Eur Arch Psychiatr Neurol Sci (1984) 234:175–183

European Archives of Psychiatry and Neurological Sciences

Eye Movements During Reading in Aphasics

Jürgen Klingelhöfer and Bastian Conrad

Department of Clinical Neurophysiology, University of Göttingen, Robert-Koch-Straße 40, D-3400 Göttingen, Federal Republic of Germany

Summary. In 40 normal subjects and in 21 patients with anomic, Wernicke's, and Broca's aphasia, eye movements were registered with DC-EOG during reading of two standardized texts and analysed with respect to the number of fixations and regressions and reading time. Patients with these aphasic syndromes developed different internal strategies of their saccadic construction: Patients with Wernicke's aphasia showed increasing difficulty in overcoming the text with a tendency to make smaller leaps over the line, with almost a complete disintegration of the saccadic structure ("strategy of small and smallest steps"). The saccadic pattern in Broca's aphasics was clearly better preserved. During oral reading there was a characteristic increase in fixation times and number of regressions ("motor waiting and searching behaviour"). Patients with anomic aphasia showed alterations most similar to the reading behaviour of unskilled normal readers.

Key words: Eye movement – Reading – Aphasic syndromes

Introduction

During the act of reading the eyes do not move in a fluid, continuous line, but move stepwise in saccades. Between the saccades there are resting or fixation periods in which the eyes remain stationary in order to take up information. Eye movements during reading involve an automatic process which is not normally influenced voluntarily. The analysis of saccades during reading thus offers a possibility for investigating rapid, automatic, cortical processes.

The analysis of disturbed saccadic behaviour during reading thus far has been mainly performed on legasthenics, and on dyslexics who exhibit a reading disability as a result of developmental disturbances (Zangwill and Blakemore 1972; Rubino and Minden 1973; Griffin et al. 1974; Heimann and Ross 1974; Dossetor and Papaioannou 1975; Heller 1979; Pavlides 1981; Romero 1982). There are also reports on eye movements in patients whose reading disorders are a consequence of oculomotor gaze defects (Holmes 1938; Nathanson et al. 1953; Prechtl and Stemmer 1959; Allen 1962; Ciuffreda et al. 1976; Ciuffreda 1983). One should expect that the contextual processing during reading is an essential factor determining the saccadic structure (Just and Carpenter 1980). In aphasic patients various parts of the language system, including reading performance, are affected in different ways depending upon the localization of the cerebral lesion. Therefore, it should be of interest to analyse the structural arrangement of the saccades during reading when the contextual processing is affected, due to lesions in the different centres involved in speech and reading. Patients with aphasic disorders offer the possibility of investigating such a problem. To our knowledge there are no detailed investigations of eye movements during reading in patients with aphasic syndromes.

The aim of this study was to examine the type and rate of disturbance of the saccadic pattern in patients with different aphasic syndromes. This investigation should be regarded as a pilot study, searching for some basic saccadic strategies in aphasic syndromes. At this stage it was not intended to correlate detailed linguistic aspects with the saccadic behaviour, but instead the emphasis was placed on a first attempt of a phenomenological description of the saccadic construction during reading in aphasics.

The following questions were of primary interest: How does the basic saccadic pattern change compared to a normal reader? Do global differences exist between the individual aphasic syndromes? Is it possible to draw conclusions from the pathological reading pattern to the physiological process during reading?

Methods and Material

Horizontal eye movements were recorded binocularly (DC-EOG) with an amplifier unit (ENG-Tönnies Type TS-4-T) on an Elema Mingograph using a pair of Beckman surface disc electrodes. A part of the original graph is given in Fig. 1. Subjects were seated with the head fixed to avoid head movements during reading, and the texts were read from plates which were placed in front of the subject at a distance of 1.50 m. The size of the characters were selected so that 1.5 to 2 characters corresponded to 1° of the visual angle. In pretests with different reading angles, a length of line which corresponded to a visual angle of 20° at the fixation of the first and last character, proved to be the most favourable for the experiment.

Two short texts were used for the reading experiment. While arranging the text it had to be taken into consideration that patients with serious language and reading disorders should also be able to read the text. The shortness of the texts should guarantee that the patients would still concentrate when reading the last lines.

The *first* text consisted of a short coherent story of 5 sentences within 7 lines with only common words and a simple

Offprint requests to: J. Klingelhöfer at the above address

* The work was supported by the Deutsche Forschungsgemeinschaft (SFB 33 – Nervensystem und biologische Information)

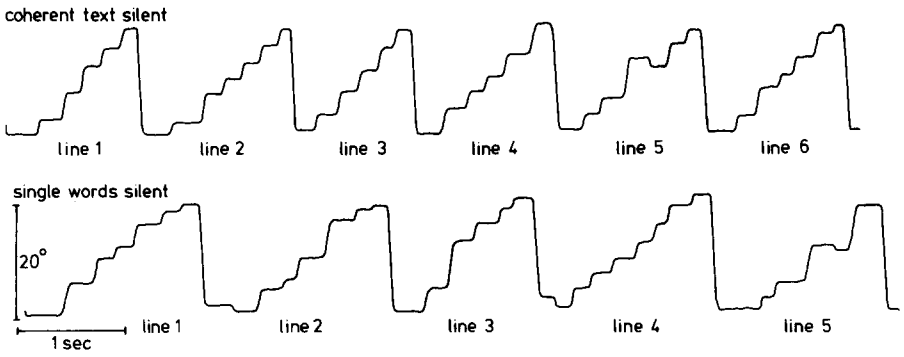

Fig. 1. Sections of the original eye movement recordings for the two experimental texts during silent reading in a skilled reader

