
Circumstances have only made it possible to consider in detail a few of the many cases observed over the previous 18 months in the base hospitals in France that have a bearing on the representation of different regions of the retina in the cortex. Furthermore, in studying cases soon after injury, the effects of shock or diascisis may have dissociated functional deficits from those that result from structural damage. Necessarily, most of the subjects are studied in cramped beds using a hand-held perimeter; seldom is a modified Bjerrum screen (a black cloth placed over a double fools-cap sheet of paper pinned to a board, with a drawing pin as the point of fixation, and held at one metre) or McHardy perimeter also used. Salomen Henschen (1847–1930) has shown that the visual cortex corresponds to the area striata with the superior half of each retina (the lower field) represented in the upper part of the occipital lobe and the inferior below and in the lips of the calcarine fissure: ‘on the other hand nothing is definitely known on the correspondence between various concentric zones of the retina and the different segments of the area striata.’ Field defects rarely reach closer than 2–10° towards the point of fixation when cases, most often vascular in origin, are seen in civilian practice; and central vision is usually spared. While this may imply that macular representation is bilateral, central vision is also often intact with bilateral hemianopia suggesting, alternatively, that the macula is represented outside the striate area. Many other anatomical and physiological explanations for macular sparing have been offered.

Because injuries to the optic radiation, as it sweeps along the outer side and behind the posterior horn of the ventricles, may also involve the underlying cortex, damage confined to fibres within the radiation projecting to the posterior calcarine cortex are those most suitable for the study of cortical localization. Based on observations at surgery and during post-mortem examinations, it is clear that the penetrating injuries of rifle bullets and shrapnel follow rather a straight trajectory between the points of entry and exit, allowing reliable anatomical assumptions to be made in such cases.

Lieutenant C (Fig. 1A) and Staff Sergeant M both experience lesions confined to the right calcarine fissure and each has a field defect restricted to the left inferior quadrant. The lesions in Lance-Corporal M and Private J are more extensive, and so too are their field defects; but on the side where the damage is confined to the upper calcarine cortex (on the left and right, respectively), there is a corresponding crossed inferior quadrantanopia. Private P provides the only example of a horizontal field defect; and he has a wound suggesting that the trajectory of the bullet damaged the left striate cortex and the posterior extremity of the right calcarine area at the pole of the hemisphere (Fig. 1B). The evidence is clear: Henschen is correct in localizing lower retinal representation to the upper calcarine cortex; and the relative absence of cases with upper quadrant defects is explained by the high fatality rate of lesions to the lower striate cortex due to concomitant cerebellar (and venous sinus) damage.

Private F suffers injury to the tips of both occipital lobes resulting in bilateral scotomas affecting the central 15° of vision. A bullet passes horizontally across the occipital poles of Private R at the level of the posterior ends of the calcarine fissures resulting in bilateral central scotomata (with additional peripheral constriction attributed to poor attention). Private L has a right paracentral scotoma extending 20° from the point of fixation, and the exit wound indicates damage to the left occipital pole. Lieutenant T suffers damage to the tip of each occipital pole and is left with asymmetric dense paracentral scotomata extending 10° and 20° into the peripheral field (Fig. 1C). ‘These observations, associated with the fact that among over 2000 cases of head injury we have never seen a central scotoma when a direct injury of the occipital poles could be excluded, afford strong evidence that central vision is represented on either the mesial or lateral surface of the poles of the occipital lobes...those cases in which there was a homonymous hemianopia in addition to a central scotoma also conform to...this view.’ Private G loses the posterior part of the optic radiation and calcarine cortex of the left hemisphere and suffers more restricted injury to the posterior extremity of the right occipital lobe; he is left with a dense right homonymous hemianopia and central scotoma (Fig. 1D). Much of the same combination is seen in Private M. Another soldier, also Private M, has the same field defects but dies from meningitis; at autopsy, extensive damage to the left optic radiation is confirmed together with destruction by the bullet of the posterior third of the left calcarine cortex. ‘The evidence so far consequently points to representation of the macula at the posterior pole of the
hemisphere.' The cases of paracentral scotoma studied by Sir Gordon Holmes (1876–1965) and Sir William Lister (1868–1944) support this interpretation and provide further evidence for the conclusion that the upper and lower halves of the retina, and hence the lower and upper fields, are represented in the dorsal, and lower and posterior, parts of the area striata, respectively.

