VISUAL CAPACITY IN THE HEMIANOPIC FIELD
FOLLOWING A RESTRICTED OCCIPITAL ABLATION

BY

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Damage to striate cortex and neighbouring regions in man is well known to produce severe loss of visual capacity in correlated regions of the visual field (Holmes, 1918; Teuber, Battersby and Bender, 1960). Depending on the duration, nature and extent of the damage, and the method of measurement, the resultant blindness may be more or less absolute. In the most extreme examples, a patient may acknowledge no visual information or only the onset or offset of a light in the scotoma. In less extreme cases vigorously moving or flickering stimuli may be seen (Riddoch, 1917). It is generally held, however, that man is more severely impaired by damage to the visual cortex than the monkey, even though the anatomical organizations of the visual pathways and cortex are closely similar. Indeed, the more thoroughly the monkey has been studied, the more remarkable has been the extent of residual visual capacity found: for example, the ability to discriminate two-dimensional patterns even when the whole of the striate cortex has been removed, with complete retrograde degeneration of the dorsal lateral geniculate nuclei (Pasik and Pasik, 1971). It has even been suggested that the monkey without striate cortex may be capable of qualitatively normal pattern vision but with reduced visual acuity (Weiskrantz, 1972; cf. Ward and Masterton, 1970). Recent animal results, however, also suggest strongly that a severe penalty is inflicted when damage to neighbouring posterior cortical areas is added to that of the striate cortex (Pasik and Pasik, 1971). For this reason, human cases in which damage is relatively restricted to area 17 (the only known cortical projection from the dorsal lateral geniculate nucleus), with only minimal damage to surrounding tissue, have a renewed interest.

There also have been suggestions, based on animal research, that the type of visual information processed by the direct pathway from the retina to the mid-brain is qualitatively different from that by the geniculo-cortical route (the "two visual system" hypothesis: Schneider, 1969; Trevarthen, 1968; Ingle, 1967). The former, it has been claimed, is primarily concerned with the detection of "salient" visual events in space and the control of ocular fixation, and the latter with the identification

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of such events once detected. Thus stated, the distinction is undoubtedly an oversimplification, and the hypothesis (of which there are a number of variants) is not free from controversy, but it does focus attention on the possibility that visual stimuli may be detected and located in the absence of striate cortex in man. Recently, Poppel, Held and Frost (1973) have claimed that voluntary ocular fixation responses can be controlled (although rather weakly) by visual stimuli placed in regions of blindness caused by cortical damage, even though the patients deny seeing the stimuli. To the extent that such an ability (if confirmed) depends on the direct input to the mid-brain from the retina, it would be important to examine this and other visual abilities in patients with striate cortex damage but with only minimal damage to the posterior association cortex, as the latter receives a projection (via the posterior thalamus) from the superior colliculus. Cases of relatively restricted visual cortex damage therefore assume special importance, and we here report our observations on one such patient, whose results have already been briefly communicated (Sanders, Warrington, Marshall and Weiskrantz, 1974).

CASE HISTORY

The patient, D. B., a man of 34 years, began to experience headaches at the age of 14. The headaches were always preceded by a flashing light which appeared in an oval-shaped area immediately to the left of the fixation point and straddling the horizontal meridian. Over the course of a few minutes the oval enlarged, mainly by extension downwards. About fifteen minutes from the onset the flashing lights were replaced by a white scotoma covering the oval area with a crescent of coloured lights around its lateral and lower margins. At this stage headache appeared on the right side followed by vomiting some fifteen minutes later, by which time the scotoma had extended to include the crescent of coloured lights. The headache would persist for up to forty-eight hours but usually the patient slept and upon waking would find his vision normal and his headache gone.

The attacks occurred at intervals of six weeks until his twenties when the frequency increased to about once every three weeks. Following one attack at the age of 25 he noticed a persistent

Fig. 1.—Visual fields as plotted on Goldmann perimeter eight months post-operatively, 1° diameter spot, maximum brightness. Broken lines show boundaries of intact normal visual fields. Hatched areas indicate intact but amblyopic regions.
field defect, smaller than the scotoma of his attacks, appearing more as a blank than as the white area, and situated to the left of fixation more below than above the horizontal. In some recent attacks there was a sensory disturbance down the left side of his body.

An angiogram performed when he was 26 years old showed an arteriovenous malformation at the right occipital pole. Drugs for the treatment of migraine, including methysergide, gave no relief nor did a right cervical sympathectomy performed in 1970. As the attacks were posing a severe threat to his employment and his family and social life, Professor Valentine Logue removed the malformation in June 1973. The excision extended approximately 6 cm anterior to the occipital pole and included the major portion of the calcarine cortex on the medial surface of the hemisphere. After operation he had a homonymous hemianopia which split the macula with a crescent of preserved vision at the periphery of the upper quadrant (fig. 1). In addition he experienced flashing lights and well-formed visual hallucinations in the left half-fields but these gradually subsided over the course of the next five weeks and then disappeared. He has had no headaches since the operation.

METHODS AND RESULTS

The experimental procedures were carried out over two five-day periods, two to eight months post-operatively, when clinical examinations were also conducted. D. B. was never given knowledge of results during the course of any experiment. With the exception of the eye fixation experiment, which was carried out in a windowless room, all experiments were carried out in an office or a corridor in which it was not possible to control the level of background lighting completely. But in these cases the conditions were as dim as venetian blinds made possible, and generally were only just bright enough for the testers to record the results. All tests were done binocularly. Experiment 1 was conducted two months post-operatively, and all other experiments eight months post-operatively.

