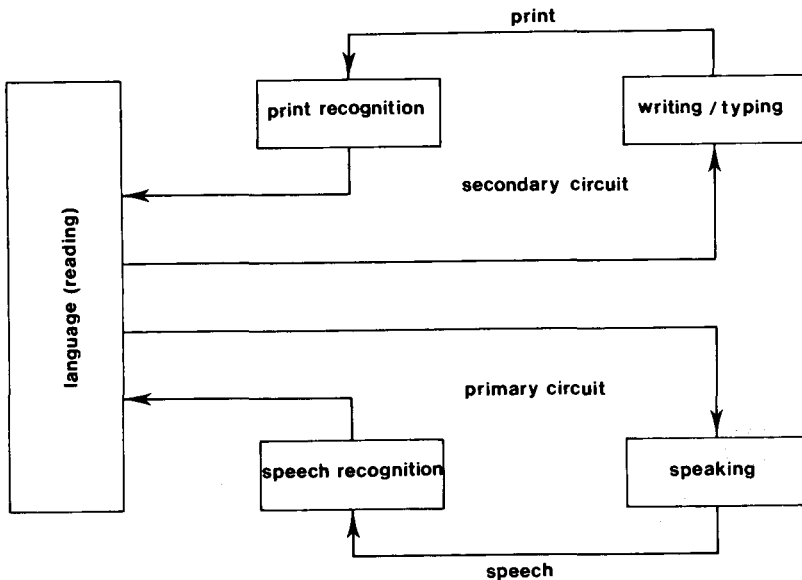

Figure 19. In fluent or silent reading the reader gets access to meaning directly, without the intermediary of speech. For clarity the influence of context is not drawn. If writing or typing skills are acquired as well a secondary language-circuit is formed.

these rules are sufficiently mastered, may a short-cut generally be developed between the visually recognized words on the one hand and the meaning on the other hand, bypassing the link to the sound of the word (Figure 19).

We take it, therefore, that during the usual development of reading skill, the recoding of recognized letter strings (visual words) into their sounds (visual speech recoding) is essential. The recent literature on visual word recognition indicates that the distinction between words and non-words is mainly made on the likelihood of the constituent letters in their proper relative position. The old opposition between the theory of analytic word recognition (words are recognized by their letter sequences) and the theory of global word recognition (words are recognized by global properties such as word shape) is thus fading away, since letter recognition is analytic and letter position in the word is a global property.

If visual-speech recoding is a common process in early reading and an optional process in skilled reading, it will be appreciated that any disturbance in phonemic recoding will have direct consequences on learning to read. One should not think too easily of the complexity of the visual-speech recoding process. Many alphabetic languages have irregular spelling to sound rules in that a visual letter represents different sounds, depending on adjacent letters and on certain idiosyncrasies. Also the so-called blending of sounds is far from easy, since the letter names differ substantially from their pronounciation in words or syllables.

We are not advocating here any particular approach to teaching children or adults to read. What we are advocating is a close study of the development of reading processes, in particular word recognition, when various methods are being used. Many children learn to read with any method, but others may show differences with different methods. To us, if anything, rigidity of method seems the least desirable.

2. Clinical Aspects

2.1 Elderly readers

When people grow older, reading becomes difficult at first by diminished accommodation. This obliges the reader to hold the text at a greater distance in order to avoid focusing stress. This has several consequences for the speed of reading, as the retinal image is smaller and also of lower contrast, resulting in prolonged recognition latencies. A more precise strategy of eye saccades is mandatory in the reading of small text. Adding spherical plus power to the fully corrected (refractioned) eyes will enable the subject to cope with these reading problems at the cost of a loss in depth of focus. Pupil size and lens transparency are other changing parameters in the older reader. With increasing age the pupil becomes narrower and lens sclerosis limits the transparency, so that retinal illumination is diminished and a low-contrast retinal image results
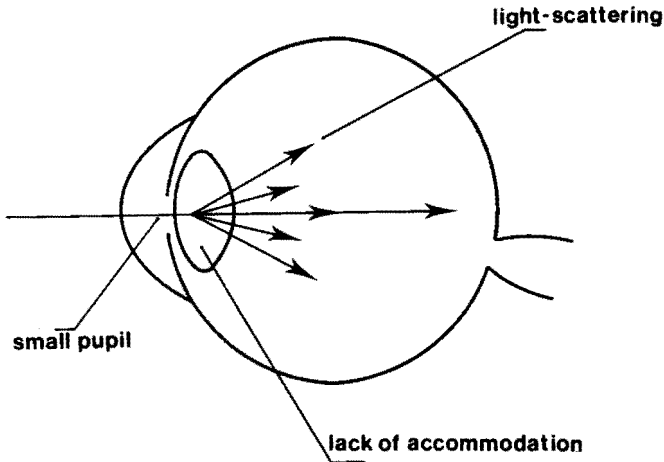
Figure 20. Common factors influencing the reading of elderly people. A small pupil requires more illumination; light scattering requires increased print-size, good contrast and avoidance of glare (bright light sources; bright windows).

