# Saccadic Eye Movement Strategies in Patients with Homonymous Hemianopia

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**Infrared oculographic recordings from three patients with hemianopia due to an occipital lesion showed that these patients employed a consistent set of (presumably unconscious) compensatory strategies to find and fixate objects. For targets in the blind hemifield, patients at first used a staircase strategy consisting of a series of stepwise saccadic search movements. This is safe but slow. When retested later, one patient had adopted a more efficient strategy employing one large saccade calculated to overshoot the target. Other strategies for finding targets in the blind hemifield were employed in response to specific situations presented by our experiments: a predictive strategy using past experience to anticipate where the target would be found, and special strategies for recovering a lost target and for awaiting the reappearance of the target. To fixate targets in the seeing hemifield, our subjects undershot the target to prevent losing it in the blind hemifield, then held it off-fovea on the seeing side of the macula.**

Meienberg O, Zangemeister WH, Rosenberg M, Hoyt WF, Stark L: Saccadic eye movement strategies in patients with homonymous hemianopia. Ann Neurol 9:537–544, 1981

Patients with hemianopia caused by an occipital lesion learn to compensate to some extent for their visual handicap. Studies in both humans and monkeys with occipital lesions or resections have demonstrated primitive extrastriate visual function in the blind hemifield [2, 4, 5, 7, 9–15, 18, 20, 22]. Some have suggested that this extrastriate vision plays a role in adaptation to occipital hemianopia [2, 4, 5, 10, 11, 18, 20, 21].

Eye movements in hemianopic patients with hemispheric lesions have been analyzed by several investigators [3, 6, 10, 11, 13, 16, 19], but no study has been reported of adaptive ocular motor strategies employed by hemianopic patients to search for objects in their blind hemifield. This report presents the results of an oculographic study of three patients with occipital hemianopia, documenting and defining various adaptive ocular motor strategies for finding targets in the blind hemifield and fixating them with a hemimacula.

## Methods and Patients

Horizontal eye movements were recorded by means of the infrared reflection method [1, 17]. Recordings were strictly linear within the range of eye movements examined. The system bandwidth was from DC to 150 Hz. Recordings were made with a rectilinear chart recorder at different paper speeds depending on the requirements of visual evaluation. Data were stored on an Ampex FR 1300 tape recorder and played back at a different paper speed if needed.

The target was a small green spot, presented on a Tektronix 611 cathode ray tube, subtending a visual angle of 10 minutes and having a luminance of 20.6 cd/m². The background screen luminance was 1.4 cd/m². All targets were presented in a horizontal plane within ±10 degrees of the midposition of the eyes. The target presentation programs were produced by a minicomputer (PDP 8/I) that performed target steps between 1 and 20 degrees. The following programs were used:

*Program 1: Predictable amplitude and time.* For the predictable program (illustrated in Fig 1), the eccentricity and duration of presentation were constant, the side was alternated, and the target light was continuously on. Recordings were made for eccentricities of 20, 10, 5, and 2.5 degrees. The target remained in the same place for 2.5 seconds.

*Program 2: Random amplitude and time.* For the random program (illustrated in Fig 2), the eccentricity, side, and duration of presentation were all randomized, and the target light was continuously on. Target eccentricity varied between 0 and 16 degrees (±8 degrees around the midposition of the eye), using calibrations of 1 degree. The target remained in one position at random durations of 200 msec to 2.5 seconds.

*Program 3: Random on/off and predictable amplitude.* For the random-on/off program (illustrated in Fig 7), the du-

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Received June 12, 1980, and in revised form Sept 23 and Nov 17, 1980. Accepted for publication Nov 24, 1980.

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ration and side of presentation were randomized, the eccentricity was constant, and the target light was randomly on or off. Recordings were made for eccentricities of 20, 10, 5, and 2.5 degrees.

Patients were seated in front of the screen with the head fixed on a chin rest. To prevent vergence movements from interfering with saccadic movements, recordings were made only from the eye with the temporal field defect; the other eye was covered with a patch. In Patient 1, no major differences in the eye movement patterns under study were observed between monocular recordings from the eye with the nasal field defect and binocular recordings with both eyes fixating or with one eye covered by placing photocells behind the cover.