Experiment 1. Locating by Eye Fixation

Method.—The subject was seated in the standard position for the Goldmann perimeter, using the chin rest. He was told that a spot of light would be flashed in his blind field and, on a verbal signal, he was to shift his eyes from the standard fixation point to the position where he “guessed” the spot had been projected. The largest stimulus size (2°) was used, with the brightest setting. On each trial the subject was asked to fixate the standard position; the stimulus was then turned on for 3 seconds at a horizontal eccentricity of 5°, 10°, 15°, 20°, 25°, 30° or 35° in random order. The spot was oscillated up and down by manual control over an arc of approximately 4° during each presentation. After every 7 or 14 trials the calibration of the recording system was checked and adjusted if necessary. The subject was asked to move his eyes only after the stimulus was extinguished, but not to move his head. On some series of trials half of the presentations were “blanks,” which were identical in all respects to the test trials except that the light was not turned on. For the present analysis a total of 35 light trials and 21 “blank” trials were used.

Eye position was measured binocularly by silver chloride electrodes placed at the medial and lateral canthi, and recorded using a DC system (Hood, 1968) located in an adjacent room. The subject did not always move his eyes to the “steady state” position in one operation, but progressed to it after two or three intermediary saccades (occasionally the intermediary position was more eccentric than the final position). For the present analysis only the “steady state” position was used, that is, the position that the eyes finally adopted and maintained for at least two or three seconds.

Results.—As can be seen in fig. 2, there was a weak correspondence between target position and eye position for stimuli placed between 5° and 25°, but not beyond. Each point represents the mean eye position (of 5 trials for lights and 3 trials for blanks) for a given target position. Also shown are the ranges. Despite the large amount of overlap and variability, the linear regression coefficient for eye position on target position, for values between 5° and 25°, is significant from zero (t-test,
(P < .01) although the difference between the regression coefficients for the lights and the blanks is only weakly significant (P < .05). When all stimulus positions from 5° to 35° were included in the analysis, the regression coefficient for responses to the lights was no longer significantly different from zero (0.05 < P < 1) nor from the coefficient for the blanks (P > 4). It should be noted that only those runs were included in which there was no drift in the records which would have required recalibration, but the subject's fixation and the electrodes were unusually stable and most runs could be included.

**Experiment 2. Locating by Reaching with Finger**

*Method.*—The subject was seated in the standard position for the Aimark perimeter, using the chin rest. He was asked to maintain constant fixation within each trial on the fixation mark, and never to move his head. He was told that a spot of light would be flashed in the blind field for three seconds and afterwards, on a verbal signal, he was to reach with his forefinger to the guessed location of the spot without shifting his fixation. The spot was varied in size from 4° 15' to 23', and in some cases (fig. 3, a to e) was projected on to the perimeter arm from behind the subject with a Keeler projector, and in others the Aimark projector itself was used (fig. 4). In all cases the spot was as bright as the apparatus would permit. All stimuli were presented along the horizontal meridian. For any one test the size of the stimulus was held constant, and its position randomly placed at each of six eccentricities from 15° to 90° (in 15° intervals). Three such tests of 12 trials each were given for each stimulus size, using a different random order in each test. The series was presented in the order of descending size, as indicated in fig. 3, a to d. Then the largest size was given again (fig. 3, e), but with half the trials randomly presented as “blanks.”
Fig. 3.—Mean finger reaching responses for targets of given eccentricity (see text). Series was conducted in order a through e. Vertical bars refer to ranges of obtained values. For each point in a to d, n = 6; in e, n = 3. In condition e blank trials (n = 18) were randomly interspersed between stimulus trials, and mean response position and range for blanks are shown to right of experimental results.
Also, the subject's reaching for stimuli in his intact right half-field was measured and compared with reaching in his "blind" field for a stimulus spot of 1° 40'. This was done by randomly intermixing the presentations in the right and left half-fields in two tests of 24 trials each, yielding 4 trials for each of the 6 positions in each half-field.

Accuracy of reaching in all cases was determined by using the smallest spot of the Aimark projector and quickly directing it to the position of the finger, and then reading the eccentricity of the spot off the Aimark scale to the nearest 0°.5°. The subject was not instructed with which hand to reach, but the perimeter made it difficult to use the hand contralateral to the half-field tested, and the subject never did so.

**Results.**—The correspondence between target position and finger position was striking for stimuli larger than 23° in diameter and requires no statistical demonstration or justification. The points in fig. 3 show the means (n = 6 for each point in sections a through d and n = 3 for section e) and the ranges for all positions. As the stimuli decreased in size, there was a tendency for the range to increase, until with the smallest size the correlation broke down. The breakdown was not simply the result of the subject's fatigue because when the large size was repeated (section e) the results were very close to those obtained previously with that size. The re-run with the large size also contained "blanks" on half the trials, and the mean value and range are shown in the panel to the right of section e (n = 18). D. B.'s responses to "blanks" were highly variable, with a range of 65°, which was larger by a factor of 7 than the mean range (9°75°) of responses to all light positions. It will be noted that with all stimuli except the smallest there was a tendency to err...
towards the fixation point for stimuli placed less than 45° eccentrically and away from the fixation point for stimuli beyond 45°. The 60° point showed the greatest stability of response, and even with the smallest stimulus size the response to stimuli at this position was accurate. This was not the result of a response bias because, as can be seen in fig. 3, e, the mean response to the "blanks" fell at 19·67°.

The results (means and ranges of 4 trials per point) of reaching to stimuli in the good and "blind" fields are shown in fig. 4. In the good half-field the accuracy was high, and for three of the positions no error (to the nearest 0·5°) could be measured. The average deviation over all positions in the good half-field was ±0·38°. The results for the left half-field were similar to the family of curves obtained in the earlier series (fig. 3, a, b, c, e), with an average deviation of ±3·8° (compared with an average deviation of ±4·9° for the earlier series).

