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Analysis and Restitution of Visual Function in a Case of Cerebral Amblyopia

I. Rentschler[2], G. Baumgartner[1], F.W. Campbell[3] and D. Lehmann[1]

[1] Neurology Department, University of Zürich, Switzerland
[2] Institute of Medical Psychology, University of Munich, Federal Republic of Germany
[3] The Physiological Laboratory, University of Cambridge, UK

Summary. In a patient suffering from a severe bilateral dysfunction in both occipital and parietal areas we have found: (1) A loss of contrast-sensitivity, being strongest in the range of spatial frequencies where the normal eye is most sensitive; (2) Virtually normal grating resolution, a severe loss in letter acuity (about 15-fold), and a very strong loss in vernier acuity (about 100-fold); (3) Rapid partial recovery of contrast sensitivity due to stimulation; (4) Slow partial recovery of letter acuity due to CAM rotating grating treatment; (5) No improvement of a 10-fold temporal retardation in the speed of reading. Evidence is presented that the residual impairment of vision depends upon improper synthesis of spatial frequency components originating from a heavy loss in processing speed and abnormally long store duration for high spatial frequency information.

Key words: Cerebral amblyopia – Visual acuity – Contrast sensitivity – Short-term memory – Visual restitution

Introduction

The study of alterations of perception in humans aims at understanding the nature of altered behaviour in terms of specific changes in normal mechanisms (Milner and Teuber 1968). This, in turn, would seem to be a prerequisite for the development of more effective means for restoring sensory function. Where pattern vision is concerned, particularly detailed knowledge is now available to the visual scientist about spatial frequency specific filter mechanisms (for a recent review, see De Valois and De Valois, 1980). Therefore, we submitted a patient with complex disturbances of her visual capacities, which could not be explained simply in terms of visual acuity and field loss, to a variety of physiological tests depending on spatial frequency specific stimulation. These measurements have provided some insight into the nature of her perceptual disturbances; also, in conjunction with a rotating-grating treatment (Banks et al. 1970) they have brought about a partial restitution of spatial vision.

As our patient suffered from visual disturbances in the presence of seemingly adequate grating resolution, we decided to measure her contrast sensitivity functions, that is her sensitivities for the detection of sine-wave gratings over the whole range of spatial frequencies. These functions, besides providing a measure of acuity (i.e. the finest resolvable grating at 100% contrast), specify the visibility of coarser objects at lower contrast. Bodis-Wollner (1972) was first to demonstrate the advantages of this method for examining patients with cerebral lesions; since then, anomalies in the contrast sensitivity function have been shown in various diseases which involve a deterioriation of vision which cannot be demonstrated by ordinary clinical techniques (see Arden 1978 for a review).

Predicting the visibility of complex patterns from the contrast sensitivity function depends, in principle, upon the use of Fourier's theorem. Accordingly, any pattern may be represented in terms of sinusoidal components differing in spatial frequency, amplitude, and position (see Caelli 1981). Indeed, considerable evidence is now available that the visual system performs a piecewise Fourier decomposition of the retinal image (Campbell and Robson 1978; De Valois and De Valois 1980). The harmonic components of visual patterns seem to be carried by spatial frequency "channels" in much the same way that pure tones, as the components of complex harmonies, are handled by the auditory system (Campbell 1974). Thus, the contrast sensitivity function may be seen as the envelope of the contrast sensitivity functions of the various spatial frequency selective channels.

The information provided by the contrast sensitivity function alone fails to account for important aspects of visual dysfunction. Some amblyopic eyes exhibit virtually normal contrast sensitivity (Hess et al. 1978) and normally tuned spatial frequency channels (Hess, 1980; Rentschler et al. 1980) although their letter acuity is poor. Some amblyopes with a normal contrast sensitivity function suffer from distortions and fragmentation of suprathreshold contours (Hess et al. 1978). Recent experiments on the amblyopic contrast sensitivity for temporally modulated gratings suggest that a disturbance of spatio-temporal vision may account for the discrepancies (Rentschler et al. 1981). Similarly, our results demonstrate that it is a loss of spatio-temporal sensitivity, rather than a mere loss of spatial resolution, that accounts for the visual dysfunction the patient is left with, after partial restitution of her spatial vision.

Case History

A 20-year-old female became suddenly disturbed by scintillating coloured lines and stars in the whole visual field. These had persisted for about 2 h when a severe headache in the occipital region appeared. Finally, she fell asleep for 13 h.

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After awakening on the following day she vomited repeatedly and complained about alterations in form and colour vision. Moreover, after looking at stairs, she experienced stair-type distortions of objects and even faces which persisted for minutes (palinopsia).

The patient previously had had no visual problems and the earlier history was regular. She had been taking oral contraceptives for 8 months before her illness.

