Facets of Dyslexia and its Remediation
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EYE AND HEAD READING PATH IN HEMIANOPIC PATIENTS

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INTRODUCTION

In 1881, Mauthner first described reading disorders in hemianopic patients. He found that patients with left homonymous hemianopia had difficulties in finding the beginning of a line. Syllables and whole words were omitted while the following part of the lines were read correctly. Patients with right homonymous hemianopia were not able to read continuously. These findings were confirmed by Willbrandt in 1907. Additionally, he reported similar deficits in patients with paracentral scotomas, i.e. scotomas that occur next to the fovea. Both authors pointed out that a right hemifield loss disturbs the reading behaviour more than a left hemifield loss. Poppelreuter (1917) and Mackensen (1962) supported the theory that a disturbed reading coordination was responsible for these reading disorders. Poppelreuter emphazised the value of compensatory strategies for guiding visual behaviour in everyday situations. Mackensen (1962) and Zihl, Krischer & Meissen (1984) stated clearly that an adequate level of reading may be achieved, when a residual hemifield of between three and five degree on the horizontal meridian remains. Global reading time, however, remains higher in these cases. Eye movements of patients with a residual hemifield of less than three degrees are mostly disorganized. Here, the classical staircase pattern, characterized by a relatively symmetrical exchange between fixation pauses and saccades from left to right, appears to be disintegrated (Gassel & Williams, 1963, Eber, Metz-Lutz, Bataillard & Collard, 1986). With perimetric saccade training Zihl (1981) and Zihl & von Cramon (1985, 1986) obtained a persistent relocation of the visual field border. There remains, however, an ongoing controversy as to whether specific training can restore vision (Campion, Latto & Smith, 1983, Balliet, Blood & Bach-y-Rita, 1985, 1986, Zihl & von Cramon, 1986).

In hemianopic patients visual information is available only in one hemifield, thus to compensate for hemianopia it is necessary to have appropriate ocular motor strategies for efficient use of the remaining half of the visual field (Poppelreuter, 1917; Mackensen, 1962; Meienberg, Zangemeister, Rosenberg, Hoyt & Stark, 1981, 1988, Zangemeister et al., 1982, 1983, 1986). To some extent, it is possible to learn to compensate for this visual handicap. Zangemeister, Meienberg, Stark & Hoyt (1981, 1982, 1983) found distinct adaptive ocular motor strategies in hemianopic patients to search for objects in their blind hemifield. They used a horizontal target, a small green light spot, the appearance of which was predictable or randomized in amplitude and time. In this artificial experimental situation the subjects employed a consistent set of presumably unconscious compensatory eye movement strategies. So far no study has reported on adaptive ocular motor strategies used in reading by hemianopic patients, including short adaptation and transient learning. With respect to a possible positive effect of head movements Zangemeister et al., (1982) pointed out that hemianopic patients often simplify search and fixation strategies by eliminating head movements.

The purpose of the present study was to extend these previous studies and to analyse the qualitative and quantitative changes of the ocular motor scanning behaviour during reading i.e. the reading path. Our hemianopic patients had to read aloud four different short texts as accurately and quickly as possible. First, in an experiment where the head was fixed and second, in a more natural head-free-to-move condition. In one of the four texts presented the distances between the letters and words were decreased. The question was whether this would have a positive or a negative effect on reading behaviour and comprehension. So far we have analysed the reading path for different strategies with respect to the efficiency of reading time and accuracy.

METHODS

Subjects

The experimental group was composed of four male patients with homonymous hemianopia due to ischemic strokes in the occipital region (mean age: 57.5 years, range 42 to 73) and four young (26 +/-3 years) healthy male subjects: two patients with incomplete homonymous hemianopia (Figures 1a,b) and one patient with a complete, dense right and left homonymous hemianopia. All subjects had undergone a complete neuropsychological assessment, which included the following tests: Mosaic and Figure Test (Hawie), Line Bisection Test, Cross Out test, Benton test (form c, instruction a), several option vocabulary Test, Body Scheme Test, remembering and recalling of twelve different geometrical figures, spontaneous drawing of a face, a sunflower and a clock. In these tests no patient showed any sign of inattention that could be attributed to neglect phenomena.

The intelligence of all patients was at an average level. Visual acuity examination, perimetry and CCT scanning confirmed the clinical investigations, with CCTs showing discrete occipital lesions in all patients. With respect to acuity, all patients were fully sight corrected. Time from the acute event to the day of EOG recordings varied between twelve days to one year. The patients did not participate in any special visual rehabilitation training. The four young normal subjects without any neurological diseases or reading disorders were recorded as a comparison group.