Table 1. Casuistic data of all examined patients

Identification of the patient	Sex, age (years)	Right or left handed	Type of aphasia (W, Wernicke's; A, anomic; B, Broca's)	Aetiology of aphasia	Aphasia severity rating scale, communication attitude[a]
W 1	F, 76	R	W	Stroke	2
W 2	F, 67	R	W	Cerebral haemorrhage	2
W 3	M, 67	R	W	Cerebral haemorrhage	3
W 4	F, 27	R	W	Stroke	3
W 5	M, 58	R	W	Cerebral haemorrhage	2
W 6	M, 30	R	W	Stroke	2–3
W 7	M, 49	R	W	Stroke	2
W 8	F, 44	R	W	Cerebral haemorrhage	2
W 9	F, 44	R	W	Stroke	2
W 10	F, 52	R	W	Stroke	2
W 11	M, 66	R	W	Tumor	3
W 12	F, 68	R	W	Cerebral haemorrhage	3
A 1	F, 31	R	A	Brain abscess	4
A 2	M, 55	R	A	Stroke	4
A 3	M, 56	R	A	Cerebral haemorrhage	3–4
A 4	M, 70	R	A	Stroke	4
B 1	M, 67	R	B	Stroke	2
B 2	M, 45	L	B	Stroke	3
B 3	M, 51	R	B	Stroke	3
B 4	M, 40	R	B	Stroke	[b]
B 5	F, 73	R	B	Stroke	3–4

[a] The communication attitude of the examined patients during spontaneous talking is given by the 6-level-rating scale from Goodglass and Kaplan (1972)

[b] Definition impossible because of extreme expressive speech disorders

syntactic structure (in total 36 words, with a mean of 5 words per line and 1.6 syllables per word). The *second* one was a single-word text mainly composed of nouns; in the first lines the nouns were monosyllabic, in the following 3 lines the number of syllables and morphemes increased and the words were more difficult to read. Line 4 was an exception; here 1 word with 32 characters of 10 syllables had to be read over the length of the line. The following lines were again composed of words with 1 and 2 syllables.

An auxiliary line was introduced before and after the actual lines of both texts to be read so that the reader had to begin the first line with a long return sweep from the foregoing auxiliary line and would not step with his eyes into the first line in an uncontrolled manner at the start of the experiment. Correspondingly, line 7 had to be finished correctly with a return sweep to the last auxiliary line. In this way the 7 lines were equally valid for evaluation.

In order to obtain the same length of lines, and thus the same visual angle between the fixations of the first and the last character of each line, the lines ended at the same space at the right margin.

Procedure of the Experiment

The text was kept covered until the actual calibration of the eye movements was achieved. Prior to the experiment the subjects were instructed to read in their usual reading manner. Furthermore, they were informed that one text consisted of a short

coherent story, the other one of single words which were not related in regard to context. This was necessary in order to avoid unusual eye movements in search of a connection in meaning. After reading the text silently, the subjects were then asked to read it aloud. At the end of the first silent reading, comprehension questions were given. In general, the experimental procedure remained the same in the patient group. However, the instructions often had to be adapted, as language comprehension was severely affected in some cases. Testing the patient's text comprehension after the first reading trial was not performed by questions but with a selection of pictures from the coherent text. Various situations were presented with reference to the text, and the patients had to select those pictures which fitted exactly into the context of the text.

To test the single word text, patients were given individual words out of this text to read again. Afterwards they had to choose a picture out of a number of graphically presented objects which corresponded to the stimulus.

Normal Subjects

The group of normal readers was chosen to give a fairly broad representation of reading skills, and was matched according to age and education to the group of aphasic patients: Thus there were "good", "bad", and also "unskilled" readers in all age groups. The definition of the factors "education and practice" turned out to be difficult. The purpose of the experiment was not to judge "education" from the saccadic pattern but to determine how an "anticipated reading ability" (according to the education level) was manifested in the reading pattern. Therefore, it was necessary to carry out a quick and simple "reading ability" classification. Each subject had to answer a short list of questions concerning his education, his actual or former profession and his daily reading time. This list of questions proved to be a useful instrument in obtaining a simple, basic classification of "reading ability".

Group of Patients

Patients with a reduced visual acuity, visual field or oculomotor defects and patients with an inadequate general state of health were excluded from the study. In addition, patients whose speech disorders (such as global aphasia) impeded a satisfactory communication or whose low reading ability clearly did not allow a realization of the experiment were rejected.

Finally 12 patients with Wernicke's, 4 with anomic and 5 with Broca's aphasia were examined (Table 1). Examination of the speech modalities and the corresponding classification of the patients were performed by means of "The Aphasic Test of Aachen" (Huber et al. 1980; Willmes et al. 1980; Weniger et al. 1981; Huber et al. 1983). Recording of eye movements during reading took place either the same day as the aphasic test or if this were too heavy a strain on the patient, 1 day later.

Localization of the cerebral lesions was obtained if possible by computer tomogram and is illustrated for patients with Wernicke's and Broca's aphasia in Fig. 2.