Since her vision did not improve, and bilateral central scotoma plus a loss of the upper right quadrant were found by the ophthalmologist, she was refered to hospital two weeks later. No other neurological symptoms were found and a complete internal and lab screening was regular. CSF protein was moderately elevated (66 mg%); the cell number was normal. A multiple sclerosis was diagnosed and ACTH therapy initiated. Ten days later letter acuity was still 0.1, but the peripheral visual fields on confrontation were normal. After a further 5 days there occurred sudden gustatory hallucinations, headache and nausea, oral automatisms, stereotyped movements with the right hand, and a loss of communication for about one hour with a subsequent tonic-clonic seizure. On admission into the neurology department on 16 May 1979, she was oriented and very anxious about her vision. Spontaneous speech was slightly, and comprehension clearly impaired. Only simple tasks were understood. Reading could not be tested. Slight dysgraphia and dyscalculia were noted. There was no apraxia. She complained about continual coloured scintillations, now in the centre of the visual field. Oculomotility, fixation, pupilary reflexes, and fundus were normal. Eye movements to command were undisturbed and slow pursuit movements were possible, but no optokinetic nystagmus could be elicited. The lower half of the visual field on confrontation and possibly the left upper quadrant were lost. Letter acuity was less than 0.1 in both eyes.

EEG: continuous spike activity at both parieto-occipital regions, but on the right more than on the left, and generalized moderate slowing. Improvement of the synchronized activity in the following days and weeks. Slow wave focus frontal right. Two months later, only intermittent beta activity with discrete focal preference about both temporo-occipital regions, on the right more than on the left.

Computertomography in several controls regular. Vertebralisangiography: hypoplastic arteria vertebralis on the left, unusually tender arteria basilaris. Static and dynamic brain scintigraphy: slightly augmented storage of activity temporo-occipital, on the right more than on the left. Dopplersonography: normal perfusion of the carotid and vertebral system.

Visually evoked potentials: at the beginning, latency on the right 145 ms, on the left 150 ms. Four weeks later 110 ms and 135 ms with strongly abnormal potentials.

Electronystagmogram (recorded on 3 April 1980): no spontaneous nystagmus. Pre- and postrotatory nystagmus normal. Optokinetic nystagmus symmetrical for stimulus velocities up to 100 deg/s. Normal pursuit movements during pendulum tracking.

Lumbal CSF, three weeks after the first control: 4 cells, 38 mg% protein with slightly reduced Gamma-globulins.

Although the patient could resume her profession as a telephone operator one year later, she is still complaining about fast fatigue, frequent headache and photopsias for 1 to 10 min of different forms, size and colours as well as metamorphopsias with distortion of familiar faces. At intervals of several months she has complex partial seizures, beginning either with dystasting gustatory sensations or elementary visual hallucinations, which occasionally lead to secondary generalization.

Results

Part I: Contrast Sensitivity and Visual Acuity

Contrast Sensitivity and its Improvement. Contrast sensitivity was determined by using the method of Campbell and Green (1965). Stationary sine-wave gratings were displayed on an oscilloscope screen. The contrast of the patterns was varied by means of a potentiometer and a psychophysical method of adjustment was applied. The contrast sensitivity functions of patient S.F. (Fig. 1) are uniformly flattened with the strongest depression at spatial frequencies where the normal eye is most sensitive (around 5 cpd; see also dotted curve). Most surprisingly, however, the high frequency roll-off of these functions is normal. This implies that the patient has normal grating acuity.

The results presented in Fig. 1, however, are after some improvement in contrast detection due to repeated measurement. Indeed, in a preliminary examination (31 May 1979) a pronounced loss of contrast sensitivity in the whole range of spatial frequencies had been found. No further psychophysical measurements were performed from then until September. Then, during three experimental sessions (11, 13, and 14 September 1979), the patient became gradually more sensitive to vertical gratings. No further improvement was obtained in session 4 (17 September). In order to assess for a possible meridional anisotropy both vertical and horizontal gratings were used in this session and in sessions 5 and 6 (19 September; 8 October 1979). Accordingly, Fig. 2 shows the improvement of contrast sensitivity functions for both orientations. Data obtained with vertical gratings in the first session (11 September) are indicated by broken lines. It is obvious that the sensitivity for horizontal gratings had not been affected by the previous improvement for vertical patterns, but the differences had almost completely disappeared after another two experimental sessions including measurements with both vertical and horizontal gratings.

Restitution of Letter Acuity. The first examination (31 May 1979) revealed a striking discrepancy between the patient's grating resolution (14 cdp and 12 cpd for the left and the right eye, or about 60% of normal performance) and Snellen letter acuity (0.07 at a distance of 5 m for each eye). On the other hand, a pronounced loss in letter acuity would have been expected from the existence of central scotomata in the visual fields of 30 May 1979 (Fig. 3, left plots) with the larger area subtended by the grating stimuli accounting for the higher grating resolution. However, at the beginning of the training period (11 September) the central scotomata were significantly diminished (Fig. 3, center) whereas no improvement in letter acuity was observed. It was this dissociation of visual field defect and letter acuity that prompted us to submit S.F. to a pattern-specific visual training procedure that has previously only been used for treating amblyopic children (CAM-trainer; Banks et al. 1978).

