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# WOUNDS OF THE VISUAL PATHWAY

## PART II: THE STRIATE CORTEX*

BY

**J. M. K. SPALDING**

*From the Department of Neurology, Radcliffe Infirmary, Oxford*

The representation of the visual field in the striate cortex (calcarine cortex, area 17) has received considerable attention. It is agreed that central vision is predominantly represented posteriorly and peripheral vision predominantly anteriorly, but the detailed representation is debated. Holmes (1918) from his study of head injuries in the first world war concluded that concentric zones from the fixation point to the periphery are represented serially in that order from the posterior to the anterior part of the calcarine cortex. Brouwer (1934) took the same view except that he believed that the area devoted to central vision protruded forward a considerable distance as a tongue in the intermediate part of the striate cortex between its upper and lower margins. German and Fox (1934) suggested that the central vision, though predominantly represented posteriorly, is also represented to some extent diffusely throughout the striate cortex.

In cases of complete hemianopia " macular sparing " is often observed, and it is said, though with scanty evidence to support it, that macular sparing occurs in lesions of the occipital lobe but not in lesions of the temporal or parietal lobes. From this comes the chief support for the view that some of the fibres subserving central vision arise in one lateral geniculate body and cross in the corpus callosum to the opposite occipital lobe, so that " the macula " is bilaterally represented.

This paper reports some of the visual field defects which occur in gunshot wounds of the striate cortex, with particular reference to the anatomical deductions which may be made from them. Evidence is presented to indicate in what part of the striate cortex central vision is represented, whether it is represented bilaterally or unilaterally, and how large is the area of cortex devoted to it.

### Material

The material is taken from a series of 958 cases of penetrating head injuries, mainly gunshot wounds. One hundred and eighty-eight of these had defects in the visual field attributable to injury of the visual radiation or striate cortex, and this paper is concerned with the 72 cases in which there was a lesion primarily affecting the striate cortex. This material overlaps with that reported by Symonds (1945), whose Case 7 is the same as the present Case 2. The visual fields were plotted with 3/330 and 2/2000 white isopters and also in abnormal areas with 20/2000 white isopter. Except where otherwise stated dense black represents a scotoma to 20/2000, and cross hatching a scotoma to 2/2000. The interval between injury and examination is shown on each chart. In the tracings of radiographs a coarsely hatched area indicates a bony defect in the skull and dense black a radio-opaque foreign body.

Fig. 1 shows the representation of the visual field in the striate cortex seen from the posterior and medial aspects. This map, though similar in many respects to those made by previous observers, has been modified and amplified as the cases described below demand. It is presented at this point rather than after the description of the cases on which it is largely based because interpretation of the cases is very much simplified by reference to it. In the visual field the different parts of the upper quadrant are indicated by numbers, the lower by letters. In both quadrants each series runs from centre to periphery so that any one series (e.g. i, ii, iii, 1, 2, 3, or A, B, C) indicates a sector, whereas corresponding symbols from adjoining series (e.g. ii, II, 2, c, C, $\gamma$) indicate an arc of the visual field. The hatched area in the diagram of the striate cortex is that part forming the walls of the calcarine fissure, shown as though the lips of the fissure had been pulled apart. The stippled area represents that part of the striate cortex which is on some aspect of the posterior pole of the occipital lobe and faces either posteriorly or postero-medially, and the area which is neither hatched nor stippled is that part which is in apposition, the falx alone intervening, with the corres-

* The first section on the optic radiation appeared on p. 99 of the previous issue

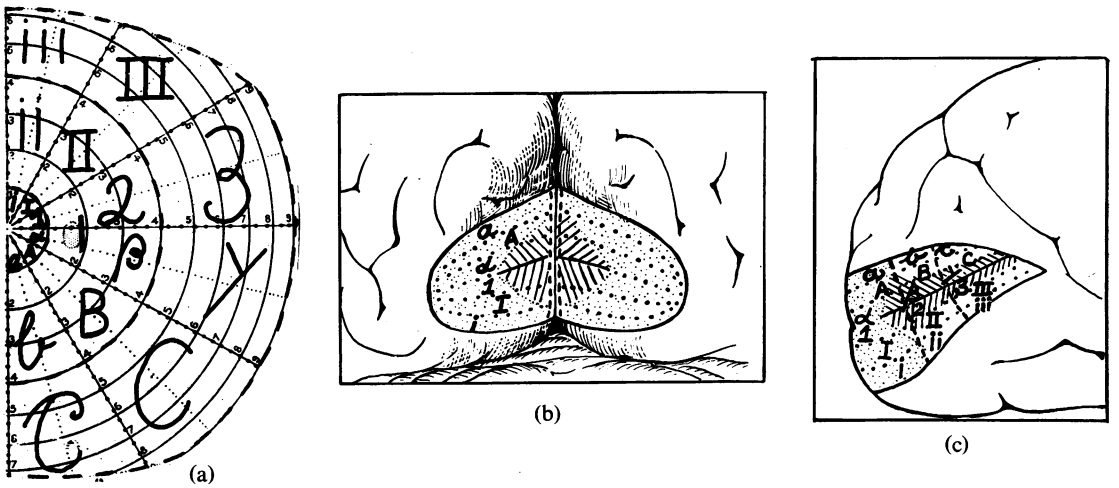



FIG. 1.—Right half visual field (a) and its representation in the striate cortex shown from the posterior (b), and the medial (c) aspects. The hatched area of the striate cortex represents the walls of the calcarine fissure illustrated as though it were pulled open. The stippled area represents that part of the striate cortex which faces posteriorly or postero-medially.

ponding area on the opposite side. It should be emphasized both that the figure is diagrammatic and that the calcarine fissure is subject to considerable variation in shape and in site relative to the striate cortex.

As Fig. 1 shows, central vision is represented at the most posterior part of the striate area and occupies a very large area relative to the area of the visual field which it represents. The peripheral field is represented most anteriorly and occupies a relatively small area. The representation of central vision is greater than Fig. 1 at first glance suggests, for as the stippling indicates, that part of the striate cortex faces posteriorly or postero-medially and therefore is foreshortened when the hemisphere is seen either from the medial or the posterior aspect.

The horizontal meridian of the visual field is represented in the depths of the calcarine fissure and the upper and lower halves of the vertical meridian in the lower and upper margins respectively of the striate cortex.

The cases to be described are chosen to illustrate this anatomy and to add some details to it. The aspects of the cases mentioned in the text are those which are immediately relevant and case histories are given in the appendix. Eight cases are described individually and their anatomical significance discussed. They are then shown together (Fig. 11) to indicate how their respective sites of injury are related to the type of defect in the visual field. In addition other cases are described which illustrate various points of interest.

Central vision is represented at the posterior pole and lesions confined to this site on one side confirm this and throw light on the problem of unilateral or bilateral representation of central vision. Case 1 (Fig. 2) is that of a man who received a low occipital injury, whose centre, measured on the radiograph, is 3·1 cm. to the left of the midline. The dura was penetrated and the lateral sinus was involved, but the injury was slight, and the patient had no retrograde or post-traumatic amnesia. Two and a half months after injury he had a right upper paracentral quadrantic scotoma indicating destruction to the left lower occipital pole. The lesion is strictly unilateral and it has caused a dense scotoma reaching to the fixation point, that is, involving " macular " vision.

It is in small lesions such as this that bilateral representation of central vision, if it occurred, would most readily show itself. Cases such as Case 1 cannot be interpreted on the assumption that central vision is represented bilaterally and afford proof that it is only represented unilaterally.