The predictable program and random program presented forced-choice situations [11, 16], in that as soon as the target escaped fixation, it had to be sought in one hemifield or the other since it was continuously illuminated. The patients were instructed always to search for the target and fixate on it. For the random-on/off program, patients were told that the target was not present all the time and that they should fixate on it as soon as it appeared.

Following calibration procedures, data collection was begun using first the predictable program, then the random program, then the random-on/off program. To avoid fatiguing the patients, each program was run in several short segments with frequent pauses and recalibrations. The predictable and random-on/off programs were run several times for each of the target eccentricities. The sequence of target eccentricities tested was randomized for each patient.

### *Case Histories*

Patients 1 through 3 had, respectively, progressively decreasing degrees of disability as a result of their hemianopia. Informed consent for participation in these experiments was obtained from all three patients.

PATIENT 1. A 55-year-old man experienced the sudden onset of complete, dense left hemianopia and left hemiparesis. Examinations revealed hemorrhage in the right occipital lobe originating from a metastasis of renal cell carcinoma and extending into the parietal lobe. The left hemiparesis completely resolved in the following weeks, but the hemianopia with macular splitting showed improvement only in a small area on the border of the upper quadrant. Vision was 20/40 in the right eye and 20/25 in the left. Eye movement recordings were made at 4 and 4½ months after the acute event, and a follow-up recording was obtained at 7½ months. The neurological findings remained unchanged. At the time of the first two recordings, the patient was severely disabled and feared walking because he often bumped into objects on the side of his blind hemifield. By the time of the follow-up recording he was less disabled and less apprehensive of walking, though he still sometimes walked into objects.

PATIENT 2. Following operation for a left occipital arteriovenous malformation, a 42-year-old man developed a complete, dense right homonymous hemianopia with macular splitting. The visual field defect was unchanged 2½ years after the event, when the eye movement recordings were made. Visual acuity was 20/20 in each eye. The patient felt moderately disabled by his visual field defect but reported that he had not walked into an object on the side of his blind hemifield for several weeks.

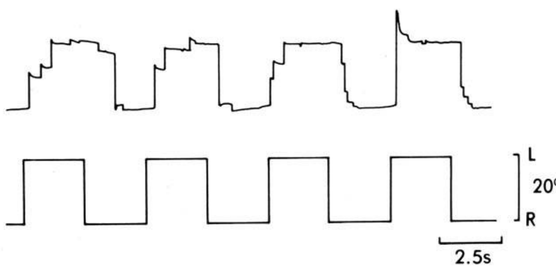
PATIENT 3. Following a cardiac operation for mitral valve insufficiency, a 55-year-old man awakened with a right hemiparesis and a complete, dense right homonymous hemianopia, that spared fixation, due to embolic occlusion of the left posterior cerebral artery. The paresis completely resolved, but the visual field defect remained. Visual acuity was 20/20 in each eye. When eye movement recordings were made 8 months after the acute event, the patient had not walked into an object in his right hemifield for 3 months and no longer regarded his visual field defect as disabling.

## Results

### *Predictable Amplitude and Time*

When the target was presented repeatedly at the same eccentricity (i.e., the same position relative to the center of fixation), alternating rhythmically between the seeing and blind hemifields, a consistent eye movement pattern was observed for steps of 10 and 20 degrees (Fig 1): the first few attempts to find the target in the blind hemifield showed a staircase pattern, more fully described in the following section. Once the target position had been learned, the staircase pattern was abandoned; subsequent attempts to find a target in the blind hemifield consisted of a single overshooting saccade followed by a backward-drifting glissadic movement, sometimes followed by a backward saccade. For the 2.5- and most of the 5-degree steps, all patients overshot the target with the initial saccade. Paralleling the disappearance of the staircase pattern, an increasing de-

*Fig 1. Eye movement patterns to predictable target presentation (Patient 1, left homonymous hemianopia); upper trace is eye position, lower trace is target position. Staircase movement toward a target in the blind hemifield disappears and is replaced by a single large, overshooting saccade (the predictive strategy). Simultaneously, there is progressive undershooting by saccades toward the target in the seeing hemifield.*



gree of saccadic hypometria toward targets in the seeing hemifield was observed.