**Experiment 3. Horizontal vs. Vertical Lines, Diagonal vs. Vertical Lines and X vs. O.**

**Method.**—The subject was seated from 119 to 168 cm in front of a white projection screen. The stimuli were projected on to the screen by a pair of projectors (Leitz Type 31 044 000, 150 watts, Elmaron lens, 1:2·8/85 mm) placed behind the subject. The size of the stimuli were varied either by changing the stimulus slides or, when necessary, the distance of the projectors from the screen. On some tests both projectors were used, one for each stimulus, and on others a single projector, with two slides placed in its carrier. The projectors were always kept switched on, and the duration of the stimulus controlled by silently masking the front of the lens. For tachistoscopic presentations an electronically controlled shutter (Compur Electronics) was placed in front of the lens. The shutter was calibrated to within ±0·5 per cent.

A number of tests, as shown in Tables I and II, were conducted over several days, in which the size, contrast (black on white or white on black), duration, and type of stimuli were varied. The testing was adapted as testing proceeded and the limits of the subject's capacity became clear; in general tests in which there was no time limit on the stimulus duration preceded those with tachistoscopic presentation, and the horizontal vs. vertical series came early and the diagonal vs. vertical series late in the experiments. For any particular test, the pair of stimuli was kept constant in size, contrast, position, and duration. For each type of differentiation the stimuli were positioned in most of the tests so that they fell in equally sensitive and acute regions of the retina; vertical and diagonal lines were usually placed below the fixation mark, so that they did not encroach upon the areas adjacent to the amblyopic remnant. The diagonal line was rotated 27° 33′ from the vertical.

Each test consisted of 30 trials, 15 trials of one of the pair of stimuli and 15 trials of the other, presented singly in random order. A different random order was used in every test. Before any series the subject was first shown the pair of stimuli in his good half-field and was told that they would be projected in his "blind" field and he would be asked to guess which of the pair it was on each occasion. Fixation was maintained on a small marker on the screen throughout each test. Before the test proper the stimuli were projected into the "blind" field and adjusted in position and size so that the subject consistently denied seeing them. During each test this was repeatedly confirmed by asking the subject whether he had seen the stimulus. The stability of the boundaries of the "seeing" field was very impressive during such preliminary tests, as was the steadiness of fixation maintained by the subject throughout the entire series of experiments. After each stimulus presentation he was asked to guess and report verbally which of the pair had been presented, for example, "X" or "O".

Although no knowledge of results was given until the end of an entire series of tests, the subject was frequently questioned not only as to whether he "saw" the stimuli but for introspective content or "feelings" he might have had about them.

**Results.**—The results of all 18 tests are shown in Tables I and II. It is quite evident that D. B. was able to guess at well above chance levels which of the pair of stimuli was presented, provided that (with horizontal vs. vertical lines and X vs. O) the stimuli were larger than a critical size. In
Table I.—Stimulus Dimensions, Durations and Performance. In all cases uppermost part of stimulus fell below horizontal meridian except where indicated “above”.

<table>
<thead>
<tr>
<th>Test</th>
<th>Length</th>
<th>Thickness</th>
<th>Top to vertical horizontal meridian</th>
<th>Contrast</th>
<th>Duration</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Right edge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Hor.</td>
<td>32° 23'</td>
<td>36'</td>
<td>9° 4'</td>
<td>0</td>
<td>W on B</td>
<td>UNL</td>
</tr>
<tr>
<td>Vert.</td>
<td>39° 46'</td>
<td>36'</td>
<td>5° 28'</td>
<td>19° 53'</td>
<td>above</td>
<td></td>
</tr>
<tr>
<td>(b) Hor.</td>
<td>33° 39'</td>
<td>36'</td>
<td>4° 5'</td>
<td>4° 5'</td>
<td>W on B</td>
<td>UNL</td>
</tr>
<tr>
<td>Vert.</td>
<td>33° 39'</td>
<td>36'</td>
<td>4° 5'</td>
<td>4° 5'</td>
<td></td>
<td>250 msec</td>
</tr>
<tr>
<td>(c) Hor.</td>
<td>12° 20'</td>
<td>37'</td>
<td>4° 15'</td>
<td>4° 52'</td>
<td>W on B</td>
<td>UNL</td>
</tr>
<tr>
<td>Vert.</td>
<td>12° 43'</td>
<td>37'</td>
<td>4° 52'</td>
<td>3° 3'</td>
<td>above</td>
<td></td>
</tr>
<tr>
<td>(d) Hor.</td>
<td>24° 26'</td>
<td>26'</td>
<td>2° 8'</td>
<td>1° 47'</td>
<td>B on W</td>
<td>62.5 msec</td>
</tr>
<tr>
<td>Vert.</td>
<td>24° 30'</td>
<td>26'</td>
<td>2° 8'</td>
<td>1° 47'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e) Hor.</td>
<td>12° 53'</td>
<td>26'</td>
<td>2° 25'</td>
<td>2° 25'</td>
<td>B on W</td>
<td>62.5 msec</td>
</tr>
<tr>
<td>Vert.</td>
<td>12° 54'</td>
<td>26'</td>
<td>2° 16'</td>
<td>2° 16'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(f) Hor.</td>
<td>8° 1'</td>
<td>26'</td>
<td>1° 43'</td>
<td>2° 27'</td>
<td>B on W</td>
<td>62.5 msec</td>
</tr>
<tr>
<td>Vert.</td>
<td>8° 1'</td>
<td>26'</td>
<td>2° 34'</td>
<td>2° 16'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diagonal vs. Vertical

<table>
<thead>
<tr>
<th>Test</th>
<th>Height</th>
<th>Width</th>
<th>Thickness</th>
<th>Top to vertical horizontal meridian</th>
<th>Contrast</th>
<th>Duration</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(g) Diag.</td>
<td>16° 56'</td>
<td>35'</td>
<td>7° 21'</td>
<td>1° 7'</td>
<td>W on B</td>
<td>UNL</td>
<td>30/30</td>
</tr>
<tr>
<td>Vert.</td>
<td>17° 15'</td>
<td>35'</td>
<td>7° 21'</td>
<td>1° 7'</td>
<td></td>
<td>125 msec</td>
<td>29/30</td>
</tr>
</tbody>
</table>

Table II.—Stimulus Dimensions, Durations and Performance.