If more peripheral vision is represented more anteriorly, an injury entering through one occipital pole and passing forward before crossing the midline will cause a paracentral scotoma on one side with a pericentral scotoma on the other. Case 2 (Fig. 3) is that of a man who received an occipital injury whose centre on the radiographs is 5·2 cm. above the occipital protuberance, and 2·2 cm. to the right of the midline. The upper half of the right occipital pole has been destroyed, giving a lower left paracentral quadrantic scotoma reaching to the fixation point, and the injury has continued forward

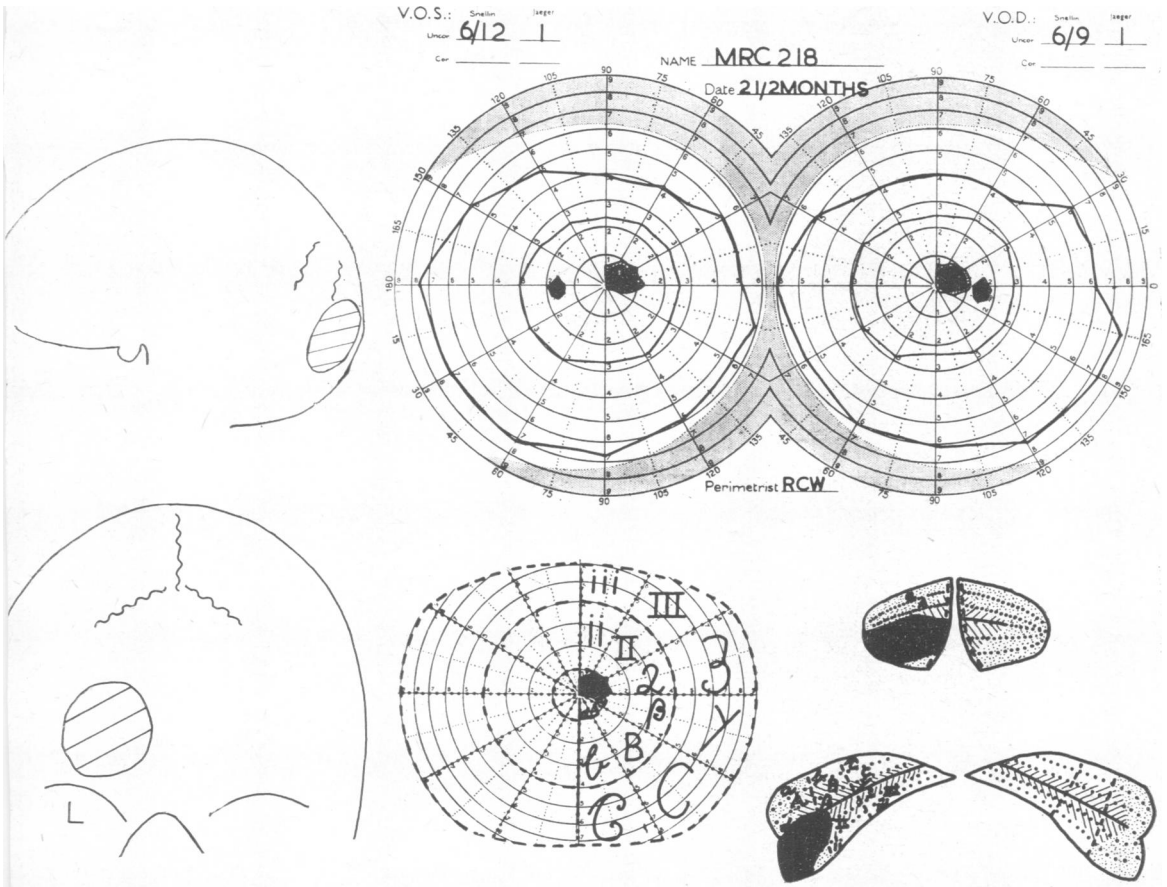



FIG. 2.—Low left occipital injury in Case 1 causing an upper right paracentral quadrantic scotoma to the fixation point. In this and subsequent figures a diagrammatic representation of the injury is shown using the same conventions as in Fig. 1.

to cross the midline and destroy the intermediate (that is, neither anterior nor posterior) part of the striate cortex on the left side, causing a partial arc scotoma in the lower right field at the periphery of the area of central vision. The sparing of the horizontal meridian on the right can be explained on the grounds that it is represented in the depths of the calcarine fissure and the injury did not penetrate so far.

Case 2 illustrates once more that central vision is represented unilaterally and shows that more peripheral vision is represented more anteriorly. It also suggests that the horizontal meridian is represented in the depth of the calcarine fissure.

Sparing of the horizontal meridian due to its representation in the depths of the fissure is more clearly illustrated in cases which suffered extensive damage confined to the medial surface of the striate cortex. Case 3 is of this type (Fig. 4). A series of foreign bodies has entered through a wound whose centre on the radiographs is 1·7 cm. above the occipital protuberance and only 0·8 cm. to the right of the midline. Four of these have destroyed the right occipital lobe causing a complete left homonymous hemianopia. A large foreign body has passed forwards and upwards crossing the midline by a very narrow margin. The field defect corresponds exactly with the radiographic appearances. For there is a deep " cove " extending from the vertical meridian (lower border of striate cortex) into the right upper quadrant about 10° above the fixation point, indicating that the missile has nicked the lower lip of the left calcarine fissure. In the lower quadrant there is a very much larger

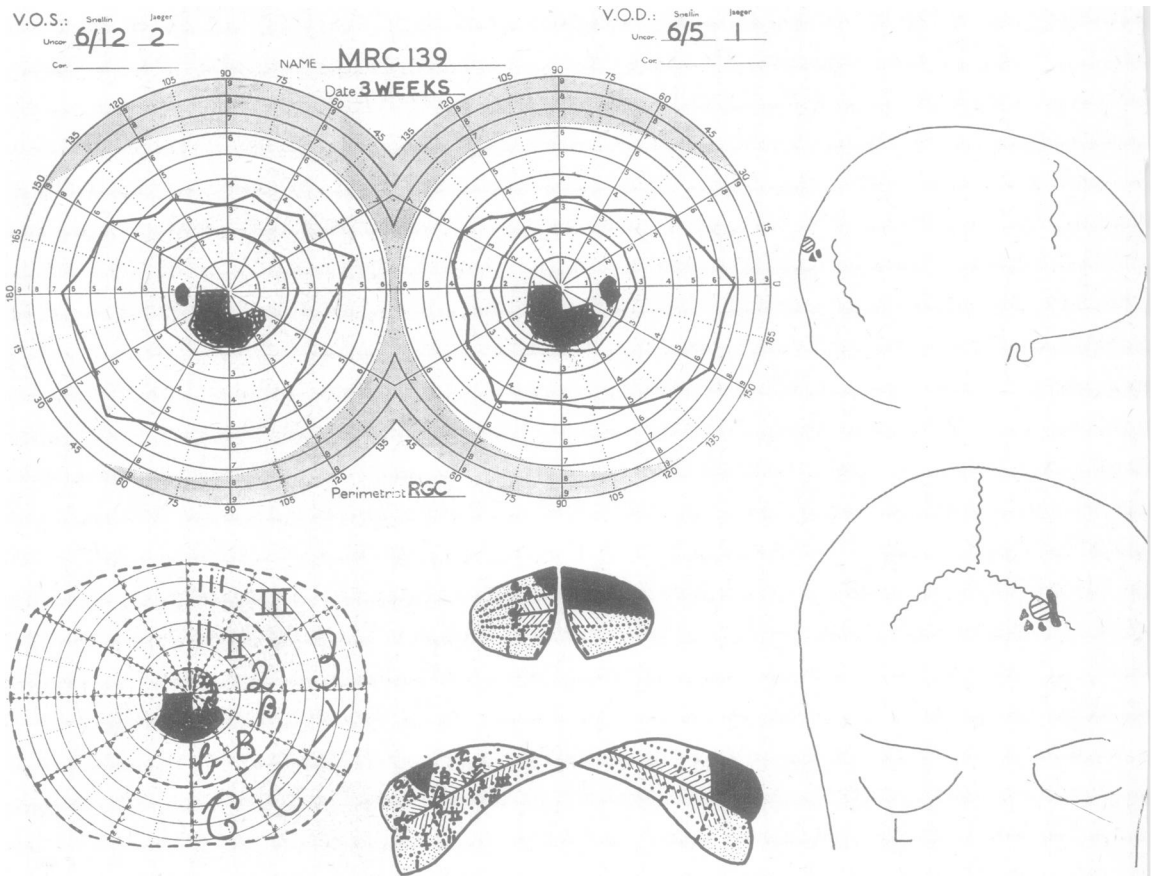



FIG. 3.—Right occipital injury in Case 2 causing a left lower paracentral quadrantic scotoma, and a right lower pericentral partial ring scotoma which is attributable to the injury passing forwards and across the midline.

cove indicating that damage to the upper lip has been much more extensive than to the lower and that the missile in its passage forwards and upwards has passed through the intermediate part of the upper striate cortex leaving its upper border before reaching the anterior end and so leaving extreme peripheral vision, that is, the area of monocular vision, intact.