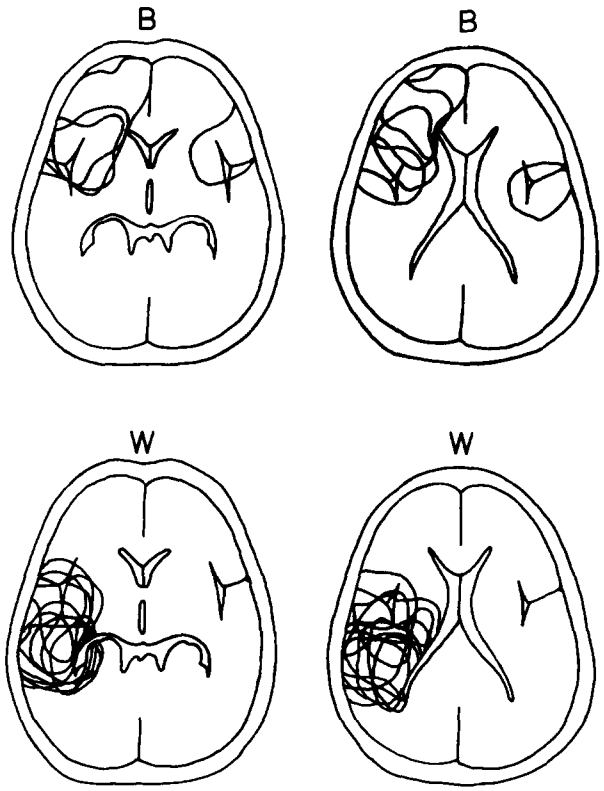

Fig. 2. Schematic drawing of the cerebral lesions derived from CT (two layers) in the examined patients with Wernicke's aphasia *(W)* and Broca's aphasia *(B)*. All the examined Wernicke's aphasics showed the cerebral lesion in the area of the left hemisphere; in one of the Broca's aphasics the lesion was found in the area of the right hemisphere (left-handed man)

Results

Qualitative Aspects

Figures 3 to 6 show eye movement recordings during reading in patients with Wernicke's or Broca's aphasia. The severity of the speech disorder differed within the same aphasic syndrome. All recordings originate from the first silent or oral reading attempt.

Wernicke's Aphasia. The saccadic pattern of this group of patients shows clear alterations in comparison to the pattern of the control subjects examined, even to those of very unskilled readers.

The record of patient W1 in Fig. 3 shows a characteristic increase of fixations and regressions, though the saccadic structure is fairly well preserved. The second patient W 2 in Fig. 3 also demonstrates a fairly intact saccadic structure during reading the coherent text. While reading single words, however, a clear tendency to a disintegration of the saccadic structure can be noted, which varies from 1 word to the other, and which is especially obvious in line 4. The longest saccades of line 3 seemed to serve only to direct the eyes over the gap between the 2 words in line 3. Longer single words were partly overcome with the help of the smallest saccades and numerous fixations. Therefore, a disintegration of the saccadic reading structure can be observed in this case.

The same alteration in the reading pattern of both experimental texts is even more pronounced by patient W4 and shown in Fig. 4. While reading the coherent text the saccadic structure is still preserved, even though deviating from a normal reader. The reading attempt of the single word text causes a strong increase in the number of fixations. Larger reading saccades can seldom be observed.

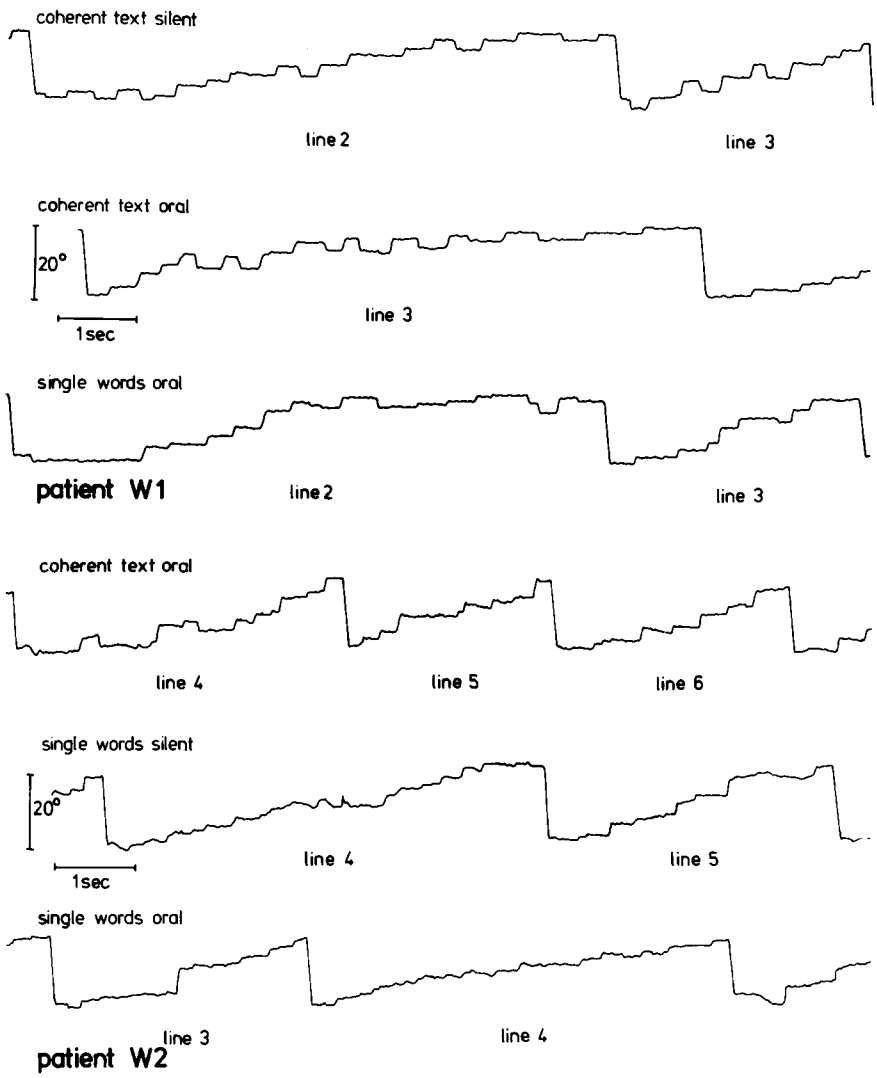

Fig. 3. Sections of the original eye movement recordings during reading in two patients (W 1, W 2) with Wernicke's aphasia

Especially in successive single words with multiple syllables, patients with Wernicke's aphasia obviously had extreme difficulty in overcoming these words with longer saccades. Some of the patients used a great deal of effort to master the text, often accompanied by a psychic excitation which could be recognized by numerous artefacts like blinking of the eyes (see patient W 4 in Fig. 4). Patient W 8, whose saccadic pattern is also illustrated in Fig. 4, directed her eyes only in the smallest of saccades over the lines of both experimental texts, indicating a complete disintegration of the saccadic structure. Nevertheless, such patients succeeded in "conquering" the whole line by "stepping from one character to the other" and finishing it correctly with a return sweep. They even overcame word caps to an angle of 4° with the help of minisaccades, although they were able to carry out large saccades, as shown by the return sweeps. In most cases these patients, certainly with numerous paraphrases, were able to pronounce the characters and words, having "read" in such a way that the passages of the text remained recognizable even though they were unable to perceive the material "read" contextually.