The results of the CAM-training are shown in Fig. 4. Thirty-five training sessions took place between 11 September 1979, and 5 May 1980. Thirteen of them were held at the hospital, where the training was followed by measurements of contrast sensitivity and visual acuity. Twenty-two sessions were supervised by the patient's mother at home. It is important to

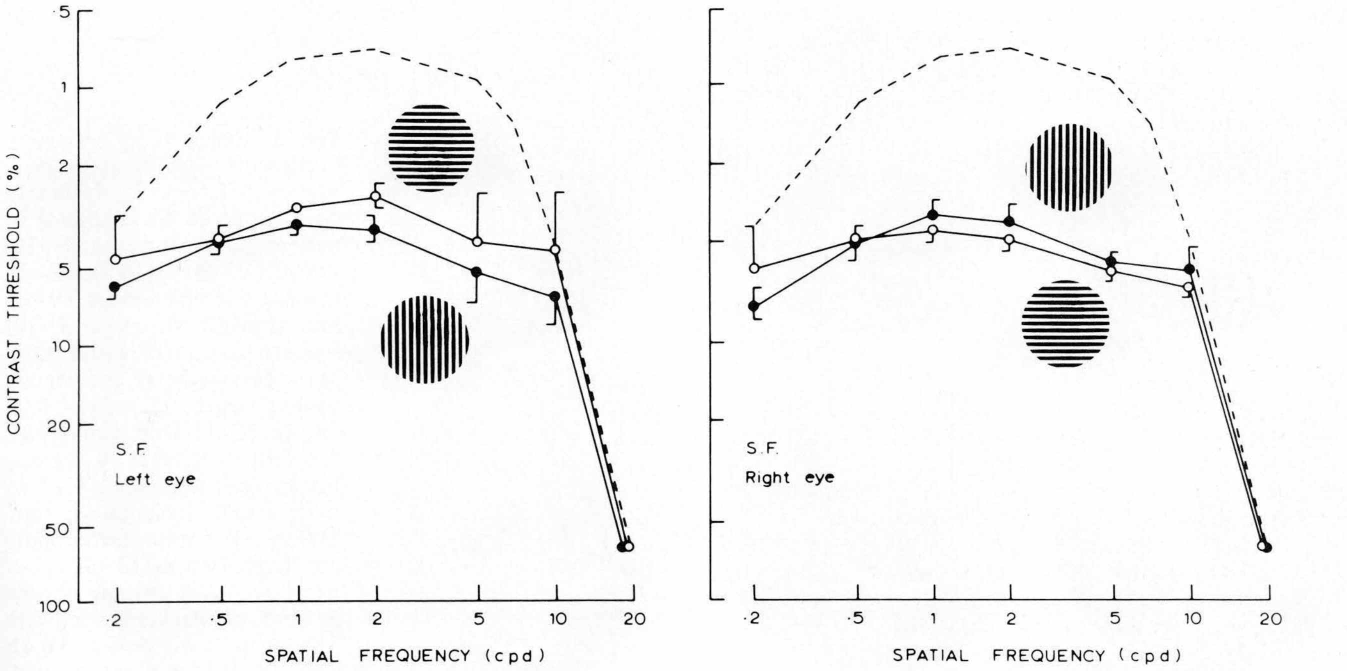

Fig. 1. Contrast sensitivity functions for vertical and horizontal gratings from both eyes of patient S. F. Field size was 10 × 8 deg, average luminance 16 cd m^{-2}. Averaged data from nine experimental sessions between 8 October and 12 December (vertical, n = 36) and six experimental sessions between 1 November and 12 December 1979 (horizontal, n = 24) are shown. Dotted curve is the contrast sensitivity function of the right eye of normal observer H. B. obtained under identical experimental conditions