<table>
<thead>
<tr>
<th>Test</th>
<th>Height</th>
<th>Width</th>
<th>Thickness</th>
<th>Top to vertical horizontal meridian</th>
<th>Contrast</th>
<th>Duration</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) X</td>
<td>16° 48'</td>
<td>12° 12'</td>
<td>2° 58'</td>
<td>7° 31'</td>
<td>3° 47' above</td>
<td>B on W</td>
<td>275 msec</td>
</tr>
<tr>
<td>O</td>
<td>18° 38'</td>
<td>15° 59'</td>
<td>3° 30'</td>
<td>5° 31'</td>
<td>4° 51' above</td>
<td>UNL</td>
<td>62.5 msec</td>
</tr>
<tr>
<td>(b) X</td>
<td>10° 59'</td>
<td>7° 55'</td>
<td>1° 53'</td>
<td>4° 35'</td>
<td>1° 53' above</td>
<td>B on W</td>
<td>UNL</td>
</tr>
<tr>
<td>O</td>
<td>11° 49'</td>
<td>10° 32'</td>
<td>2° 10'</td>
<td>3° 15'</td>
<td>3° 14' above</td>
<td>250 msec</td>
<td>22/30</td>
</tr>
<tr>
<td>(c) X</td>
<td>4° 48'</td>
<td>3° 49'</td>
<td>50'</td>
<td>3° 2'</td>
<td>1° 23' above</td>
<td>B on W</td>
<td>UNL</td>
</tr>
<tr>
<td>O</td>
<td>5° 50'</td>
<td>4° 38'</td>
<td>58'</td>
<td>3° 10'</td>
<td>1° 6' above</td>
<td>250 msec</td>
<td>17/30</td>
</tr>
</tbody>
</table>
the case of diagonal vs. vertical lines, his performance was perfect for the one size used and with unlimited duration. Nor, apparently, in the case of horizontal vs. vertical lines, did it matter whether the stimuli were white upon black background or black upon white background; the latter condition also effectively rules out a possible artifact based on diffusion of light into intact regions of the visual fields. (A similar check was also carried out for X vs. O, with comparable results, but is not reported here.) The effect of size on performance is shown in fig. 5, for those stimuli in which contrast, approximate position, and duration were held constant. If threshold is arbitrarily defined as the 75 per cent performance level, then the threshold for horizontal vs. vertical at 62.5 msec is approximately equal to X. vs. O at 250 msec, and is approximately 12°.

**Fig. 5.—**The effect of size of stimulus on performance. Size scale logarithmic. Maximum score in all cases is 30; chance performance is 15.

As size decreased, the effect of duration may have become more critical (fig. 6). Thus, with a large size horizontal vs. vertical task (Table I, b), performance was 29/30 even at 62.5 msec duration, but for the smallest size performance was only 19/30 at this duration (Table I, f). Both of the other tasks also were sensitive to decreasing duration, but in neither case was a very large size stimulus used. The results also demonstrate that performance could be well above chance even with the durations shorter than the latency for the initiation of a saccade, and hence it was not likely to have been dependent upon a fixation shift.

Not only was there internal consistency in the results for size and duration within each type of differentiation, but the three tasks could be roughly ordered in difficulty according to *a priori* expectations. Thus, at 62.5 msec performance on X vs. O (Table II, a) was poorer than on diagonal vs. vertical (Table I, g), which was in turn poorer than on horizontal vs. vertical (Table I, e), with the size of all three types of stimuli in the same intermediate range of 13°–18°. Similarly, performance on diagonal vs. vertical with unlimited exposure and 125 msec (Table I, g) was superior to X vs. O with unlimited exposure and 250 msec (Table II, a). No effort was made, of course, to make a direct experimental comparison among the tasks, but the consistency is noteworthy considering their separation over several days and the lack of rigid control over background conditions such as lighting levels.
Experiment 4. "Minimal Separable Acuity"

Method.—The subject was seated 53 cm in front of the apparatus that contained diffraction gratings that could produce moiré fringes of varying width and separation. (The apparatus was the same as that used in monkey experiments by Weiskrantz and Cowey (1963), who describe it in detail.) In the normal field one could see a circular aperture (6° 39' in diameter) containing a variable number of vertical dark and light bars depending on their width. The design of apparatus ensured that the flux remained constant independently of the spatial frequency of the bars. A fixation point was placed 8° 48' to the left or the right of the centre of the stimulus field, according to which half-field was being tested. Every test consisted of 30 trials in which the narrowest grating (which appeared homogeneous in the good half-field) was paired with a particular larger bar width. These were presented singly in random order, and the subject asked to report verbally whether there were lines or no lines. In his "blind" half-field, of course, the subject did not "see" any lines, nor indeed even the entire stimulus field, and he was simply asked to guess. Testing was first carried out in the left half-field, starting with the largest bar width possible (25'6') and proceeding progressively to narrower bar widths (7'5', 2'24', 1'85', 1'63'). Then two more tests were given to check the reliability of the results for bar widths 7'5' and 1'63'. Finally a control test was given in which both stimuli were set equally at the narrowest possible bar width (1'28'). Testing in the good half-field was done in the order 2'24', 1'63', and 1'36'. Also a rough test of acuity in the amblyopic remnant in the upper left half-field was carried out with a suitable fixation point by varying the bar width to wider and narrower values and determining the value at which the subject reported just seeing the lines.