(Figure 20). For these reasons most older people need more illumination for an improved contrast sensitivity and this may prove to be rather critical due to the light-scattering of the lens: too much light narrows the pupil too much and lowers vision owing to optical diffraction and diffusion by the lens nucleus. Good advice for the elderly reader could be to have a reading light with a regulating mechanism, permitting individual adjustment to an optimal level. Apart from diffuse lens sclerosis, scattering lens-opacities can develop in the cortical layers of the lens, leading not only to blurred vision (especially for the opacities in the posterior lens cortex) but also to annoying diffusion of light. In such cases the reading illumination is critical and many are grateful for the advice to try a reading-window consisting of a dark grey piece of paper with a shallow rectangular opening in it through which just two or three lines can be seen. In this way scattering of the light from the white page and loss of contrast is sufficiently reduced (Figure 15).

Macular alteration is frequently encountered among elderly people and loss of visual acuity leads to reading difficulties. Magnification of the text with low vision aids has its limits, not only for contrast reasons but also for search problems.

When there are visual field abnormalities such as relative or absolute scotomas or hemianopsia, reading problems could also arise because an abnormal field of effective vision calls for an adapted eye movement strategy and especially hemianopsia in the left visual field interferes with adequate correcting and line saccades. In hemianopsia in the right visual field, the reading of text upside-down restores reading saccades, but interferes with correction and line saccades.

The eye movements of elderly people become more and more restricted

and have to be compensated by moving the head, thus stressing the neck muscles. These considerations, together with search and line saccade troubles and imaging difficulties, give rise to the following recommendation concerning printed text for elderly people: the print should not be too small, preferably 3 mm, and should be of good contrast, preferably in relatively narrow columns to be read with adjustable illumination. A reading mask could help in cases where too much light reflecting from the white page lowers the contrast of the retinal image by diffusion.

2.2 Low vision

Optical aids

Low vision patients with insufficient reading capacity can be helped with optical aids varying from high-power spherical lenses hand-held or stand magnifiers (maximum 2.5x); telescopic systems (max. 8x) to electronic devices such as the TV-magnifier "TV-loupe" giving up to 25x magnification or even more. All of these tools have their own specific restrictions such as in working distance, magnification, optical quality, width of visual field, illumination, portability and, last but not least, cosmetic acceptability. As to illumination, this should be both high and adjustable and restricted to the text portion to be read. It should not cause glare and therefore the lamps should be shielded from view. Despite adequate magnification and illumination these aids are frequently not useful even to motivated patients, and an analysis in terms of reading processes could explain this phenomenon.

Spherical high power (+) lenses are relatively cheap, can be fitted in conventional frames, have a relatively wide field but have the disadvantages of optical aberrations, short reading distance, and critical focussing due to a small depth of field. Also, binocular vision is only effective up to + 5D. A short reading distance implies more spaced eye saccades and line saccades over a greater distance. Correction jumps are also difficult to make correctly. What is more, it is difficult to maintain the correct level of illumination, owing to shadow-casting from the readers head. The critical depth of focus requires a well balanced hand-arm versus head movement too, and preferably a reading desk.