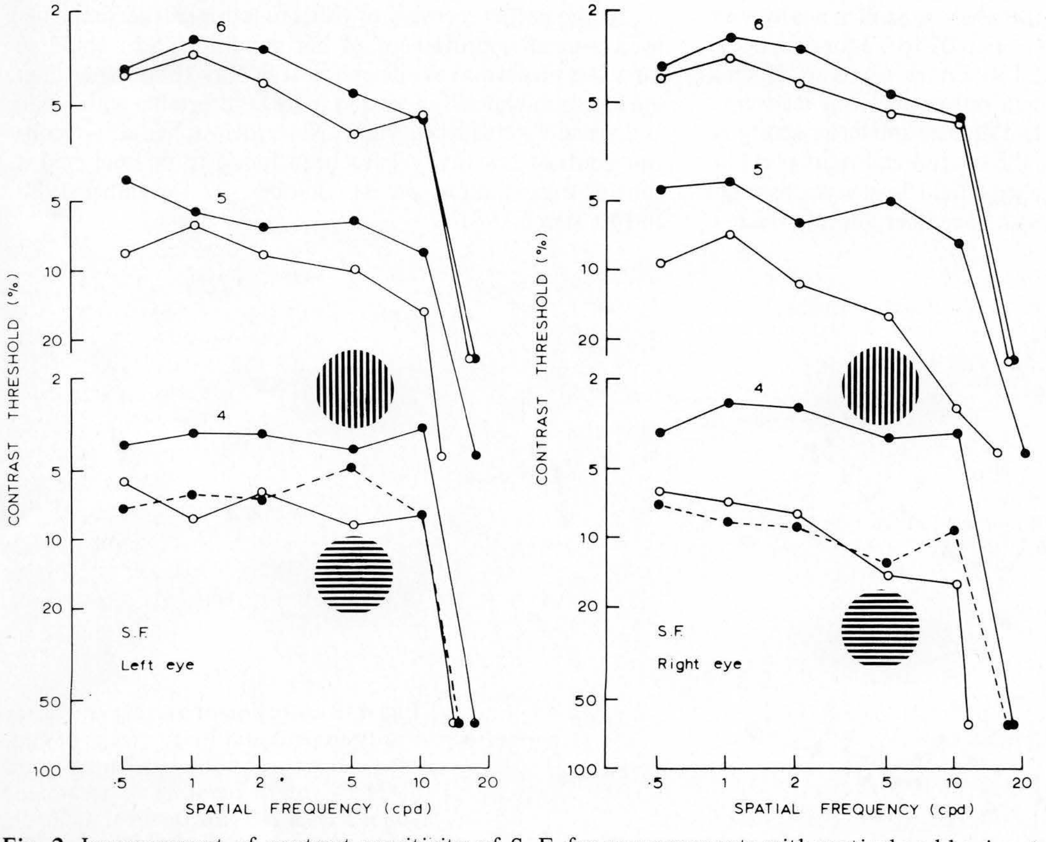

Fig. 2. Improvement of contrast sensitivity of S. F. for measurements with vertical and horizontal grating patterns obtained in three experimental sessions (No. 4: 17 September, No. 5: 19 September, No. 6, 8 October 1979). Session No. 4 was the fourth in which vertical gratings were used and the first in which horizontal gratings were used in addition. Data points correspond to mean values of 4 theshold adjustments. Dotted curves indicate results obtained with vertical gratings in session No. 1 (11 September 1979)

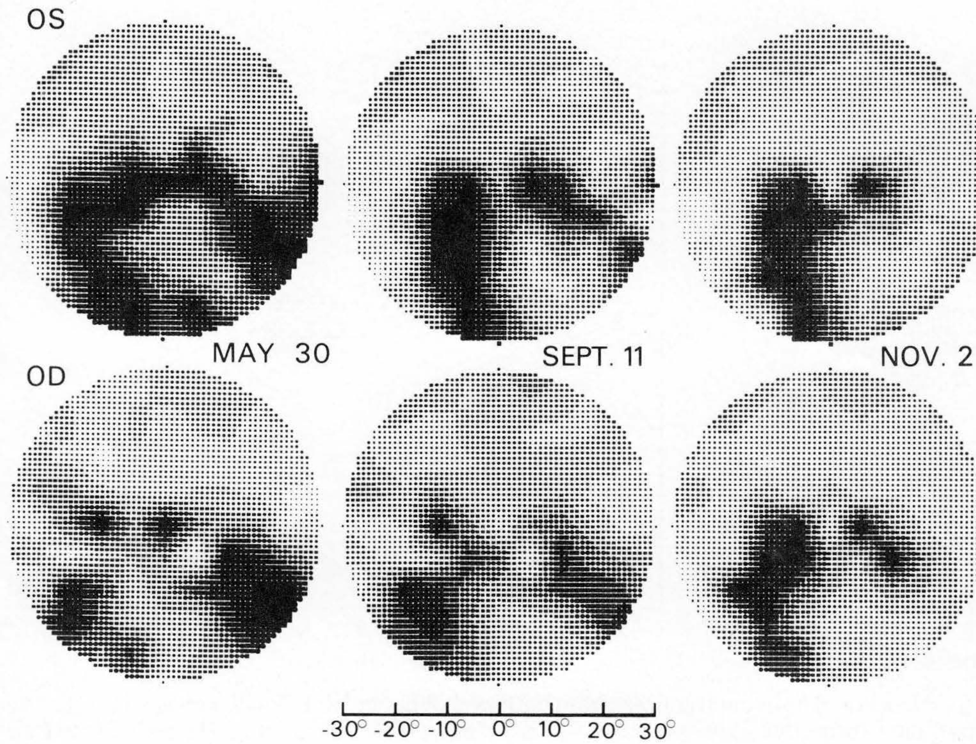

Fig. 3. Visual field perimetry (automatic Goldmann perimeter "Octopus", Interzeag AG, Schlieren Switzerland) in patient S. F. during hospitalisation (30 May 1979), before the 1st (11 September 1979), and after (2 November 1979) the 8th session of visual training. The perimetry parameters were: target diameter 0.43 degrees (Goldmann stimulus 3), visual field diameter 60 degrees, background luminance 1.27 cd m^{-2}, target presentation time 100 ms. The interpolated plots are derived from 73 test positions at 6 deg spacing chosen at random. Black areas indicate 318 cd m^{-2}, big dots 6–10 dB attenuation, intermediate dots 21–25 dB, smallest dots 36–51 dB

note that the increase in grating acuity due to measurement (from 14 cpd and 12 cpd to 21 cpd for the left and the right eye respectively) is less than 60% whereas Snellen acuity was improved more than four-fold (from 0.07 to 0.3 for each eye). The improvement of both visual functions seems to depend on the training period rather than on spontaneous recovery.

The dissociation of visual field defects and letter acuity is confirmed by a comparison of the central and right plots in Fig. 3. Little change in the central field loss was observed over the period 11 September – 2 November, during which a clear improvement in contrast sensitivity and letter acuity was achieved.

