

## **Association and Dissociation of Visual Functions in a Case of Bilateral Occipital Lobe Infarction**

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**Summary.** A severe restriction of the visual field was observed in a patient suffering a bilateral occipital lobe infarction. Soon after the lesion, the visual field had an angle of approx. 4°. Some recovery was observed within the following months. Within this restricted visual field, several visual functions were tested. Increment threshold, for instance, was found to be one log unit higher than would normally be expected. Color vision was completely lost soon after the lesion, but some recovery was later observed. Although binocular interaction was demonstrated by the interocular transfer of after-effects, the patient never experienced stereopsis. He also seemed unable to recognize faces. Despite the small visual field, optokinetic nystagmus could be elicited. A notable slowing down of visual analyses was observed in experiments on visual reaction time, on the inversion of the Necker cube, and on binocular rivalry.

The complete loss of certain functions like stereopsis or face recognition in contrast to a quantitative reduction of other functions like visual acuity or color perception can be discussed in the light of two conceptual models of perceptual processing. One model suggests the representation of different visual functions within one neuronal network, each function represented by a different number of neurons or a different algorithm within the network. The second model suggests a spatial segregation of different visual functions in different cortical areas that receive input from one common structure, presumably the striate cortex.

**Key words:** Vision – Visual cortex – Perimetry – Stereopsis – Aftereffects.

**Zusammenfassung.** Bei einem Patienten mit bilateraler Läsion im Okzipitalbereich wurde eine starke Einengung des Gesichtsfeldes beobachtet. Kurz nach der Läsion hatte das Gesichtsfeld einen Durchmesser von etwa 4 Grad; in den folgenden Monaten stellte sich eine geringfügige Erweiterung des Gesichtsfeldes ein. Innerhalb des begrenzten Gesichtsfeldes wurden verschie-

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dene visuelle Funktionen geprüft. Die Inkrementalschwelle beispielsweise lag um 1 log.-Einheit höher, als normalerweise zu erwarten wäre. Die Farbtüchtigkeit war zunächst völlig verschwunden, doch stellte sich später eine geringfügige Besserung ein. Es konnte binokuläre Interaktion mit Hilfe des interokularen Transfers von Nacheffekten gezeigt werden; dennoch wurde in keinem Fall Stereopsis beobachtet. Außerdem war der Patient nicht in der Lage, Gesichter zu erkennen. Trotz des stark eingeschränkten Gesichtsfeldes konnte der optokinetische Nystagmus ausgelöst werden. Auffallend war die erhebliche Verlangsamung bei visuellen Aufgaben, die sich in der optischen Reaktionszeit, bei der anschaulichen Umkehr des Necker'schen Würfels und beim binokulären Wettstreit zeigte.

Der vollständige Verlust einiger Funktionen wie Stereopsis und Gesichtererkennen im Gegensatz zur quantitativen Verschlechterung bei anderen Funktionen kann im Hinblick auf zwei Wahrnehmungs-Modelle erörtert werden. In einem Modell wird die Repräsentation verschiedener visueller Funktionen in *einem* neuronalen Netzwerk angenommen, wobei jede Funktion durch eine unterschiedliche Anzahl von Neuronen oder durch einen bestimmten Algorithmus in diesem neuronalen Netzwerk repräsentiert wird. In einem anderen Modell wird die räumliche Trennung verschiedener visueller Funktionen in *verschiedenen* corticalen Bereichen angenommen, wobei eine gemeinsame Struktur, vermutlich der visuelle Cortex, diese Bereiche informiert.

**Schlüsselwörter:** Sehen – Visueller Cortex – Perimetrie – Stereopsis – Nacheffekte.

## Introduction

The neurophysiologic and neuroanatomic analysis of the visual system of vertebrates suggests the hypothesis that visual information might be decoded in a hierarchic fashion. Hubel and Wiesel (e.g., 1965 and 1968) described cells in the cortical visual areas of cats and monkeys as having simple, complex, or hypercomplex receptive fields. The visual stimulus must become more and more 'complex' in order to activate the cells at successive processing stages. The authors believe that these hierarchic transformations are the first steps leading to the perception of shapes encountered in everyday life (Hubel and Wiesel, 1965, p. 286). Barlow (1972) further developed the notion of a hierarchic analysis of sensory information. He suggests that each perceptual act in the last stage of this hierarchic analysis involves the activity of very few cells ( $N \approx 10^3$ ), and he calls the units at this final processing stage 'cardinal' cells.

Besides evidence of a hierarchic analysis, there is also evidence that certain aspects of the visual world appear to be analyzed in a parallel fashion. Schneider (1969) suggested that, in lower mammals, visual information represented in the midbrain informs the animal where something is located in visual space, whereas the retino-thalamo-cortical pathway carries the information of the visual stimulus with regard to its contents. This capacity to identify the locus of visual stimuli in the

absence of the striate cortex has also been shown to exist in man by Pöppel et al. (1973). Neurophysiologic studies of the cat cortex showed parallel functioning of areas 17 and 18 (Singer et al., 1975; Tretter et al., 1975). Both areas receive direct input from the lateral geniculate bodies and are thought to analyze different aspects of the visual world.

If a lesion destroys a particular area in the visual system, different effects on visual functions must be expected if the neuronal analysis is either hierarchic or parallel. If information processing is parallel, i. e., if different aspects of visual information are analyzed in spatially different regions, one should get a clear dissociation of functions (Teuber, 1955; Milner and Teuber, 1968) with the possibility of 'double dissociation of functions'; a lesion of area A results in a loss of function A' sparing function B', and a lesion of area B results in a loss of function B' sparing function A'. In the case of hierarchic information processing, an associative loss of functions might occur if a lesion happens to lie at an early processing stage; a dissociation of functions might also occur if the lesion happens to lie at a later processing stage with *no* possibility of 'double dissociation of functions,' because later stages of the hierarchy depend on the output of the earlier stages; a function B' might be lost if a lesion destroys area B, and function A' might be spared; but it would not be possible to observe the reverse, i. e., if area A is destroyed, functions A' and B' will be lost.

We worked for several months with a patient who had severely reduced visual functions due to a bilateral occipital lobe infarction. Several observations on this patient suggest the association of some visual functions and the dissociation of others. In presenting these data we believe we are contributing to our knowledge of hierarchic and parallel information processing in the visual system.

### Case Report

A 69-year-old stonemason discovered one morning that he had become completely blind during the night. Two to three weeks later, he regained a minimal visual capacity in the central area of his visual field. At that time he discovered that he was unable to see colors; everything looked as though it was on black-and-white television. He also discovered that his visual acuity was considerably reduced. Besides loss of vision, he complained of headaches in the occipital region and of dizziness.

During the two years before onset of the blindness, the patient suffered occasional visual disturbances such as blackouts, transient blurring of vision or double images, and sometimes dizziness. He also complained that his memory had become worse during this time. Medical records show that he had had hypertension for the last 30 years and diabetes mellitus for 10 years.

The patient had to be treated like a completely blind person. To find his way around the hospital, he used a stick; he memorized turnings and counted the number of steps on a staircase. He walked in a very stiff upright position with pronounced dorsal flexion of his neck.

When responding to a peripheral acoustic stimulus, he turned his entire body sideways instead of turning his head alone. Besides some old peripheral nerve lesions on his arms and legs due to war injuries, there were no other neurologic signs. Pupillary reaction and convergence were easily elicited. The fundus of both eyes showed no notable alterations and there were no signs of a diabetic retinopathy.