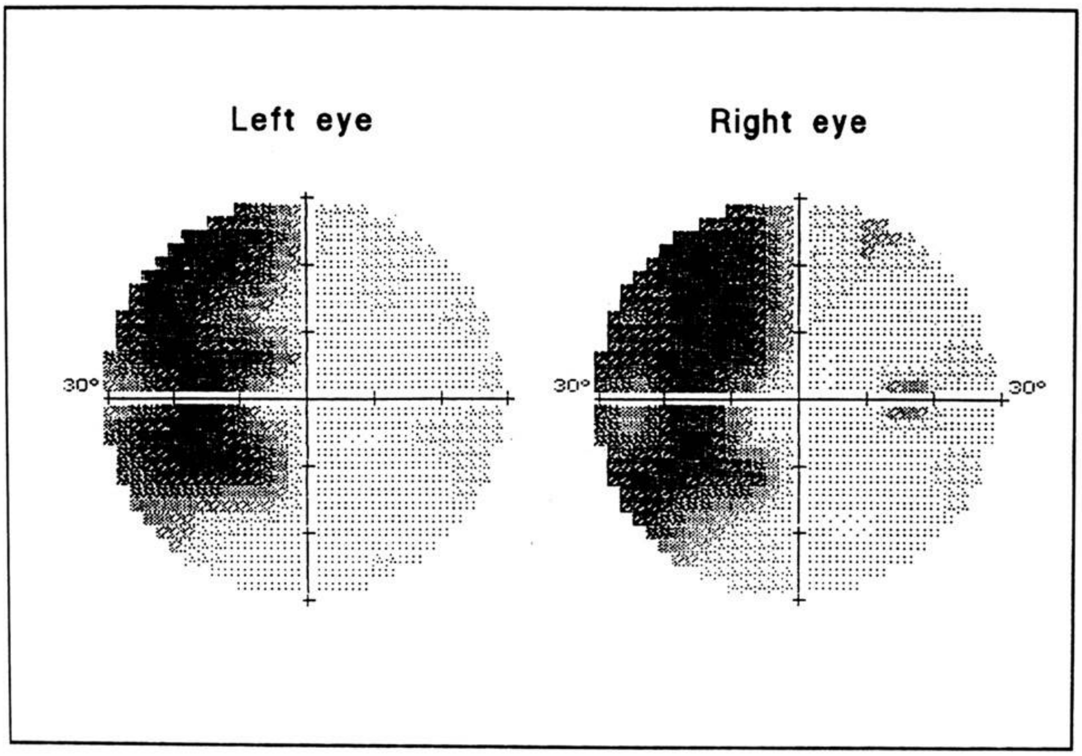
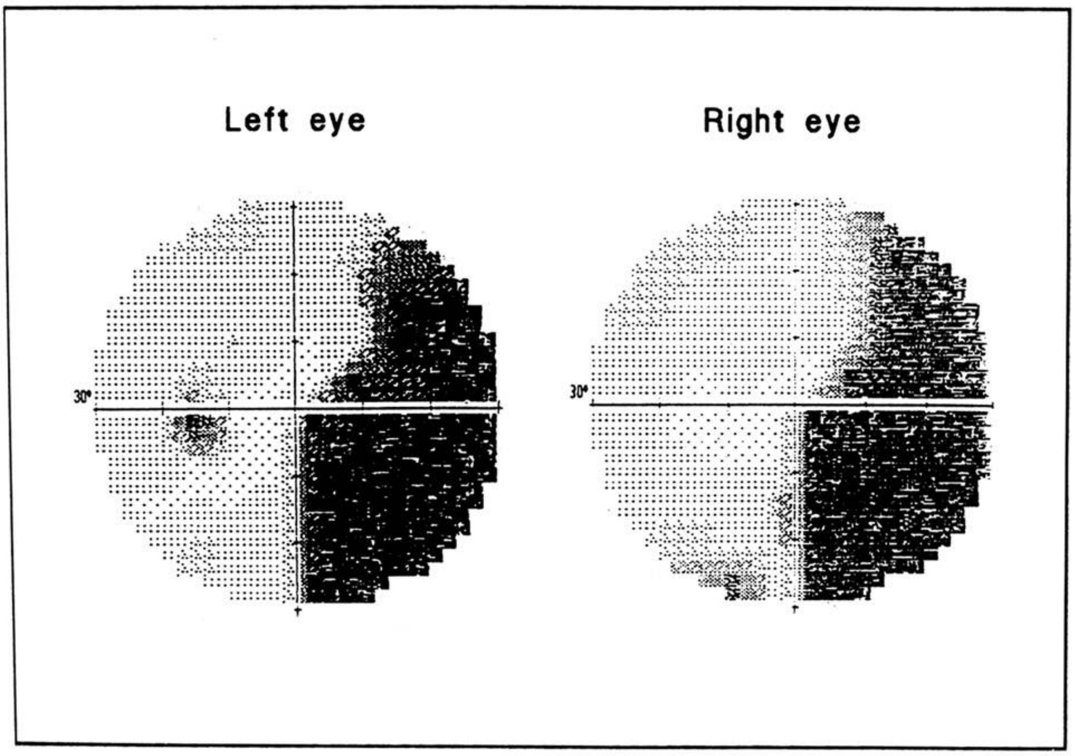


FIG. 1. Visual fields of left & right eyes of two well adapted patients with incomplete left hemianopia with five degree sparing (1a) & incomplete right hemianopia (1b).



Apparatus

Subjects were seated on a dental chair in front of a white screen. The room was darkened and at least ten minutes were permitted for eye adaptation before any recording started. Horizontal binocular and vertical monocular DC EOG signals (analogue filtered at 10 Hz) were recorded on-line with an 80286 12 CPU computer, running at 12 Mhz. Horizontal recordings were consistently linear within the range of eye movements examined, that were always coordinated, i.e. showed the same velocities and position. Additionally, a high resolution ceramic potentiometer and a high resolution torquemeter for horizontal head rotations and torque recordings were used. The distance between the screen and the head rotation axis was 1.2 m. Sampling rate of the system was 25 Hz DC. Texts were projected on a white screen in front of the subjects. Text borders varied between 24 to 26 degrees to the left, and 26 to 28 degrees to the right. Size of characters and spaces within words was 1.5 degrees, between words 4 degrees. The vertical size of the text was ± 15 degrees.

Several calibrations were made before and after each reading set. With a specially developed software the text and frame calibrations were presented immediately on-line on the computer screen, such that the electrodes could be replaced if necessary. Overall accuracy of the EOG was estimated to be ± 1 degree horizontally and vertically, ± 0.25 degree for the potentiometer, ± 0.01 relative torque units for the torquemeter. One relative torque unit equals 70 newton micrometer.

Subjects had to read the texts aloud and they were asked to read them as accurately and as quickly as possible. Additionally, an acoustical back up was recorded for control reasons. We used eight different texts, that were not simple but also not too easy to comprehend. In a low letter density mode they had 28 letters per line, in high density mode they had 46 letters per line. The following text gives an example of a typical short text:

Es treibt mich aus dem Zimmer hinaus,
ich muß in den Straßen schlendern:
die Seele sucht eine Seele und späht
nach zärtlich weißen Gewändern.

RESULTS

Normal Subjects

The reading eye movements of the normal subjects were in accordance with the classical `staircase pattern', as demonstrated in Fig. 2 by time functions of the vertical and horizontal EOG (upper) and head horizontal torque (lower). In Fig. 2 the eye trace and