It was possible to test some of the patients a second time. The speech disorders had improved in patients W 4 and W 5 with Wernicke's aphasia. Figure 5 shows parts of the records of these patients. The eye movements during reading had been recorded initially when the patients suffered from serious speech disorders, and secondly when these disorders had declined to lesser residual symptoms. Both patients showed a normalization of their reading structure in the second examination, and were able to read the text correctly. Only insecurities in more difficult single words of the second text could be recognized, and both patients could comprehend the texts.

Anomic Aphasia. The saccadic reading patterns of this group of patients did not differ in principle from normal readers, both in silent and oral reading of both experimental texts, even though an increased number of irregularities was present—i.e. a decrease of the regular "staircase structure" and an increase of the number of fixations, regressions and reading time. These alterations were similar to the reading behaviour of unskilled normal readers.

Broca's Aphasia. The reading patterns of patients with Broca's aphasia usually showed, as opposed to the majority of patients with Wernicke's aphasia, maintenance of a precise and stable guiding of the eyes (Fig. 6). Even for long fixation periods the eyes were usually kept stationary on the same passage of the text, both in silent and oral reading. This patient group hardly ever showed the tendency to drive the eyes in minisaccades over the lines. There was normally no disintegration of the sac-

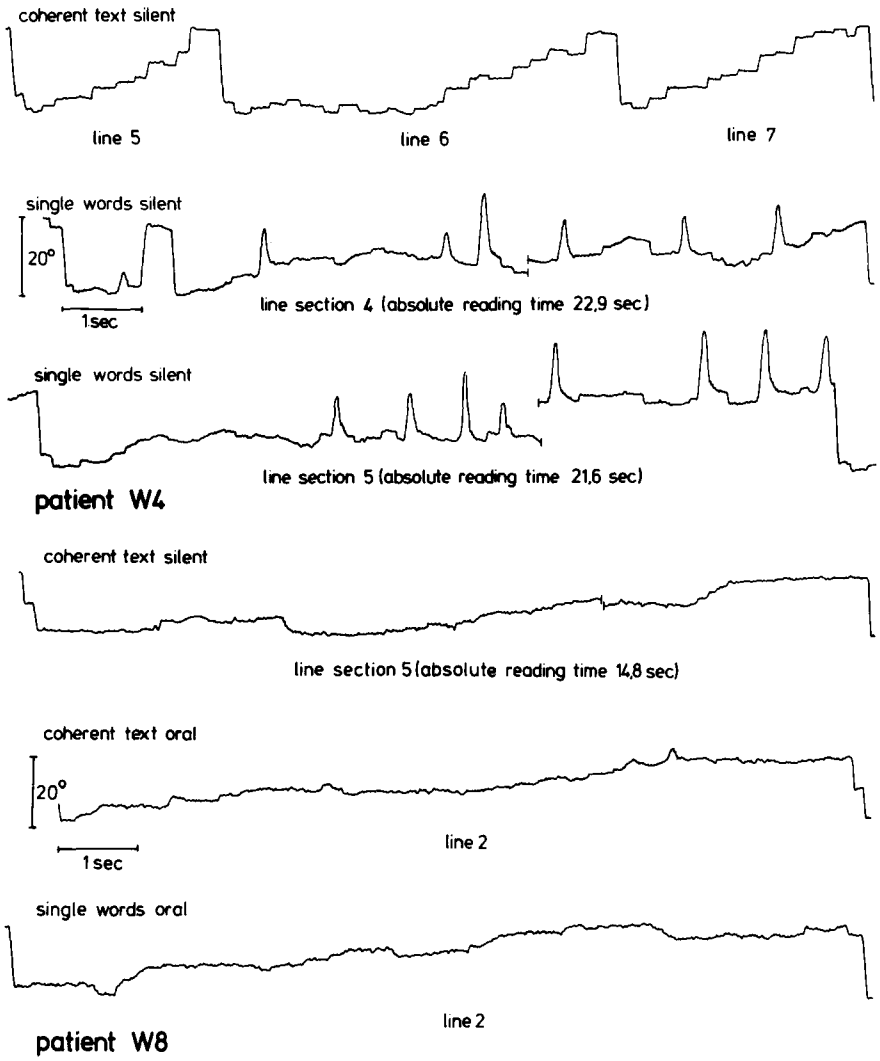

Fig. 4. Sections of the original eye movement recordings during reading in two patients (W 4, W 8) with Wernicke's aphasia