During the period in which the patient was being observed, there were no signs of speech disturbance and he had no difficulty understanding speech. Specifically, the following tests showed

no decrement of verbal functions: Word repetition, object naming, short story repetition, and short-story invention using given words. Furthermore, there were no signs of apraxia; movements requiring visual control were, of course, disrupted. Despite his reduced visual field, he was able to produce very good drawings of objects.

His clinical picture did not change during the time he was observed. He was first seen in our clinic four months after onset of the blindness. He was kept in the hospital from February to June and again from September to November 1975.

## Results

Because of the great number of tests employed, the methods are described together with the results. For better orientation, the tests are listed below:

### 1. *Computer tomography* (Fig. 1)

#### 2. *Perimetry*

Visual field size (Fig. 2)

Increment threshold (Fig. 3)

Acuity

Critical flicker fusion

#### 3. *Fatigue site*

Optic and acoustic reaction time (Fig. 4)

Postretinal adaptation (Fig. 5)

### 4. *Color and brightness perception* (Table 1)

#### 5. *Stereopsis*

#### 6. *Aftereffects and illusions*

Afterimages

Hermann grid illusion

Spatial frequency aftereffect

Orientation aftereffect

Motion aftereffect

Virtual contours

Binocular rivalry

Necker cube

#### 7. *'Higher' cortical functions*

Object recognition

Face recognition

Reading

#### 8. *Oculomotor behavior*

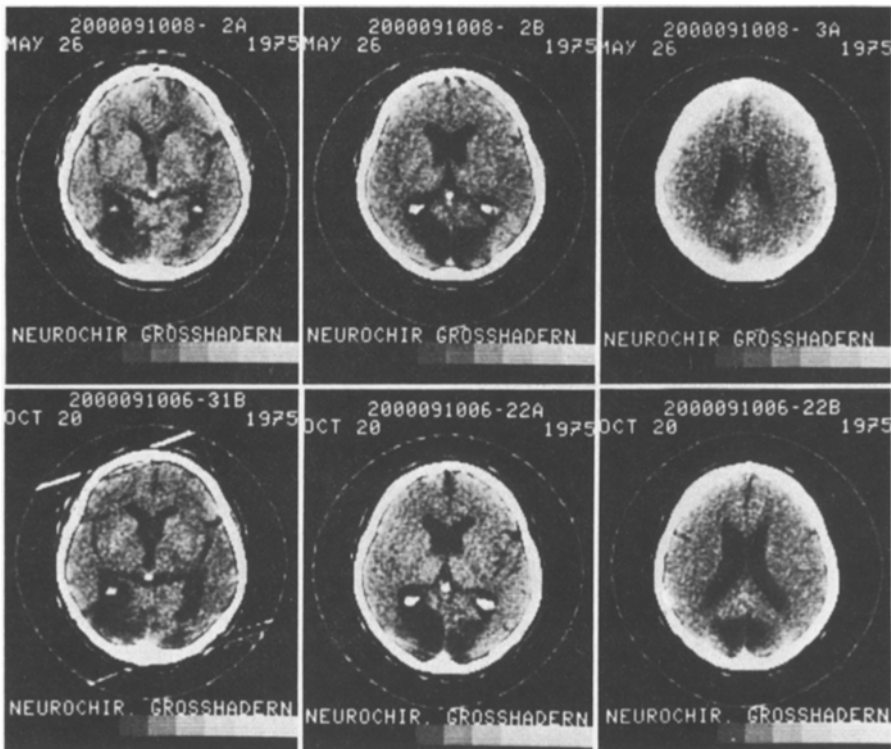
Optokinetic nystagmus (Fig. 6)

Saccadic and pursuit movements

'Residual vision'

### 1. *Computer Tomography*

The CT scan of the patient indicated a posterior cerebral lesion. To get a clearer picture, a CT scan was performed in May and again in October 1975. The results of these examinations are shown in Figure 1. Only scans for the occipital levels

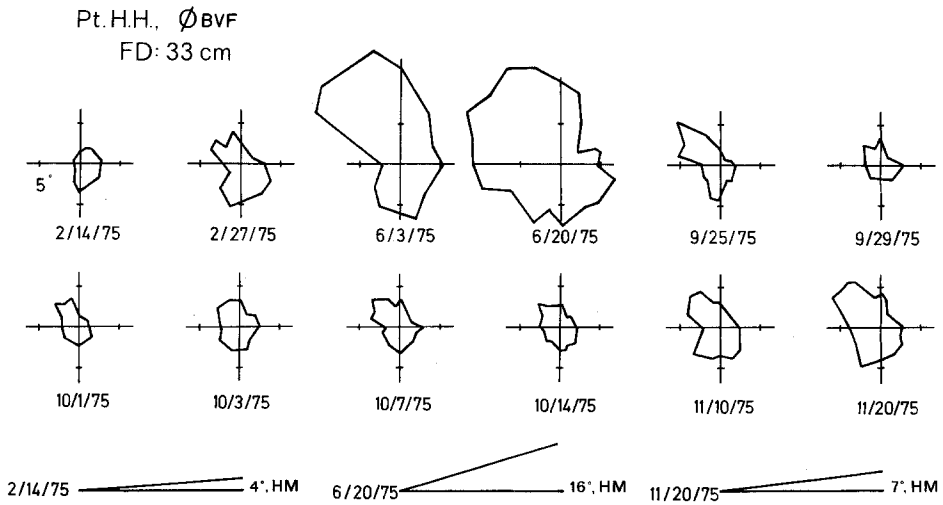


**Fig. 1.** Results of CT scans obtained at three levels on two different dates. Note the infarcted area at both occipital regions, especially on the left side

are presented because there were no pathologic signs outside of the occipital area. The pictures show a large ischemic necrosis in both occipital lobes. The necrotic area is larger on the left side than on the right. In the region of the calcarine fissure, it extends to the midline. Both occipital poles are spared by the lesion. A comparison of the CT scans from May and October shows that the necrotic area apparently became larger in the right hemisphere. According to parametric studies (Kazner et al., 1975) such a conclusion may, however, be invalid due to a slight shift of the analyzed levels. Furthermore, the digital values did not show a significant difference. Thus the extent of the lesion probably remained constant throughout the time the patient was tested.

## 2. Perimetry

The visual field was mapped with the Tübingen perimeter (Sloan, 1971; Aulhorn and Harms, 1972). The background luminance was 10 asb; the fixation point had a diameter of 30'. The target used in most field measurements had a diameter of 116'. The target to be detected was moved from the periphery toward the visual axis; target speed was approx. 1°/s, if not otherwise indicated. The result of 12 field measurements obtained with binocular fixation is shown in Figure 2. The fields obtained with monocular fixation with both the left and right eyes are of



**Fig. 2.** Visual fields of a patient with bilateral occipital lobe infarction measured on 12 different dates within 9 months. Note the increase of these binocular visual fields (*BVF*) between February and June 1975, and again their constriction in September with a slight increase thereafter. The fields have their largest extent in the upper left quadrant, suggesting a smaller infarcted area in the right hemisphere. At the bottom, the angular size of the patient's visual field is shown for three different dates. *FD*: Fixation distance

essentially the same size and shape. Therefore the results shown in Figure 2 can be considered typical. The visual field measured the first time the patient was observed had an angle of  $4^\circ$  for the horizontal meridian. The next measurements, especially those of June, indicated a slight increase of the field. The largest visual field observed had an angle of  $16^\circ$  (see bottom center of Fig. 2). In late June the patient was sent home and the next field measurements were taken in September when he returned to the hospital. As indicated, the fields decreased considerably in size while the patient was away. Between September and November a small increase in field size was again observed.