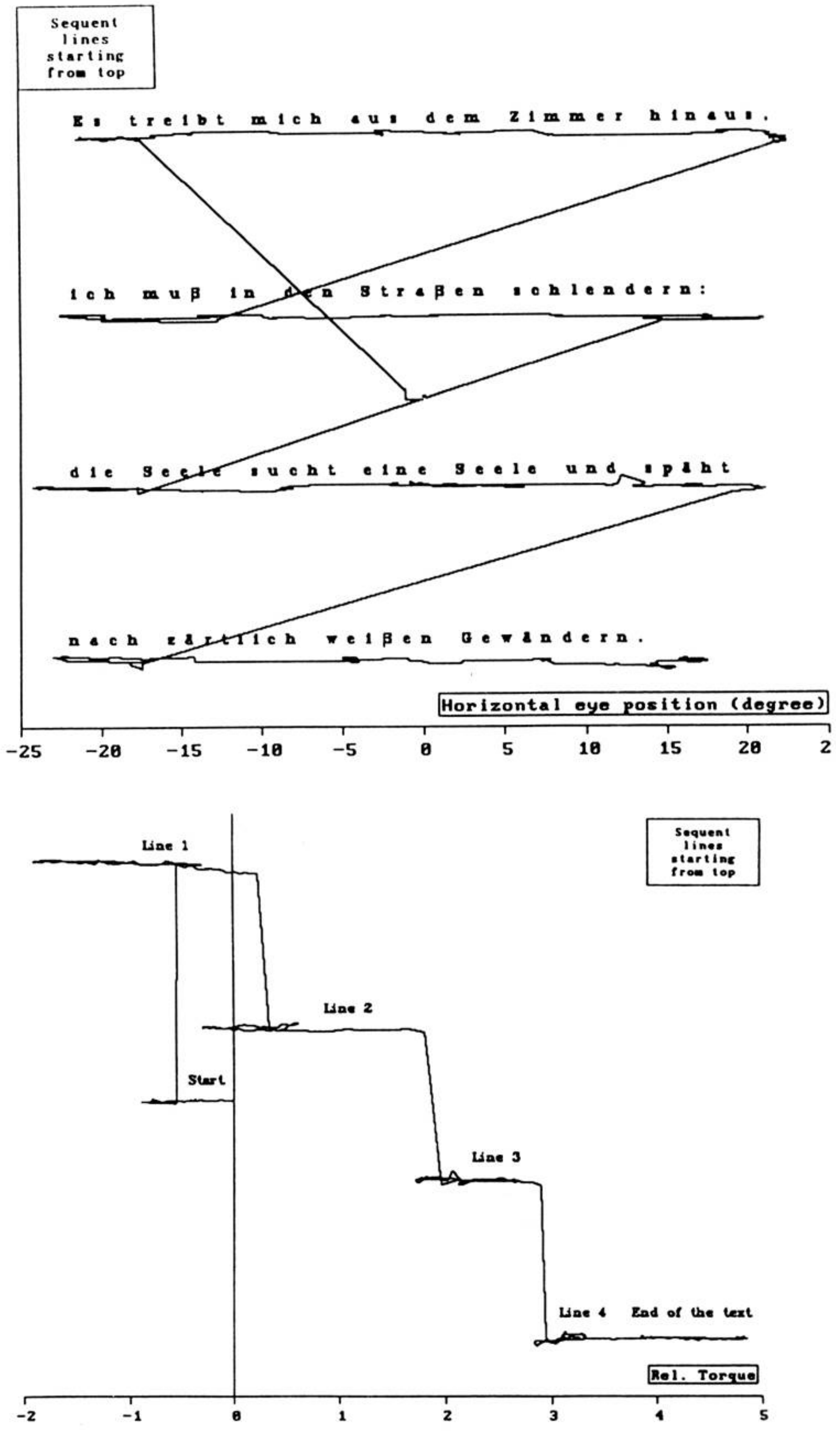
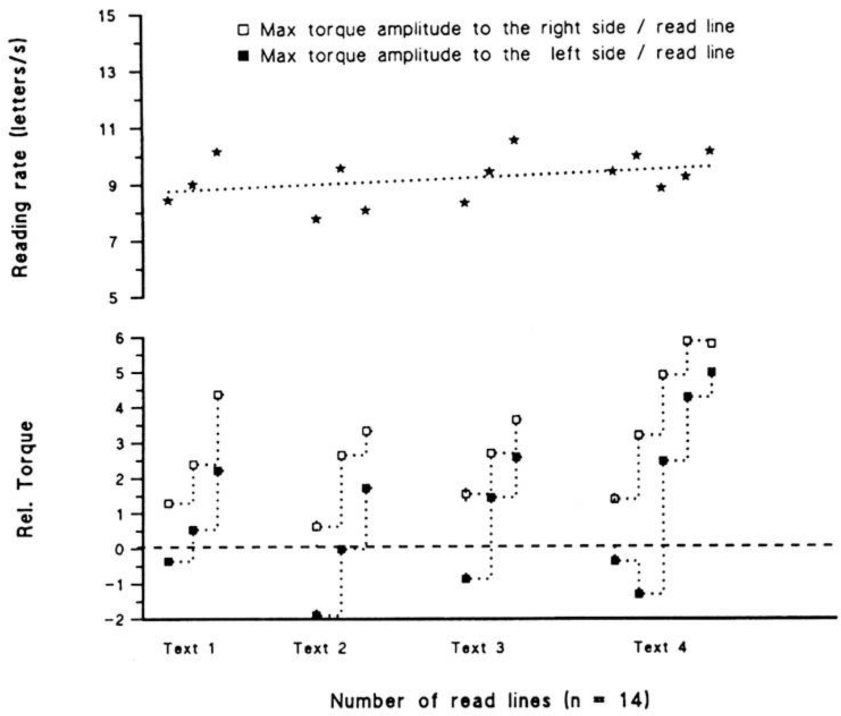


FIG. 2. Normal subject reading 4 lines of text in 2 fixed head condition, starting at the centre (dot). Upper: Left to right reading path: Vertical and horizontal eye movements (time functions in degree) plotted successively. Lower: Horizontal head torque during reading path. Ordinate: Lines from upper to lower. Abscissa: Relative horizontal torque.



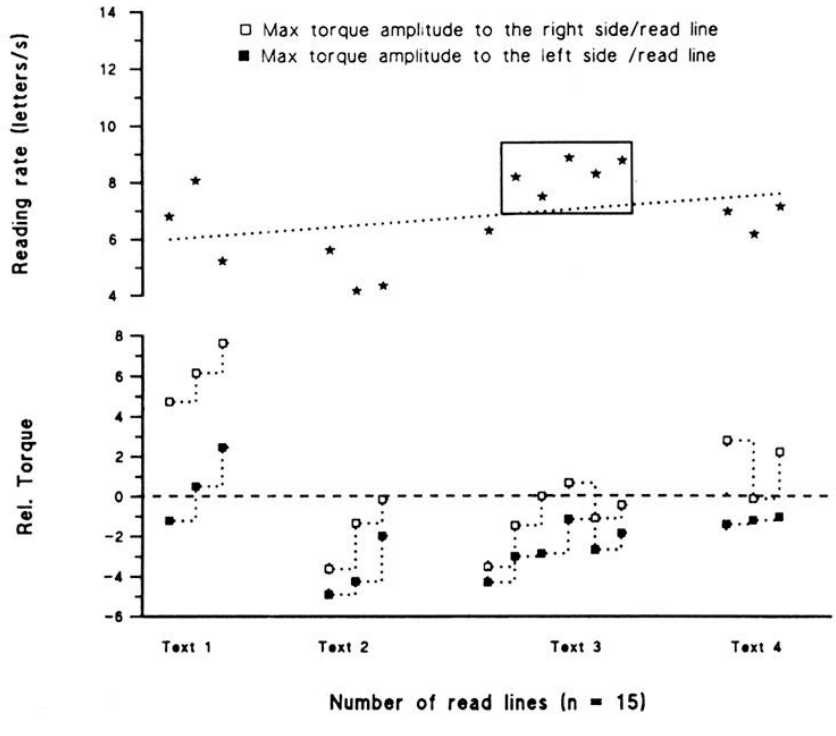


FIG. 3a. Upper: Head fixed condition of a normal subject reading different texts successively. Lower: Same procedure and description for the well adapted patient with right homonymous hemianopia. Note: In text three the distances between letters are reduced. The reading rate is increased.

typical corresponding horizontal torque pattern of one of the normal subjects reading in the head fixed condition is shown. The subject had an individual touque accentuation to the right side and performed in all texts the same `staircase' torque pattern to the right-hand side. It was characterized by decreasing maximal torque amplitudes to the left side from line to line, and synchronously increasing amplitudes to the right-hand side. The duration of torque to the right-hand side predominated in three out of four texts.