Private B is left with paracentral scotomata splitting the macula and extending $30^\circ$ into the right homonymous field in association

Figure 1 In these figures, the position of the wound is represented approximately on a diagram of the back of the head. The horizontal lines on this represent the distance in inches of the plane above the inion, and the vertical lines represent the distance in inches from the middle line of the skull (Holmes and Lister, 1916).
with a bullet wound to the left posterior cerebral hemisphere, but
with an uncertain trajectory on its way to the left cerebellar hemi-
sphere. Another Private B, suffering contusion of the left occipital
pole at the upper lip of the calcarine fissure, develops a right
inferior quadrantic paracentral scotoma not reaching the fixation
point. Much the same defect is present on the left in Lieutenant
H in whom the posterior extremity of the upper lip of the right
calcarine fissure is damaged. Private A has a sharply defined para-
central lower quadratic scotoma splitting the macula although
the trajectory of the bullet cannot reliably be ascertained (Fig. 1E).
The same is true for Lieutenant F who has a similar
field defect, somewhat larger, resulting from injury of the upper
and posterior portions of the area striata. Sergeant D has a small
quadrantic paracentral scotoma resulting from a well-demarcated
wound of the posterior extremity of the upper lip of the calcarine
fissure. The field defect in Private C, who survives damage below
the extremity of the left calcarine fissure, is a right upper quad-
trantic paracentral scotoma just dipping across the horizontal; and
Private T has a more or less identical visual defect from a proven
bullet wound of the posterior and inferior aspects of the left oc-
cipital pole. Lance-Corporal G is left with an hemipinic paracentral
scotoma on the right and a lower quadrantic defect on the left
after a bullet passes through his left occipital pole; and causes
concomitant injury of the upper part of the right calcarine fissure
by an in-driven flake of bone. ‘We can conclude that central vision
is [is] represented towards the posterior part of the occipital lobe...the upper portion of the retina in the immediate neighbourhood
of the macula corresponds with the upper and most posterior part
of the area striata, while the central portion of the retina below
the level of the macula is represented in its lower and posterior
part...we can suggest tentatively that the portion of the area
striata which extends to the margin and on to the lateral surface
of the occipital lobe is the cortical focus of central vision.’ And the
case of Lieutenant C in whom destruction of the posterior occipital
lobe on the left results in right homonymous blindness reaching the
fixation point, supports the conclusion that the macula is repre-
sented on the posterior pole of the hemisphere: ‘we believe, in
common with every other part of the retina, [that] the macula is
not represented bilaterally.’

Why then should macular sparing characterize vascular lesions
of the occipital lobe? The likely answer is that the posterior pole
is at the watershed of supply from two major sources—the middle
and posterior cerebral arteries being tributaries of independent
major vessels—and so is usually spared when one or the other
is occluded. The corollary, that more anterior lesions select periph-
eral vision within the defects, is less easy to document. Private F
retains only a few degrees of central vision after a bullet passes
through his head destroying the anterior parts of both striate areas
but also, no doubt, damaging each optic radiation (Fig. 1F).
Holmes and Lister note that the shape and size of defects in the
two eyes are often not symmetrical and this they attribute to poor
attention. On colours: ‘we have no conclusive evidence that
achromotopsia, with intact vision for white, is produced by cere-
bral lesions which involve either the cortex or the optic radiations’. And in a spirit of ‘médecine sans frontières’, in addition to the
work of Pierre Marie (1853–1940) and Charles Chatélin (nk),
and Tatsui Inouye (1880–1976) making observations during the
Russo-Japanese Wars of 1900 and 1904–05 [see Brain 2000; 123
(Suppl): viii, p. 101], the authors acknowledge the contributions
made to knowledge on the cortical representation of vision by
German authors writing during the same conflict on the effects
of bullets fired by the Allied Powers traversing the heads of their
own soldiers.