The largest extent of the visual field was seen at the  $135^\circ$  meridian in most measurements. This was mainly due to the greater extent of the upper left quadrant. The superiority of the left visual field was paralleled by a slightly smaller necrosis in the right hemisphere (see Fig. 1). If the 12 visual fields shown in Figure 2 are superimposed, a conspicuous regularity can be seen; both the upper right and lower left quadrants show wedge-shaped scotomatous areas oriented toward the center. As other investigators (cf., Teuber et al., 1960) have observed that these wedge-shaped regions of blindness are directed toward the visual axis, we believe that this patient showed central fixation and did not use a pseudofovea.

Some fields were measured with jerky movements of the target with a target velocity of  $30\text{--}40^\circ/\text{s}$ . In this case the field showed a larger extent, especially in the upper left and lower right quadrants. The greatest angle of visual field at the most sensitive meridian ( $135^\circ$ ) was  $27^\circ$  at the maximum of the patient's performance in June. Interestingly, the relative increase of visual field size

Pt.H.H  
 Binoc. static Perimetry  
 135° - Meridian  
 S: 116' ∅, white, A<sub>t</sub>s = 500ms  
 FP: 30' ∅, 1000 asb, red  
 BG: 10 asb, white

10 - 11 - 75

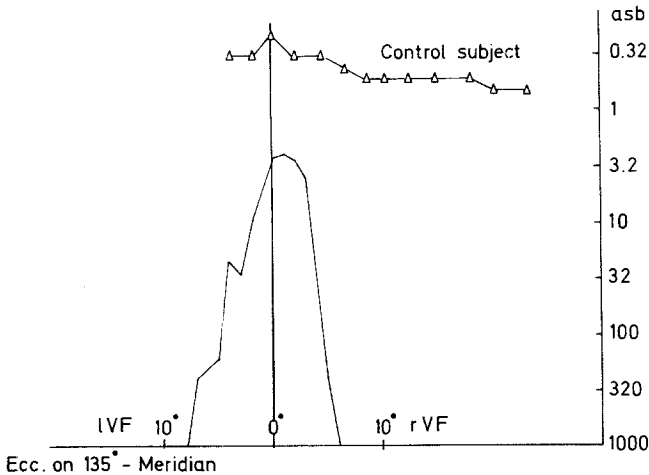


Fig. 3. Increment threshold measured along the most sensitive meridian (135°) in a patient with bilateral occipital lobe infarction. At the visual axis, increment threshold is approx. 1 log unit higher than would be normally expected (see results of a control subject)

through jerky target movements was disproportionately small when the patient performed badly, i.e., when the field size was small as for example in late February.

Prolonged measurements resulted in an apparent shrinkage of field size. The patient usually complained of fatigue after approx. 5 to 10 min of continuous perimetric analysis. If the measurements were continued despite fatigue, field size frequently became half of that normally measured.

For measurement of increment threshold the most sensitive meridian (135°) was chosen. Target size was 116' and targets were presented for 500 ms. Fixation was controlled by a 30' red point in the center of the perimeter. Background luminance was 10 asb. As in previous studies (e.g., Pöppel and Harvey, 1973), the ascending method of limits was employed. Luminance was increased by 0.1 log unit steps until the patient indicated seeing the target by pressing a buzzer. The results show (Fig. 3) not only that the visual field was laterally reduced, but also that there was a severe reduction of sensitivity in the center of the spared visual field. Increment threshold was approx. 1 log unit higher than normally expected. The transition from the visual axis to the border of the visual field was rather steep compared with that of other patients (Zihl et al., 1977).

Visual acuity was measured foveally and at 2° eccentricity both left and right of the fixation point. For the determination of acuity, the perimeter was again used. The patient was to discriminate in a forced-choice procedure between

circular and diamond-shaped targets of identical flux. Targets were presented for 1 s with a luminosity of 100 asb and were projected onto a homogeneous background of 10 asb. The sequence of the different targets was random. The patient could see no difference between circular and diamond-shaped targets up to 44' when acuity was tested in the visual axis. Targets with an angle of 69' were discriminated without error. This corresponds to a visual acuity of 10% (equivalent to approx. 20/200 measured with the Snellen chart). With longer presentation time (ad lib) he could discriminate targets subtending only 18' of visual angle. His right eye was slightly better than his left eye.

To determine perifoveal acuity, targets with an angle of 69' were presented for 200 ms at 2° eccentricity both left and right of the fixation point along the horizontal meridian. Target luminance was again 100 asb. At each position, 20 stimuli of the two target types were presented in a random sequence. The patient showed a clear response bias, always reacting with the 'circle' reaction when he could not discriminate. The results suggest clear superiority of the left visual field; in 70% of the cases, he gave a correct answer when stimuli were presented in his left visual field, and only 20% of his responses were correct for targets in his right visual field.

The patient repeatedly observed during acuity measurements that the diamond-shaped target did not show clear corners. Particularly the corners along the horizontal meridian appeared to be round. Even the largest targets (116') had fuzzy corners. The response bias may thus result from the reduced power of his visual system to detect sharp corners; diamond-shaped targets of smaller size (for instance 10') were actually perceived as circular targets.

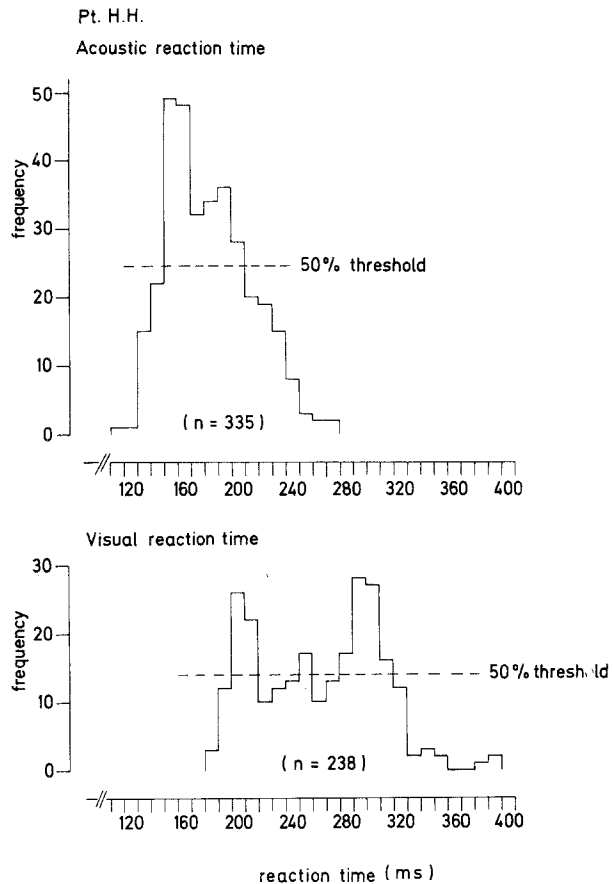
Critical flicker fusion (CFF) was measured both foveally and at 2° eccentricity left and right of the visual axis. The target for these measurements had an angle of 116' and a luminance of 1000 asb. The ascending method of limits was employed, i.e. the patient had to indicate when he no longer perceived flicker. Foveal CFF was 35.7 and 35.8 Hz as measured in March and May (arithmetic mean of ten separate measurements). Thus the temporal acuity of the visual system remained stable over a two-month period but the increase in visual field size during this time was quite evident. Visual field size was 8° at the time of the first CFF measurement, but 15° at the second CFF measurement, determined on both occasions at the most sensitive meridian (135°).

Reliable CFF measurements for eccentric visual field positions were obtained only once. They suggest a small superiority in the temporal acuity of the left visual field. At a position 2° left of the visual axis, CFF was 40.1 Hz, compared to 39.0 at a position 2° right of the visual axis (both figures are arithmetic means of six separate measurements with a range of 3 Hz).