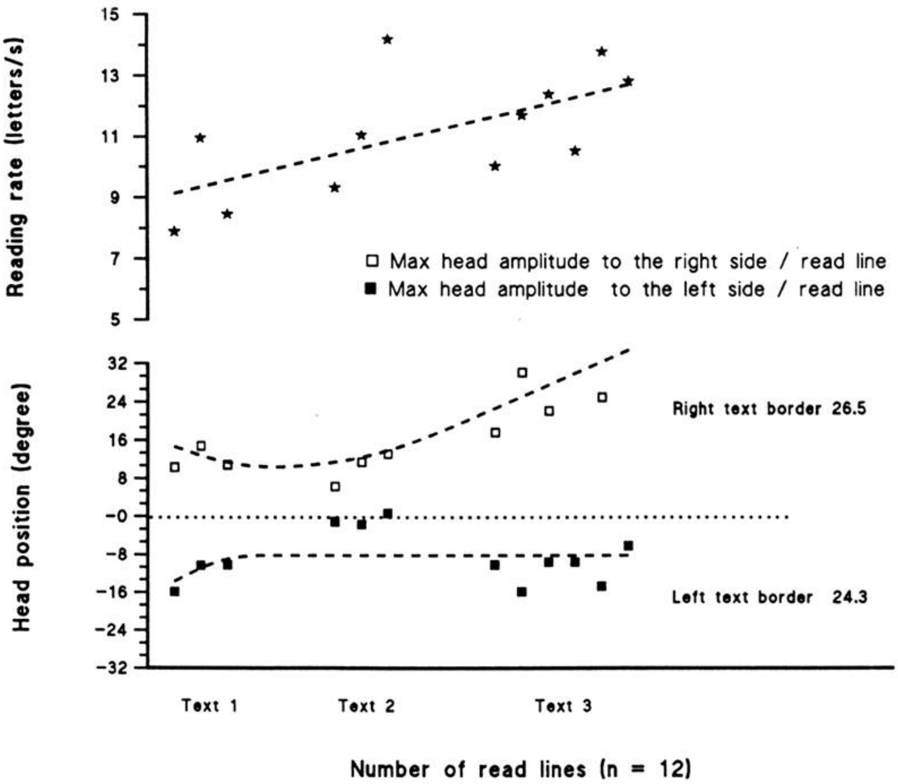


FIG. 3b. Head free condition for a normal subject with reading rate on the upper part and head position in degree as time function in the lower part. Reading rate is increased when the reader employs active and forced horizontal head movements during reading shown through the correlation of increase of head position to the right together with elevated reading rate.

This torque pattern appeared in all texts the same way without any adaptation (Fig. 3a upper). In the more natural head free-to-move situation the healthy readers were able to reduce their global reading time with active and forced head employment (Fig. 3b). Therefore, the mean number of positional fixation pauses (a fixation pause of 60 to 130 msec) was increased, whereas the mean number of lexical fixation pauses (a fixational pause of 200-300 msec) was decreased. Because of this the mean reading rate became faster. In general the mean duration of lexical fixation pauses did not change in texts with decreased spaces between letters and words.

In the head fixed condition, the mean reading rate was rather constant and fluctuated much less than in the hemianopic patients (Fig. 3a upper & lower). This was accompanied by a low number of regressions and a comparatively low global reading time. The constant reading rate generated a synchronous torque pattern (Fig. 3a upper) that appeared in all tested normal subjects to be individually accentuated.

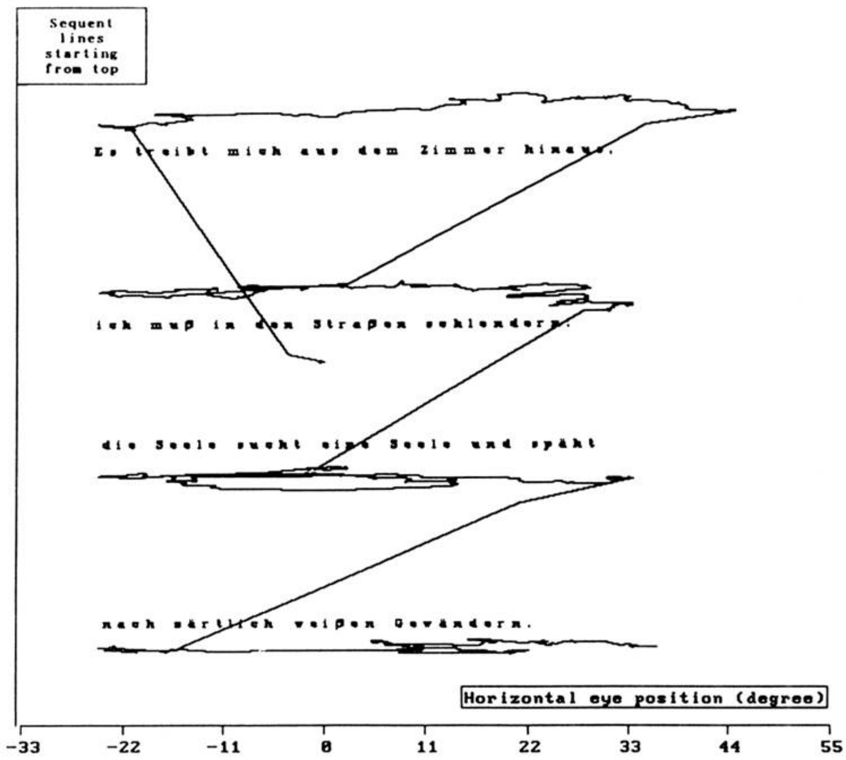
Hemianopic Patients: Ocular Motor Strategies

No patient had participated in any special visual rehabilitation training. The two patients with incomplete homonymous hemianopia (Figs. 1a, b) did not produce any acoustical reading errors. As these two out of the four patients appeared to be better adapted, we describe their ocular motor patterns of adaptation in more detail.

The patient with incomplete right homonymous hemianopia (Fig. 1b) was a 56 years old former policeman, who came along to the investigation with his own car against medical instruction. For two weeks he had regarded his visual field defect to be no longer as disabling. He was the most agile and intelligent subject in the experimental group. Recordings were made three months after his acute event. The subject with incomplete left homonymous hemianopia (Fig. 1a) was a 73 year old self-employed industrialist, who appeared to be very active and motivated in all kinds of rehabilitation training. Recordings were made three weeks after his acute event. Both subjects had developed particular adaptive ocular motor strategies to compensate for their visual handicap.

The patient with right homonymous hemianopia (Figs. 1b, 3a lower, 4) often overshot especially the end of the first line of a text as he looked for the general end of the line and text. In the following line he often changed his strategy and approached the end of the line with small, staircase-like saccades followed by small regressions. We called this the blind hemifield `overshooting' strategy, and the `end of line' detective strategy. In the seeing hemifield the saccadic amplitudes were most often smaller than in the blind hemifield: Because of this we called it 'the saccadic resolution' strategy. The application of the three different reading strategies appeared to be completely interchangeable.