Results.—The results are shown in fig. 7. (The scale 0–180 on the abscissa refers to the calibration curve for this apparatus, cf. Weiskrantz and Cowey, 1963.) For the sake of simplicity the graph shows only the points as measured in directly descending order, and not the two replication checks for bar widths 7'5' and 1'63'. (The results for these two points were 26/30 and 21/30 respectively, as compared with 29/30 and 18/30 in the original series.) Taking the 75 per cent performance level as threshold, the “blind” half-field has an acuity of 1'9' and the right half-field an acuity of 1'5'. There was some slight evidence for a practice effect in this task, in that in the first test with the widest bars, in which the score was 27/30, the 3 errors occurred within the first 7 trials. If all the results are plotted in terms of per cent correct of the final 20 trials in all tests, the threshold in
the "blind" half-field is marginally improved to 1·8'. On the control run in which both stimuli were set at the narrowest bar width, a chance score was obtained.

The threshold in the amblyopic remnant in the upper half-field was approximately 8·2'. Even though this is considerably worse than in the acuity for the region of the "blind" field that was measured, the subject always reported "seeing" the bars in the remnant when they were above threshold (and "seeing" the illuminated homogeneous aperture when they were below threshold), whereas he consistently reported seeing nothing, not even the aperture, in the "blind" region under any conditions of this test.

**Experiment 5. Red vs. Green**

**Method.**—This experiment must be considered as preliminary because of shortage of time and of a limited range of filters. Five tests of 30 trials each were given under the following conditions: (a) the subject was seated in the standard position for the Aimark perimeter. The stimulus was a 4° 15' red or green spot projected on to the perimeter arm from behind the subject to a position 15° to the left of fixation. The Keeler projector was used, with Wratten filters 29 and 61, which have peak transmission at 700 and 530 nanometers respectively. (b) The Aimark projector itself was used to produce a red or green spot 1° 40' in diameter, 10° horizontally to the left of the fixation point. The filters had maxima at 700 and 510 nanometers. (c) To control for differential sensitivity to the two coloured lights, condition (a) was repeated with the brightness level alternated between maximum brightness and a distinctly dimmer setting throughout the 30 trials. It was not possible to calibrate the dimmer setting. The order of red and green continued to be random. (d) Similarly condition (b) was repeated except that maximum brightness and a dimmer brightness alternated throughout the 30 trials. In this condition, D. B.'s head was positioned 7·6 cm nearer to the fixation point, and hence the effective angular size and the angular separation of the spot from the fixation point were slightly larger than in condition (b). (e) This was identical to condition (d) except that the two brightness levels varied randomly from trial to trial instead of in alternation, and the dim level was made weaker so that it appeared as a faint coloured spot.

**Results.**—In the first condition (a), with a large stimulus size and no brightness variation, D. B. achieved a score of 29/30. With the smaller stimulus (b), his score was 21/30. With brightness levels alternated in conditions (c) and (d), his scores were 22/30 and 24/30. Finally, with the
brightness level randomized, the score was 19/30. When questioned about the task, he denied that he saw anything when the stimulus was presented, let alone colour, but after persistent probing he said that he reported “green” when he had a “stronger feeling of something being there,” and said “red” when he “felt there was nothing there.” This is borne out to a certain extent by the data, which showed that he responded “green” to 28 out of the 45 bright stimuli in the last three tests, and “red” to 24 out of the 45 dim stimuli. In fact, he correctly identified every bright stimulus that actually was green (23/23) and only failed on 7 occasions to correctly identify every dim stimulus that actually was red (16/23). On the other hand, even when the physical brightness was in the opposite direction to his reported criterion (i.e. dim greens and bright reds) his performance did not drop below chance (26/44), and his over-all level of success in the last three control trials was 65/90. While these scores are in the direction of indicating at least some residual capacity to differentiate red vs. green, in the absence of more systematic and better stimulus control they cannot be taken as being more than suggestive.

**DISCUSSION**

*Properties of residual vision.*—On the basis of the results thus far it would appear that in his defective field D. B. can locate stimuli in the frontal plane, can differentiate orientation of lines and at least one pair of shapes. All of these differentiations, however, require moderately large stimuli. The evidence also suggests that a slightly longer duration of exposure may be required, at least for a difficult discrimination such as vertical v. oblique lines, than is adequate for discrimination in the good field. (But to establish definitively whether duration *per se* is a more critical variable in the “blind” half-field than in the good half-field it would be necessary to test the good half-field with even smaller stimuli so that the two half-fields were matched with respect to their size thresholds.) This functionally “amblyopic” aspect of the defective field is combined with a lack of acknowledged awareness of vision even for those stimuli that yield consistently near perfect performance. One can dismiss the suggestion that the “amblyopia” itself is sufficient to account for the unawareness, because the subject will always report actually “seeing” stimuli when they fall in the amblyopic remnant in the upper left far peripheral field, even though its minimal separable acuity is in fact poorer than that of the “blind” field in which the grating can be differentiated but not “seen.”