### 3. *Fatigue Site*

Two experiments were performed to determine the site of fatigue that was always observed during experiments of long duration. The first experiment was to determine whether this fatigue was of a general nature or limited to the visual system. Visual and acoustic simple reaction times were measured on two separate days. In each experiment, 50 consecutive stimuli were presented, and the patient





**Fig. 4.** Acoustic and visual reaction time in a patient with highly reduced visual field. The histogram of the acoustic reaction time shows modes at 150 and 190 ms, indicating normal functioning of the acoustic channel; the visual reaction time is considerably prolonged; the histogram shows modes at 200, 250, and 290 ms, indicating an impairment of the visual channel

was to react as quickly as possible to the appearance of each stimulus. The temporal interval between succeeding stimuli was random, ranging from 2 to 7 s and averaging 4 s. Thus the patient could not anticipate the occurrence of the stimuli and had to pay constant attention. It was found that acoustic reaction time remained stable throughout such a testing period. Average acoustic reaction time to the second ten stimuli was 168.6 ( $\pm 25.6$ ) ms and 168.8 ms ( $\pm 16.8$ ) to the last ten stimuli. The reactions to the first ten stimuli were considered as training ( $x=174.3$  ms). In contrast, reaction time to visual stimuli notably increased throughout the testing period. Average reaction time to the second ten stimuli was 268.2 ms ( $\pm 41.1$ ) and 371.6 ms ( $\pm 55.6$ ) to the last ten stimuli. In the training period, i.e., the first ten stimuli, average visual reaction time was 323.4 ms.

These results indicate not only a modality-specific fatigue, but also a selective prolongation of visual reaction time as compared to acoustic reaction time. Normally a difference between simple acoustic and visual reaction time of 30 to 40 ms can be expected (Woodworth and Schlosberg, 1966), and this difference is slightly higher (40–50 ms) for choice reaction time (Pöppel et al., 1970). As Figure 4 indicates (data pooled from several testing periods), this difference in

reaction times in our patient was considerably longer. Because distributions of reaction time measured under stationary conditions usually show several modes (Pöppel, 1970), it is preferable to indicate the positions of these modes. For acoustic reaction time, they are seen at 150/160 and 190 ms and for visual reaction time they are seen at 200, 250, and 290/300 ms. Under normal conditions the modal distance between adjacent peaks is identical for acoustic and visual reaction times (Pöppel, 1970). Thus, besides an increase in average visual reaction time, an increase in intermodal distance was also observed in this patient. It was roughly 35 ms for acoustic reaction time, but close to 50 ms for visual reaction time.

The next step was to determine whether this visual fatigue was dependent on the injured cortical structure. To try out this hypothesis, it was tested whether fatigue would transfer from one eye to the other. The results of such a test of fatigue transfer are shown in Figure 5. In the first instance, a control measurement was obtained: eccentricity along the 135° meridian of the left eye was measured at which the patient could detect the target. The patient detected the 116' target that was moved with 1°/s toward the visual axis at 3.8° eccentricity. Then the left eye was covered with an opaque occluder and the right eye was subsequently tested with an intertrial interval of 15 s. The eccentricities at which the patient detected the targets in the right eye decreased from 3.2° to 2.6°. The left eye was then tested while the right eye was covered. The eccentricity for the left eye decreased from the earlier 3.8° to 3.2°. A slight additional fatigue due to continuous testing is seen, but this shift is very small. The results suggest that fatigue experienced in one eye leads to fatigue in the untested eye. Thus there is transfer of fatigue between the two eyes, indicating that there is a structure involved in which the information of the two eyes has converged. For the primate visual system, the first locus of binocular convergence is the striate cortex and the

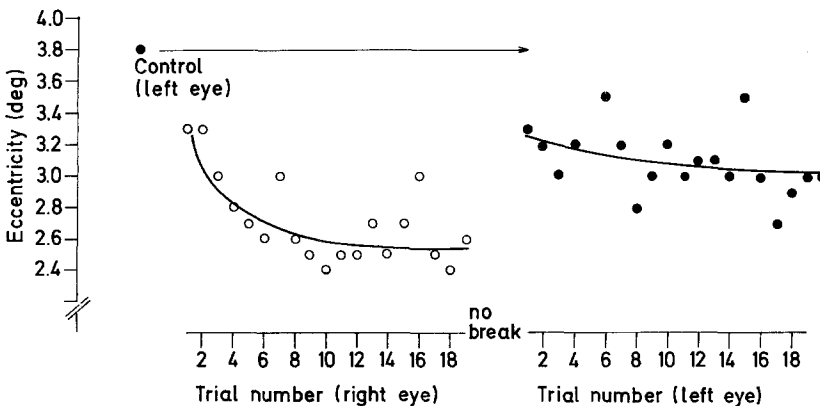


Fig. 5. Adaptation and transfer of adaptation from one eye to the other. Note the decrease of eccentricity for the right eye at which the target is detected after repetitive stimulation. Although the left eye has not been stimulated, the eccentricity in detecting the target is approx. half a degree less than prior to stimulation of the right eye. The transfer of adaptation from the right to the left eye suggests a rather central localization of adaptation

superior colliculus. Continuous testing of one eye apparently leads to decreased responsiveness at the central stage, resulting in a loss of sensitivity in both eyes.

The different levels of eccentricity at which targets are seen in the left and right eyes result from different sensitivities of the nasal and temporal retinae (e.g., Harvey and Pöppel, 1972). It is well-known that regions of the visual field spared after occipital lesions are often of different sizes in the temporal and nasal visual fields (e.g., Koerner and Teuber, 1973). The spared area of visual field is usually larger in the temporal visual field. In the experiment described above, the less sensitive eye was fatigued, the consequences of which were observed in the more sensitive eye. This sequence allows a more powerful statement about central fatigue than if the reverse sequence had been applied. Experiments performed in this reverse sequence also indicated interocular transfer and showed that fatigue outlasts stimulation by at least 10 min. Central fatigue of such long duration was also seen in other studies recently performed in our laboratory (Singer et al., 1977). In this latter case, neuronal adaptation at the subcortical level was assumed to account for long-lasting threshold elevations. On the basis of that study, one might prefer the term 'adaptation' rather than 'fatigue' to label the increase of thresholds after prolonged testing.

#### *4. Color and Brightness Perception*

A serious problem for the patient that caused him much suffering was that he could no longer see colors. The first experiment performed in the perimeter in February confirmed a complete loss of color discrimination. However, a small recovery of function within the following months indicated a weak residual competence in color recognition. Instead of presenting in the perimeter differently colored stimuli which are not identical in luminance, the Farnsworth-Munsell test was used to obtain more reliable data (Farnsworth, 1943). In this test the different stimuli are of equal luminance. The test was not applied in its standardized form because of fatigue. Four differently colored stimuli were chosen from the reduced form of the test (No. 1: blue, No. 6: green, No. 9: yellow, No. 12: red), and the patient's task was simply to identify the color of the stimulus. The stimuli were presented in a random sequence at a fixation distance of 20 cm and an intertrial interval of approx. 6 s; 20 stimuli were usually presented in one sequence. The stimuli appeared at a visual angle of approx. 3.5°. The results of several such tests performed on different days, summarized in Table 1, show a distinct difference in correct responses for different colors. The red stimulus was identified most often (96%) and only occasionally incorrectly perceived as yellow (4%). The other three colors were much more difficult to identify (60% on the average). If yellow was incorrectly perceived, the response was usually red; however green and blue were often mistaken one for the other.