When the amplitude of the target steps was unexpectedly increased or decreased, the first saccade toward the new target position in the blind field had the same amplitude as the preceding step. When the new target position was more eccentric, this erroneous saccade was followed by a staircase movement. After the amplitude prediction had been established, staircase patterns reappeared when concentration on the task was reduced (e.g., consistently when the subject was engaged in conversation) and after recording pauses of more than about 5 seconds.

*Random Amplitude and Time*

When the eccentricity, side (seeing or blind hemifield), and duration of target presentation were unpredictable, eye movements toward the target in the blind hemifield almost always demonstrated a staircase pattern (Fig 2).

The initiation latencies for saccades toward targets in the blind hemifield are shown in Figure 3. In all three cases they were the same, regardless of whether the saccade led to a staircase movement. The latencies did not show any dependence on target eccentricity. By comparison with the initiation latencies of normal individuals [8, 16], those of our patients were prolonged for both the blind and the seeing hemifields.

The amplitudes of the first saccade toward targets in both the blind and the seeing hemifields are represented in Figure 4. In the blind hemifield, all three subjects almost always overshot targets with eccentricities of 5 degrees or less; with larger eccentricities, the first saccades mostly fell short. Undershooting saccades were nearly always followed by further small saccades producing a staircase pattern. In a few instances, no staircase pattern followed an undershooting saccade because the presentation time

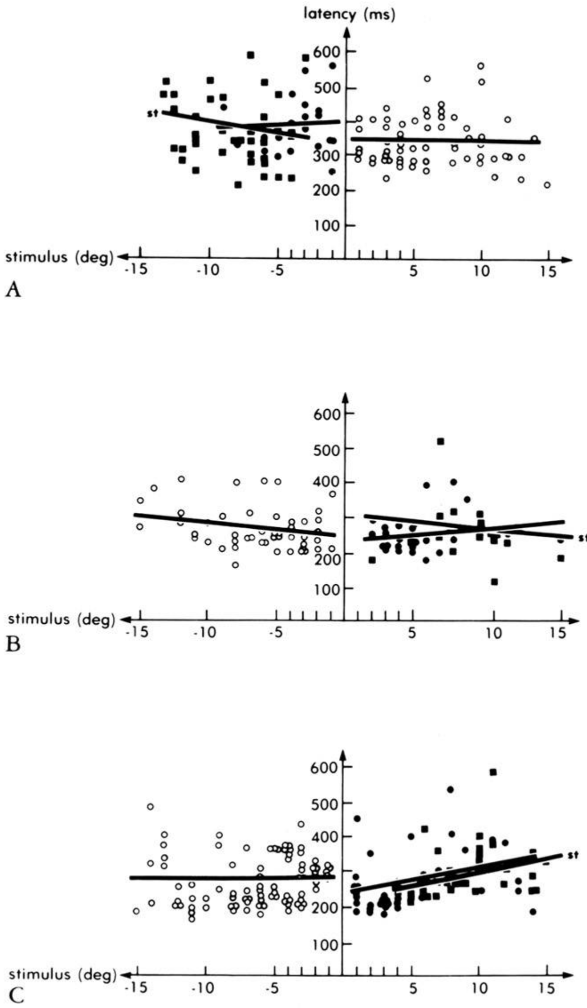
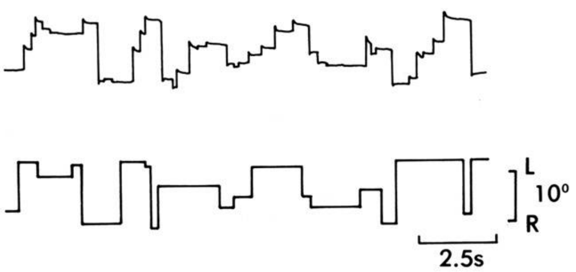