Fifteen years later, Gordon Holmes returns to the cortical rep-
resentation of vision. Although not described at the time (in Brain), he recalls having seen examples among the several hun-
dred men observed following gunshot wounds of the occipital
lobes, of sector scotoma: a narrow band—upper, lower or both—along the vertical axis through the fixation point and broadening towards the extremities of the field but rarely extend-
ing to the periphery. Because these defects are associated with
large low-velocity injuries in which the bullet is embedded and
abuts the falx cerebri, Holmes concluded at the time that the
lesion is due to bruising of the medial surface of the opposite
hemisphere; and in one case, a fragment of bone had indeed
penetrated the falx in exactly this way. It follows that the vertical
meridian of the retina is represented on the exposed medial sur-
f ace of the occipital lobe; and the retina corresponding to the
horizontal meridian is projected onto that part of the area striata
lying in the wall of the calcarine fissure. In fact, Henschens has
already reached the same conclusion. Now, Holmes reports a
case that bears on this anatomical issue.

B.J. has intermittent headache with visual spectra but develops
fixed deficits following an episode suggestive of intracranial bleed-
ing. Her defect is hemianopic but with sparing of the field along
the vertical axis other than at the horizontal meridian (Fig. 2). She
has a naevus on her right cheek. After making the diagnosis of
cerebral tumour, Sir Percy Sargent (1873–1933) operates and finds
two enormous dilated vessels on the surface of the hemisphere
with an extensive anastomosis extending across the right occipital
lobe. Death occurs the same evening. Autopsy confirms the pres-
ence of an arteriovenous malformation centred on the anterior
occipital sulcus with feeders from the middle of the right occipit-
fissure and veins draining into the longitudinal and lateral sinuses.
There is evidence for previous haemorrhage in the occipital lobe
extending from the hippocampus to the tip of the pole. The sub-
cortical white matter along the floor of the calcarine fissure was
involved along the whole length of the fissure to such a degree
that few afferent fibres could have reached the cortex, and in
places the cortex itself had suffered,’ whereas connections from the
dorsal and ventral borders of the damaged central sagittal
strata could be traced into the white matter of surviving cortex.
Significantly, the cortex and subcortical white matter on the mesial
surface of the hemisphere and along the lips and adjoining por-
tions of the walls of the calcarine fissure are intact. Holmes argues
that the field defect involves loss of retinal representation adjacent
to the horizontal and vertical meridians and field dependent on
structures that are deep and located on the lips of the calcarine
sulcus; and on the differential representation of peripheral and
central vision in the anterior calcarine region and posterior occipital
pole, respectively. ‘It seems justifiable to conclude that no afferent
impulses could have reached those portions of the striate cortex
buried deeply in the calcarine fissure...vision subserved by these
parts...was lost while the cortex on the mesial surface of the
brain and along the lips of the calcarine fissure [was] intact and receiving afferent geniculo-cortical fibres capable of function.' In 1916, Holmes and Lister had concluded that fibres are arranged in regular laminae within the optic radiations according to the retinal quadrants they represent, those of the upper and lower quadrants being separated by an anatomical interval; based on the present case, to that can be added the conclusion that sectors of the retinæ along their horizontal axes are represented in the cortex around the floor of the calcarine fissure.

As a neurologist, teacher, author, editor and mentor Gordon Holmes left an indelible mark on the development of clinical neurology and knowledge on functions of the cerebellum, the visual system and much else besides. His method was astute clinical observation with faithful recording of what the patient said or experienced; rigorous and ritualized but intuitive examination; pathological examination when possible; and, above all, interpretation of the findings in the context of anatomy and physiology. Through his uninterrupted service with the British Expeditionary Force in France during the Great War, he had the opportunity of observing an unprecedented number of wounded officers and ordinary soldiers. Neurology benefitted; and the roll-call of names recorded in Holmes’s papers from that period serve as a memorial to the many on all sides who served in the conflict and died or were left with devastating and permanent brain injuries that blighted their subsequent civilian lives.

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