In line with the observations on fatigue, performance deteriorated at the end of each experimental session. The patient actually complained after several minutes of testing that all colors looked alike. Another remark he often made was that the 'old color is still present', i.e., the color of preceding stimuli apparently

**Table 1.** Percentage of responses to four color stimuli taken from the Farnsworth-Munsell test

Stimulus Farnsworth-Munsell test	Response ( $N = 91$ )
No. 1: blue	60% blue, 34% green, 5% yellow, 1% red
No. 6: green	64% green, 28% blue, 3% yellow, 5% red
No. 9: yellow	56% yellow, 35% red, 9% green
No. 12: red	96% red, 4% yellow

resulted in long-lasting positive afterimages and this phenomenon seemed to make the task particularly difficult.

Color recognition was tested left and right of the visual axis on three different occasions. For these tests, target presentation in the perimeter was used because an accurate stimulation of different areas of the visual field otherwise would not have been possible. Background luminance was 10 asb, the fixation point had a diameter of 30', and the target had a diameter of 27' and was presented for 200 ms 1.5° left and right of the visual axis. Color sequence and target location was random. These experiments indicated a slight superiority in the left visual field. Targets in the left visual field were recognized in 71% of the cases (chance expectation: 25%) and targets in the right visual field were recognized in 58% of the cases. As in the tests using the Farnsworth-Munsell test, red was recognized best. These observations show, as do the earlier ones on visual field size, increment threshold, acuity, and critical flicker fusion, that the patient's right hemisphere had maintained a slightly higher functioning level than did the left hemisphere.

Measured on the basis of target presentation in the perimeter, color discrimination was slightly better than when measured with the Farnsworth-Munsell test. A possible explanation for this difference is the fact that color stimuli in the perimeter are slightly different in luminance, in contrast to the stimuli in the Farnsworth-Munsell test. Besides color information, the patient might have here used different apparent brightness of the stimuli as an additional cue. This hypothesis is favored by the observation that, in addition to equal luminance, there was also no *apparent* brightness difference in the stimuli of the Farnsworth-Munsell test. When asked to indicate whether two stimuli presented simultaneously were equal in brightness, the patient reported that both adjacent and nonadjacent colors seemed identical. Thus, besides indicating that the patient might actually have used brightness cues when he recognized colors presented in the perimeter, this brightness estimation experiment also strongly supports the notion that his performance in the Farnsworth-Munsell test was based solely on color information.

Several experiments performed on different dates confirmed that the patient did not suffer a color-naming deficiency. When asked to give the color of different flowers, fruits, or animals, he did so without mistakes—he actually knew flowers

better than the experimenter. Thus the reduction of color discrimination, especially for yellow, green, and blue, seems to depend on a reduction of sensory analysis.

### 5. *Stereopsis*

Although the experiment on interocular transfer (Fig. 5) clearly showed that information of both eyes converges on a joint neuronal population at a postretinal level, the patient never experienced stereopsis. To test stereopsis, the Titmus-fly test was applied. In a forced-choice paradigm, the four stimuli with the lowest necessary stereoacuity were presented in a random sequence and the patient had to guess which one of the four targets was in front of the other three. The patient gave six correct responses to 20 target presentations, one response more than the average chance expectation. For the stimulus that entailed the lowest stereoacuity (800 s of arc), none of the responses was correct.

Even more significant than this test was the patient's failure to see the fly in depth. After looking at this stimulus for 5 min through polaroid glasses with a fixation distance of 20 cm, the patient did not note any change in the picture when he removed the polaroid glasses. This experiment was repeated several times at different fixation distances (20—50 cm), but on no occasion did the patient report a depth impression.

It can be argued that the missing stereopsis is a consequence of the patient's highly reduced visual acuity. However, a few numerical relationships between visual acuity and stereoacuity should be considered that may suggest a different hypothesis about the missing stereopsis. Schober (1964) pointed out that Vernier acuity is approx. 3 to 10 times higher than visual acuity as, for instance, measured with the Landolt ring. According to the law of Münster (Schober, 1964), stereoacuity and Vernier acuity are numerically identical for one observer. Measurements in the perimeter showed that the patient's maximal acuity was 0.4, i.e., he could discriminate targets with a visual angle of 18 min of arc, allowing him enough time to inspect them. Thus his stereoacuity (and Vernier acuity) should, at the most conservative estimate, be below 6 min of arc. Measurements of the fly stimulus show, however, that at a fixation distance of 20 cm the stereoacuity necessary to see the fly three-dimensionally was approx. 30 min of arc at the fly's head and 50 min of arc at the trunk. For the wings, the necessary stereoacuity was considerably more than 1°. Thus the patient's theoretical stereoacuity was at least a factor of 5 to 10 better than was necessary for the fly to be seen in depth. One can conclude therefore that the patient should theoretically have been able to experience stereopsis because binocular interaction was present and visual acuity was sufficient. This conclusion is supported by the following observation: The reduction of visual acuity and field size in an intact observer to the level we observed in the patient did not lead to a loss of stereopsis as measured by our test.

In contrast to increment threshold, critical flicker fusion, and color discrimination, which all showed an associative reduction, stereopsis was completely lost after the lesion. In discussing these results it will be shown, however, that this dissociation does not necessarily invoke a specific cortical area for stereopsis.

### 6. *Aftereffects and Illusions*

It is of particular interest to find out how such a reduced visual system behaves when confronted with more complex tasks. Interestingly, all aftereffects were elicited except for the negative afterimage, which is usually considered a rather simple and peripheral aftereffect (e.g., Boring, 1942). At no time could the patient observe a black-and-white or color afterimage. However, another rather peripheral illusion, the Hermann grid illusion, (Baumgartner, 1960; Spillmann, 1971) was observed. The patient described the intersection of two white bars as clearly less bright than the light bars themselves. This observation would suggest that the retinal receptive fields were still working properly, if the hypothesis of Baumgartner (1960) is valid, i.e., that the Hermann grid illusion is a consequence of retinal receptive field organization.

The other aftereffects tested are apparently of more central origin. In a test of the spatial frequency aftereffect (Blakemore and Sutton, 1969), the patient fixed his eyes for 3 min on a point between a low-frequency and a high-frequency conditioning grating. He then had to compare two identical gratings with a spatial frequency between that of the previous two gratings and stated that the lines were closer together for the grating that fell into the position of the conditioning grating with the low spatial frequency. This qualitative result—quantitative threshold measurements were not possible—indicates a spatial frequency channel that is still intact. Experiments on the orientation aftereffect (Gibson, 1933; Köhler and Wallach, 1944; Campbell and Maffei, 1970) also produced a positive result, i.e., the patient experienced an apparent change in orientation of a vertical grating after looking for 3 min at a grating  $12^\circ$  off the vertical axis. Again no quantitative measurements were possible, but the existence of the aftereffect indicates that basic organizational principles of cortical areas were still intact.

Another question was whether the motion aftereffect could still be elicited. The patient fixed his eyes on the center of a rotating spiral for 60 s. When the spiral was stopped, he reported that there was either a motion toward him or away from him depending on whether the stimulus was a converging or diverging movement. The motion aftereffect lasted only about 5 s. This result indicates intact central analyzing mechanisms (Scott and Wood, 1966); specifically, it might show a properly functioning retinocollicular pathway (Richards and Smith, 1969).

When the patient viewed patterns consisting partly of contours without gradients, he reported seeing, for instance, a triangle located in front of other patterns (cf., Kanizsa, 1974; Fig. 28). The subjective contours could be eliminated and the perceptual reality of a triangle was lost, as for a normal observer when the segments of the subjective contours adjacent to the background patterns were filled in with lines (cf., Kanizsa, Fig. 29).