Magnifiers, especially the aspherical bridge-types, are preferable because of their excellent optical quality and stable, well-focused image, which is not dependent on head position; but magnification, however, is limited to some 2.5x (+ 10D) (Figure 21). Magnification and field of view are optically coupled in such a way that the higher the magnification, the smaller the field of view. Preferably, a full column of text should be covered. Often, specular reflections in the lens are disturbing the reading process. Other limitations are encountered in finding the beginning of new lines of prints (line saccades), shortcomings in illumination and in the positioning relative to the reader. A reading desk with a movable magnifier with inbuilt illumination can compensate to a great extent for these handicaps; a transportable version is presently under construction.
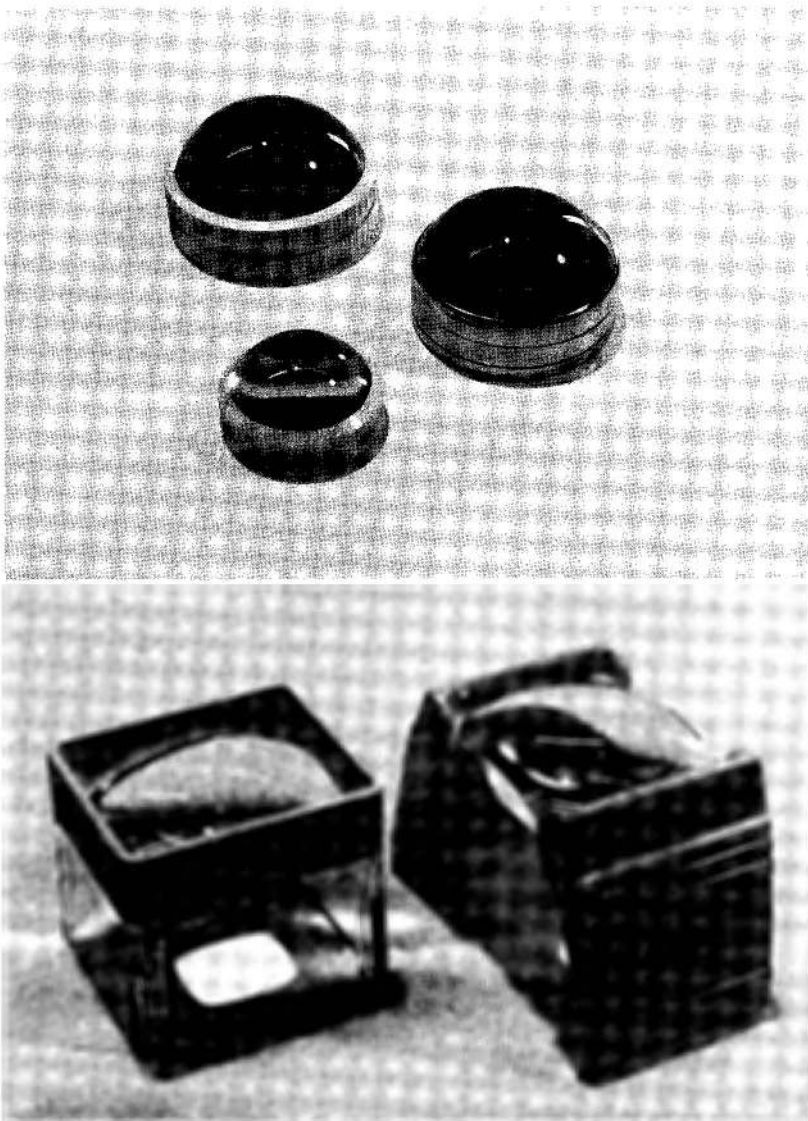
Figure 21. Some optical magnification aids.

Telescopic optical systems

The advantage of these optical aids is the possibility of fitting them to a frame, allowing more mobility for the patient and a greater working distance than with high-power spherical glasses. The more magnification the narrower the area that can be viewed and the more critical the depth of focus. Reading with these systems calls for good hand-head coordination; jumps to the next line are also difficult to make. Apart from these considerations the frames can

become somewhat heavy when high-power telescopes are fitted to them. Optimum illumination is essential. Magnifications above 8x are not practical.