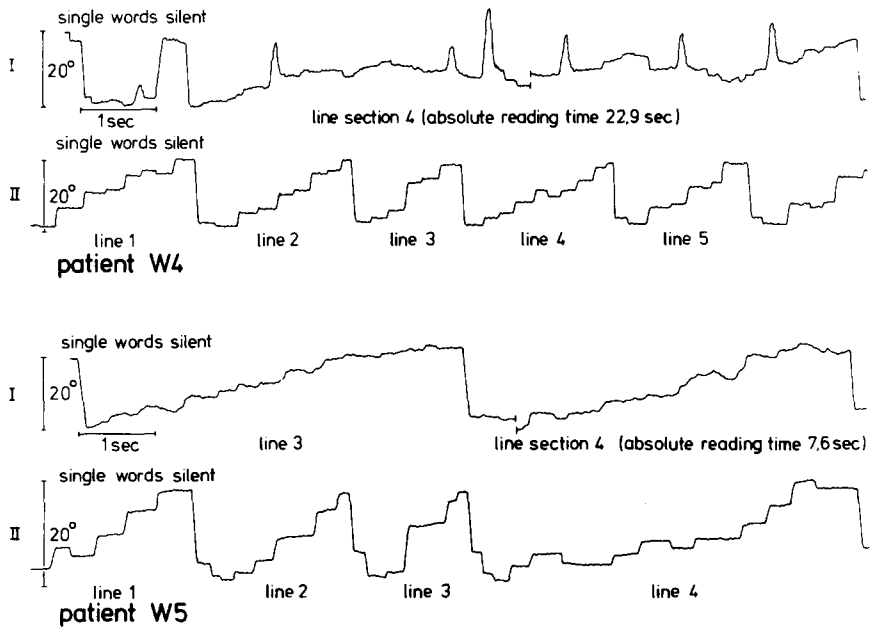

Fig. 5. Sections of the original eye movement recordings during reading in two patients (W 4, W 5) with Wernicke's aphasia (I) and after the decline of the speech disorders (II). By patient W 4 the time between recording I and II was 17 days, by patient W 5 16 days

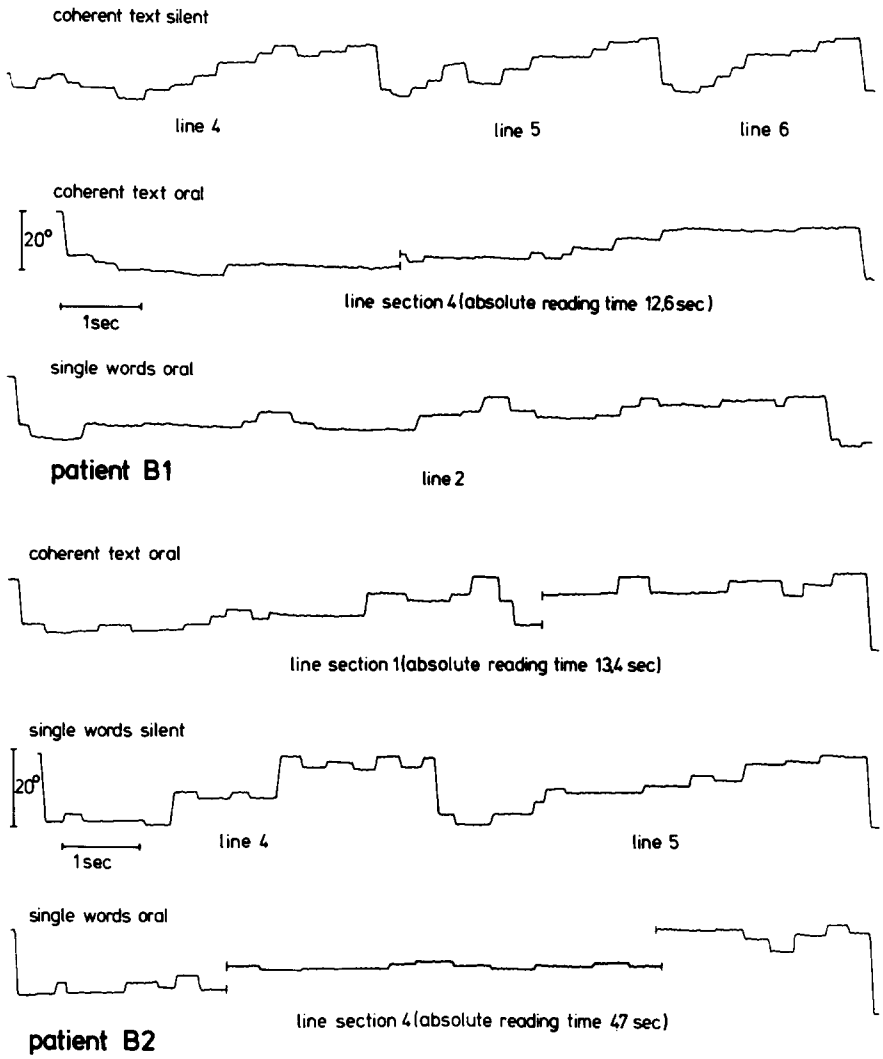

Fig. 6. Sections of the original eye movement recordings during reading in two patients (B 1, B 2) with Broca's aphasia

cadic pattern and fixation periods, and the saccades could be well recognized in the majority of these patients, although they demonstrated clearly altered saccadic reading patterns.

There was a discrepancy in the reading patterns between silent and oral reading. Clearly pathologically altered saccadic reading patterns during silent reading (e.g. Fig. 6, patient B 2) and patterns that were at least similar to the reading behaviour of unskilled normal readers could be observed (e.g. Fig. 6, patient B 1). On the other hand, during oral reading the saccadic structures and consequently the number of fixations, regressions and reading times in Broca's aphasics moved into pathological values with a characteristic increase of the fixation times. Occasionally there were fixation periods with a duration of several seconds, where the eyes remained on the same fixation point or moved only slightly forward and backward (e.g. Fig. 6, patient B 2; single words oral, line 4).

Quantitative Aspects

Fixations. The number of fixations, regressions and reading times during silent and oral reading of all examined patients were compared to the control group's data. Figure 7 gives the number of fixations, the double line indicating the contour of the histograms of the normal subjects. Patients with Wernicke's aphasia who demonstrated a partial or complete disintegration of the saccadic structure are illustrated on the dotted part of the abscissa without an exact value: in these patients it was impossible to distinguish small and smallest saccades from the fixation periods and to determine precise values.