The other right homonymous patient presented a complete, dense right homonymous hemianopia. He employed these strategies only rudimentarily. The `end of line' detective strategy was often employed but much slower in this patient, that is more regressions occurred that were most often inaccurate. Correspondingly, the global reading time was significantly prolonged. Sometimes this patient overshct the end of a line, but obviously he did so unsystematically. The increased number of regressions and the frequent acoustical reading errors mirrored the uncertainty of this patient.



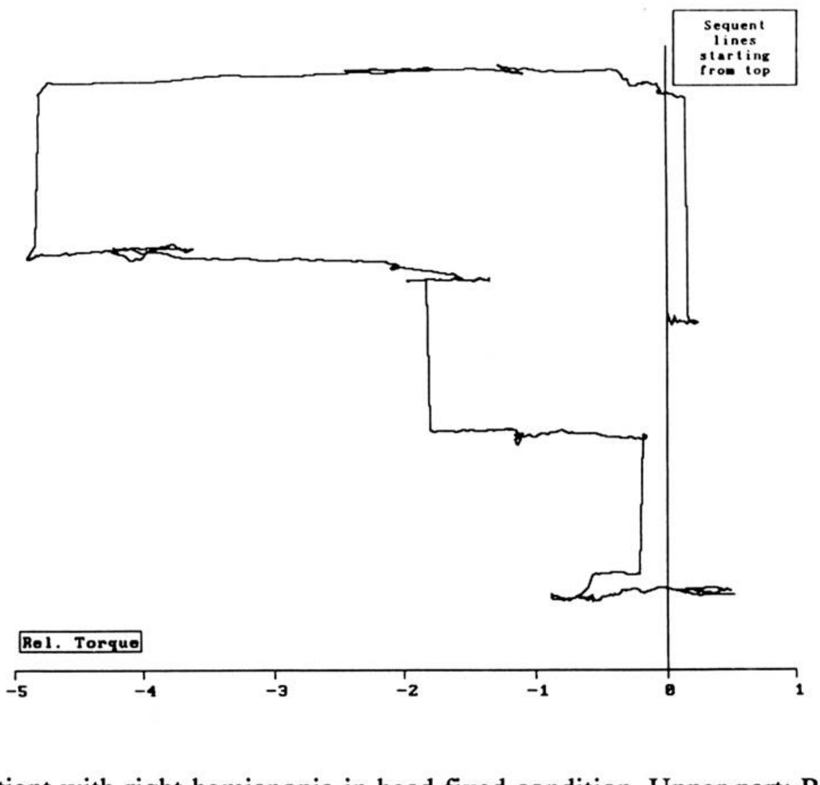


FIG. 4. Patient with right hemianopia in head fixed condition. Upper part: Reading path as in Fig. 2. Lower part: Horizontal head torque during reading path.

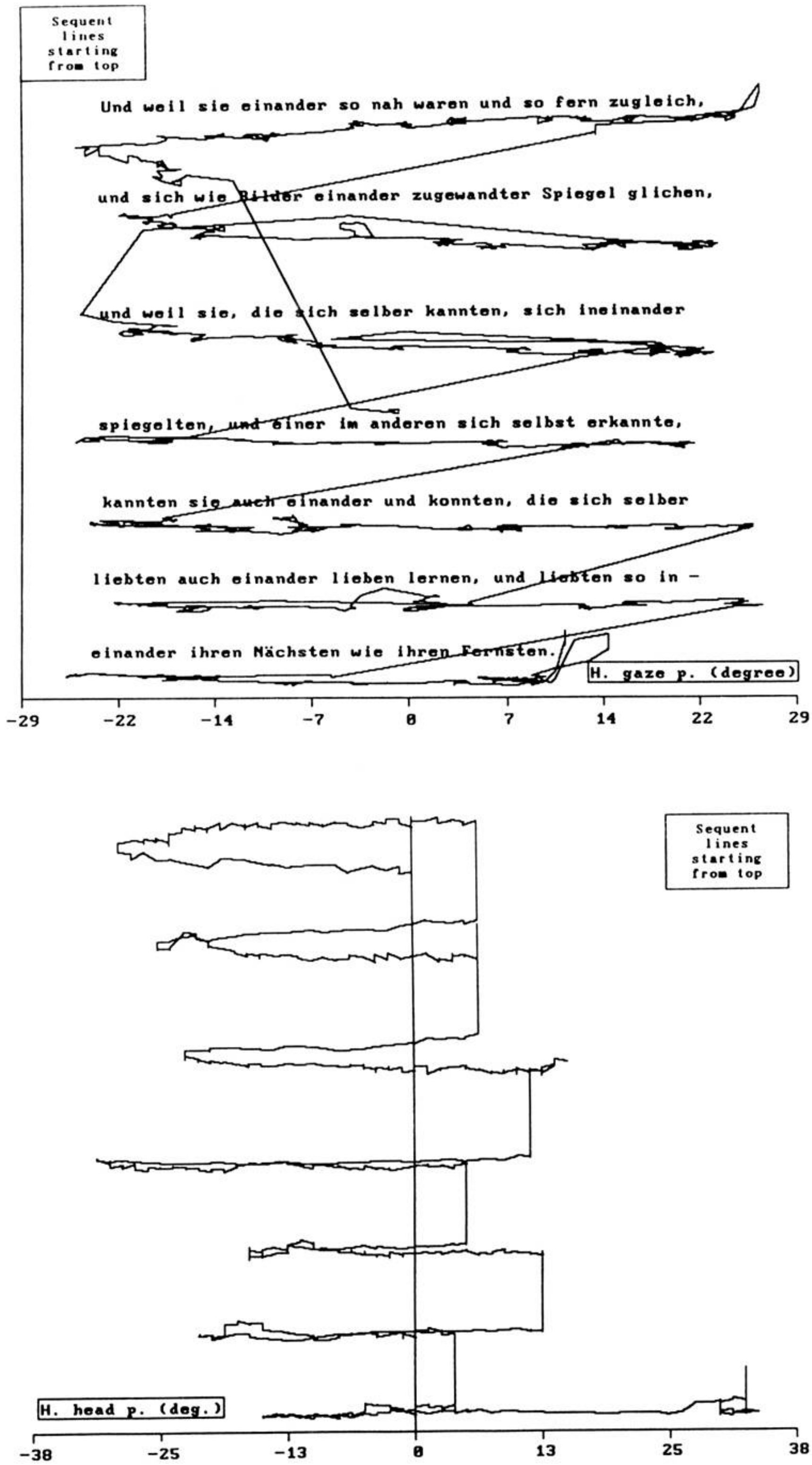


FIG. 5. Patient with left hemianopia in head free-to-move condition. Reading path as in Fig. 2 (gaze defined as sum of horizontal eye movement and horizontal head movement). Lower: Horizontal head movement.

The patient with incomplete left homonymous hemianopia (Fig. 1a) generated a high number of small saccades that were sometimes followed by regressions at the beginning of a line (Fig. 5). Because of this we defined the `beginning of line' detective strategy for patients with left homonymous hemianopia. In some lines there was an accumulation of saccades without regressions at the beginning. The other part of the eye movement pattern was in accordance with the classical `staircase pattern'.