A stimulus published by Gregory (1970, Fig. 74) was used to test binocular rivalry. Particularly interesting was the low frequency of alterations between vertical and horizontal lines that the patient reported. The period of alterations is in the order of a few seconds for the normal observer (e.g., Levelt, 1966). This period was prolonged in the patient by a factor of at least ten; he saw the

horizontal lines with the left eye for approx. 40 s, and the vertical lines with the right eye for approx. 20 s. It is very interesting how the transition between horizontal and vertical lines and vice versa occurred. Apparently the transition between horizontal and vertical lines always started at an edge on either side or at the top or bottom, e.g., when he saw the horizontal lines, vertical lines suddenly appeared to the left or right and gradually moved toward and across the center of the pattern suppressing the horizontal lines like a traveling wave. Such a gradual transition between the two orientations required 6 to 8 s to complete the new pattern.

A similar retardation of visual mechanisms was observed for the reversal time of the Necker cube. The spontaneous reversal time for the normal observer is in the order of a few seconds (Borsellino et al., 1972), but the patient saw the Necker cube from one perspective for approx. 40 s, then a reversal occurred and he saw the cube from the new perspective for a similar interval. He was asked to intentionally speed up the reversal rate as fast as he could, but could not do better than approx. 10 s for each perspective. This rate is at least a factor ten slower than for a normal observer. Thus the basic operational mechanisms of his reduced visual system appeared to be intact, but a notable prolongation of these processes was found, as already indicated in his visual reaction time (Fig. 4).

### 7. 'Higher' Cortical Functions

Object recognition was tested with pictures that had a visual angle from 2° to 4°, i.e., their angular extent was smaller than the patient's visual field. Many of the pictures were identified correctly, but, as might be expected, with considerable delay. When he failed to recognize an object, the likely explanation was that his visual acuity was simply insufficient. It took, for instance, 8 s for a bottle, 12 s for a watch, 15 s for a cigarette, and 20 s for a key to be recognized. When he did not respond after 60 s, the correct answer was given by the experimenter. He failed, for instance, to recognize a tree—his answer was bouquet of flowers; a comb was seen as a fence, and a pair of shoes as a fly. After he received specific visual training during occupational therapy, he could recognize objects that he had not seen before, sometimes within a second, but others, such as a telephone, still took a minute.

It was psychologically quite important for the patient to make a gradual improvement in object recognition, perhaps because it partly compensated for his inability to tell faces apart. He was never able to recognize people around him visually; mainly the tone of voice, but also the sound of another person's walk, were cues for individual identification. In a more formal test on face recognition, he viewed pictures of faces that were presented to him for 5 s each. Then these five pictures and four additional pictures of faces were shown, and the patient had to tell which of the faces he had seen before. Of the five faces seen already, he recognized two, of the four pictures not seen before, he said he had seen two before. When asked how he recognized faces, his answers made it clear that he tried to use secondary cues like a beard or a high forehead. One can conclude therefore that face recognition was severely disturbed, much more so than would be expected on the basis of his performance in object recognition.

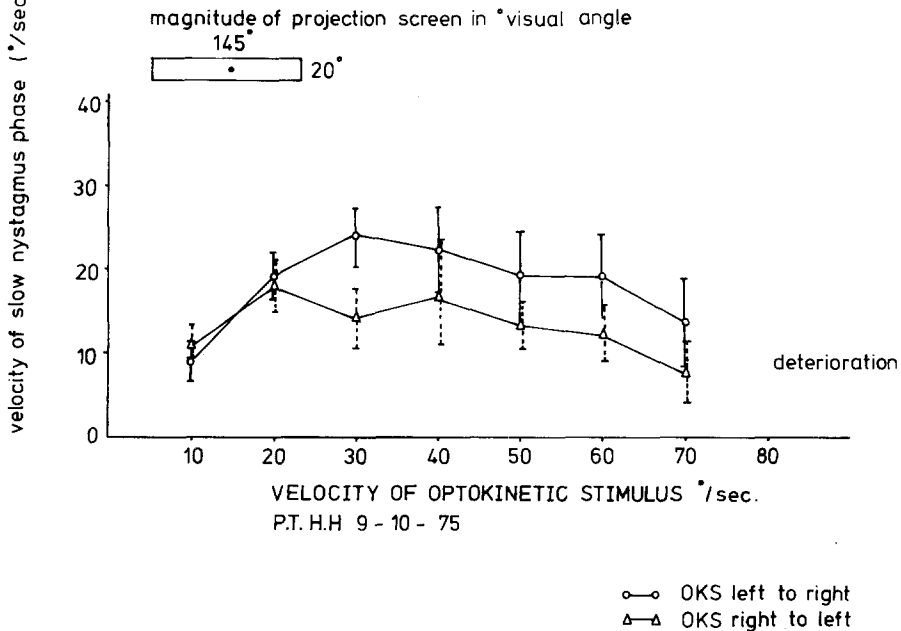


Fig. 6. Optokinetic nystagmus in a patient with highly reduced visual field. The slow phase of the OKN followed the optokinetic stimulus up to velocities of 20°/s. The dot in the center of the rectangle indicates the size of the patient's visual field as compared to the size of the stimulation field

Because of the limited visual field and the reduced acuity, the patient was not expected to be able to read. A test on letter recognition showed, however, that he could correctly identify letters that had a visual angle of 1.5°; if letter size was increased up to 3° visual angle, his performance was faster, as would be expected according to other observations (e.g., Woods and Pöppel, 1974). When he had to read sentences, it was apparently such a great effort requiring so much time to recognize single letters that it was not possible for him to catch the meaning of the sentence. During occupational therapy, an attempt was made to train his residual reading capacity. He was finally able to read short words provided they were large enough, but he never acquired a sufficient level of competence. The patient had no trouble writing and wrote his signature and other words correctly. He was even capable of keeping his handwriting on a straight line.

### 8. Oculomotor Behavior

One might think that the patient's visual field was too small to allow proper control of eye movements. The experiments on optokinetic nystagmus and pursuit eye movements showed, however, a substantial visual control of oculomotor behavior. Observations on optokinetic nystagmus are shown in Figure 6. As can be seen, the velocity of the slow phase of the nystagmus followed the optokinetic stimulus almost perfectly up to 20°/s. Higher stimulus velocities



could no longer be followed but still elicited the nystagmus. Beyond 70°/s of stimulus velocity, the nystagmus deteriorated.

To test pursuit movements, a bar stimulus 2° high and 1° wide was moved with constant velocity back and forth on the horizontal plane. The patient had no problems in following this stimulus up to velocities of 15°/s. Stimuli moving at 30°/s were also followed properly, but small saccades apparently correcting mismatches between the visual axis and the target position were often seen. Target velocities of 60°/s mainly resulted in saccadic responses.

It was of particular interest to see whether the patient would show 'residual vision' as defined by Pöppel et al. (1973). Previous experiments showed that patients with cortical scotomata can discriminate different positions of visual targets presented in the blind regions of the visual field, if they have to direct their eyes or hands toward such targets (Pöppel et al., 1973; Weiskrantz et al., 1974; Perenin and Jeannerod, 1974). Experiments were performed on three different dates in February, June, and November. The Tübingen perimeter was used for target presentation. Background luminance was 10 asb, target luminance either 100 or 1000 asb. Target diameter was 116' visual angle and the target was presented for 100 ms. During presentation the target was either stationary or moved over an area of approx. 5°. Both left and right visual fields were tested, but stimuli were presented only in one half-field during an experimental session. Target eccentricities were 10°, 20°, and 30° along the horizontal meridian. The stimulus sequence was random and each eccentricity was stimulated ten times. The presentation of the targets was accompanied by an acoustic cue signaling to the patient the occurrence of the visual target (which he could not see) and informing him to look toward the target. Eye movements were recorded using de-electro-oculography. No other procedure was employed to test residual vision.