Many other aspects of “blind-sight” remain to be determined, but those aspects which are already revealed are quite remarkable, given the dense scotoma yielded by conventional perimetry or by other methods that depend on asking the subject whether or not he “sees” something. The possibility that the subject perhaps inadvertently may have moved his good field on to the stimulus cannot be entirely ruled out, but it seems extremely unlikely that this occurred or could account for the results. Eye fixation was monitored visually by the investigators in all experiments, and in one experiment eye position was continuously monitored electrographically. Moreover, the subject could perform well above chance even with brief exposures below the latency for the initiation of a saccade. D. B.’s performance was also highly systematically related to parameters of the stimuli, such as size, duration, and angular separation. As he was never given knowledge of results until the completion of an entire group of experiments (which sometimes lasted a number of days),
including replication runs and “blank” trials, it would have required an extraordinary degree of skill on the part of the subject to have generated the results by some stratagem. Finally, D. B. throughout convinced us of his reliability. If the projected stimulus happened to fall on to the edge of the intact remnant of his left field he reported this promptly. When he was shown his results he expressed surprise and insisted several times that he thought he was just “guessing.” When he was shown a video film of his reaching and judging orientation of lines, he was openly astonished. In an interview just afterwards he commented that he could see none of the stimuli and that he would have told us if he could have seen any, “because otherwise he would have been cheating himself.”

Needless to say, he was questioned repeatedly about his vision in his left half-field, and his most common response was that he saw nothing at all. If pressed, he might say that he perhaps had a “feeling” that the stimulus was either pointing this or that way, or was “smooth” (the O) or “jagged” (the X). On one occasion in which “blanks” were randomly inserted in a series of stimuli in a reaching experiment, he afterwards spontaneously commented he had a feeling that maybe there was no stimulus present on some trials. But always he was at a loss for words to describe any conscious perception, and repeatedly stressed that he saw nothing at all in the sense of “seeing,” and that he was merely guessing.

D. B. was able to reach with impressive accuracy using his arm and forefinger, whereas he was able to shift his eye fixation to the locus of the stimulus only slightly better than would be expected by chance, and then only if the stimulus required a shift of less than 30° from the initial fixation position. The eye fixation results are in accord with the findings of Pöppel, Held and Frost (1973). It is possible that if he had been able to move his head freely, his fixation performance might have been much better. It is, in general, rare to find saccadic shifts of more than 30° in free observation situations; more commonly, one uses the head to effect a gross movement, with the eyes “homing in” with saccades somewhat less than 30° in extent. The head was also not moved in the finger-pointing experiment, but under these conditions it may be easier to “reach” accurately with the arm and finger than with the eyes.

Before operation D. B. had a very small left homonymous paracentral scotoma no doubt caused by tissue destruction by the angioma, and so post-operatively he had a large “fresh” left field defect in combination with a much older one. It remains to be determined whether with more sensitive measures, for example brightness incremental thresholds using the “guessing” technique, one could differentiate the old and the new scotomatous regions. Whether or not this proves possible, one must leave open the question as to whether D. B.’s “blind-sight” will change with time and knowledge of results, as is true of the monkey (cf. Weiskrantz and Cowey, 1970).

A whole host of questions about the possible properties of “blind-sight” remain to be explored in detail, among them colour, depth, acuity as a function of retinal locus, adaptation, number of stimulus alternatives available, the perceptual constancies—in short, all of the attributes of normal “seeing” itself. The fundamental question, of
course, is whether D. B.'s "blind-sight" is merely degraded normal vision or whether it represents a qualitatively distinctive visual capacity.

**Relation to animal lesion studies.**—Total removal of striate cortex in the monkey, with consequential total degeneration of cells in the dorsal lateral geniculate nucleus, does not abolish pattern discrimination altogether, although such animals are slower to learn such discriminations (Pasik and Pasik, 1971). They can also be trained to reach for a visual stimulus, such as a flash of light, placed randomly in the field, and can do this successfully even when the flash is very brief and below the saccade latency (Weiskrantz, Cowey and Darlington, in preparation, but in this study there is not yet histological confirmation). But the monkey's reaching behaviour is not absolutely precise and if two stimuli a few inches apart are presented the animal may reach in between them; with a single stimulus it tends to reach to a region in which the stimulus falls rather than to hit it precisely and reliably. On the basis of results of animal research, it has been speculated that the residual vision of a monkey lacking striate cortex is essentially normal qualitatively but is amblyopic, lacking capacity to discriminate fine detail (Weiskrantz, 1972).

In these respects, D. B.'s capacity is quite similar. His ability to differentiate failed when the stimuli were smaller than a critical size (roughly 10° in length for orientation and X vs. O), and his reaching also failed with a small stimulus (the critical size being somewhere between 50' and 23'). His "minimal separable acuity" was also lower than that of a corresponding portion of his good field. His reaching behaviour was less accurate for a stimulus in the bad field than in the good, with a mean deviation of approximately ±5°, and he showed a reliable tendency to mis-reach towards the fixation point for stimuli with an eccentricity of less than 45° and to mis-reach away from fixation point for more eccentric stimuli. Whether or not the monkey without striate cortex can discriminate colour is still unsettled, there being both positive and negative reports (Pasik and Pasik, 1971; Humphrey, 1970). The evidence for D. B. is no more than marginally positive for a discrimination between red and green (with intensity difference randomly varied), and more work remains to be done. A monkey with total unilateral striate removal or partial bilateral striate removal shows a raising of the incremental threshold for a 1° light flash, but there is a gradual improvement with post-operative training (Cowey and Weiskrantz, 1963; Cowey, 1967). This threshold was not measured in D. B.'s defective field.

The capacity of the destriated mammal has also been interpreted in the light of distinctions made under the rubric of "two visual system" theories between recognizing, identifying, or examining, on the one hand, and detecting or orienting on the other. Perhaps the best-known subject is "Helen," a monkey with a large bilateral striate cortex lesion who was studied by Humphrey over several years (Humphrey and Weiskrantz, 1967; Humphrey, 1970, 1972). He described her as being "unable to identify even those things most familiar to her. After six years she still does not know a carrot when she sees one, nor apparently can she recognize my face," despite an excellent ability to locate and detect visual events in her environment and to avoid obstacles in a free field. "In one sense she sees everything,
in another sense, nothing" (Humphrey, 1972, p. 684). In one sense D. B. also fails to recognize familiar objects, but he also is unaware that he can detect. In behavioural terms he can both "detect" and "identify," at least under our conditions of testing, but he admits to no awareness of either capacity. It is possible that his ability to "identify" might derive from a capacity that is primarily attentional in character, in that the sharp onset or offset of different patterned stimuli might generate different degrees of "saliency" (Humphrey, 1970) and elicit directional orienting responses. It remains to be determined whether D. B.'s ability to differentiate orientation or pattern would diminish when the stimuli are presented for long durations.