Case 3 indicates that the horizontal meridian is represented in the depths of the calcarine fissure. Moreover it is clear that in the vertical meridian at least 5° of the visual field above and below the fixation point is represented in the walls of the calcarine fissure.

A midline injury may miss both occipital poles since these lie 1·5–2·0 cm. lateral to the midline, and injure both striate cortices where they reach the medial surface of the hemisphere and are separated only by the falx cerebri. Case 4 (Fig. 5) received a midline injury whose centre on the radiograph is 5·8 cm. above the occipital protuberance. The injury apparently first affected the right upper part of the striate cortex and travelled forward to cross the midline and cause more extensive damage to the left upper part of the striate cortex. The fact that the scotoma is very much larger on the right than on the left, though it is more peripheral (anterior), suggests that the missile did not entirely pass through the right striate cortex to reach the left, but must have traversed the interval between the two occipital poles.

It is reasonable to conclude from Case 4 that the point at which the two striate cortices reach the medial surface of the hemisphere represents a part

of the visual field not less than 5° from the fixation point in the vertical meridian. It may be argued that the injury reached the striate cortex from above instead of passing between the occipital poles. However, as Fig. 11 shows, the injury was less far above the level of the calcarine fissure than the occipital protuberance is below it, and therefore the injury may reasonably be supposed to be at the level of the upper border of the striate cortex.

The injury in Case 4 was quite considerable, and Case 5 (Fig. 6) suffered a very much smaller lesion. The tracing of the radiograph shows a foreign body lying in the skull defect with a piece of indriven bone immediately within the skull. The site of entry was on the right but the injury crossed the midline. It mainly involved the posterior fossa, and the report on the operation 17 hours after injury states that the torcula was also penetrated, but, fortunately for the patient, had become occluded with debris. Three weeks after he was wounded the visual fields were examined, although the patient made no complaints about his vision, and a small bilateral scotoma was found in the upper half field 8–10° from the fixation point involving the vertical but sparing the horizontal meridians.

This man (Case 5) suffered a minimal injury at the point where the striate cortex reaches the medial surface of the hemisphere, and indicates that this part of the striate cortex represents vision about 10° from the fixation point and therefore provides information about the area of striate cortex devoted to central vision.

A very small single lesion can involve both lower lips of the calcarine fissure at the point where the striate cortex reaches the medial surface of the hemisphere. Case 6 (Fig. 7) shows an example of this. A wound centred on radiographs 4·2 cm. above the occipital protuberance and 2·2 cm. to

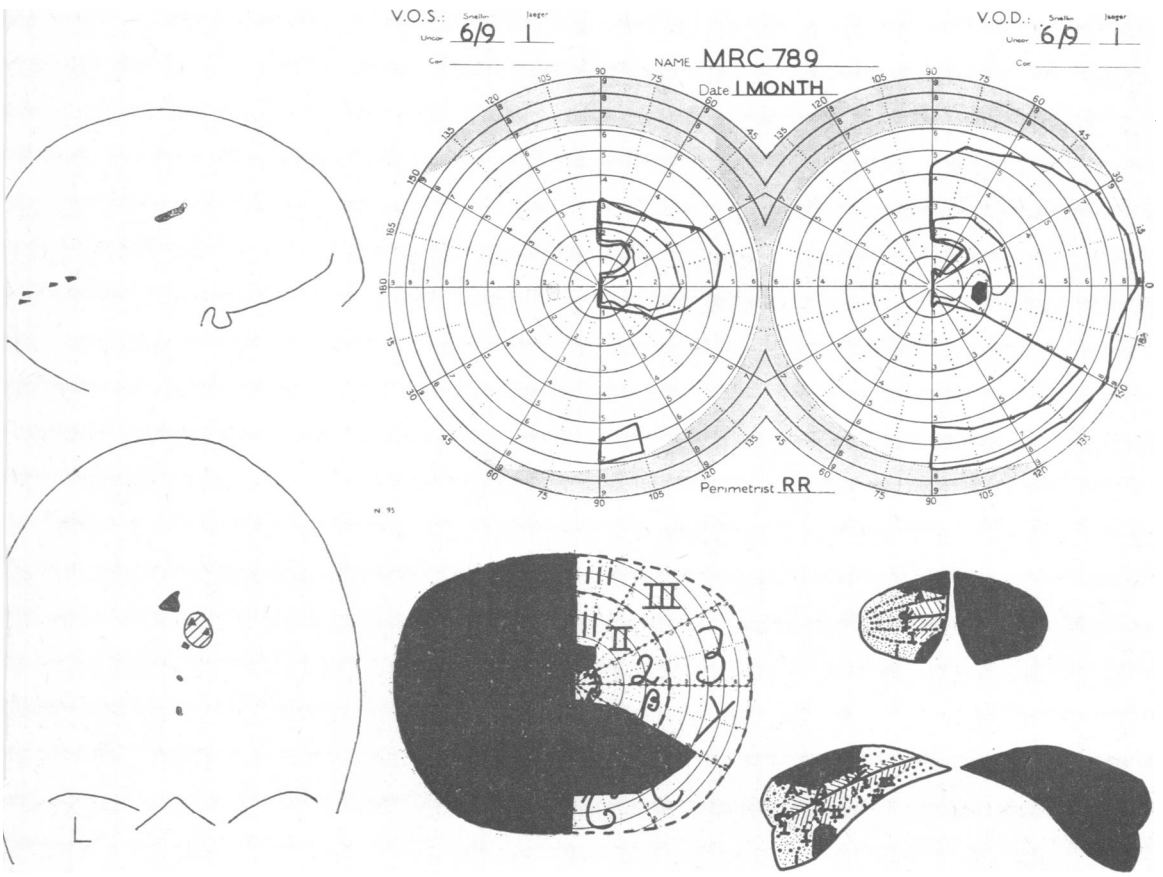



FIG. 4.—Right occipital wound in Case 3 causing left homonymous hemianopia. The large foreign body has just crossed the midline and damaged the medial surface of the left hemisphere. The horizontal meridian of the visual field represented in the depths of the calcarine fissure (hatched in the diagram) is spared.