Electronic devices

Primarily these are developed for patients needing magnification of text more than about five times. The commercially available devices have magnification up to 40x, but commonly used values are rather between 6x and 12x and more than 20x is rare. For photographs and handicrafts, lower magnifications are practical. The patient sits facing a TV screen, displaying with normal or with reversed contrast. Although most patients can read this way, many problems remain to be solved. For example: the position of the reader relative to the screen should be comfortable, so as to avoid neck muscles complaints. With high magnification only one or two words can be displayed at a time and good hand-coordination is essential for convenient reading. In general, fluent reading is hardly possible with progressive magnification, because reading rate becomes too low. Contrary to purely optical magnifiers, closed circuit
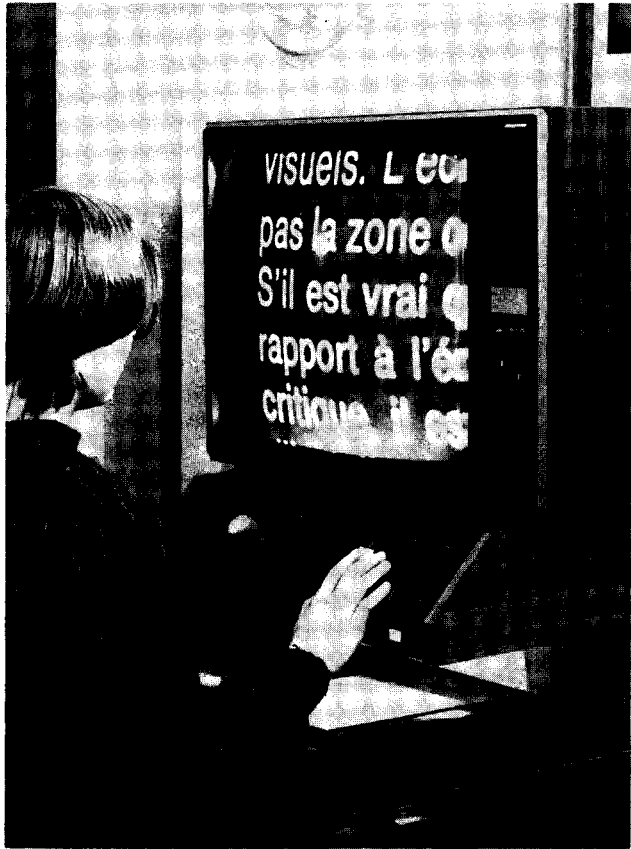

Figure 22. Electronic magnification aid (closed circuit television or CCTV).

TV systems offer the option of a reversed contrast (white letters on a dark background) (Figure 22). Theoretically this should be an advantage in cases of opacities in the eye optics because of a better retinal contrast and practice bears this out. About 50–60% of "TV-loupe" users indeed prefer a reversed contrast. The "TV-loupe" has lowered the acuity boundary below which no visual reading can be achieved to a value of about 1.5% (visual acuity 0.015) and in this way restricted functional retinal areas can be utilized for reading. As far as can be judged at present, colour TV offers little extra help for reading, but practice still has to bear this out. For many patients, the "TV-loupe" has proved to be the one and only aid which enables them to read and write.

2.3 Blindness

It is an apparent contradiction that blind people can read. As so often, the paradox can be solved by choosing appropriate definitions, in this case both for blind and for reading. Among those people registered as blind the majority still have some form of useful vision and only a small minority cannot see at all. A functional definition of socially blind would be: those who despite available optical aids cannot read text of normal size. Alternatively, a definition could be: persons whose visual function is seriously impaired such as the central visual field (smaller than $10°$) and visual acuity (0.03 or less). The concept of reading can be restricted to visual reading, in which case it seems useful to require a reading rate of at least 20 words per minute, since reading as slow as this makes it virtually impossible to get the meaning of a sentence. Also, one may choose to include tactile reading with one or more fingers, these being so far the only part of the body that allows a sufficiently quick and detailed tactile sensation to provide access to the meaning of tactually displayed letters and words. We will briefly indicate here the reading options open to those who are totally unable to read visually.

Braille

Unlike visual letters, the Braille letter configurations have little redundancy in the sense of overdetermined information, although of course the words proper have just as much as in visual language. As compared to the visual reading of text, Braille reading has a number of limitations. The first is that it is practically only young people who can learn to read Braille fluently; elderly people above 60 yrs, comprising the majority of blind people in many countries, find it virtually impossible to read Braille. Secondly, even for those fully adapted to the Braille system, reading rates remain rather low, of the order of 100 words/minute. In fact there are two slightly different types of Braille: normal Braille (type I) and contracted Braille (type II), in which certain frequent letter combinations are presented by one Braille symbol. For a number of Braille readers, Braille II seems to allow slightly higher reading rates. There is no evidence to indicate that Braille is the best tactile display – in fact the lack of redundancy in the dotted letter symbols makes one suspect that better configurations could be designed.