Figure 7 demonstrates that 90% of the patients investigated were outside the range of normals. The patients with anomic aphasia differed from the mean value of the group of normals in 20% to 40% of cases. Some of the patients with Wernicke's aphasia showed evident differences in reading the two experimental texts; on the other hand, there were only small shifts between silent and oral reading of the same text. All numbers of fixations of patients with Broca's aphasia exhibited great differences between silent and oral reading of the same text.

Regressions. The number of regressions in patients with anomic aphasia did not differ principally from that of normals, but was situated in the upper distribution region of the group of normal subjects.

If we take into account those patients whose saccadic structures could be analysed exactly, the number of regressions in patients with Wernicke's aphasia was approximately two or threefold the mean value in the normal group.

During silent reading Broca's aphasics reached numbers of regressions which were similar to those of Wernicke's aphasics; during the oral reading attempt an obvious increase of the

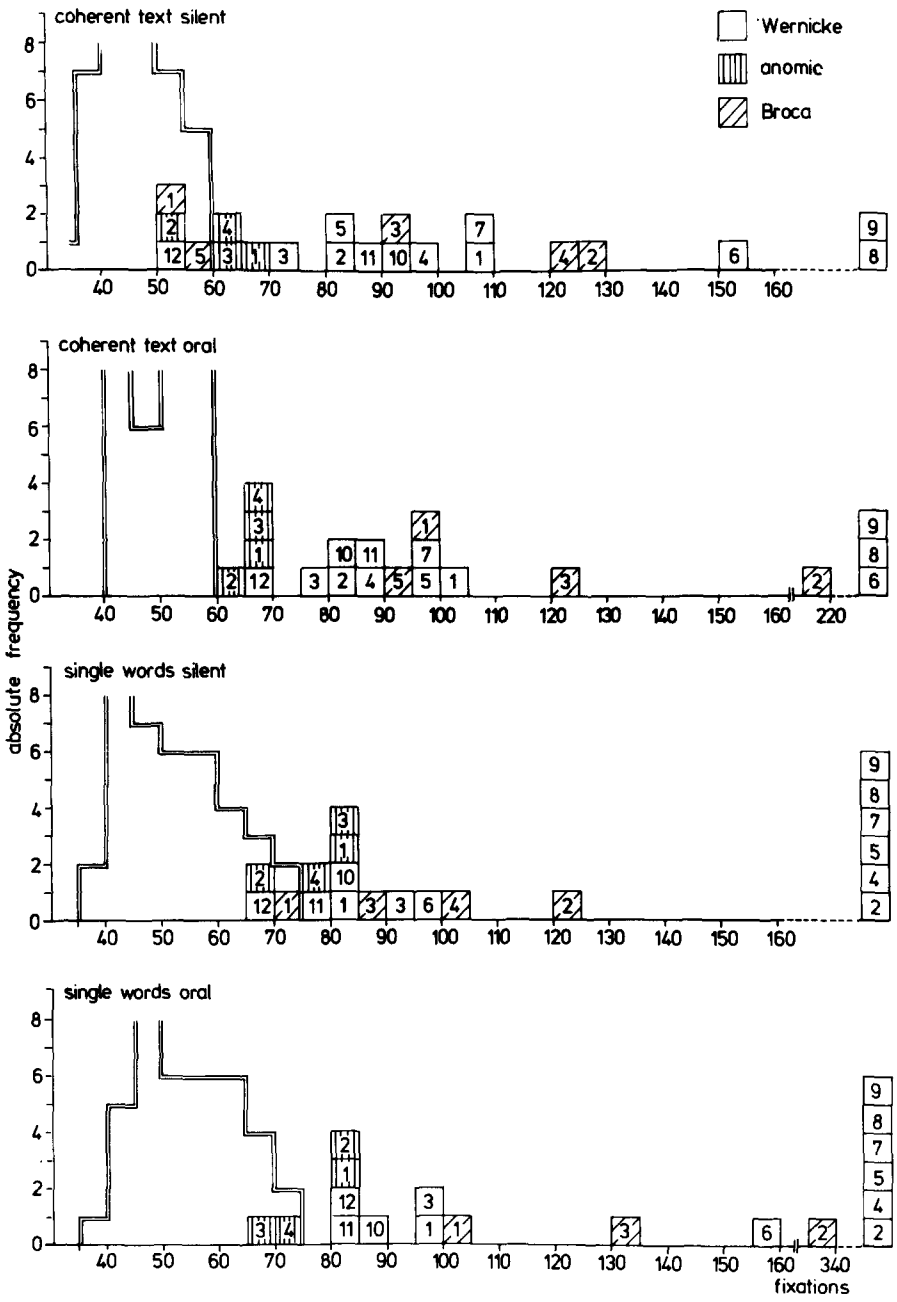

Fig. 7. Comparison of the number of fixations of all examined patients (one square represents one patient's value) to the data of the normal readers. The double line indicates the contour of the histograms of the normal subjects. The numbers per square correspond to the numbers of the patients in Table 1. Patients with Wernicke's aphasia who demonstrated a partial or complete disintegration of the saccadic structure are illustrated on the dotted part of the abscissa without an exact value

regressions was observed. If the number of regressions is related to the fixations registered, then some Broca's aphasics showed during oral reading one return step for two or three fixations. This relationship is not true for Wernicke's aphasics with analysable saccadic structures.

Reading time. A considerable number of patients reached reading times which were either within the limits of the group of normals or at least in the borderline range. Patients with anomic aphasia always belonged to this group. Changing from silent to oral reading Broca's aphasics needed two to four times more reading time. In the other groups of patients no uniform tendencies were observed. Investigating the relation between the total reading time and the necessary number of fixations, Broca's aphasics showed an increase of the average fixation time of approximately 40% from silent to oral reading. During oral reading all Broca's aphasics reached average fixation times of 450–650 ms: their average fixation times during oral reading were thus nearly twice as large as those in the other patient groups.