As the partial recovery of visual function was accompanied by a general improvement of her condition, S.F. could resume her profession as a telephonist in May 1980. Since then, she has found herself more and more comfortable with seeing and visually guided behaviour. Nevertheless, her letter acuity and contrast sensitivity have been found to be unaltered in control examinations on 31 October, 22 December 1980, and 13 March 1981.

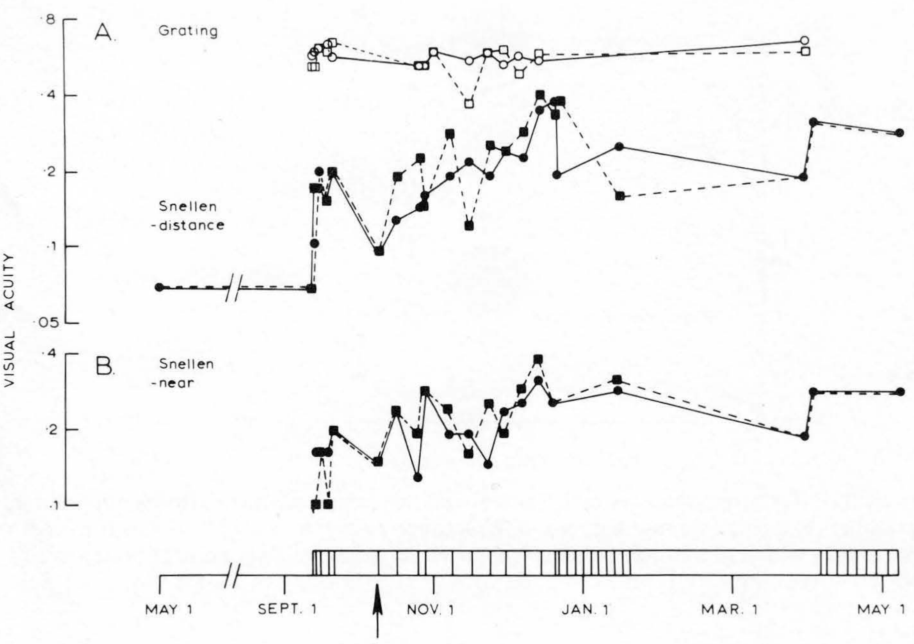

Fig. 4. Restitution of grating and letter acuity in patient S.F. by means of contrast sensitivity measurement and CAM rotating-grating treatment (Banks et al. 1978). Decimal acuity is plotted vs a time scale (May 1979–May 1980) where vertical barks mark sessions with CAM-treatment and (if represented by data points) acuity and contrast sensitivity measurement

Persistent Loss of Vernier Acuity, Stereo Acuity, and Reading Speed. From the lack of correlation between visual field loss and letter acuity one can conjecture that the loss of visual function in patient S.F. concerns mechanisms more complex than those assessed by static perimetry. Further evidence for this conclusion comes from the fact that vernier acuities of 510 s of arc and 810 s of arc for the left and the right eye respectively have been obtained for S.F. (8 May 1980). Thus the loss of acuity is 85-fold and 135-fold (normal performance 6 s of arc).

Stereoscopic vision has been demonstrated by having the patient thread a needle. Also with the Titmus-fly test the patient succeeded in seeing contours in depth. With the TNO test a stereo-acuity of 1320 s of arc retinal disparity was found. This means an 88-fold loss of stereo-acuity (normal performance 15 s of arc). Measurements of cortical evoked potentials with on-line computer generated dynamic random-dot stereograms (Julesz-patterns) agree with these results. Such stimuli reliably evoke detectable average brain potentials (Lehmann et al. 1978) when binocular disparity detectors are operating (Petrig 1980). No detectable potentials have been obtained from S.F. with a 680 s of arc disparity checkerboard stimulus, whereas a monocularly visible control checker-board with 680 s of arc check-size evoked a significant response.

Additional evidence for the complex nature of S.F.'s visual dysfunction came from observations made during letter acuity measurements: a severe retardation in reading the test-chart persisted after the treatment in the absence of any abnormality in oculomotor response. Therefore, we investigated spatio-temporal sensitivities of the patient more thoroughly.

Part II: Spatio-Temporal Vision

Reaction Time as a Measure of Detection Time. Reaction time has been measured by presenting 50% contrast sine-wave gratings on the otherwise uniformly illuminated oscilloscope screen. The patient, who was gazing at the screen, had to press a button as soon as she detected the pattern. During this time interval the stimulus was continuously displayed. Two different field sizes were used; the rectangular field subtended 10 × 8 deg and the circular field 3 deg in diameter.

In Fig. 5 mean reaction time is plotted as a function of the spatial frequency of the targets. Results obtained from three normal observers are indicated by the hatched area. In agreement with the data of Breitmeyer (1975), reaction time increases (with a few exceptions) for all observers monotonically with spatial frequency. A most surprising abnormality in the patient's response, however, is the abrupt increase in reaction time between 7.5 cpd and 10 cpd. Such a loss of visual performance cannot be explained in terms of contrast sensitivity for stationary gratings as, at the time, the latter was already normal for a 10 × 8 deg field at 10 cpd (see Fig. 1). Another experiment with S.F. has established that the use of a circular 3 deg field reduces the contrast sensitivity at 10 cpd only by about 50%.