Optacon

A different way to display characters tactually is to take the letter configurations just as they appear in print. The Optacon is a reading aid which picks up printed letters from paper by means of a small hand-held camera and displays them tactually to the top of the index finger by means of a vibrating matrix (Figure 23). One hand is then used to scan with the camera the line of print, while the finger of the other hand picks out the letter-shapes for tactual recognition. A distinct advantage is that ordinary print can be used. Long and intensive training is required for mastering this reading skill, and even then the resulting reading speeds of adults are not higher than some 50 words per minute. It is hoped that higher speeds may be reached by children if they get their training at an early age, when one might hope the learning of tactile recognition may still be more versatile. Nevertheless, it should be appreciated that this tactile recognition is essentially much slower than visual recognition, since the reading field is so narrow (just one letter) and the scanning process so much more rigid than with normal visual faculties. Efforts to widen the reading field by using two fingers have not produced any improvement so far. As far as tactile recognition itself is concerned, one can perhaps compare this with parafoveal visual recognition in that relatively low 'acuity' and extensive lateral masking occur. For Optacon reading, relatively simple letter configurations should be preferred without extensive serifs.

Print to speech conversion (Reading machine for the blind)

For the last few decades there has been work and speculation on a reading machine for the blind, which automatically translates printed characters to speech. The concept is very attractive, but its realization has suffered from continuous delays, due both to the great difficulties involved in the spelling-to-sound translation with its many irregularities, and to problems in speech synthesis , with its intricate coarticulations. Also, speech contains properties not directly represented by printed text, such as intonation and stress. Thus,

Figure 23. The Optacon transfers the optical image of about one letter in a similar configuration of vibrating rods which can be felt by the finger tips. Normal text is thus accessible for the blind, but speed of reading is lower than in Braille.

the natural print-to-speech converter, which is the reading human being, has not yet been effectively simulated. Recently, however, the prospects have improved, because of the increased mastering of speech processing combined with the enormous advances in micro-electronics. The first laboratory models of a reading machine for the blind have recently been demonstrated consisting of: optical character recognition, application of spelling to sound rules, and speech synthesis (Figure 24). It will probably take a number of years before stand-alone apparatus becomes available, firstly in English or, perhaps, Japanese. Whereas neither Braille nor Optacon is suited for people who go blind at the age of 60 or later, the reading machine for the blind offers prospects for the elderly as well. It should be appreciated, that the scanning process remains a relatively inflexible part of such a system. Nevertheless, the wedding of phonetic sciences with technology now holds promises of a vital offspring for the blind.

2.4 Developmental dyslexia (word blindness)

A child is called dyslectic if there is a reading backwardness of two school-grades notwithstanding normal vision, normal intelligence and also absence of emotional or social disturbing factors. In Western countries about 5% of all boys and 1% of all girls can be classified as dyslectic. As mentioned before, a young child has to master reading by pronouncing the recognized letters aloud and synthesizing them into words. Through training in this way a direct link can be built up between the recognized word and its meaning and silent reading becomes possible. Extensive experiments with a group of normally reading young children and dyslectic ones (Figure 25) have led us to propose a location for a defective link in the reading processes in dyslectic children. Summarizing, our experiments have led us to the following conclusions.

— Dyslectic children have a normal, close to perfect knowledge of letter forms and in tachistoscopic (brief presentation) recognition experiments they score as high as normally reading children (Figure 26).
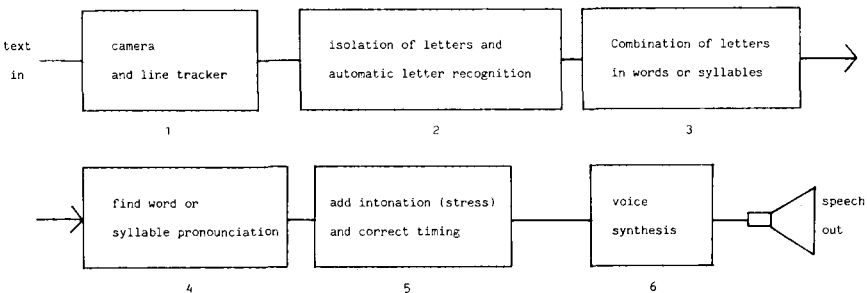