In all of our testing to date with D. B. we had the advantage of being able to instruct him both by telling him what the range of possible stimuli were to be in any series and also by showing him examples in his good half-field. To train the destriated monkey to reach accurately or to discriminate requires long and patient training. Whether D. B. would be able to guess the identity or orientation of stimuli without previous instruction is an open question, but certainly it would make his task very much harder.

The doctrine of "encephalization of visual function" postulated that visual capacity becomes increasingly dependent on cortical structures with ascending phylogenetic status. The evidence for the doctrine was always far from adequate (cf. Weiskrantz, 1961), and the present results are a distinct embarrassment to it. In one important respect, however, it is difficult to make direct comparisons between D. B.'s capacity and that of lesioned animals. In terms of behavioural measures, as we have seen, they are not dissimilar, but D. B. is unaware of "seeing" the stimuli he differentiates. We do not know whether the lesioned animal similarly might be said to have "blind-sight." Operational purists might argue that such a question directed at the animal research is meaningless. It seems arbitrary to deny the monkey states of awareness or unawareness, but the design of a programme for studying such states in an animal presents something of a methodological and philosophical challenge.

Neural basis of residual vision.—D. B.'s left half-field can be divided into two regions, the larger portion in which the location, orientation, and distribution of stimuli can be differentiated within certain limits but in which the subject has no acknowledged awareness of those stimuli, and a smaller remnant in the upper peripheral region which definitely has reduced acuity (compared with a symmetrical region in the right half-field) but otherwise seems to be normal and in which awareness of stimuli is readily acknowledged. Two views can be offered for the anatomical dispositions of his right hemisphere lesion, depending upon whether it is assumed that a striate cortex lesion alone is sufficient to produce a scotoma with "blind-sight." It has been commonly assumed, following Gordon Holmes (1918), that a striate cortex lesion is sufficient to produce a scotoma and that the amblyopic fringes of such a scotoma are due to partial and perhaps patchy interruption of radiations or surrounding cortical tissue. On this basis, it would be inferred that there is still some intact and functional striate cortex in the anterior portion of the inferior bank of the calcarine fissure on the right side. An alternative suggestion (Weiskrantz, 1972) is that isolated
striate cortex damage causes amblyopia, but that the greater the additional damage to prestriate and posterior association cortex the more severe is the deficit and the more it tends towards a capacity limited to total luminous flux discrimination. (The animal research does not allow us yet to say just which non-striate cortical regions are critical.) On this view, D. B. would have little if any functional striate cortex in the right hemisphere, but the lesion would be expected to be smaller and more nearly restricted to area 17 in the far anterior lower bank of the calcarine fissure, and more posteriorly to involve area 17 together with the surrounding prestriate and additional association cortex.

The same issue is involved in understanding whether “blind-sight” depends upon there being a region of intact vision in a half-field. The control of eye fixation by stimuli in a scotoma reported by Pöppel, Held and Frost (1973) has not been found by them in either of their two cases with a complete homonymous hemianopia (personal communication). Because striate cortex is largely buried in the medial region of the human brain (Weiskrantz, 1972), any lesion leading to its complete destruction *ipso facto* would be highly likely to cause considerable damage to extra-striate tissue in addition, thereby removing the areas critical for “blind-sight.”

In the absence of striate cortex in the primate, visual information can still reach the mid-brain and also other regions of the brain by parallel pathways. From the superior collicular there is a projection to the several areas of posterior association cortex through the posterior thalamus, and many of these same areas probably also normally receive direct projections from the intact striate cortex. Whether there are any regions of posterior association cortex which are critical for any of the capacities displayed by D. B., and whether it is the convergence of information from more than one route which is necessary for “seeing” cannot be answered as yet. But in evaluating D. B.’s capacities, attention naturally focuses on the tuning properties of superior colliculus cells and the retinotopic map found there. Collicular cells which respond selectively to orientation of lines in the cat or monkey are very uncommon if indeed they exist at all. Nevertheless, the organization of the relay pathways to the cortex may allow a sensitivity to orientation to emerge, just as orientation sensitivity is seen in area 17 but not in the lateral geniculate nucleus; there is a danger of evaluating the properties and capacities of the “second visual system” merely in terms of the responses of single units at one way-station, the superior colliculus.

The retinotopic map found in the superior colliculus of primates, especially in the upper layers in which the input arrives, may provide the basis for the adequate reaching responses shown by D. B. There has as yet been no anatomical demonstration in the monkey of a direct pathway from the foveal and parafoveal regions of the retina to the colliculus, perhaps because the fibres may be of small diameter (Wilson and Toyné, 1970), although an indirect pathway by way of the striate cortex certainly exists. On the other hand, electrophysiological responses in the colliculus to foveal and parafoveal stimulation of the retina are still preserved after striate cortex removal in the monkey (Schiller, Stryker, Cynader and Berman, 1974). It would be interesting
to determine D. B.'s accuracy of reaching within the parafoveal region, but this remains to be done. Information regarding the "magnification factor" of the superior colliculus is also too imprecise to allow one to estimate effective resolving power in different regions of the field, but it is not surprising, given a much smaller population of cells in the colliculus for the visual field as a whole than in striate cortex, and also given the larger optimal stimulus size to which Y-cells are tuned (see below), that D. B.'s differentiations of location and orientation break down with smaller stimuli.