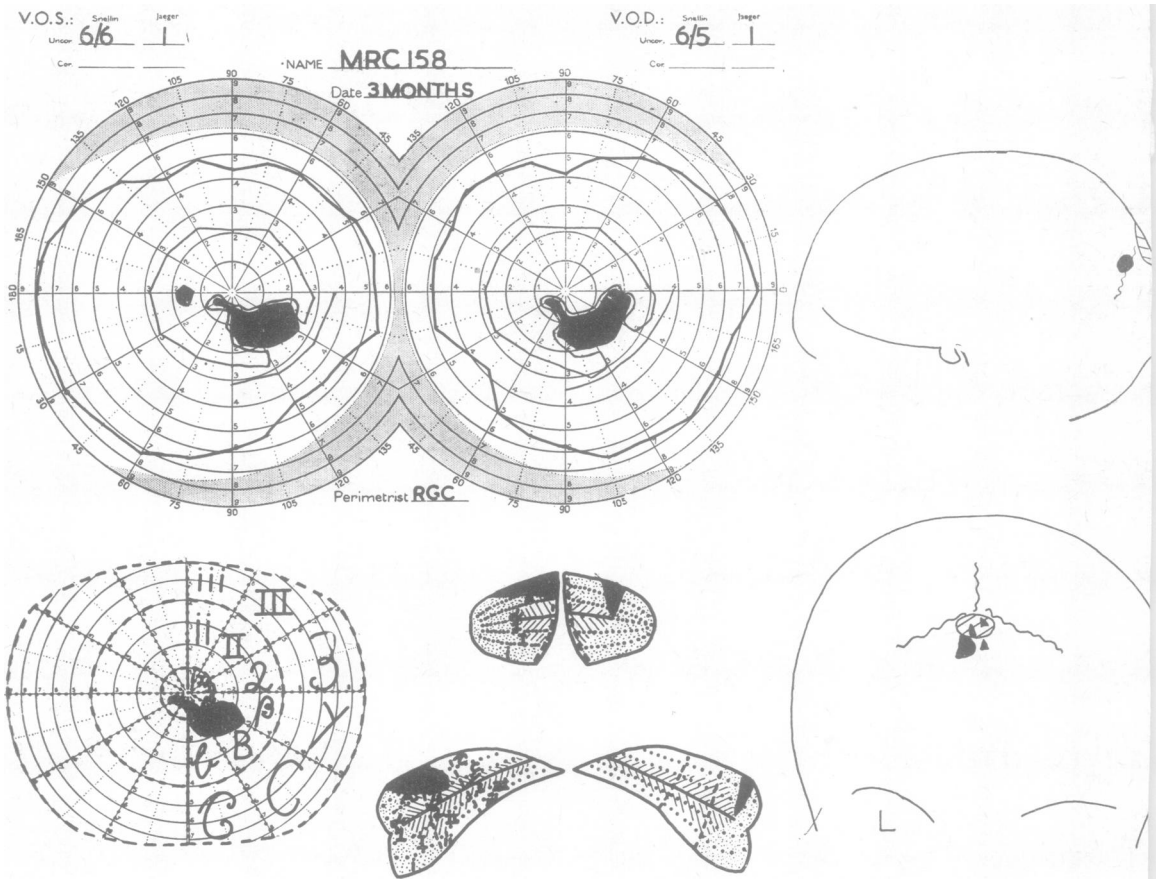
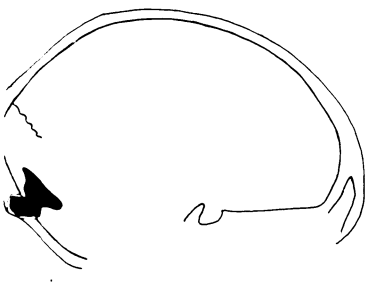


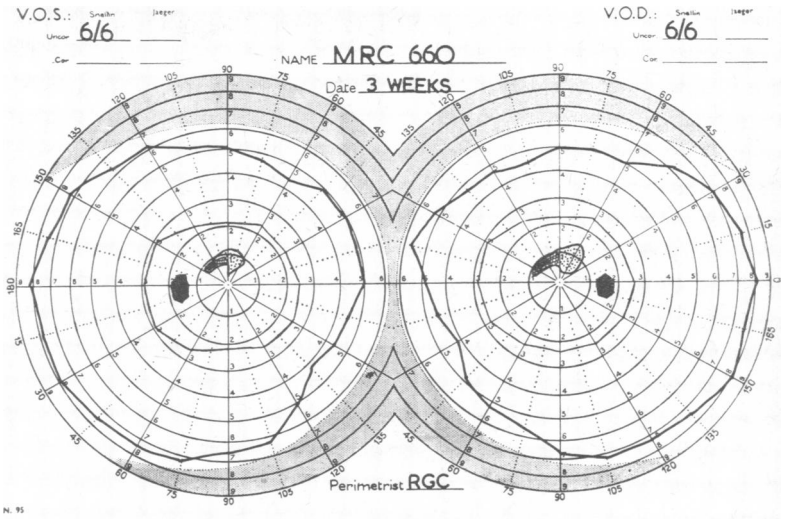

FIG. 5.—Midline occipital injury in Case 4 in which the most central vision has escaped. The scotoma on the right is the larger, though it is the more peripheral (more anterior lesion) suggesting that the injury passed partly through the space between the two occipital poles.

the right has destroyed a considerable part of the upper half of the posterior pole causing a left lower quadrantic paracentral scotoma reaching to the fixation point. This scotoma crosses the vertical meridian into the right lower quadrant indicating that the injury also crossed the midline. The two small circular scotomata in the upper half of the field indicate that the injury has also travelled to a minimal extent below the calcarine fissure and damaged the lower lips of the calcarine fissure on each side as described above. In this way a visual field which at first sight appears bizarre can be understood as the result of a single lesion.

Case 6 shows that the lower lip of the calcarine fissure at the most posterior part of the striate cortex, which lies on the medial surface of the hemisphere, represents that part of the visual field which lies 8° to 10° from the fixation point along a radius 30° from the vertical. Moreover the existence of small dense scotomata provides clinical evidence that in man as in animals the retina is represented in the striate cortex in a precise point-to-point manner.

Most of the injuries considered above involve only small parts of the striate cortex. A more severe injury may destroy a great part of it on one or both sides. The cases of unilateral hemianopia, of which there are 54 in this material, will not be considered here in detail, but the relatively rare altitudinal hemianopia are of some interest. Case 7 (Fig. 8) received an extensive midline injury whose centre is 8·2 cm. above the occipital protuberance. Eleven months later he had an almost complete inferior altitudinal hemianopia.





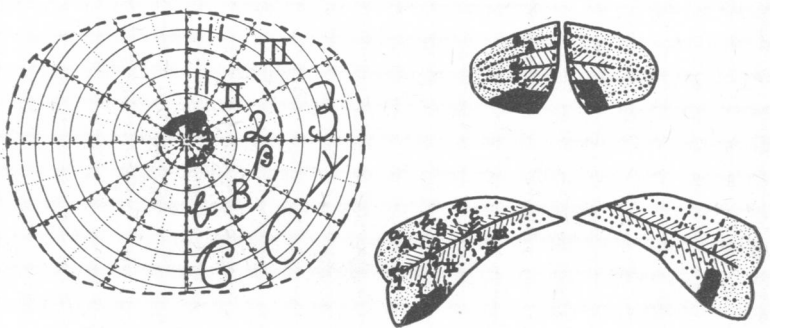



FIG. 6.—Midline injury in Case 5 primarily involving the posterior fossa but also penetrating the torcula. The small symmetrical scotomata are attributable to minimal damage to the striate cortex at the point where its medial and postero-medial faces meet. In the stippled area of the visual field vision was blurred to 2/2000.

The upper half of the striate cortex was destroyed or damaged severely enough to prevent it functioning, and this lesion is characteristic of extensive midline injuries in this situation, for they damage the whole antero-posterior length of the striate cortex from above.

Superior altitudinal hemianopia is much less common than the inferior variety. Case 8 (Fig. 9) has a field defect of this type due to a right occipito-temporo-parietal injury with a foreign body passing across the midline to reach the inner table of the skull on the left at about the same position as the site of entry. The position of the ventricle as determined by pneumoencephalography is shown in Fig. 9, and it is plain that the foreign body passed below the posterior horn of the ventricle, that is, directly through the lower half of the striate cortex on both sides.

This type of injury, the occipito-temporo-parietal wound with a foreign body passing horizontally across the midline, is characteristic of penetrating injuries causing superior altitudinal hemianopia. Cases with large midline injuries are not seen with this field defect, for such an injury will necessarily damage very severely the torcula and the great venous sinuses that drain into it and the victim does not reach hospital alive.

Total destruction of the striate cortex is so severe an injury that patients rarely survive it. Very few cases have been reported (see Brouwer, 1934), and, unless stringent precautions are taken in excluding the presence of perception of light, it is often open to doubt in reported cases whether the whole striate cortex is involved. Case 9 (Figs. 10 and 11) received a through and through bilateral parieto-occipital wound, and six months after the injury he had barely perception of light.

Extensive occipital wounds over the striate cortex are almost always fatal due to extensive damage to the venous sinuses. Complete or almost complete destruction of the striate cortex is therefore generally due to a parieto-occipital injury with a foreign body crossing the midline to reach a similar position on the opposite side. Case 9 is a typical example of this rare injury.