Figure 24. Block diagram of a possible 'reading machine for the blind'. In particular stages 4 and 5 may present difficult problems.
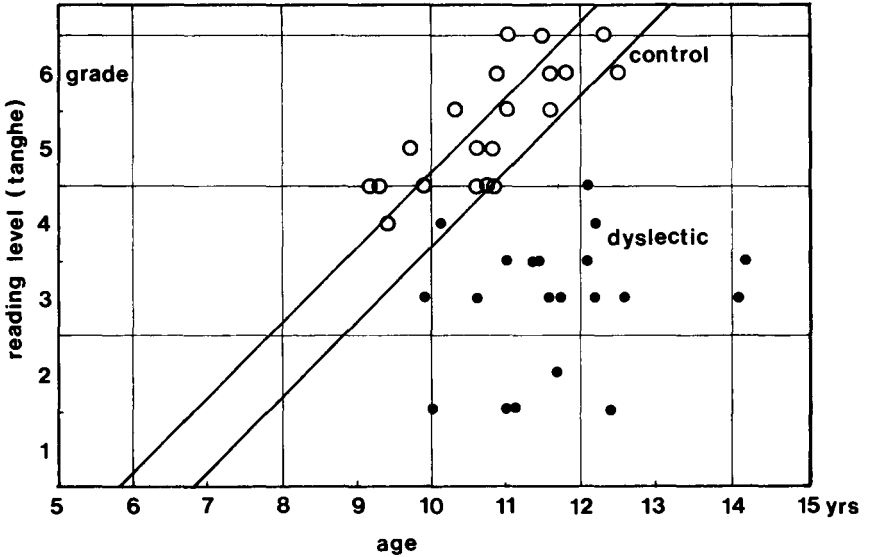
Figure 25. Classification of reading quality levels of 40 subjects versus age levels according to grades of elementary school. Normal level between oblique lines. One subject from the dyslectic group had a 'normal' score on the reading test, although his way of reading sounded peculiar. In order not to bias our results by a posthoc selection of subjects, we retained him as one of the dyslectic group.
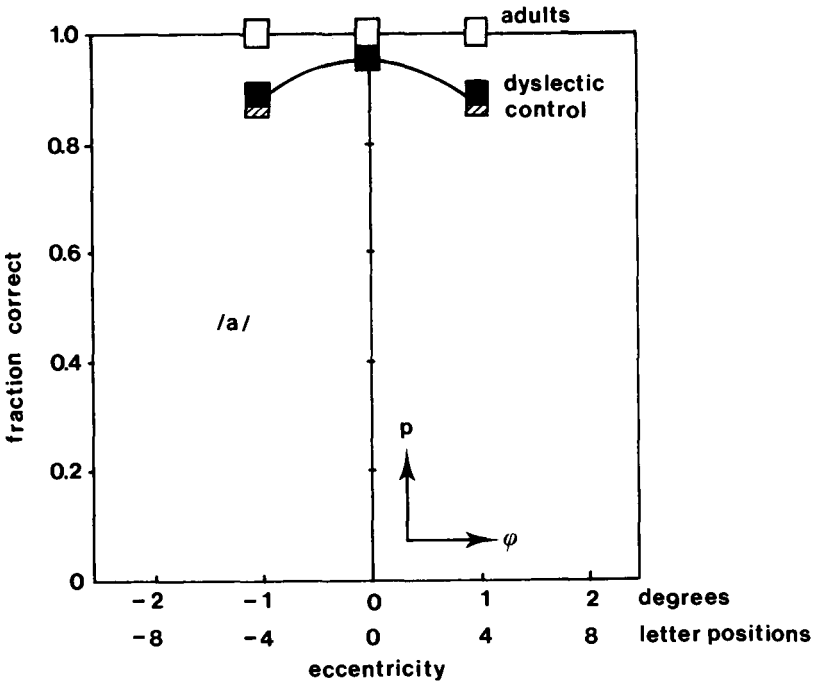

Figure 26. Group averages of recognition scores of isolated test letter /a/ in foveal and parafoveal presentation. There is no difference between the dyslectic group and the control group.