*Fig 3. Initiation latencies of first saccades toward targets in the blind or seeing hemifield in (A) Patient 1 (left homonymous hemianopia), (B) Patient 2, and (C) Patient 3 (both, right homonymous hemianopia).* Black squares *represent first saccades of a staircase movement;* black circles *represent nonstaircase saccades toward a target in the blind hemifield;* open circles *represent saccades toward a target in the seeing hemifield;* st *denotes the regression line for the first saccade of a staircase movement.*

*Fig 2. Eye movement patterns to randomized target presentation (Patient 1). Eye movements toward targets in the blind (left) hemifield are consistently staircase patterns (the staircase strategy) except when the target steps are small. Movements to targets on the seeing (right) side are mostly accurate.*




was too short to allow the target to be found. As indicated by the regression lines in Figure 4, for small eccentricities (0 to 5 degrees), the amplitude of saccades for Patients 1 and 3 was proportional to the degree of eccentricity, with a consistent overshoot of about 1 degree, while for Patient 2 the saccades for all eccentricities had about the same amplitude. Patient 2 showed more marked fixation instability. For all target eccentricities above 5 degrees, the amplitude of each patient's first saccades toward a target in the blind hemifield remained approximately consis-

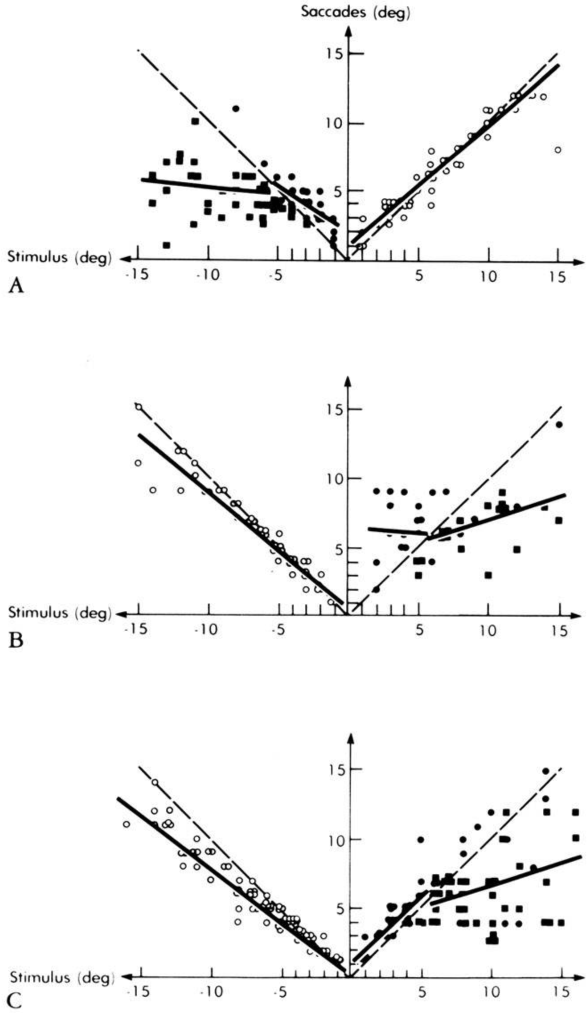



*Fig 4. Accuracy of first saccades toward targets in the blind or seeing hemifield in (A) Patient 1 (left homonymous hemianopia), (B) Patient 2, and (C) Patient 3 (both, right homonymous hemianopia).* Dashed lines *represent supposed sites of accurate saccades;* black squares *represent first saccades of a staircase movement;* black circles *represent nonstaircase saccades toward a target in the blind hemifield;* open circles *represent saccades toward a target in the seeing hemifield.*

tent.* In their first saccades toward a target in the seeing hemifield, Patients 1 and 2 overshot slightly with small eccentricities and undershot with larger ones, as is also usual with normal subjects. Patient 3 showed an abnormally high incidence of undershooting for all target eccentricities.

The duration of staircase movements toward targets in the blind hemifield, shown in Figure 5, depended on both the number of steps employed and the intersaccadic intervals. Most staircase movements of Patients 1 and 2 took more than 500 msec, often 1,000 msec or more, whereas those of Patient 3 generally took about 500 msec. How inefficient a staircase movement is for finding and fixating a target becomes evident when its duration is compared with the 50 msec required for a normal one-step saccade of 15 degrees. On the other hand, the staircase movement is a very reliable way of finding a target in the blind hemifield.