The second left hemianopic patient had a more complete, dense homonymous hemianopia. He was much more insecure and produced multiple acoustical reading errors. During the whole reading path there was an increase of progressive and regressive saccades in this patient. The global reading time was therefore significantly prolonged.

Short Adaptation in Horizontal Head Torque and Free Head Rotations

Both hemianopic subjects with incomplete hemianopia (Figs. 1a, b) and *without* acoustical reading errors demonstrated a high short adaptation that appeared side inverted with respect to the right- and left hemifield loss. In the subject with left homonymous hemianopia (Figs. 1a, 6a) this was most clearly marked. A head accentuation to the blind hemifield predominated in the first two texts. The maximal torque and head amplitudes to the blind left hemifield were mostly enlarged compared with those to the seeing right hemifield. Correspondingly, the duration spent in a left side head position predominated. The relative zero position of the head was shifted into the blind hemifield.

In the texts the maximal amplitudes to the blind hemifield were small compared to amplitudes with direction to the seeing hemifield (Fig. 6a, text 3). The leftwards shifted zero position was changed into primary zero position (Fig. 6a, text 4). In the head fixed condition the percent time of horizontal head torque (Fig. 7) to the seeing hemifield was 95% in the fourth text. In the head-free-to-move condition (Fig. 7) the percentage time of head movements to the right-hand side was 48% in the last text. Evidently, the head movement component was reduced and minimized (Fig. 6a, 8), and the side of attention had changed from the blind hemifield to the seeing hemifield with increased reading time.

The same adaptive behaviour occurred in the well adapted right homonymous patient with incomplete homonymous hemianopia (Fig. 1b, 6b). In both subjects a distinct accentuation of the blind hemifield through the reading stimulus obviously caused a neglect-like phenomenon of the seeing hemifield. After all the reading rate did not increase and global reading time could not be reduced.

The other two less adapted patients did not show this kind of short term adaptation. The patient with the complete, dense right homonymous hemianopia that produced acoustical reading errors did not use his head at all. The less adapted left homonymous

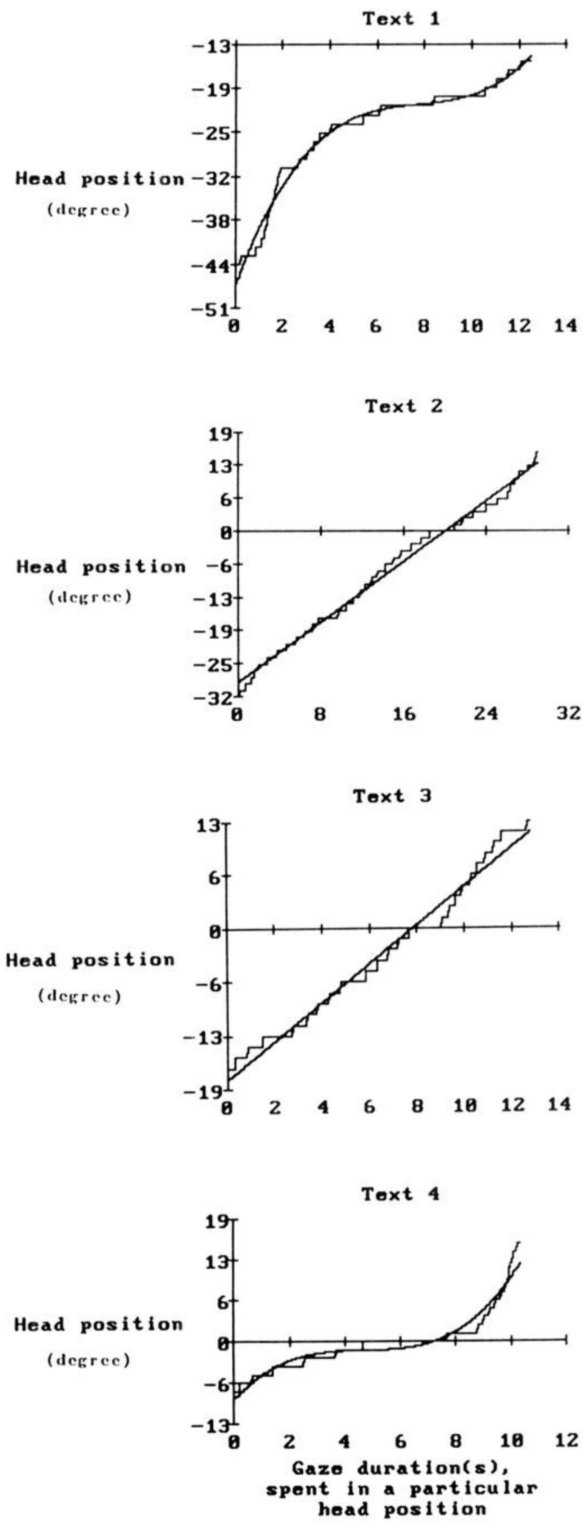


FIG. 6a. Well adapted patient with left homonymous hemianopia reading texts successively in the head free condition. Abscissa: Head position as function of gaze duration spent in a particular head position; head position to the left is negatively displayed, to the right positively displayed.

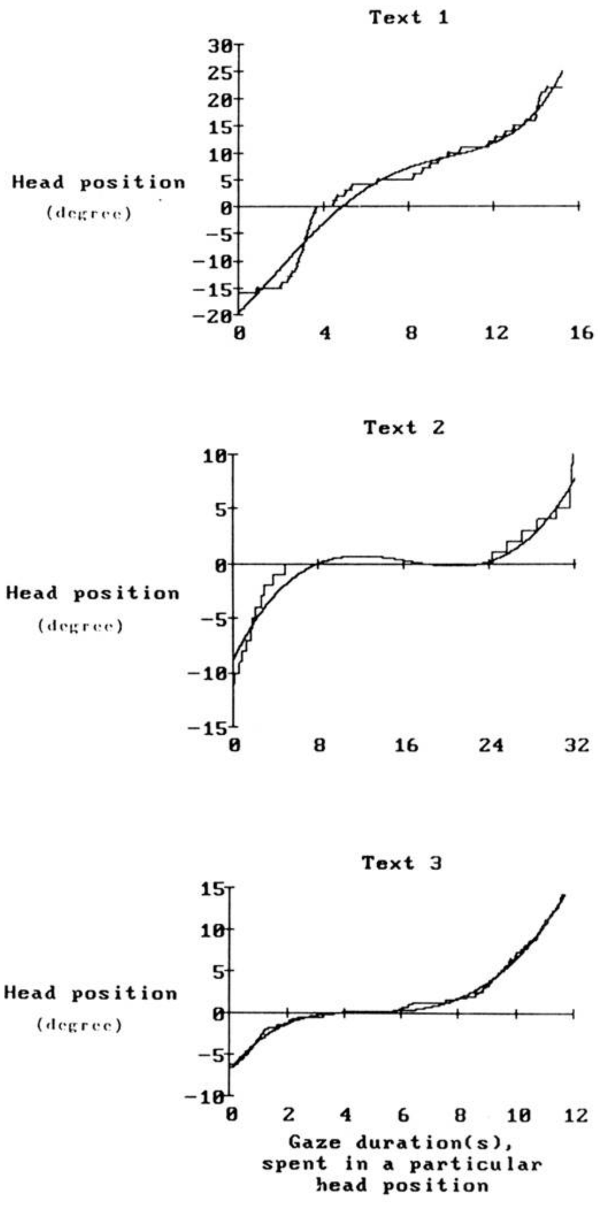


FIG. 6b. Side inverted the same kind of short adaption as in Fig. 6a for the well adapted patient with right homonymous hemianopia.

patient showed a distinct blind hemifield accentuation for all reading paths. The duration from the acute event to the day EOG recordings were made was twelve days in this patient, so it was a very recent lesion. The active head accentuation of the blind hemifield in the head-free-to-move situation had no positive effect on reading accuracy of this patient. On the contrary, the mean number of regressions in the seeing hemifield and the acoustical reading errors were increased.