Cases 1 to 9 give a survey of the various defects in the visual field due to penetrating occipital wounds, and Fig. 11 shows the site of injury in these nine cases plotted on a single skull outline by the measurement from the radiographs. The skull outline was

traced from a half axial radiograph in which the occipital protuberance is just visible above the floor of the anterior fossa. The figure shows that the sites of injury correspond well with one another, and so confirm the interpretations which were put upon them when they were described above. It also enables an estimate to be made of the position of the calcarine fissure which is indicated by a dotted line in Fig. 11. It is nearly 3 cm. above the occipital protuberance. The wound of Case 9 (Fig. 10), who was virtually blind, passed right through this region, whereas that of Case 8 (Fig. 9), who had a superior altitudinal hemianopia, passed from one side to another directly below it.

The evidence presented above confirms the view of Holmes on the representation of the visual field in the striate cortex and amplifies it as regards the extent of the posterior striate cortex which is devoted to central vision. It indicates that central vision (including " macular " vision) is represented strictly unilaterally, and that representation is of a sharp, point-to-point character.

## Discussion

This investigation is based on a series of 72 cases of injury to the striate cortex by wounds, mainly gunshot, which penetrated the dura mater. This material is in accord with Holmes and Lister's (1916) view that central vision is represented most posteriorly in the striate cortex ; that serial concentric zones of the visual field from the fixation point to the periphery are represented in this order

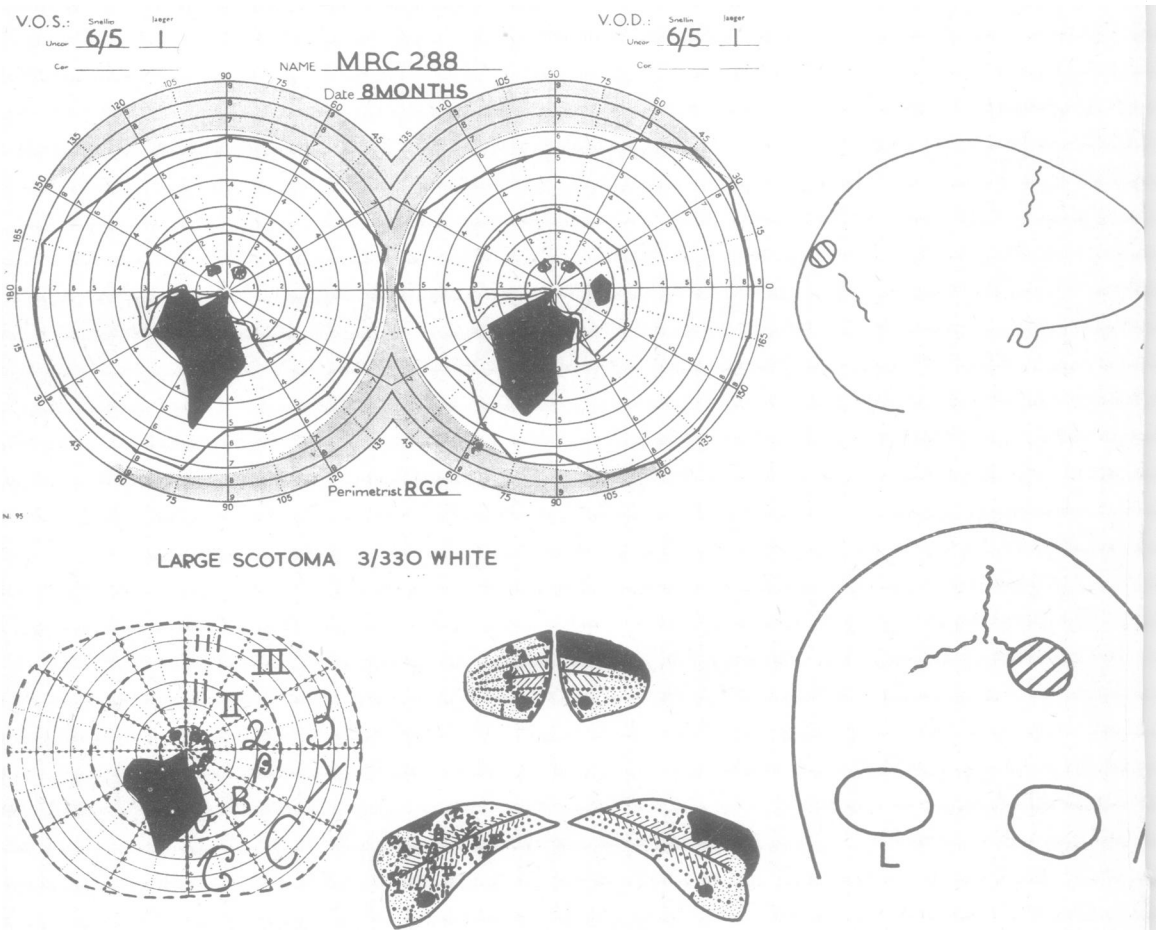



FIG. 7.—Right occipital injury in Case 6 with extensive damage to the right occipital pole causing a left lower paracentral scotoma. The two small symmetrical scotomata in the upper field are attributable to involvement of the lower lips of the calcarine fissure at the point where the medial and postero-medial faces of the striate cortex meet. Since the hatched area in the diagram represents the walls of the calcarine fissure pulled apart, the lesion is single.

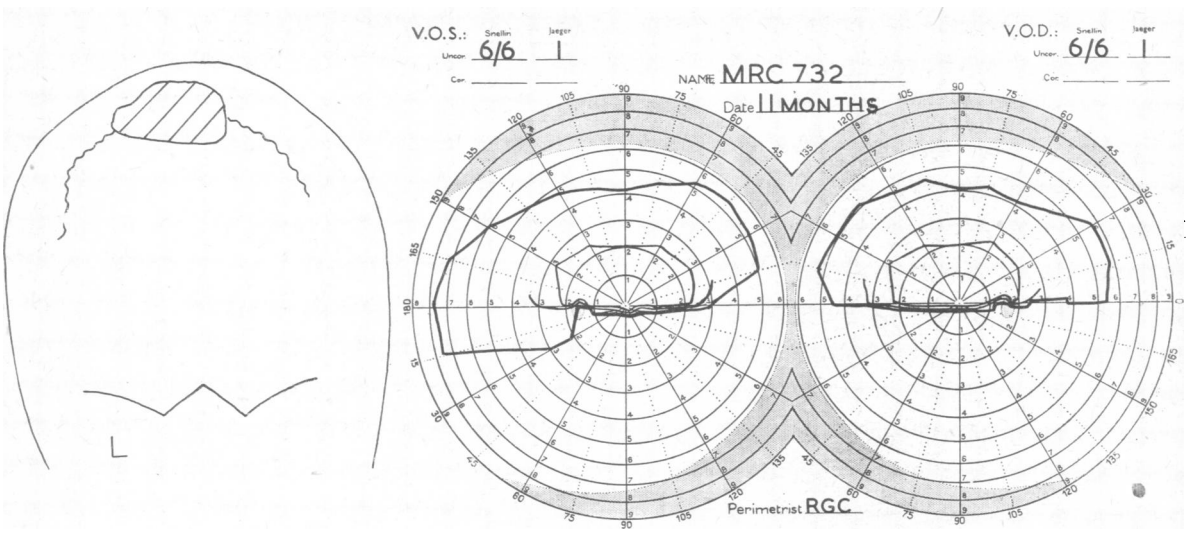



FIG. 8.—Extensive midline high occipital injury in Case 7 causing inferior altitudinal hemianopia.