— In word recognition experiments dyslectic children score lower (Figure 27); the longer the word the lower their scores. As one can observe when listening to the reading of a dyslectic child, long words are particularly difficult to recognize (Figure 28).

— We also found that response-latencies for words even of correct answers were about 200 msec longer in dyslectic children than in normally reading children. When we changed the mode of presentation in the recognition experiments in such a way that the visual analysis became more difficult (presenting words offset from the point of fixation, i.e. parafoveally instead of foveally centered) we found longer reaction times (as expected) but the time difference between the two groups was still about 200 msec (Figure 29). From this experiment we concluded that the visual analysis phase in the reading processes is as normal in dyslectics as in normally reading children. The major argument for this statement lies in the above-mentioned experiment, because defective visual recognition in dyslectics would increase the recognition time difference, which we did not find. This is in agreement with Vellutino et al. (1975, 1979), who refute the hypothesis of a visual deficiency on the grounds of copying experiments in which dyslectic children performed just as well as controls.
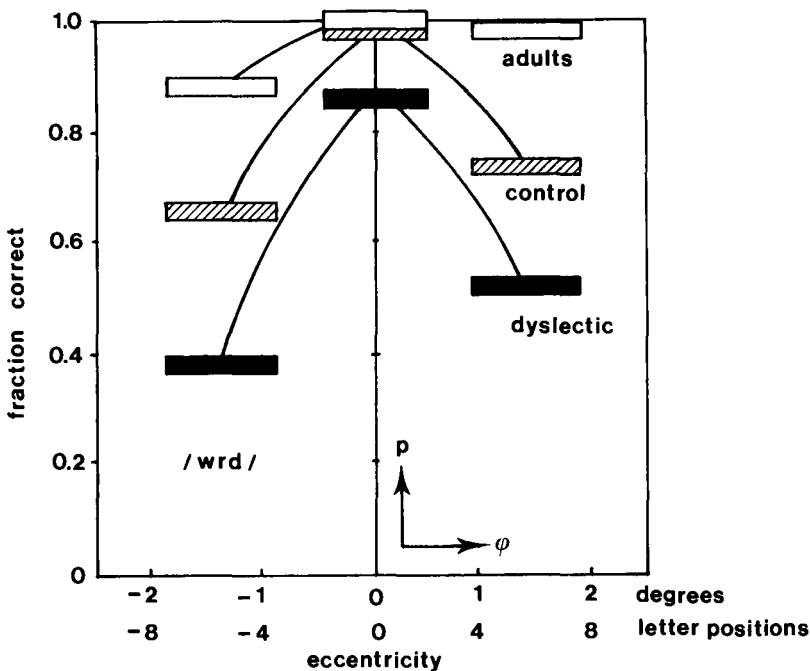

Figure 27. Group averages of recognition scores for isolated Dutch words in foveal and parafoveal presentation. Word lengths three to five letters.

	dysl.	contr.
l = 3	96	98
l = 4	87	98
l = 5	75	98
l = 6	42	100
l = 7	38	100
l = 8	33	96

Figure 28. Foveal word recognition of different word lengths for both groups of children. Data for 1 = 6, 7, 8; four subjects. Note that dyslectics have decreasing scores with increasing word length.

Our interpretation of the constant time difference between the two groups of children leads to the conclusion that recoding visually recognized words to a speech code is a more time-consuming process in dyslectics than it is in normally reading children. The same holds for the transformation of speech to writing (Figure 30). As between the visual analysis phase and the pronunciation phase few storage facilities are available, information has to be turned over quickly; otherwise it fades away and a new visual analysis has to be made.

In our opinion the crucial point for dyslectics is located at this point. For them, converting correctly visually analysed words into speech code is so time-consuming that before the last part of a long word is to be pronounced the first part is not available anymore. The only possibility not to lose the already seen parts is by rehearsing while analysing the next part. This is what can be observed in dyslectic children reading long words. We also did experiments to check the speech channels by presenting auditory long words and asking for repeating them. We found no substantial difference between the two groups of children. Nor did we find any substantial difference between the two groups in the way they speak.

	latency (ms)		
	Dysl.	Contr.	Diff.
Foveal words	900	680	220
Parafoveal words	940	730	210

Figure 29. Average response latencies of correct word recognition in foveal and parafoveal presentation. Note the constant latency difference of about 220 msec between the dyslectics and the normally reading children.