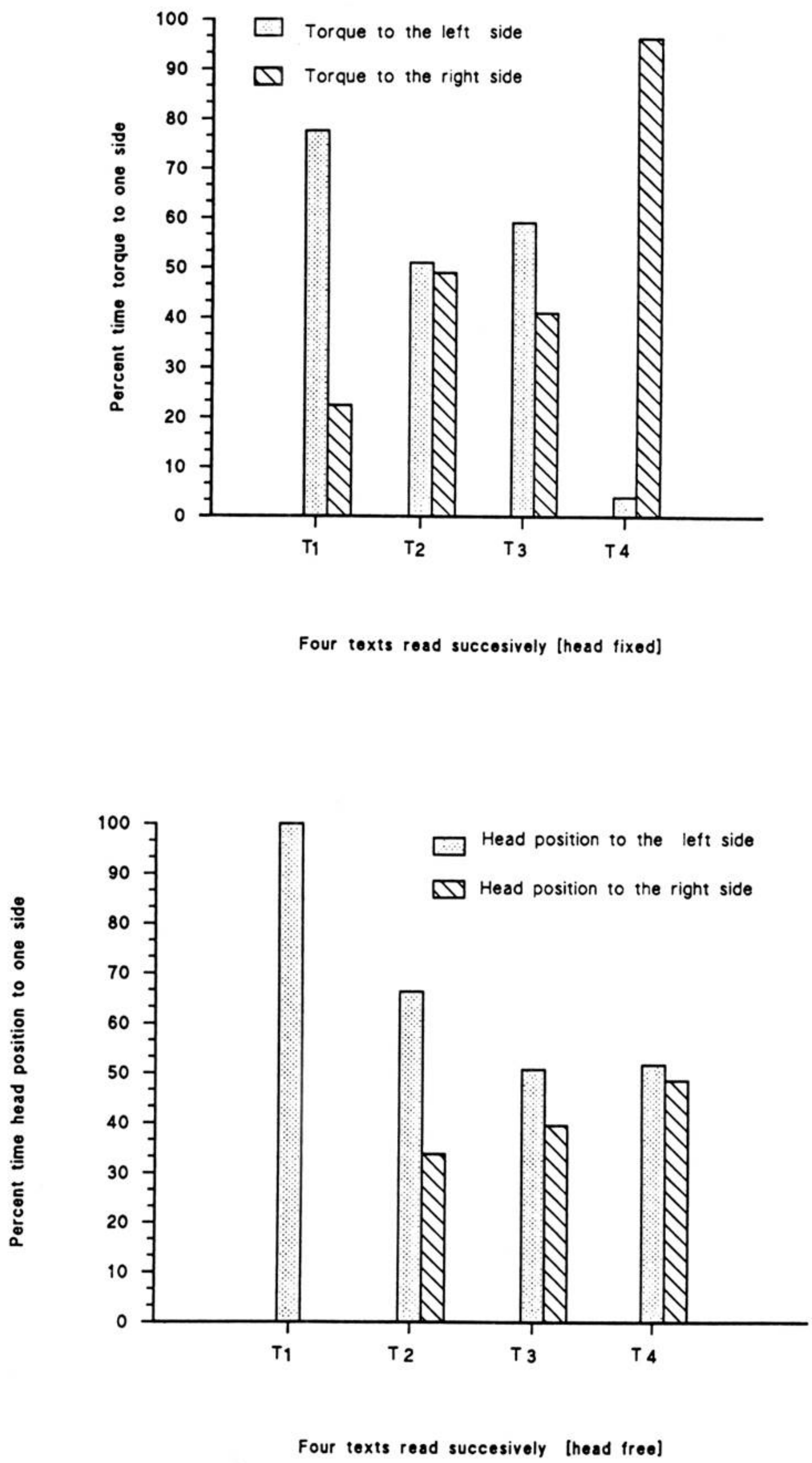


FIG. 7. Statistical distribution of percent time of relative torque and percent time of horizontal head position to one side for four texts read successively.

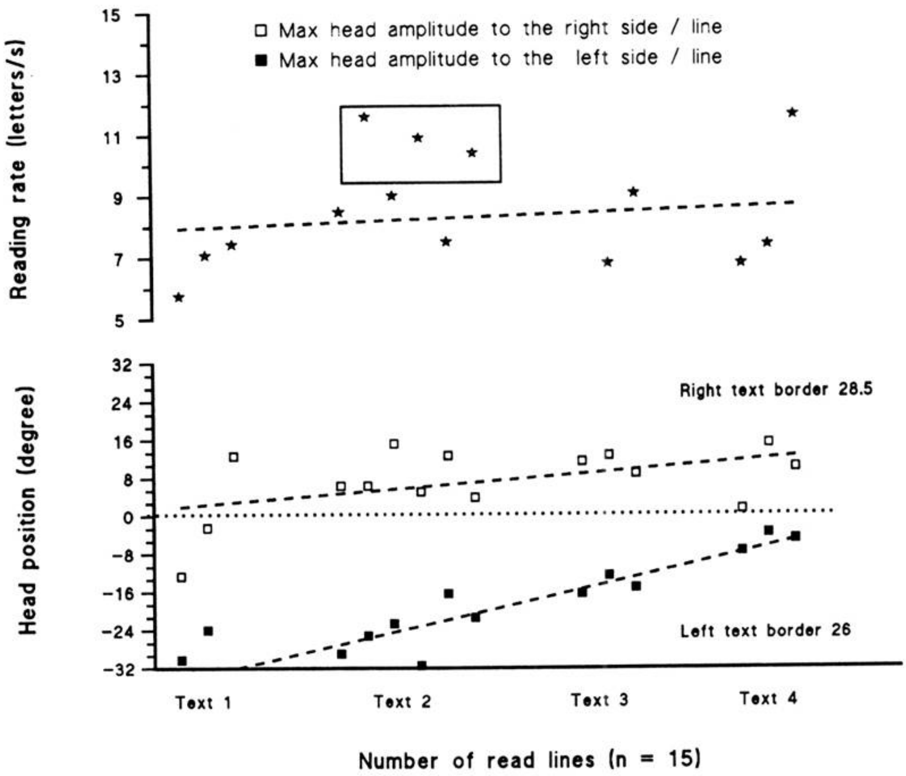


FIG. 8. Reading rate and horizontal head position as a function of numbers of read lines in a patient with left homonymous hemianopia. Note the short adaptation of head movements and reading rate with successively decreasing accentuation from the left to right, from text to text with reduced head movements at the last text. Note: In text two the distances between letters are reduced. The reading rate is increased.