The fixation of targets is illustrated in Figure 6. The staircase movement (Fig 6, left) removes the blind hemifield from the target stepwise, the hemifield (which moves with the eye) being pulled back like a curtain. As soon as a saccade overshot the target and brought it into the seeing hemifield, fixation was accomplished by a backward glissade, sometimes followed by a backward saccade toward the target. Backward saccades usually occurred when the target was not fixated within 200 msec after it had been overshot.

The amplitudes of the single steps varied randomly from one staircase movement to another as well as within the same movement. Generally the first saccade of a staircase movement was the largest, with subsequent ones ranging between 2 and 10 degrees. The step amplitudes did not increase or decrease when the eye got closer to the target, nor did they depend on target eccentricity or show any relationship to eye position in the orbit. The last saccade of a staircase movement overshot the target by an average of 1 to 2 degrees. The latencies between steps (intersaccadic intervals) likewise varied randomly, most ranging between 200 and 400 msec, which is the same as the range of latencies for the first saccade toward a target in the blind hemifield (see Fig 3). After each step, the eyes made a backward glissade like that observed following saccades that overshot the target. The extent of this backward drift varied from step to step (see Figs 1, 2). The sometimes very pronounced backward glissades of Patient 3 serve to explain why in a few instances he developed a staircase movement even though the first saccade had already hit the target or overshot it. Thus, the number of saccades toward a target in the blind hemifield depended not only on the amplitude of the saccades, but also on the amount of backdrift between them.

Patterns of eye movement toward targets presented in the seeing hemifield are represented on the right in Figure 6, where the top four patterns are identical to those found in normal subjects. The frequencies of these various patterns in Patients 1 and 2 corresponded to those found in healthy subjects. Patient 3 had an abnormally high proportion of under-

*The tendency for slightly larger saccades to occur as target eccentricity increased does not necessarily imply that extrastriate vision was involved. It was probably due to the means of target presentation: to obtain large steps, it was necessary to start from very eccentric positions, from which the subsequent movements were usually greater.

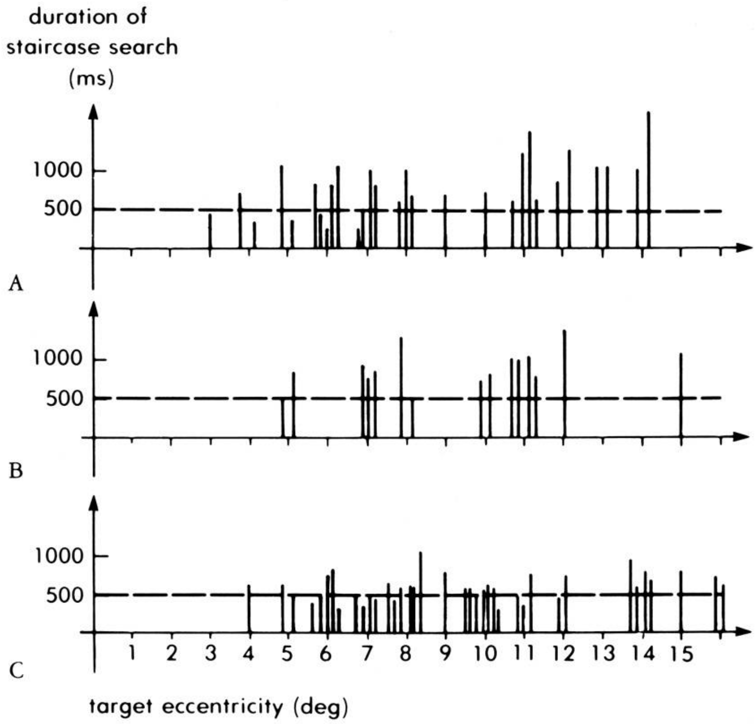



*Fig 5. Duration of staircase movements: (A) Patient 1, (B) Patient 2, and (C) Patient 3. Each vertical bar represents a staircase movement.*