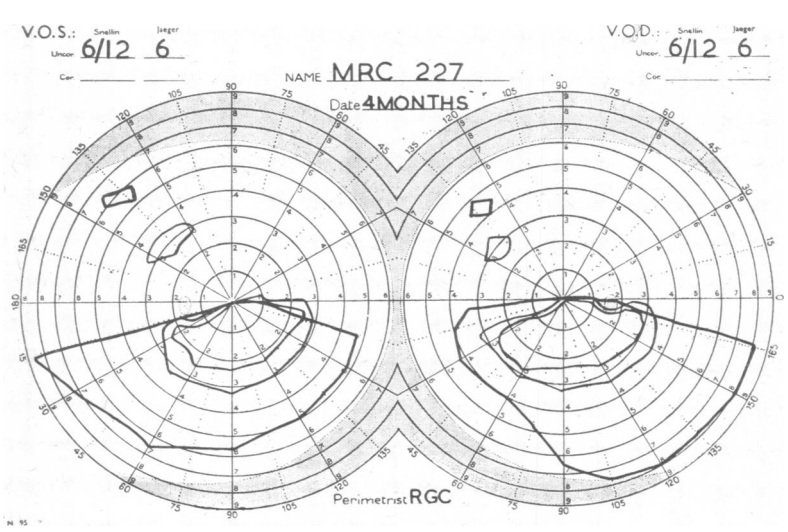



FIG. 9.—Right occipito-temporo-parietal injury in Case 8 with a foreign body crossing the midline immediately below the posterior horn of the ventricle and causing superior altitudinal hemianopia.

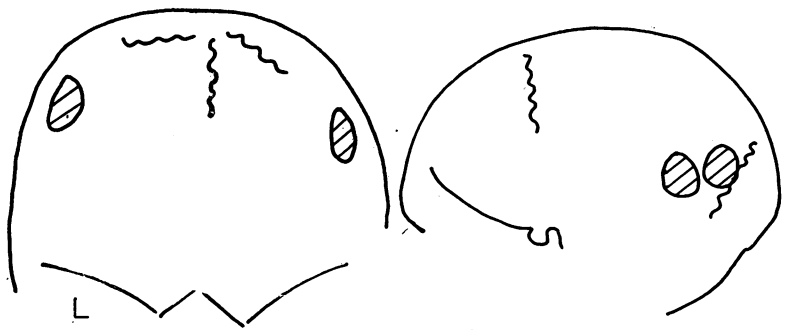



FIG. 10.—Through and through bilateral parieto-occipital injury in Case 9 causing almost complete blindness.

from behind forward ; and that the lower half field is represented in the upper half of the striate cortex and vice versa. It also throws new light on some debatable problems and makes it possible to localize certain parts of the visual field on the striate cortex in greater detail than before.

**" Macular " Representation.**—The thesis that the " macula "—which seems to vary considerably in size from one author to another and is rarely defined*—is represented bilaterally is based solely on the alleged observation that in occipital lobe lesions, but not in lesions of the anterior radiation, there is " macula sparing ". This observation is, however, open to considerable doubt, for Allen (1930) in a review of a large series of tumours involving the occipital lobe from the National Hospital, London, found that there was hemianopia splitting the macula in 32·5%. Horrax and Putnam (1932) from Cushing's clinic reviewed another large series of occipital tumours, including only those strictly confined to the occipital lobe, and found that 12·5% had hemianopia splitting the macula. These two figures do not agree well and have been brought forward as evidence in favour of bilateral representation of the macula. Horrax and Putnam, however, did not draw this conclusion and it is difficult to see how one can. For in tumour material it is never possible to say that all the visual cortex has been rendered functionless, and Horrax and Putnam's stricter criteria may well account for the difference by excluding all the large tumours which are more likely to destroy the whole visual pathway. And in any case there remains to be explained the fact that in at least 12·5% the hemianopia split the macula. Moreover Bender and Kanzer (1939) found that there was no correlation between preservation or splitting of the macula and the site of the lesion in the radiation or striate cortex, and Austin, Lewey, and Grant (1949) found the sparing of central vision was no greater in cases after occipital lobectomy than in those with chiasmal lesions.

The crucial experiment in this controversy is to determine whether a small lesion of one occipital lobe can produce a field defect reaching to the fixation point. It is impossible to decide this point by experiments on animals, and it is essential that the lesion must be small because large lesions such as occipital lobectomy have given contradictory results (Halstead, Walker, Bucy, 1940), possibly owing to the severity of the visual disability which the patients suffer. The cases (Nos. 1 and 2) reported above (Figs. 2, 3) are accidental experiments of this type of which there are many other examples in this material and in the literature (Holmes and Lister, 1916 ; Greear and McGavic, 1946 ; Symonds, 1945), and they show that in small lesions of the occipital pole the scotoma reaches to the fixation point.

Two objections to these cases may be raised. First it may be said that without microscopic examination of the brain it is impossible to say exactly how extensive each lesion was. Although there is some truth in this, it does not affect the argument since for the present purposes all we have to be sure of is that the injury affected one occipital pole but not the other. The slightness of the injury is indicated by the absence of retrograde or post-traumatic amnesia and by the report on the operation. It is unlikely that an injury such as these would cause more than local damage, but if it involved the opposite occipital pole, there would be unmistakable evidence of it in a scotoma in the opposite half field.

The second objection that may be raised is that the visual fields are inaccurately charted. This is always a possible reply to unwelcome evidence, but to make it valid it is desirable to show how the inaccuracy could have crept in. In these cases the observations were made on a Bjerrum screen by trained observers who were constantly doing such tests, but who had no preconceived ideas about what they " ought " to find. The scotomata are small and dense (20/2000) and have well-defined borders, that is, they are of a type that is particularly easy to chart accurately when once they have

* Putnam and Liebman (1942) however state that the macula subtends an angle of 9°, the fovea centralis an angle of 2°.

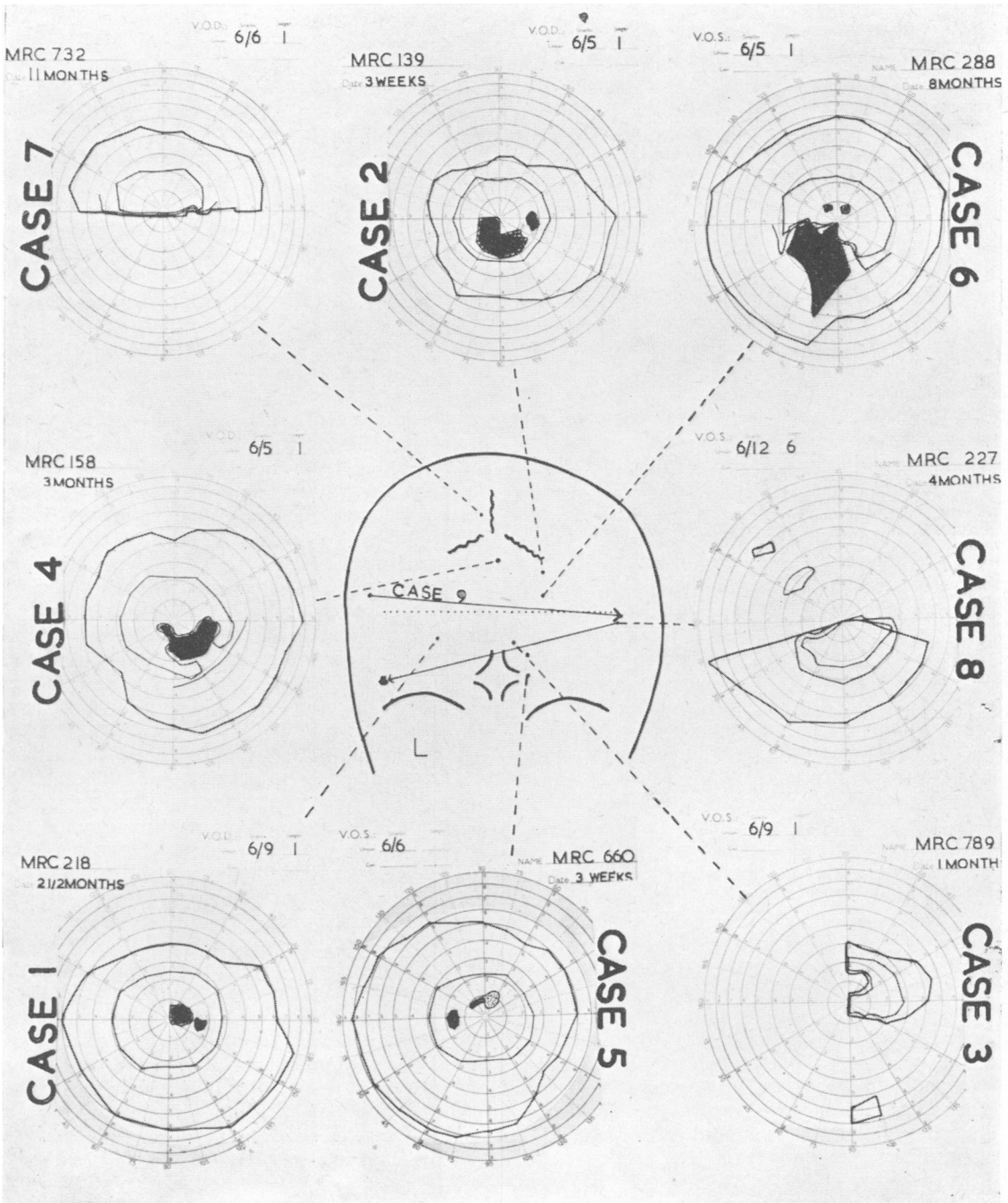



FIG. 11.—The sites of injury in Cases 1 to 9 plotted by measurement on the radiographs from the occipital protruberance. The dotted line indicates the approximate level of the calcarine fissure.