Discussion

Patients with various aphasic syndromes developed different internal strategies of saccadic construction. Patients with Wernicke's aphasia showed increasing difficulty in overcoming the text with a tendency to make smaller leaps over the line, with almost a complete disintegration of the saccadic structure. The saccadic pattern in Broca's aphasics was clearly better preserved. During oral reading there was a characteristic increase in fixation times and number of regressions.

The number of fixations and regressions and reading times in patients with Broca's or Wernicke's aphasia scattered con-

siderably (Fig. 7). This is especially true for patients with Wernicke's aphasia; some of them obviously "ran over" the experimental text so that the reading times and fixations and regressions were rather low. Patients with a completely disintegrated saccadic structure did not understand the texts any more. This was confirmed by the control of the text comprehension of these patients. The majority of them belonged to the group of Wernicke patients with very low capacities in all speech modalities, although text comprehension in Wernicke patients with a fairly well preserved saccadic structure was limited to a high degree. Comprehension of parts of subunits of the text obviously still existed but comprehension of the text contents as a whole was clearly disturbed.

When compared to the Wernicke's aphasics, the Broca's aphasics, however, attempted to read the experimental texts correctly. During oral reading the pathological values of fixations, regressions and reading times are comprehensible. Regarding the strategy of reading, it seems that the readers with Broca's aphasia again and again endeavoured to produce a "speech output", even after repeated failures. One could view this attitude as "motor waiting and searching behaviour". This can be related to an extremely distorted "eye voice span" (Buswell 1920): because of their disturbed speech production, Broca's aphasics might be especially susceptible to visually progressing too far during the repeated attempt to "articulate" a part of the text orally. They were forced again and again by regressions to approach parts of the same text anew. Consequently Broca's aphasics belonged to the group of patients with the greatest number of regressions during oral reading. They also took the lead in regard to the fixation times during oral reading, whereas in silent reading Broca's showed lower reading times. The altered saccadic pattern during silent reading also indicated that not only is the "expression" disturbed but also the "reception". The saccadic structure during silent reading of patients with Broca's aphasia evidently proved to be dependent on the extent of the receptive disorder. With an increase of the receptive part of the disorder the alterations in the reading pattern also increased during silent reading.

One would expect the smallest variance in the number of fixations, regressions and reading times in patients with anomic aphasia due to the nature of this aphasic syndrome. During reading this group of patients is the least disturbed by their linguistic deficiency: the number of fixations in fact reached only slightly increased values, and the number of regressions and reading times were within the range of the control group.

The patients with anomic aphasia and a saccadic structure similar to the standard readers barely had a lower word and sentence comprehension.

Saccadic eye movements belong to the group of ballistic target movements. Before the saccade occurs, the decision for a release of a movement and the programme for the movement (amplitude) have to be defined. After the start of the saccade its amplitude cannot be further altered (Westheimer 1954) even for a sudden change in the reading condition. We can take for granted that the tasks of the cortex concerning saccadic construction consist of analysing, selecting, and judging visual target area, meaning that an initial "programme" for the generation of the saccadic amplitude must be developed and elaborated at a cortical level. For the reading process some assumptions have to be made: during the development of the "programme" and after the performance of each saccade the speech and reading centres have to give information to the cortical oculomotor fields about text reception and processing and about expectations concerning the following text. Simultaneous to this flow of information decisions about the precise eye guidance have to be transmitted to the brain stem and cerebellum from where the final saccade generation is organized.

Even though numerous experimental details have been obtained concerning the functional meaning of various cortical oculomotor fields (Bizzi 1968; Mountcastle et al. 1975; Robinson and Goldberg 1977; Lynch et al. 1977; Robinson et al. 1978; for a review see Robinson 1981), a definite statement about individual performances and functions of the different oculomotor fields cannot yet be given.

All theories and models of eye movement control during reading developed in the past came from experimental psychology (Rayner and McConkie 1976). In recent experimental work, Rayner and Pollatsek (1981) dealt with a comparison of five possible eye guidance models during reading, orienting on models which had been developed earlier: *global control models* (the eyes are driven in a regular pattern independent from the process of reading which is just being performed), *current fixation control models* (the decisions on how long the eyes are kept in a certain fixation position, when and where they move further on, are completely dependent on the actual fixation phases and are taken exclusively within this phase), *buffer control models* (the saccadic structure is controlled by means of a cognitive buffer), *mixed control models* (the decisions on when a new saccade is introduced during a fixation phase and where the eyes are driven by means of this saccade are partly made by the information during the actual fixation phase and partly by the context and by the information which have been accumulated in previous fixation phases), *direct control* (there is a dependence of the length of a fixation phase or the length of the following saccades on the information given during this fixation—here current fixation control and mixed control models are combined by direct control). Rayner's results stress the preeminent importance of mixed control models for eye guidance during reading.

What can our results contribute to the discussion of the organisation of reading saccades? The experimental investigations on aphasic patients show that saccadic strategies have been developed which obviously correspond to the individual speech disorders: the increase of fixations is especially characteristic for the majority of the patients with Wernicke's aphasia. It is obvious that increased smaller saccades are programmed by an internal message about difficulties in text processing and comprehension. This behaviour could be regarded hypothetically as meaningful from a physiological point-of-view, since only a small number of letters or syllables have to be processed at one glimpse. If there is no message of success about the text contextually processed after this change of strategy (this must be true for the majority of patients, because their speech centres are considerably damaged) instructions for even smaller leaps are given until a complete disintegration of the saccadic structure has been achieved. Obviously the eyes are driven from one letter to the other in an attempt to keep the information which has to be processed as small as possible (strategy of small and smallest steps).