The patient was completely unable to discriminate the position of visual targets presented in his blind field by the saccadic system. The saccadic eye movements appeared normal if compared with those of normal observers (e.g., Frost and Pöppel, 1976) suggesting no obvious problem on the motor side, but there was no correlation between target eccentricity and eye movement amplitude. In one session, for instance, the average eye movement amplitude to stimuli in the left visual field was 41.8°, 40.8°, and again 40.8° for target eccentricities of 10°, 20°, and 30°; for the right visual field these amplitudes were 42.2°, 41.4°, and 41.3°. This result is similar to previous observations (Pöppel et al., 1973) which showed that patients with complete hemianopsia also did not show 'residual vision' as determined by this nonverbal oculomotor response.

## Discussion

Several observations obtained with this patient suggest an associative model of perceptual processing. It has been shown that except for stereopsis and face recognition, all other visual functions tested were still present, although most of them at a rather low level of performance. The argument for association of function is based on the hemispheric difference that was observed. The lesion in the left hemisphere was slightly larger than in the right hemisphere (Fig. 1). This

difference in the magnitude of lesion between the two hemispheres is paralleled by a left-right (i.e., hemispheric) difference for increment threshold, acuity, critical flicker fusion, and color perception. In each of these functions, the level of performance was better in the left visual field, corresponding to the slightly smaller lesion in the right hemisphere. The visual field (Fig. 2) also was slightly larger on the left side. This positive correlation of hemispheric differences between the various visual functions and the extent of the cortical lesion suggests that these functions are analyzed in *one* central area, perhaps the striate cortex. Obviously, this does not imply that this area is the only one that analyzes these specific aspects of the visual world. There may be other areas receiving input from this area that are specialized in further analyzing particular aspects of the visual world, e.g., colors (Meadows, 1974; Zeki, 1974).

At none of the experimental sessions could the patient see objects in depth or recognize faces. This dissociative loss of some visual functions does not necessarily mean that these functions are analyzed in areas of the brain other than those for which an associative representation has been suggested. Assume that a minimal number of functional neurons had to be available in a specific area of the brain in order to achieve perceptual competence of specific visual functions. It could then be argued that such a minimal number of neurons was still present in this patient for functions such as brightness or color perception, but that this minimal number was no longer present for the detection of disparities or the recognition of faces. This idea generally implies that different visual functions associatively analyzed in one neuronal network entail a different minimal number of neurons; only a small number of neurons is necessary for brightness perception; the number of neurons would have to be much higher for stereopsis—and the threshold was too high in this patient. Such a hypothesis stressing the importance of the number of neurons for different qualities of perception is supported by the observations made on the recovery of function, e.g., soon after the lesion the patient was unable to see colors, but his performance gradually improved. The mechanisms responsible for the recovery of function possibly increased the number of functional neurons or changed their sensitivity, resulting in an increase of functional neuronal population.

An associative model of perceptual processing, which assumes different thresholds of the number of neurons for different visual functions, stands in contrast to the idea that the lesion in this patient might indeed have destroyed other areas of the brain that are specifically developed to analyze disparities or faces (e.g., Yin, 1970). It has been argued in the results sections that visual acuity in this patient should have been sufficient for stereopsis. Thus the dissociative loss of stereopsis suggests that, under normal circumstances, stereopsis is processed in a different area of the brain, an area that has been destroyed completely in this patient. This conclusion is favored by neurophysiologic observations in the monkey visual system that indicate that neurons responding selectively to disparities are absent in area 17 but are present in area 18 (Hubel and Wiesel, 1970). Because there is apparently no direct projection from the lateral geniculate bodies to area 18 in the primate visual system, it must be concluded that 'double dissociation of functions' is not possible for stereopsis and those functions that

appear to be associated, such as brightness and color perception. The analysis of disparities appears to occur at a higher processing stage and depends on neuronal analysis of visual information at a preceding stage, presumably the striate cortex. Thus, assuming dissociation of function, in this case one would have to conclude that brightness or color perception may remain intact while stereopsis is lost, whereas the reverse is not possible.

The goal of neuronal analysis of visual information is the identification of objects in the visual world. Neuronal operations responsible, for example, for contrast enhancement or various constancies like size constancy, essentially serve to maintain the perceptual identity of objects (Pöppel, 1977). The observations obtained with the patient have shown that both these object identifying mechanisms and the neuronal operations are basically intact even after the severe lesion the patient has suffered, except for, of course, stereopsis and face recognition. It has been demonstrated that all the aftereffects that are thought to indicate central mechanisms could be elicited; many pictures of objects were even identified correctly. In all tasks, however, an obvious slowing down of the responses was observed and the patient tired quickly when solving visual problems. The ability to perform most tasks despite fatigue and slowing down suggests that the basic neuronal 'machinery' responsible for visual perception can function with a greatly reduced number of neurons.

This slowing down of the analyzing processes possibly allows a closer look at some basic neuronal mechanisms. Here the observation on binocular rivalry proved the most interesting. The patient reported that a new perceptual surface, e.g., one with vertical stripes, gradually developed by 'pushing aside' the old perceptual surface (horizontal stripes). This process, whereby the new perceptual surface took over, lasted several seconds. Presumably an identical strategy is present under normal circumstances, but the process is much too fast to result in a perception itself. This phenomenon of a gradual development of a perceptual surface is perhaps analogous to a similar phenomenon in complex random dot stereograms (Julesz, 1974). It often takes several seconds before a homogenous perceptual surface develops. The observations on binocular rivalry obtained with this patient favor the hypothesis by Julesz (1974) that 'cooperative phenomena' play an essential role in perceptual analysis.

Several experiments showed that fatigue was restricted to vision. Long-lasting tests on visual and acoustic reaction time indicated that reaction time increased only with respect to visual stimuli, presumably because it became more and more difficult to deal with the visual information. Experiments on binocular transfer of fatigue made it clear that the site of fatigue must be postretinal. As mentioned earlier, the main reason for the behavioral blindness of the patient was that he tired too quickly when engaged in visual tasks. One can therefore argue that the observed fatigue is a consequence of the reduction of neuronal population size due to the lesion.

An additional speculation might be added at this point. Barlow (1972) suggested that perceptual acts may result from the activity of a limited number of neurons. As previously mentioned, the basic circuitry for most perceptual acts is still intact. Therefore one is inclined to conclude that the enormous number of neurons normally present, e.g., in the striate cortex, essentially serves to maintain

performance by preventing modality-specific fatigue. All the visual tasks can apparently be done with a much smaller number of neurons, but a much larger number is required to maintain performance over a longer period.

Although most visual tasks could be solved by the patient, he was behaviorally blind. This appears to be important with respect to rehabilitation of function. Our impression was that rehabilitation of visual functions did not lead anywhere with this patient. Although his performance improved over several months, he never learned to rely on his visual capacities, e.g., he developed other behavioral strategies in order to find his way around. To use vision was simply too strenuous. One has to conclude that the presence of certain functions does not imply that they are useful behaviorally. With this patient, we finally concluded that rehabilitation of visual functions was a mistake and that much more effort should have been made to help the patient develop nonvisual strategies. Generally, one should carefully consider if rehabilitation of a severely disturbed system is advisable. The mere presence of functions is not a sufficient reason.