been detected. The patient was watched to see that fixation was well maintained, and though a patient may alter his fixation to bring a scotoma further from the fixation point, it is hardly credible that he should alter it to bring the scotoma towards the fixation point.

We are therefore justified in accepting the evidence that a partial lesion of one occipital pole will produce a scotoma reaching to the fixation point, and therefore we must conclude that the " macula " is represented strictly unilaterally. Holmes and Lister (1916) and Lister and Holmes (1916) reached the same conclusion from their experience in the first world war, as did Greear and McGavic (1946) in the second world war, and Putnam and Liebman (1942) from an extensive review of the literature. The advocates of bilateral representation of the " macula " postulate a tract from one lateral geniculate body to the opposite striate cortex crossing the midline in the corpus callosum, but Putnam and Liebman conclude that on the one hand there is no good evidence to show that such a tract exists and on the other there is a great deal of evidence that it does not. The subject of bilateral representation of the macula has only been discussed here again because belief in it appears not yet to be dead.

The apparent sparing of central vision which may occur in cases of hemianopia has been explained by Bender and Kanzer (1939). Tumours and certain types of injury often do not involve the visual pathways directly but may damage them diffusely either by oedema, by interference with blood supply, or by anatomical distortion due to an expanding lesion. In such cases the visual acuity in the affected half field is depressed, and in extreme cases the only part of the field where appreciable vision is retained is that part where visual acuity is normally the highest, namely around the fixation point. In cases of tumour it is impossible to be sure in any given case whether this mechanism is not responsible for macula sparing. Cases in which the occipital lobe has been destroyed may also show sparing of central vision, but, as Bender and Kanzer have shown, the sparing is not confined to central vision, and on careful testing the whole dividing line between the normal and blind half fields can be shown to be slightly to the affected side of the fixation point. In these cases the patient learns to use a pseudo-fovea as the fixation point. This mechanism, which is analogous to that commonly used by sailors who wish to see faint lights at night, was spontaneously described by a hemianopic patient from this series of head injuries who said that each time he fixed on an object he saw only half of it and automatically shifted his gaze to include as much of it as possible. Undoubtedly many such patients employ the same mechanism unconsciously.

It has been suggested that cerebral vision is represented not only in the posterior part of the striate cortex but also more anteriorly (Brouwer, 1934 ; German and Fox, 1934 ; Penfield and Evans, 1934). Case 1, in which a very slight occipital injury caused a dense paracentral quadrantic scotoma to the fixation point, is strong evidence against any representation of central vision in the anterior part of the striate cortex. Brouwer, on the strength of experiments on monkeys supported by some clinico-pathological evidence, believed that in the cortex " the macula area reaches further frontal, becoming smaller between the dorsal and ventral parts of the retina ". The cases just mentioned are evidence against this. Moreover, if Brouwer's view were correct we would find that when a vertical lesion has occurred through part of the striate cortex the field defect would encroach on the macula near the horizontal meridian, but in Case 4 (Fig. 5) in which a lesion of this nature presumably occurred on the left side, the resulting scotoma is an arc reaching from the vertical almost to the horizontal meridians. This conforms to Holmes and Lister's view (1916a) that serial concentric zones of the retina from the macula to the periphery are represented in this order from behind forwards in the visual area.

**Representation of Horizontal Meridian.**—Henschen (1911) was the first to suggest on the basis of a single case studied clinically and pathologically that the horizontal meridian was represented in the depths of the calcarine fissure. Holmes (1918) independently reached the same conclusion from his studies of head injuries in the first world war, and in 1931 reported a case of cerebral vascular anomaly studied clinically and pathologically which supported this view. In the first world war radiography was not readily available and the site and track of intracranial foreign bodies were therefore open to some doubt. In the civilian cases, though necropsy demonstrated the site of the lesion, the examination of the visual field was done during the course of the patient's last illness shortly after a cerebral vascular accident, conditions which make accurate examination of the visual fields difficult. In the present material this suggestion that the horizontal meridian is represented in the floor of the calcarine fissure offers an explanation of the frequent sparing of the horizontal meridian with involvement of the vertical meridian in lesions of

the medial surface of the hemisphere (Cases 2 and 5, Figs. 3, 6). More important, however, is Case 3 (Fig. 4). The radiograph shows that a foreign body must have skimmed the medial surface of the left striate cortex, and the visual fields were examined four weeks after injury when the patient was fit to cooperate well. The field defect with sparing of the horizontal meridian confirms the view that the horizontal meridian is represented in the floor of the calcarine fissure.

**Extent of the Representation of Central Vision.**—It is generally agreed that in the striate cortex central vision obtains a very large representation compared to peripheral vision, but there is little evidence to indicate just how large it is or to localize accurately in the striate cortex any part of the central or pericentral visual field. The present material gives some help in this problem.

In Case 3 (Fig. 4) an injury which destroyed the right striate cortex also involved some of the left striate cortex where it lies on the medial surface of the hemisphere. In the right upper quadrant of the visual field there is a small semicircular defect running in from the vertical meridian and extending from about 5° to 15° from the fixation point. It is reasonable to suppose that this is due to an injury to the lower lip of the calcarine fissure and the striate cortex inferior to it near the point where the striate cortex passes from the occipital pole to the medial aspect of the hemisphere, and therefore we may provisionally localize this area of the visual field in this part of the striate cortex.

Cases 5 and 6 (Figs. 6, 7) confirm this suggestion and make the localization more accurate. In Case 5 there was a midline injury principally involving the posterior fossa. The very small scotomata, of which the patient was unaware (Fig. 6), represent minimal injury to both striate cortices at the most posterior point where the two are in apposition. An injury in this situation due to a wound from below would extend up from the inferior border of the striate cortex and if of minimal severity would spare the calcarine fissure; in accordance with expectation the scotomata extend from the vertical meridian around the 8° arc and spare the horizontal meridian. In Case 6 there was a considerable injury to the right occipital pole. The two small scotomata in the upper half of the field at first sight appear bizarre, but are readily explicable as the result of an injury coming from above and behind and just reaching the lower half of the striate cortices to involve to a minimal degree the lower lips of the calcarine fissure at the most posterior point where the two striate cortices are in apposition. In this way they can be interpreted as the result of a single lesion. As the cases presented above lead us to expect, the scotomata lie 8° from the fixation point. The two scotomata lie on the radii 30° from the vertical meridian, and this suggests that at least in this part of the visual field the walls and floor of the calcarine fissure represent two thirds of the visual field above and below the horizontal meridian.

## Summary

A series of 958 cases of penetrating head injury, mainly gunshot wounds, has been reviewed to determine what light they throw on the anatomy of the striate cortex (area 17). In 188 of these there was a visual field defect attributable to injury to the visual radiation or striate cortex. In 72 cases the injury primarily affected the striate cortex, and of these characteristic examples are presented and their anatomical significance discussed.

Central (" macular ") vision is represented unilaterally.