In this context the current fixation model could be discussed for the saccadic strategies of the examined Wernicke's aphasics. A processing of the current fixation together with the information of the previous fixation phases and already accu-

mulated textual information such as in the mixed control models seems not to be possible any longer by this group of patients because the reading comprehension on the whole is disturbed. Postulating that the mixed control model fits best for the eye guidance during reading by normals (corresponding to Rayner's results), the Wernicke's aphasics, because of their distinct receptive speech disorders, thus would adapt their saccadic strategy from a "more complex" eye guidance to a "more simple" model.

On the other hand it was noticable that the patients with Broca's aphasia need more time, especially during oral reading, because of their distinct expressive speech disorders. The system adapts to the higher demand on time by a sudden increase in fixation times; the eyes remain at the same fixation point or are kept in the same passage of the text with small forward and return steps (strategy of prolonged fixation phases). In analogy to the normal reader, the saccadic pattern of the examined Broca's aphasics in silent reading fits best with the mixed control model. The receptive speech modalities must also be disturbed to some degree in the Broca's aphasics, but to such a degree so that in our opinion a processing of the current fixation together with the information of the previous fixation phases and already accumulated textual information appears quite possible (possibly analogous to patients with anomic aphasia). For the pathological saccadic patterns during oral reading of the examined Broca's aphasics it can also be assumed that the influence of the current fixation period on the eye guidance dominates.

Refernces

Allen IM (1962) Exaggeration of fixation of gaze. NC Med J 61:101–107

Bizzi E (1968) Discharge of frontal eye field neurons during saccadic and following eye movements in unaesthetized monkeys. Exp Brain Res 6:69–80

Buswell GT (1920) An experimental study of the eye—voice span in reading. Suppl Educ Monogr 17:1–105

Ciuffreda KJ (1983) Saccadic intrusions contributing to reading disability: a case report. Am J Optom Physiol Opt 60:242–249

Ciuffreda KJ, Bahill AT, Kenyon RV, Stark L (1976) Eye movements during reading: Case reports. Am J Optom Physiol Opt 53:389–395

Dossetor DR, Papaioannou J (1975) Dyslexia and eye movements. Lang Speech 18:312–317

Goodglass H, Kaplan E (1972) Assessment of aphasia and related disorders. Lea & Febiger, Philadelphia

Griffin DC, Walton HN, Ives V (1974) Saccades as related to reading disorders. J Learning Disabilities 7:310–316

Heimann JR, Ross AO (1974) Saccadic eye movements and reading difficulties. J Abnorm Child Psychol 2:53–61

Heller D (1979) Eye movements in dyslexic and normally reading children. Z Psychol 187:106–115

Holmes G (1938) The cerebral integration of the ocular movements. Br Med J II:107–112

Huber W, Weniger D, Poeck K, Willmes K (1980) Der Aachener Aphasie Test. Aufbau und Überprüfung der Konstruktion. Nervenarzt 51:475–482

Huber W, Poeck K, Weniger D, Willmes K (1983) Der Aachener Aphasie Test (AAT). Hogrefe, Göttingen

Just MA, Carpenter PA (1980) A theory of reading: From eye fixations to comprehension. Psychol Rev 87:329–354

Lynch JC, Mountcastle VB, Talbot WH, Yin TCT (1977) Parietal lobe mechanisms for directed visual attention. J Neurophysiol 40:362–389

Mountcastle VB, Lynch JC, Georgopoulos A, Sakata H, Acuna C (1975) Posterior parietal association cortex of the monkey: command functions for operations within extrapersonal space. J Neurophysiol 38:871–908

Nathanson M, Bergman PS, Bender MB (1953) Visual disturbances as the result of nystagmus on direct downward gaze. Arch Neurol Psychiatr 69:427–435

Pavlides GT (1981) Do eye movements hold the key to dyslexia? Neuropsychologia 19(1):57–64

Prechtl HFR, Stemmer JC (1959) Ein choreatiformes Syndrom bei Kindern. Wien Med Wochenschr 109:461–463

Rayner K, McConkie GW (1976) What guides a reader's eye movements? Vision Res 16:829–837

Rayner K, Pollatsek A (1981) Eye movement control during reading: Evidence for direct control. Q J Exp Psychol 33A:351–373

Robinson DA (1981) Control of eye movements. In: Brookhart JM, Mountcastle VB, Brooks VB, Geiger SR (eds) Handbook of Physiology, Section 1, Vol II. Bethesda, Md: American Physiological Society, pp 1275–1320

Robinson DL, Goldberg ME (1977) Visual properties of neurons in the parietal cortex of the awake monkey. Invest Ophthalmol Vis Sci [Suppl] 16:156

Robinson DL, Goldberg ME, Stanton GB (1978) Parietal association cortex in the primate: Sensory mechanisms and behavioral modulations. J Neurophysiol 41:910–932

Romero R (1982) Analysis of sequential saccadic eye movements during the act of reading: comparison between normal and dyslexic subjects. Arch Invest Med 13:185–189

Rubino CA, Minden HA (1973) An analysis of eye movements in children with a reading disability. Cortex 9:217–220

Weniger D, Willmes K, Huber W, Poeck K (1981) Der Aachener Aphasie Test. Reliabilität und Auswertungsobjektivität. Nervenarzt 52:269–277

Willmes K, Poeck K, Weniger D, Huber W (1980) Der Aachener Aphasie Test. Differentiale Validität. Nervenarzt 51:563–560

Westheimer GH (1954) Eye movement responses to horizontally moving visual stimulus. Arch Ophthalmol 52:932–943

Zangwill OL, Blakemore C (1972) Dyslexia: Reversal of eye-movements during reading. Neuropsychologia 10:371–373

Received March 30, 1984