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## References

- Aulhorn, E., Harms, H.: Visual perimetry. In: Handbook of sensory physiology, VII/4: Visual psychophysics (D. Jameson, L. M. Hurvich, eds.), pp. 102—145. Berlin-Heidelberg-New York: Springer 1972
- Barlow, H. B.: Single units and sensation: A neuron doctrine for perceptual psychology? *Perception* **1**, 371—394 (1972)
- Baumgartner, G.: Indirekte Größenbestimmung der receptiven Felder der Retina beim Menschen mittels der Hermannschen Gittertäuschung (Abstract). *Pfluegers Arch.* **272**, 21—22 (1960)
- Blakemore, C., Sutton, P.: Size adaptation: A new aftereffect. *Science* **166**, 245—247 (1969)
- Boring, E. G.: Sensation and perception in the history of experimental psychology. New York: Appleton-Century-Crofts 1942
- Borsellino, A., de Marco, A., Allazetta, A., Rinesi, S., Bartolini, B.: Reversal time distribution in the perception of visual ambiguous stimuli. *Kybernetik* **10**, 139—144 (1972)
- Campbell, F. W., Maffei, L.: Electrophysiological evidence for the existence of orientation and size detectors in the human visual system. *J. Physiol.* **207**, 625—652 (1970)
- Farnsworth, D.: The Farnsworth-Munsell 100-hue and dichotomous tests for color vision. *J. Opt. Soc. Am.* **33**, 568—578 (1943)
- Frost, D., Pöppel, E.: Different programming modes of human saccadic eye movements as a function of stimulus eccentricity; indications of a functional subdivision of the visual field. *Biol. Cybern.* **23**, 39—48 (1976)
- Gibson, J. J.: Adaptation, after-effect and contrast in the perception of curved lines. *J. Exp. Psychol.* **16**, 1—31 (1933)
- Gregory, R. L.: The intelligent eye. New York-St. Louis-San Francisco: McGraw-Hill 1970
- Harvey, L. O., Jr., Pöppel, E.: Contrast sensitivity of the human retina. *Am. J. Optom.* **49**, 748—753 (1972)
- Hubel, D. H., Wiesel, T. N.: Receptive fields and functional architecture in two non-striate visual areas (18 and 19) of the cat. *J. Neurophysiol.* **28**, 229—289 (1965)
- Hubel, D. H., Wiesel, T. N.: Receptive fields and functional architecture of monkey striate cortex. *J. Physiol.* **195**, 215—243 (1968)

- Hubel, D. H., Wiesel, T. N.: Cells sensitive to binocular depth in area 18 of the macaque monkey cortex. *Nature* **225**, 41—42 (1970)
- Julesz, B.: Cooperative phenomena in binocular depth perception. *Am. Sci.* **62**, 32—43 (1974)
- Kanizsa, G.: Contours without gradients or cognitive contours? *G. Ital. Psicol.* **1**, 93—113 (1974)
- Kazner, E., Lanksch, W., Steinhoff, H., Wilske, J.: Die axiale Computer-Tomographie des Gehirnschädels — Anwendungsmöglichkeiten und klinische Ergebnisse. *Fortschr. Neurol. Psychiatr.* **43**, 487—574 (1975)
- Köhler, W., Wallach, H.: Figural after-effects. An investigation of visual processes. *Proc. Am. Philos. Soc.* **88**, 269—357 (1944)
- Koerner, F., Teuber, H.-L.: Visual field defects after missile injuries to the geniculo-striate pathway in man. *Exp. Brain Res.* **18**, 88—113 (1973)
- Levelt, W. J. M.: The alternation process in binocular rivalry. *Br. J. Psychol.* **57**, 225—238 (1966)
- Meadows, J. C.: Disturbed perception of colours associated with localized cerebral lesions. *Brain* **97**, 615—632 (1974)
- Milner, B., Teuber, H.-L.: Alteration of perception and memory in man: Reflections on methods. In: *Analysis of Behavioral Change* (L. Weiskrantz, ed.), pp. 268—375. New York: Harper & Row 1968
- Perenin, M. T., Jeannerod, M.: Residual vision in cortically blind hemifields. *Neuropsychologia* **13**, 1—7 (1975)
- Pöppel, E.: Excitability cycles in central intermittency. *Psychol. Forsch.* **34**, 1—9 (1970)
- Pöppel, E.: Relating perceptual phenomena to neuronal mechanisms. In: *Neuronal mechanisms in visual perception* (E. Pöppel, R. Held, J. Dowling, eds.). *Neurosci. Res. Program Bull.* Vol. XV, No. 3, 1977
- Pöppel, E., Aschoff, J. C., Giedke, H.: Tagesperiodische Veränderungen der Reaktionszeit bei Wahlreaktionen. *Z. Exp. Angew. Psychol.* **17**, 537—552 (1970)
- Pöppel, E., Harvey, L. O., Jr.: Light difference threshold and subjective brightness in the periphery of the visual field. *Psychol. Forsch.* **36**, 145—161 (1973)
- Pöppel, E., Held, R., Frost, D.: Residual visual function after brain wounds involving the central visual pathways in man. *Nature (Lond.)* **243**, 295—296 (1973)
- Richards, W., Smith, R. A.: Midbrain as a Site for the motion after-effect. *Nature (Lond.)* **223**, 533—534 (1969)
- Schneider, G. E.: Two visual systems. *Science* **163**, 895—902 (1969)
- Schober, H.: *Das Sehen*, Band I u. II, 3. Aufl. Leipzig: VEB Fachbuchverlag 1960 u. 1964
- Scott, T. R., Wood, D. Z.: Retinal anoxia and the locus of the aftereffect of motion. *Am. J. Psychol.* **79**, 435—442 (1966)
- Singer, W., Treter, F., Cynader, M.: Organization of cat striate cortex: a correlation of receptive-field properties with afferent and efferent connections. *J. Neurophysiol.* **38**, 1080—1098 (1975)
- Singer, W., Zihl, J., Pöppel, E.: Subcortical control of visual thresholds in humans: Evidence for modality specific and retinotopically organized mechanisms of selective attention. *Exp. Brain Res.* **29**, 173—190 (1977)
- Sloan, L. L.: The Tübinger perimeter of Harms and Aulhorn. *Arch. Ophthalmol.* **86**, 612—622 (1971)
- Spillmann, L.: Foveal perceptive fields in the human visual system measured with simultaneous contrast in grids and bars. *Pfluegers Arch.* **326**, 281—299 (1971)
- Teuber, H.-L.: Physiological psychology. *Ann. Rev. Psychol.* **6**, 267—296 (1955)
- Teuber, H.-L., Battersby, W. S., Bender, M. B.: *Visual field defects after penetrating missile wounds of the brain*. Cambridge: Harvard Univ. Press 1960
- Treter, F., Cynader, M., Singer, W.: Cat parastriate cortex: A primary or secondary visual area? *J. Neurophysiol.* **38**, 1099—1113 (1975)
- Weiskrantz, L., Warrington, E. K., Sanders, M. D., Marshall, J.: Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain* **97**, 709—728 (1974)
- Woods, B. T., Pöppel, E.: Effect of print size on reading time in a patient with verbal alexia. *Neuropsychologia* **12**, 31—41 (1974)
- Woodworth, R. S., Schlosberg, H.: *Experimental psychology*. London: Methuen 1966

- Yin, R. K.: Face recognition by brain-injured patients: a dissociable ability? *Neuropsychologia* **8**, 395—402 (1970)
- Zeki, S. M.: The mosaic organization of the visual cortex in the monkey. In: *Essays on the nervous system. A Festschrift for Professor J. Z. Young* (R. Bellairs, E. G. Gray, eds.), pp. 327—343. Oxford: Clarendon Press 1974
- Zihl, J., Pöppel, E., von Cramon, D.: Diurnal variation of visual field size in patients with post-retinal lesions. *Exp. Brain Res.* **27**, 245—249 (1977)

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