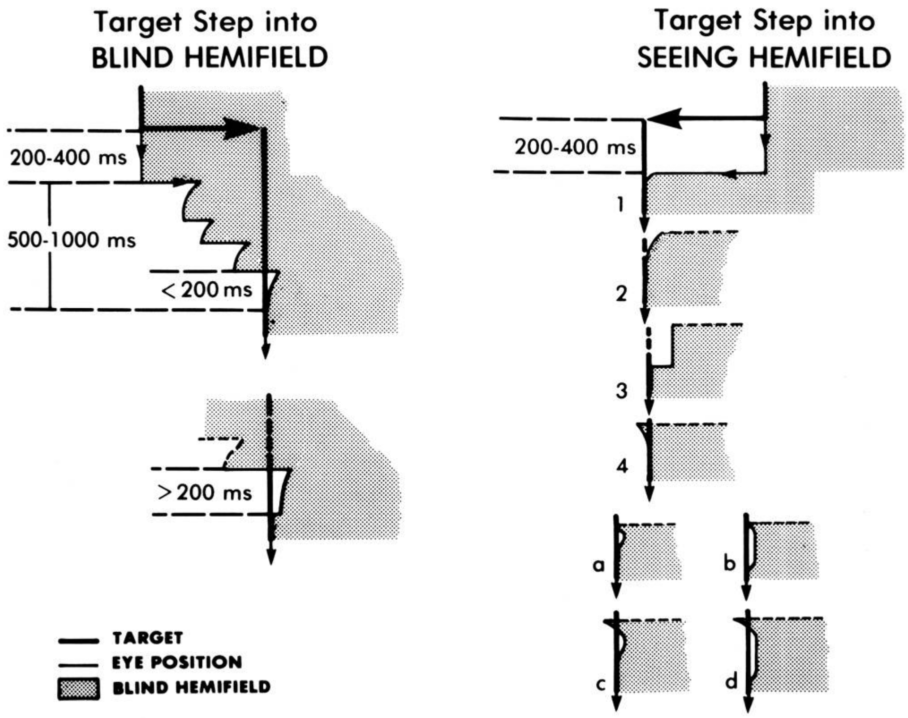



*Fig 6. Eye movement patterns in patients with homonymous hemianopia:* (upper left) *staircase pattern with glissade to the target from the seeing hemifield;* (lower left) *glissadic-saccadic target approach from the seeing side as an alternative fixation movement;* (right) 1 *through* 4 *represent initial saccades with kinds of corrective movements also found in normal subjects;* a *through* d *represent movement patterns (the hemimacular fixation strategy) observed in Patients 1 and 2 immediately following patterns 1 through 4.*

shooting saccades (pattern 3). In Patients 1 and 2, these movements were followed immediately by another movement pattern (represented by patterns *a* through *d* in Fig 6): a fast movement in the opposite direction to a position 1 to 1.5 degrees short of the target, followed by either a backward glissade or a backward saccade to the target. Forty-three (81%) of 53 saccades in Patient 1 and all 46 saccades in Patient 2 showed one of these latter patterns. Both patients had macular splitting, whereas Patient 3, whose 82 saccades never showed such a pattern, had an intact macula.

*Random On/Off and Predictable Amplitude*
The random-on/off program served to differentiate genuine ocular motor reactions to a target in the blind hemifield from reactions simply to the disappearance of the target. None of our patients reacted to targets presented at unpredictable moments at eccentricities of 5, 10, and 20 degrees in the blind hemifield, though their attentiveness was established by comparing their reactions to targets in the seeing hemifield.

For all eccentricities tested, the patients always responded to disappearance of the previously fixated target from the side of the seeing hemifield by making an eye movement toward the side of the blind hemifield, even though they knew that a target did not always have to be present. Three such off-reactions are illustrated in Figure 7. Their latencies were within the range of those obtained with the random program. Rarely, reaction to a target in the blind hemifield was simulated when a spontaneous search movement coincided with the target appearance (illustrated in Fig 7 at *b*). Such pseudoreactions could generally be identified by the implausibility of their "latency." Another phenomenon, prediction of amplitude, is illustrated in the upper recording of Figure 7: though no target was present in the blind hemifield at the times indicated by *a*, single saccades were made to the place where the target had last appeared. All three patients were able to predict the amplitudes of saccades, as they did with the predictable program. The staircase pattern at *b* illustrates loss of that learned ability after the target had failed to appear for more than 6 seconds.