print

print recognition	writing / typing

language (reading)

visual to speech transformation	speech to spelling transformation

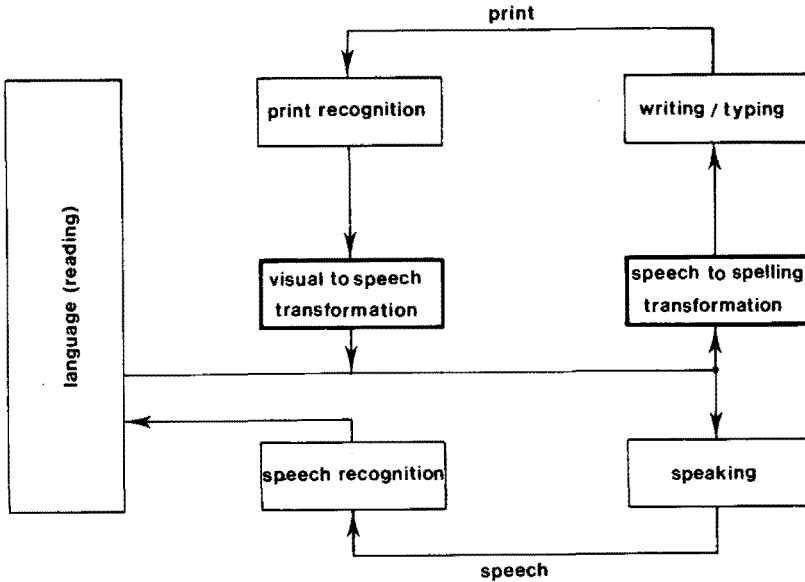|	
speech recognition	speaking

speech

Figure 30. In dyslectic children both reading and spelling are deficient probably due to defective transformations from visual information to speech signals as well as from speech information to spelling. Both visual recognition and speech functions are assumed to be normal.

The proposal is that a slow recoding process from visual symbols into speech signals is responsible for the reading problems of dyslectic children. As speech is essential for young children in converting printed symbols into already known words, one can understand why dyslectics are so handicapped. Quite different evidence arguing against a primary visual deficiency of dyslectic children can be derived from the consistent reports that dyslexia is virtually unknown in Japan. The Kanji symbols, which are adapted from Chinese, directly represent meaning, not mediated by sound. In the two Kana scripts which do represent sound (syllables) there is a one-to-one correspondence between sign and sound, which is much more regular than in most alphabetic languages. Despite of the complexity of the visual configurations, Kanji symbols are more easily learned by young children than Kana.

As to therapy the authors will not advocate one regime and disregard all others. Although training programmes prove to be quite different, one from another they seem all successful to a certain extent. In our view all therapeutic measures have at least one common factor: acceptance of the child's handicap and intensive individual attention. This is of the utmost importance as by proper training dyslexia in itself will improve a great deal as time goes on, if not blocked by emotional stress of the child. Based on our hypothesis mentioned above we advocate reading exercises in which text or words are to be read aloud and difficulties leading to delays are immediately solved, e.g. by vocal aid of the child's trainer. In this way assessment of meaning of full sentences can be built up as a necessity for silent reading.

3. Conclusions

The ophthalmologist may realise that for fluent reading the quality of refraction in relation to eye optics, eye motility, and retinal function is an important, but not the only point of view. As is pointed out in chapter one the eye movement strategy, the recognition in a single eye pause and the integration of the information of successive eye-pauses are important just as well. Due to the saccadic nature of eye movements in reading, parafoveal vision contributes essentially in word recognition. Parafoveal recognition is limited not just by a low acuity but by strong masking effects of supra-retinal (cortical?) origin.

A most important factor in reading is the strong interrelation in time between subsequent reading processes. The normal reader can adjust his reading speed at will within these time constraints. This means, for example, that slow recognition implies inflexible reading.

Reading complaints of patients may continue despite adequate correction or magnification. The analysis of these problems and their possible solutions may profit from the proposed approach.

As an example, our hypothesis of word blindness as a recoding deficit is the result of such an approach and may also contribute to well-founded treatments.

The main aim of the authors is to bring in focus for the ophthalmologists a rather underdeveloped area of interesting clinical research which may be profitable for many patients with reading problems.

Acknowledgement

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