The horizontal meridian of the visual field is represented in the floor of the calcarine fissure.

The extent of striate cortex devoted to central vision is defined. Central vision within the 8° to 10° circumference (i.e. macula vision) is represented on that part of the striate cortex which faces posteriorly or postero-medially. The remainder which faces medially represents vision more peripheral than 10° from the fixation point.

The lips of the calcarine fissure at the point where the striate cortex on the medial surface of the hemisphere becomes continuous with that on the postero-medial surface represents the points 8° from the fixation point and 30° from the vertical meridian.

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We much regret an error in Fig. 8 of Part I (p. 103). Fig. 8 comprises the three line drawings only marked (*a*), (*b*), and (*c*).

# APPENDIX

**Case 1.**—M.R.C. 218,* a man aged 19, on August 7, 1944, received a gunshot wound in the left occipital region 3·1 cm. from the midline and through the upper margin of the transverse sinus (Figs. 2 and 11). He did not lose consciousness and had no retrograde or post-traumatic amnesia. He was blind for about 10 minutes, and when seen at a mobile neurosurgical unit 18 hours after injury there was a right homonymous hemianopia and a slight right facial weakness. At operation 56 hours after injury the lateral sinus was found to have been almost completely torn across by a metallic foreign body which was lying partly outside the dura. Debris was removed from a cavity the size of a small plum, exposing the tentorium.

On arrival at the Military Hospital for Head Injuries, Oxford, five days after injury no abnormal physical signs were detected clinically but full examination of the visual fields revealed a right paracentral scotoma reaching to fixation point and about 10° out from it. It involved the right upper and part of the right lower quadrant. Two months after injury the visual field remained almost unchanged except that the lower quadrant was involved to a smaller extent (Fig. 2).

**Case 2.**—M.R.C. 139, a man aged 30, on July 21, 1944, received an occipital gunshot wound whose centre was 5·2 cm. above the occipital protuberance and 2·2 cm. to the right of the midline (Figs. 3 and 11). He was momentarily unconscious and all limbs were paralysed for a few minutes.

On admission to the Hospital for Head Injuries two days after the injury he was rational and fully orientated, and no abnormal physical signs were detected clinically. At operation 64 hours after injury a defect in the dura was found measuring 1·5 × 0·73 cm. and a funnel-shaped track led in from it from which debris was removed to a depth of nearly 2 cm. His convalescence was delayed by meningeal infection lasting a week but three weeks after injury he was free of symptoms and the only abnormality was in the visual fields. They showed a left lower quadrantic paracentral scotoma continuous with a right lower pericentral partial ring scotoma (Fig. 3).

**Case 3.**—M.R.C. 789, a man aged 30, on April 15, 1945, received a gunshot wound in the right occipital region whose centre was 1·7 cm. above the occipital protuberance and 0·8 cm. from the midline (Figs. 4 and 11). He had a retrograde amnesia of about an hour and a post-traumatic amnesia of five or six days. Thirty-four hours after injury the wound was debrided but the track was not followed deeply.

On admission to the Hospital for Head Injuries five days after injury he was moderately confused and grossly disorientated in time, but there was no dysphasia. The left pupil was larger than the right. His ability to appreciate the direction of passive movement of the digits of all limbs was impaired but other modalities of sensation were normal, and there was no astereognosis or finger agnosia. There was no weakness and no reflex abnormalities.

He made a good recovery and three months after injury the only abnormality on physical examination, apart from the field defect, was moderate disturbance of joint sense in the fingers of the right hand.

Five days after injury he was thought on confrontation to have vision only in the right upper quadrant of both eyes. Four weeks after injury the visual fields showed a complete left homonymous hemianopia with a small "cove" penetrating from the vertical meridian into the right upper quadrant about 8° from the fixation point, and a very much larger cove involving a large part of the lower quadrant and bounded in part only by the area of monocular vision (Fig. 4).

**Case 4.**—M.R.C. 158, a man aged 24, on May 23, 1944, received a gunshot wound in the midline 5·8 cm. above the occipital protuberance (Figs. 5 and 11). There was no retrograde amnesia and post-traumatic amnesia was less than an hour. At operation the following day the wound was found to have penetrated the sagittal sinus which bled very freely. Superficial debris was removed but full exploration of the extent of the wound was not possible owing to difficulty in controlling the bleeding from the sagittal sinus.

Seven days after injury he was thought to have an inferior altitudinal field defect. When admitted to the Hospital for Head Injuries two and a half months after injury the only abnormality on physical examination was in the visual fields, in which there was a large right lower quadrantic paracentral scotoma and very much smaller left lower paracentral scotoma (Fig. 5).

**Case 5.**—M.R.C. 660, a man aged 29, on February 27, 1945, received an occipital gunshot wound. There was no retrograde amnesia and post-traumatic amnesia lasted half an hour. At operation 17 hours after injury the site of entry was found to be in the posterior fossa immediately to the right of the midline, but an indriven bone fragment (Figs. 6 and 11) had penetrated the torcula, bleeding from which had fortunately been checked by debris.

On admission to the Hospital for Head Injuries three days after injury he was alert and well orientated, and no abnormalities were detected on clinical examination. He made no complaints about his vision, but examination

* Reference number of the M.R.C. Penetrating Head Injury File, Military Hospital, Wheatley, Oxford.

of the visual fields three weeks after injury showed that he had a small bilateral scotoma, complete on the left, incomplete on the right, in the upper half field 8–10° from the fixation point and involving the vertical but not the horizontal meridian. The scotoma was unchanged seven weeks after injury.

**Case 6.**—M.R.C. 288, a man aged 22, on September 10, 1944, received a gunshot wound centred 4·2 cm. above the occipital protuberance and 2·2 cm. to the right of the midline (Figs. 7 and 11). There was neither retrograde nor post-traumatic amnesia, but for 10 minutes the whole of his vision was very indistinct.

On admission to the Military Hospital for Head Injuries two days later he was rational and well-orientated, and to confrontation was found to have a defect in the left lower quadrant of the visual field. There were no other abnormal physical signs. At operation 66 hours after injury a dural tear was found measuring 1·5 × 0·5 cm. and debris was removed from the track to a depth of 1·5 cm.

Ten days after injury the fields were charted in bed and the left lower quadrantic defect was found to extend also into the right lower quadrant. One month after injury the visual fields were first fully tested and were identical with those eight months after injury (Fig. 7). There was a large left lower paracentral scotoma extending also into the right lower quadrant and a small scotoma in each upper quadrant about 8° from the fixation point and 30° from the vertical meridian.

**Case 7.**—M.R.C. 732, a man aged 23, on May 12, 1944, received an extensive midline gunshot wound whose centre was 8·2 cm. above the occipital protuberance (Figs. 8 and 11). There was no retrograde amnesia and the post-traumatic amnesia was about 10 days.

On admission to the Hospital for Head Injuries 11 months after injury he had an inferior altitudinal hemianopia (Fig. 8) and no other abnormal physical signs except slight increase in the reflexes of the left upper limb.

**Case 8.**—M.R.C. 227, a man aged 23, on May 13, 1944, received a gunshot wound in the right occipito-temporo-parietal region and a metallic foreign body passed across the midline immediately below the posterior horns of the ventricles and came to rest in the left temporo-parietal region (Figs. 9 and 11). He had no retrograde amnesia, was unconscious for half an hour, and had a post-traumatic amnesia of three days during which there were a few episodes which he remembers. The wound was debrided about 18 hours after injury, when sight began to return.

On admission to the Hospital for Head Injuries three months after injury there were no abnormal physical signs except for an upper altitudinal hemianopia which remained unchanged during the next five weeks (Fig. 9). As this involved central vision he had great difficulty in reading for he had to scan words up and down.

**Case 9.**—M.R.C. 851, a man aged 23, on January 29, 1945, received a through and through bilateral parieto-occipital wound (Figs. 10 and 11). His retrograde amnesia was two or three hours and post-traumatic amnesia about five weeks.

On admission to the Hospital for Head Injuries six months after injury the only abnormal physical signs were complete anosmia and virtually complete blindness, for he could barely distinguish light from darkness.

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