Two additional strategies were used to prevent missing the appearance of the target in the blind hemifield. For target eccentricities of 2.5, 5, and 10 degrees, as soon as the patients lost the previously fixated target on the side of the seeing field, they moved their eyes to the place in the blind hemifield where they expected the target to appear and waited for it; or, if they had fixated on the side of the blind hemifield, they kept their eyes fixed in place (Fig 7, lower part). For the 20-degree target eccentricity

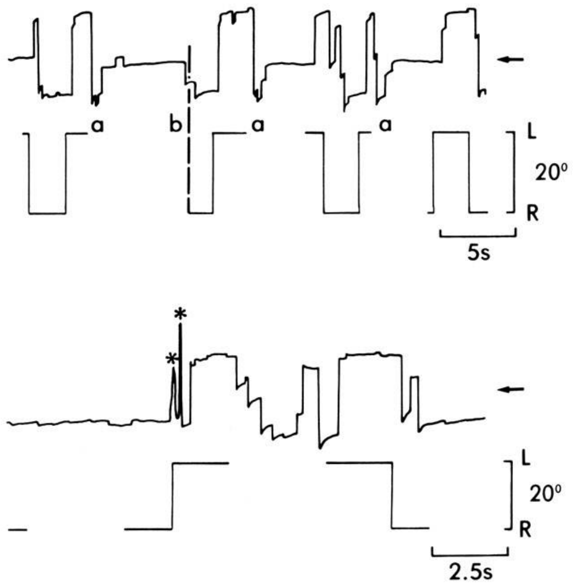



*Fig 7. Eye movement patterns with randomly lighted target (the target recovery strategies). In the* upper recording *(Patient 3),* a *represents off-reaction to a fixated target, accompanied by a prediction of amplitude;* b *represents coincidence of staircase search with target appearance in the blind hemifield, with the eye movement starting before the target appears. The subject's strategy is to wait for the target with the eyes in midposition, making repeated search movements toward the blind side. In the* lower recording *(Patient 2), the strategy is to wait for the target on the blind side, where it is expected to appear (the target awaiting strategies).* Arrows *indicate midposition of the eye;* asterisks *represent blink artifacts.*

they sometimes used a second strategy: after making an eye movement to the place in the blind hemifield where they expected the target to appear, if it did not appear they went to midposition, from which they then made repeated searching movements toward the blind side (Fig 7, upper part).

*Evolution of Eye Movement Patterns*
The follow-up recordings made 7½ months following the acute occipital lesion in Patient 1 (Figs 8, 9) showed findings different from those in the earlier recordings (cf. Figs 1, 2). In the later recordings, targets in the blind hemifield were generally overshot (often by 50% or more) with the first saccade, even when the eccentricities were large. Staircase movements toward the blind side were found only occasionally, usually for 20-degree target steps. The backward glissades were faster and much more pronounced than in the earlier recordings. The target acquisition time (cf. Fig 5A, Patient 1) was much shorter (mostly between 250 and 400 msec). The responses to predictable target presentations (Fig 8) also differed from the first recordings in that the

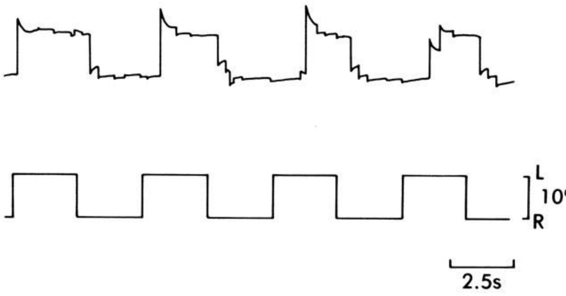



*Fig 8. Eye movement patterns with predictable target presentation (follow-up recording of Patient 1; cf. Fig 1). From the beginning, single large, overshooting saccades are made toward target presentations on the blind (left) side (the overshoot strategy). Undershooting first saccades toward targets in the seeing hemifield are present from the beginning (the undershoot strategy).*