It is of interest to consider whether the "blind-sight" of D. B. may be similar to the impairment of vision by split-brain patients for certain types of stimuli in their left half-fields (Gazzaniga, 1970; Trevarthen and Sperry, 1973), but there are also apparent differences; for example D. B. cannot "see" even those stimuli which the commissurotomy cases admit seeing in their left half-fields, and D. B.'s difficulty does not lie with access to verbal labels. There is no reason to believe that D. B. has an interruption to callosal fibres as such, but without further research using common testing methods it is premature to comment in detail on the similarities and differences between him and the split-brain patients. But quite independently of the resemblance, superficial (as we suspect it is) or otherwise, between split-brain phenomena and D. B.'s "blind-sight," it would be of considerable interest to compare the possible differences in the various components of "blind-sight" in cases of right vs. left hemisphere occipital damage. It should be noted that Pöppel, Held and Frost's (1973) study of the control of voluntary eye fixation shifts included cases both of right and left half-field scotomata. It would also prove interesting to examine separately the two eyes and the four eye-hand combinations of D. B. and any other comparable patients.

Within recent years there has been increasing evidence in the cat for at least two classes, X and Y, of retinal ganglion cells and optic nerve fibres, with different tuning characteristics and partly different target regions in the brain (cf. Wright and Ikeda, 1974). The Y cells are larger and have larger axons, respond to transient rather than sustained retinal stimulation, are optimally tuned to larger stimuli than X cells, and project both to cortex (through the lateral geniculate nucleus) and to the colliculus. The projections of the X cells appear to be confined to the geniculostriate pathways (although it may be too soon to conclude that there are absolutely no X-type responses in the colliculus, especially in its most rostral portion). D. B.'s "minimal separable acuity" may reflect the operation of the Y system in the absence of the cortical target region of the X system. If this is so, the variation of his acuity as a function of retinal locus might be expected to be different from the well-known normal function relating acuity to retinal eccentricity. For this reason it is especially important to study his acuity at different retinal loci. It is even possible that this function would predict in detail the density distribution of Y cells in the retina, which in turn might be revealed independently by studying the retina of monkeys deprived of striate cortex for several years (Cowey and Humphrey, in preparation) as well as by direct measure of normal retina. It is claimed, but not in detail, that there are differences between the distributions of X and Y cells in the cat's retina.
**Future practical implications.**—The remarkable visual capacities of D. B. to differentiate stimuli within his “blind” field, displayed without acknowledged awareness, would appear to demand the re-examination of the whole range of field defects associated with retro-chiasmal damage. Any method that depends upon asking a patient whether or not he “sees” may seriously underestimate his residual visual capacity. We might expect, from the animal research, that the more extensive the posterior cortical damage the more restricted will be the capacity of the residual “blind-sight.” The medial and buried disposition of striate cortex in man makes it extremely likely that when it is damaged surrounding association cortex also suffers damage, and this almost certainly applied to the two cases described by Brindley, Gautier-Smith and Lewin (1969) of virtually complete “cortical blindness.” With further study, it might also emerge that damage to specific cortical regions might affect specific sub-categories of residual vision, including the acknowledgment of awareness itself. Therefore from future studies results might emerge allowing greater diagnostic power than is possible with the plotting of field defects by conventional perimetry or confrontation methods.

It has become clear that monkeys with bilateral striate cortex removal, if given the benefit of protracted and specific post-operative training regimes, can display much greater visual skill than would have been accepted traditionally. The improvement that the animals show is neither spontaneous nor inevitable without such training. The critical features of such therapy remain to be determined, but one important aspect appears to be the arranging of visual events in the animal’s space in such a way that he can at first relate them to distinctive features of a tactile-kinästhetic space and obtain rapid and reliable feed-back from those features. At the outset of such training, it looks to the human observer very much like an act of “discovery” by the animal that he possesses a viable visual space, and after the initial discovery performance can improve rather rapidly (Humphrey and Weiskrantz, 1967). Whether patients with “blind-sight” can be taught to exploit this capacity remains to be determined. The possible benefits to patients with cortical damage described clinically as “blind” in all or part of their visual fields obviously makes it important to explore the therapeutic potentialities of “blind-sight” intensively.

**SUMMARY**

A patient with a restricted lesion of the right occipital lobe was investigated to assess the possibility of some visual capacity in his hemianopic field which was blind on conventional perimetric testing. Even though the patient had no awareness of “seeing” in his blind field, evidence was obtained that (a) he could reach for visual stimuli with considerable accuracy; (b) could differentiate the orientation of a vertical line from a horizontal or a diagonal line; (c) could differentiate the letters “X” and “O”. These tasks could be performed accurately only if the stimuli were larger than a critical size, but good performance was still possible even with brief stimulus durations below the latency for the initiation of a saccadic eye movement. In addition, (d) the results of Poppel, Held and Frost (1973) were confirmed in that
there was a weak but significant correlation between target position and eye fixation for loci out to 30° eccentricity in the “blind” field, but not beyond. (e) The subject could differentiate a grating of vertical bars from a homogeneous field when the bars were sufficiently wide, and this provided a measure of “minimal separable acuity,” which was only slightly poorer than the acuity of the symmetrical region in the good half-field. (f) Suggestive but inconclusive evidence was obtained for an ability to differentiate between red and green projected stimuli.

The observations suggest that the visual capacity remaining after damage to striate cortex may be much greater than is commonly accepted. The properties of the residual vision are compared with the behavioural capacities of monkeys with striate cortex damage. The possible neural basis of “blind-sight” is discussed, together with some implications for diagnosis and therapy.

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