An additional experiment was performed in order to decide whether the abnormal reaction times depended on an increase in detection time or recognition time. The patient was instructed in one experimental situation to respond only when she had recognized the pattern striation. Alternatively, she was instructed to respond whenever she saw a change in the uniformly illuminated display. No significant difference in reaction time was found between the two conditions. Therefore, we concluded that the response latencies of S.F. depended upon an increase in detection time.

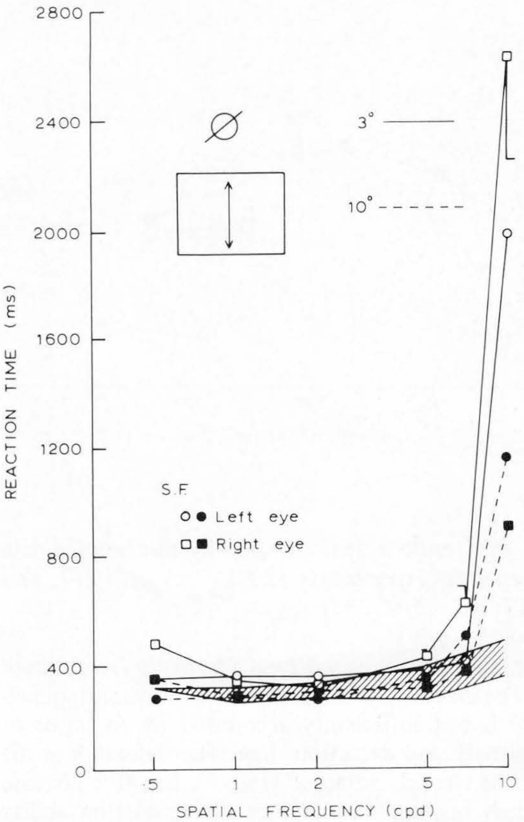

Fig. 5. Reaction time of patient S. F. for 50% contrast sine-wave gratings. Data are displayed for a 10 × 8 deg rectangular test field and a 3 deg diameter circular test field. Mean values of 20 trials performed at two experimental sessions (20 December 1979, and 14 January 1980). Error bars (±1 S. E., n = 20) are given at one condition. The hatched area represents the range of mean reaction times (n = 10) for three normal observers (I. R., H. B., and T. D.) and for both the 10 × 8 deg and the 3 deg test field conditions

Abnormal Detection Time Impairs Pattern Discrimination. A conceivable theory of the patient's difficulty in pattern recognition seemed to be that, due to the highly abnormal differences in processing time, information conveyed by low and high spatial frequency channels did not coincide sufficiently at some neural stage of pattern resynthesis. Therefore, we tested her ability to discriminate gratings of different luminance distributions. The patterns used were a sine-wave grating having only one spatial frequency – the fundamental – and a square-wave grating having in addition all the odd higher harmonics; 3rd, 5th, 7th etc.

Figure 6 shows cumulated percentage of correct responses vs. presentation time. The normal observers achieved a criterion of 90% correct choices between a 3 cpd sine-wave grating and a 3 cpd square-wave grating at about 100 ms presentation time. S.F. did much worse. She reached only a relative maximum of performance (80% correct) at 700 ms, and returned to chance level at longer presentation time. The

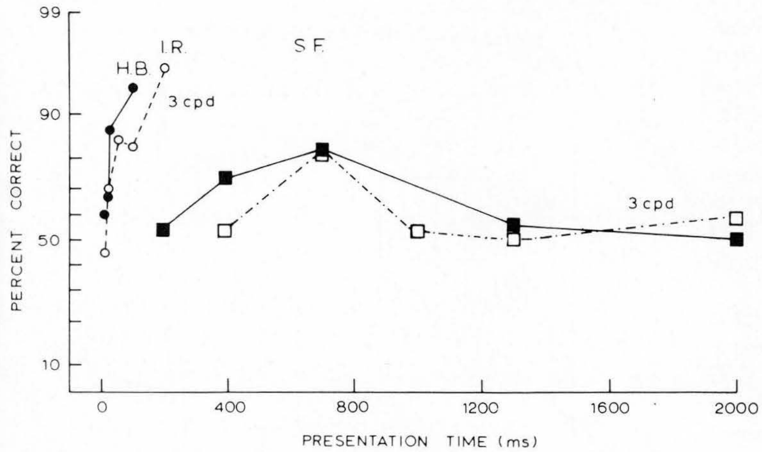

Fig. 6. Discrimination of square-wave gratings and sine-wave gratings as a function of presentation time. The targets had the same fundamental spatial frequency (3 cpd) and contrast (50%). Results obtained monocularly from two normal observers (I. R. and H. B.) and patient S. F. (left eye). Cumulated percentage of correct responses is plotted on the ordinate. Data of I. R. and H. B. obtained 17 January 1980 from 20 presentations at each temporal condition. Data of S. F. mean values (n = 10) of two experimental sessions at 20 December 1979, (open squares) and 16 January 1980 (black squares)

reliability of this result is demonstrated by plotting the data from two separate experiments (20 December 1979, and 16 January 1980).