We concluded that hemianopic patients at first had the intention of compensating their hemifield loss with active and forced head employment to the affected side. However, in doing so they could not gain an advantage in such a complex, high level task as reading. Successively, they reduced their head movements and relied on eye movements instead.

Influences of Decreased Spaces Between Letters and Words

Change of distances between letters had no significant effect on the mean number of fixation pauses during reading. Generally, the mean number of positional fixation pauses was increased with active and forced head employment. Correspondingly, the ratio between mean number of lexical fixation pauses and mean number of positional fixation pauses was reduced in the head-free-to-move situation (Table 1). In the two hemianopic subjects that produced no acoustical reading errors (Figs. 1a,1b) the global reading time was increased with reduced spaces between letters. Simultaneously, the reading rate was enhanced in some lines. The increase of the global reading time correlated with an increased duration (Table 2) of lexical fixation pauses for both head fixed and head free conditions.

TABLE 1

Ratio of Lexical Fixations Divided by Positional Fixations in Hemianopic Patients without Acoustical Reading Errors.

	LHH	RHH	NOR
Head fixed	5.2	4.0	4.8
Head free	1.8	3.0	2.6

TABLE 2

Lexical Fixation Durations of Well Adapted Hemianopic Patients & a Normal Subject for a Low Letter Density Mode (28 letters/line) & High Letter Density Mode (46 letters/line).

	LHH	RHH	NOR
Mean letters / line	28 (+18=) 46	28 (+ 18=) 46	28 (+18= 46)
Head fixed mean duration of lexical fixations	272 ms + 49 ms	253 + 42 ms	250 ms + (=) ms
Head free mean duration of lexical fixations	253 + 24 ms	254 ms + 29 ms	268 ms - 11ms

Reduced spaces had the most distinct effect in the subject with left homonymous hemianopia that was recorded twelve days after the acute event. The global reading time of a text with 48 letters per line was nearly the same as in texts with 28 letters per line. Correspondingly, the mean reading rate was significantly higher in texts with reduced spaces between letters and words (see Table 3). Obviously, this hemianopic subject had more trouble in understanding the meaning of especially long words. Also, it was difficult for him to get the idea of a sentence with enlarged spaces between letters and words. This correlated with an increase in acoustical reading errors and of global reading times.

TABLE 3

Mean Reading Rate Change of Less Adapted Left Hemianopic Subject with Acoustical Reading Errors. Time from the Acute Event to Day of EOG Recordings was 12 Days.

Less adapted patient with	MEAN READING RATE	
acoustical reading errors	Head fixed	Head free
28 letters per line	5.4 1 / s	5.7 1 / s
46 letters per line	7.5 1 / s	8.2 1 / s

DISCUSSION

None of our four patients showed any sign of inattention that could be attributed to neglect phenomena. Two of them did not produce any acoustical reading errors (Figs. 1a,b). Characteristically, they were the best adapted patients. The patient with right homonymous hemianopia had a complete dense right lower quadrantic hemifield loss that reached far over the horizontal meridian into the right upper quadrant. The macula was not affected in the upper quadrant (Fig. 1b).

The patient with left homonymous hemianopia had an incomplete left hemifield loss with macular sparing (Fig. 1a). The residual hemifield on the horizontal meridian was about five degree. In this patient our results were in accordance with earlier findings. He was able to read without acoustical reading errors, whereas the global reading time was increased. To compensate for the blind hemifield, the patient had a `beginning of line' detective strategy while the other part of the eye movement patterns resembled normal behaviour.

The patient with incomplete right homonymous hemianopia (Fig. 1b) could read the texts immediately, without any acoustical reading errors. Of course, the global reading time was increased compared with a normal subject. The eye movement pattern did not appear to be disorganized in this patient, although ocassionally the classical hemianopic staircase pattern was evident.

This subject had adopted three different reading strategies to compensate for the hemifield loss. The application of these strategies appeared completely interchangeable. Pommerenke & Markowitsch (1989) concluded that a specific and systematic exploration training can be of significant help for improving visuo-spatial behaviour in hemianopic patients. Both of our subjects were highly motivated in any training and did not appear to be satisfied with the present situation. As the application and efficient use of different ocular motor strategies during reading represents the highest level of visual control (Stark et al., 1991), high motivation of the patients is essential for a successful rehabilitation.

Both of our well adapted hemianopic patients demonstrated the similar kind of short term adaptation in horizontal head torque and horizontal head rotations: The side of attention changed from the blind hemifield into the seeing hemifield. The reduction of head movements with increased reading time were in accordance with earlier results of Zangemeister et al., (1982). Consequently, with this reduction of especially large head amplitudes to the blind hemifield the seeing hemifield was more and more accentuated. Obviously, both patients had at last a subjective advantage in using head movements of an equal amount to both sides. It is well known that hemianopic patients often try to assume an oblique head position to the blind hemifield that shifts the gaze direction additionally into the seeing hemifield (Zihl et al., 1984). This kind of adaptation is inefficient, because the gaze direction is shifted into the opposite direction. Nevertheless, our results demonstrate that in an advanced stage it may be useful to train the same rehabilitation tasks in a head-free-to-move condition. A well trained and highly motivated patient should be able to profit from a well accentuated horizontal head employment to both sides.

Our two other hemianopic subjects displayed simpler adaptive mechanisms. They produced the typical acoustical reading errors that have been known since Mauthner (1881). While the right hemianopic patient did not use his head at all, the left homonymous patient displayed a distinct blind hemifield accentuation in all texts. As he had a very recent lesion, this patient did not have much experience in compensatory strategies. His behaviour was not in accordance with our previous results (Zangemeister et al., 1982, 1986).

With enlarged spaces between letters and words hemianopic patients had more problems in understanding especially long words. In the two well adapted subjects we found the duration of lexical fixation pauses increased with decreased spaces between letters and words. This confirms the results of Eber et al., (1988), who suggested that ocular motor behaviour is related to altered sensorial input such as size of words or extension of spaces between words.

CONCLUSION

To compensate for hemianopia it is necessary to have appropriate ocular motor strategies for efficient use of the remaining half of the visual field. Our study indicates that patients with pure hemianopia and foveal sparing optimally learn to compensate their visual handicap by active and motivated visual training. Characteristically, the two of our four hemianopic subjects that did <u>not</u> produce any acoustical reading errors were the best adapted ones. In daily life they had developed a consistent set of ocular motor strategies to compensate for their specific visual handicap.

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