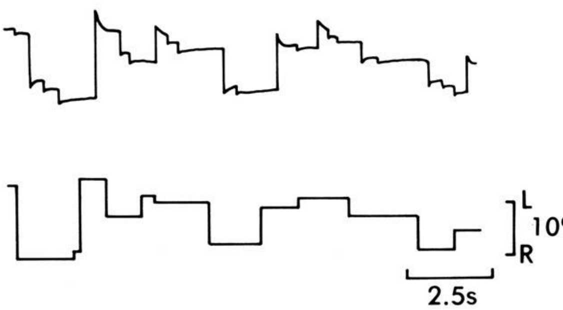



*Fig 9. Eye movement patterns with randomized target presentation (follow-up recording of Patient 1; cf. Fig 2). Instead of staircase movements toward targets on the blind (left) side, there are now single large, overshooting saccades. A pronounced saccadic undershoot is nearly always made toward targets in the seeing hemifield.*

targets were usually overshot by the first step of a series. The few staircase movements that appeared occurred following several overshooting saccades toward the target in the blind hemifield, possibly representing the subject's effort to adjust his eye movements after having made excessive overshoots in his previous attempts (see the last movement to the left in Fig 8).

In the follow-up recordings, saccades toward targets in the seeing hemifield were consistently hypometric, and two or more corrective saccades were often needed to achieve fixation (see Figs 8, 9). Between the corrective saccades there were also backward glissades, though these were much less marked and much slower than those accompanying movements toward the blind hemifield. In the earlier recordings, backward glissades did not occur within movements toward the seeing side. After large overshoots of targets in the blind field, sometimes even the backward corrective saccades were hypometric (see Fig 8, backward corrections after the second and third saccades to the left). Under these circumstances, the time from the beginning of the movement until the target was fixated was sometimes as long as that for a staircase movement (more than 1 second), but the target was already "in view" in less than 100 msec even though it was not yet fixated.

## Discussion

Our recordings indicate that patients with hemianopia due to an occipital lesion employ a consistent set of compensatory strategies to find and fixate objects. There is no evidence that the ocular motor responses to targets presented in the blind hemifield were modified by extrastriate vision. Nor is there any reason to think that the saccadic output system of these patients was deficient. The amplitudes of the saccades were quite accurate once a patient could predict the target position in the blind field. The velocities of saccades were the same toward the blind as to the seeing side.

Subjects with normal visual fields use the eccentricity of a new target's image on the retina to calculate the size of a saccade needed to get to it. Within the range of target steps used in this study, the eye movements of normal subjects would in most cases have consisted of a single saccade directly to the target. Since our patients did not have visual information about the position of a target in the blind hemifield, they had to search for the target. At first they employed a staircase strategy consisting of a series of stepwise saccadic search movements. This is safe but slow. The patient subsequently retested had by then adopted a more efficient strategy employing one large saccade calculated to overshoot the target. Other strategies for finding targets in the blind hemifield were employed in response to specific situations presented by our experiments: a predictive strategy using past experience to anticipate where the target would be found, and special strategies for recovering a lost target and for awaiting the reappearance of the target. To fixate targets in the seeing hemifield, our subjects undershot the target to prevent losing it in the blind hemifield, then held it off-fovea on the seeing side of the macula.

To compensate for hemianopia, it is necessary to have an appropriate ocular motor strategy for efficient use of the remaining half of the visual system. Our studies provide some indication of the ways a patient with homonymous hemianopia from an occipital lesion looks for and fixates objects. Our results show what hemianopic patients do in an artificial, experimental situation, however, and not necessarily what they do in their daily environment. Extension of studies such as ours should provide the practical information about adaptation that is requisite to rehabilitation of patients with homonymous hemianopia.

Supported by grants from the Schweizerische Stiftung für medizinisch-biologische Stipendien and Geigy Jubilaeumsstiftung Basel and by the Deutsche Forschungsgemeinschaft, Bonn.

The authors wish to thank Don Shevlin for editorial assistance.

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