Pattern Discrimination Impaired by Abnormally Long Visual Persistance. The inability to discriminate sine-wave and square-wave gratings is not sufficiently accounted for in terms of contrast sensitivity and detection time. The detection of the 3rd harmonic is strongly retarded (Fig. 5). But this increase in latency does not explain why the discrimination ability drops to chance level at longer presentation times. Such a result would be predicted if S.F. suffered not only from a delay in detection but also from prolonged persistance of high spatial frequency information. We decided to measure critical-blank-duration (Corfield et al. 1978) in order to test for this possibility.

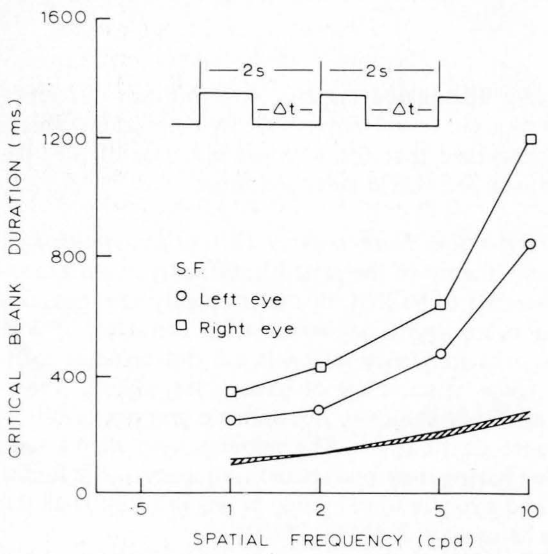

Fig. 7. Critical-blank-duration obtained with 50% contrast sine-wave gratings. Observer S. F. The hatched area represents the range of averaged results (n = 10) for two normal observers (R. H. and I. R.). The inset demonstrates how the presentations of a 50% contrast sinusoidal grating alternated with a blank field. Subjects were to adjust detection thresholds Δt for the blank

Figure 7 shows critical-blank-duration for sine-wave targets as a function of spatial frequency. The data have been obtained in experiments where a uniform field (blank) occured at a temporal rate of 0.5 Hz on the oscilloscope screen, alternating with a sinusoidal grating of equivalent average luminance and of 50% contrast. The subject's task was to adjust the duration of the blank until she could no longer see it as a separate event. This duration was measured as the critical-blank-duration. Results obtained from two normal observers are indicated by the hatched area. They agree with the data by Corfield and coworkers. By contrast, the patient shows a considerable prolongation in this task. More specifically, a comparison with the large field data of Fig. 5 reveals that reaction time for sine-wave gratings and critical-blank-duration are prolonged almost to the same extent.

Discussion

This patient suffered from a severe bilateral dysfunction of sudden onset in both occipital and parietal areas. The reason for it could not be definitely established. But since there was no indication of encephalitis, vasculitis, an angioma or an aneurysm, we assumed an hypoxic lesion due to either a severe basilar migraine attack or an obstruction of the upper basilar artery with secondary recanalisation. Considering her age, the latter assumption seems less probable, although the patient had been on oral contraceptives for 8 months before the event. However, additional evidence for a migraine complication is also weak.

If one accepts an hypoxic lesion one could also assume, due to selective vulnerability, partial damage especially in the third, possibly also in the 5th and 6th cortical layers (Brierley 1976). The lesion would not be severe enough to show up in the CT-scan, but obviously sufficient to disturb seriously information processing. We cannot indicate the extension of the lesion in the prestriate areas, but judging from the enduring paracentral scotomata, the region of the occipital pole must have been most seriously affected. The visual symptoms in the beginning can be understood as hypoxic excitation, and the later intermittent photopsias and partial complex seizures with occasional secondary generalisations indicate the establishment of a focus with insufficient control of excitation.

Contrast Sensitivity

The alteration of contrast sensitivity in our patient (Fig. 1) suggests that a particular subset of spatial frequency channels is more affected by the disease than others. Such nonuniform loss of contrast sensitivity may pose a greater difficulty in pattern recognition than a simple drop in visual acuity (Bodis-Wollner 1972). Indeed, assuming that the brain performs a quasi-harmonic analysis of the retinal image, an improper balance of the signals from independent spatial frequency channels would cause perceptual distortions. It should be noted, however, that it is the range of *intermediate* but not of high spatial frequencies that is affected. Therefore, the loss of contrast sensitivity does not suficiently explain the deficit in letter acuity.

Contrast sensitivity has been partially ameliorated by repetitive stimulation, but this only happened during the first three training sessions. It was most noteworthy, however, that the effects of training with vertical gratings failed to transfer to horizontal gratings (Fig. 2). It is unlikely, therefore, that the increase in performance has resulted merely from an improvement in motor skills or from a change in threshold criterion. Rather, the observed orientation specificity of the training effect invokes an explanation in terms of neural plasticity occuring at the level of visual cortex. Similarly, Fiorentini and Berardi (1980) found perceptual learning in normal subjects to be orientation specific when they tested discrimination of gratings of different waveforms.

Restitution of Letter Acuity

The neural mechanisms involved in the CAM-treatment (Fig. 4) remain unknown but it seems that the rotation of the grating would cause a temporally organised discharge pattern among sets of cortical neurons with different orientation preferences. Such a highly unusual response pattern may reactivate a reduced cooperativity among visual neurons. (A. Fiorentini, personal communication to F.W.C.). Other workers have claimed that the efficacy of the CAM-treatment of (unilateral) amblyopia might be exclusively attributed to short-term occlusion of the unaffected eye and/or the enhanced activity of the amblyopic eye, without the grating stimulus being particularly effective (Keith et al. 1980). Such explanations do not easily accomodate the significant training results obtained with the binocular CAM-treatment in our patient.

An improvement of diminished visual function by means of systematic stimulation has been observed previously in behavioural experiments with monkeys (Cowey and Weiskrantz 1963 Cowey 1967). Results from patients with cerebral lesions (Pöppel et al. 1978; Zihl and von Cramon 1979) agree with these findings. However, they depend upon the measurement of luminance increment thresholds and the resulting enlargement of a restricted visual field; information on the extent of improvement of specific functions of spatial vision has not been provided. We have observed a spontaneous improvement of visual fields in our patient during the initial period of recovery (Fig. 3, 30 May – 11 September) which has not been accompanied by any change in letter acuity at all (Fig. 4). Systematic stimulation, on the other hand, of spatial frequency specific mechanisms (Figs. 2 and 4) had no comparable effect on visual fields. Instead there was a loss of sensitivity in the central visual field of the right eye, whereas that of the left eye improved somewhat (Fig. 3, 11 September – 2 November). Thus, our results revealed a dissociation of visual field improvement and restitution of spatial vision.

Retardation in Detection Time

The abrupt increase in detection time, which we have found for high spatial frequencies (Fig. 5), may pose a serious difficulty in the patient's pattern recognition performance. Indeed, the memory span for pattern is limited when components of the pattern are distributed in time. Hogben and Di Lollo (1974) found a memory span of 120–140 ms for dot patterns. Our experimental conditions are not strictly comparable, but we may safely assume that the neural synthesis of harmonic components of a retinal image is performed within a limited cycle time smaller than the observed difference in detection time between low and high spatial frequency components (about 2 s). Thus, the retardation of the high frequency information would prevent it from being perceptually integrated. A deficit in spatio-temporal performance will, therefore, result in a lower effective spatial cut-off frequency than is indicated by the contrast sensitivity function for stationary gratings (Fig. 1). Evidence in favour of this hypothesis is provided by the fact that the finest grating S.F. could detect without a notable delay was the 5 cpd target (Fig. 5). The corresponding grating resolution is about 20% of the performance of normal observers in the same situation. This estimate agrees with the letter acuity of 0.2 that the patient had at the time of the reaction time experiments. From these arguments it would seem reasonable that vernier acuity which depends upon the precise assessment of a single relevant cue would suffer most strongly from the visual dysfunction.

A retardation in discriminating complex gratings would seem natural as the detection of sine-wave gratings is delayed. Indeed, the sine-wave grating is the first harmonic of the square-wave grating with the same fundamental spatial frequency (i.e. F = 3 cpd). Discrimination of the two patterns is possible when the third harmonic of the square-wave (3 F = 9 cpd) is detected independently (Campbell and Robson 1968). Thus, a delay in detection time for 3 F would cause an increase in presentation time required for discrimination. Such delay has been found (Fig. 6). However, it does not explain why there is a non-monotonic dependence of correct responses on presentation time.

Persistance of Visual Images

The measurement of critical-blank-duration (Gorfield et al. 1978) is a modified version of the gap-detection paradigm of Meyer and Maguire (1977) which has been recently used by Lovegrove et al. (1980) for testing normal and disabled readers. The latter showed abnormally *short* store duration for high spatial frequency information. Therefore, disabled readers would have problems with tasks requiring integration of successive fixations because they will lose information on details within patterns, as has been pointed out by Lovegrove and coworkers. By contrast, the abnormally *long* store duration of our patient would prevent her from getting rid of high spatial frequency information from previous fixations. This lack of "reset" in visual short-term storage would explain why prolonged presentation time may impair the discrimination of complex patterns (Fig. 6). Therefore, it would be an additional factor impairing the performance on letter acuity testcharts.

Persistence of visual images as such (palinopsia) has been reported by our patient during hospitalisation in May 1979. This is a rare disorder, but it is more common in patients with left sided field defects (Meadows and Munro 1977). Palinopsia has also been described as a manifestation of temporal lobe epilepsy (Swash 1979). We do not know whether there is a relation between the disorder of visual short-term memory and such hallucinations. The time course of the latter, however, suggests that they originate from different mechanisms.

Conclusions

From our analysis of visual function in a case of cerebral amblyopia it would appear that there are at least two basic mechanisms of perceptual distortion. The one is improper balance between the contrast dependent signals from spatial frequency channels. This deficiency is indicated by nonuniform alterations of the contrast sensitivity function for stationary gratings. The other is temporal imbalance of the signals, this being indicated by spatial frequency selective retardation of detection and erasure in short-term storage. Such retardation would prevent pattern components from being integrated in the percept. The observed pattern specificity of restitution of visual functions suggests, therefore, that both spatial and temporal aspects of stimulation should be carefully considered in visual rehabilitation.

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