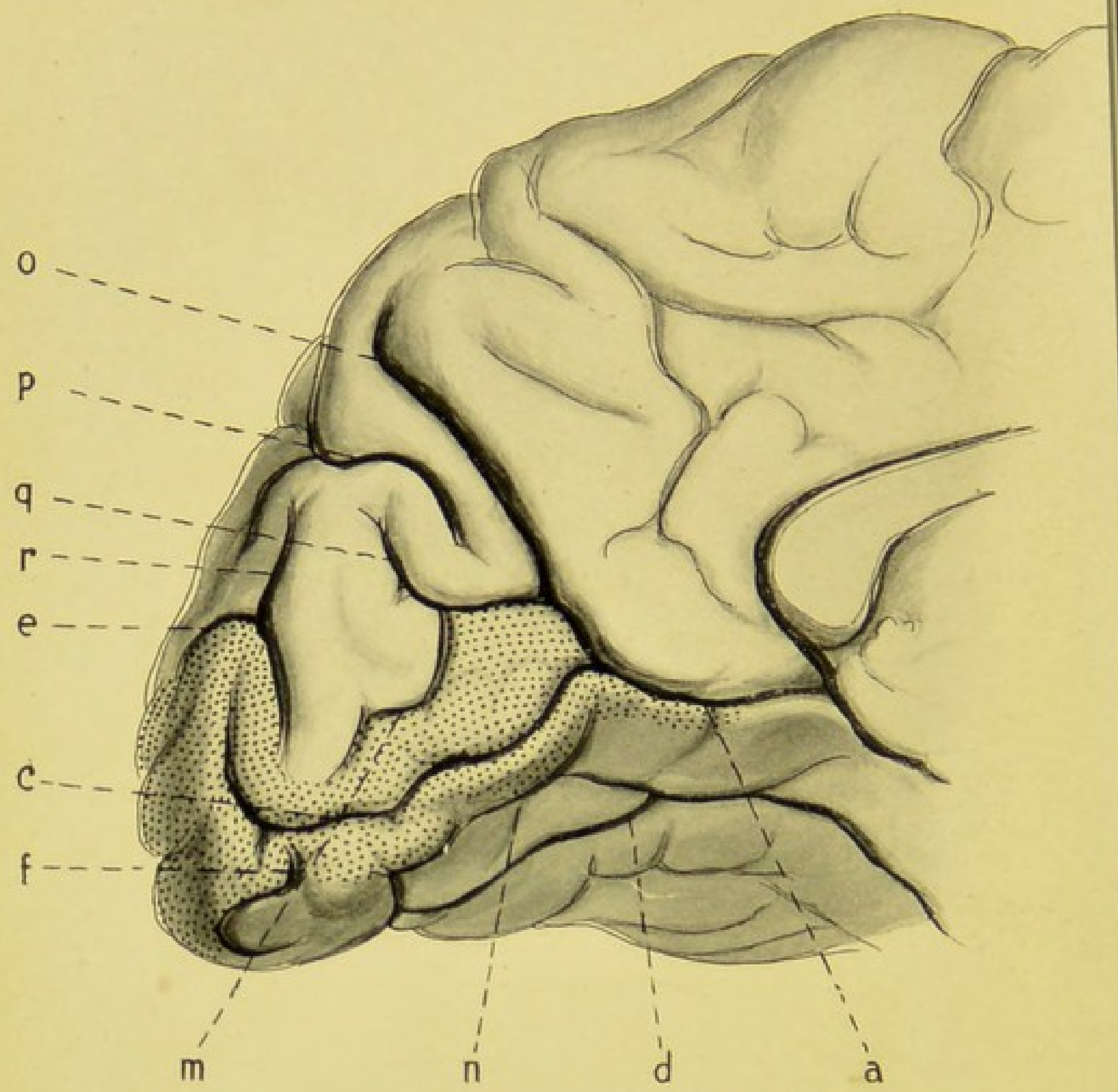
BRADSHAW LECTURE

The Brain Structures concerned in Vision

F. RICHARDSON CROSS

THE BRAIN STRUCTURES CONCERNED IN VISION AND THE VISUAL FIELD



MEDIAL SURFACE OF BRAIN—MAN.

Specially drawn from a brain in Royal College of Surgeons' Museum, and kindly approved by Professors Keith and Elliot Smith.

a—Calcarinus anterior. *c*—Calcarinus posterior *d*—Collateral. *m*—Sulcus limitans superior areæ striatæ. *n*—Sulcus limitans inferior areæ striatæ. *e*—Sulcus polaris superior. *f*—Sulcus polaris inferior. *o*—Sulcus limitans præcunei. *p*—Incisura parieto occipitalis. *q*—Sulcus paracalcarinus. *v*—Sulcus paramedialis.

The Bradshaw Lecture

ON

The Brain Structures concerned in Vision and the Visual Field

Delivered before the Royal College of Surgeons of England
on December 11th, 1909

BY

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I DESIRE to pay my tribute to the memory of Mrs. Sally Hall Bradshaw, through whose generosity this lecture is annually given, and also to that of her husband, in whose honour the lectures were founded.

In Foster's *Alumni Oxoniensis,* Vol. I., 1888, we find his name: *Bradshaw,* William Wood—2nd son of John of St. James', Bristol, armiger—New Inn Hall, matric. 14 Nov., 1844, created M.A. 17 June, 1847. And in the *London Medical Directory,* 1866, this record: *Bradshaw,* William Wood, Portland Place, Reading; M.A. Oxon.; D.C.L., LL.D.; M.D. Erlangen, 1833; M.R.C.P. Lond., 1859; Extr. L. (exam.), 1841; F.R.C.S. Engl., 1854; 1833 (Westminster and Middlesex); Mem. Oxford University Art. Soc.; Gentl. Commoner New Inn Hall, Oxon.; Hon. Mem. Roy. Jenn. Soc., Lond.; Corr. Member Natn. Vacc. Institute, Lond.; late Vice-Pres. Path. Soc.; Royal Berkshire Hospital. Various contributions to Medical Journals and various articles in *Miscellany* and other periodicals by "Beta."

He died on August 18th, 1866.

Sir James Paget, in the first Bradshaw Lecture, Dec. 13th, 1882, paid him an elegant and well-merited tribute, and also to his widow, who survived him for fourteen years.

THE BRAIN STRUCTURES CONCERNED IN VISION AND THE VISUAL FIELD.

Mr. President, Ladies and Gentlemen,—I must first thank you, sir, for conferring on me the honour of delivering the Bradshaw Lecture within these walls. For its subject I have gone to our great Hunterian Museum and have surveyed there the collection of brains of Vertebrata, and I have made some study of the College catalogue, *Of the Physiological Series of Comparative Anatomy*, Vol. 2, 1902, in which these are described and discussed.

From this book I have closely followed the work and statements of Professor Elliot Smith in regard to the comparative anatomy of the occipital region, and particularly of its medial surface, and of the calcarine sulcus and its relations, and I have freely copied from them: I am further greatly indebted to him for other papers.

To Professor Keith I am very much obliged for his constant advice and kind help, and to Henry George, who has drawn for me the many large diagrams which illustrate the lecture.

Comparative Anatomy.

In the lower vertebrata a simple brain is formed by enlargement of the anterior end of the spinal cord and by the widening and division of its central canal to form ventricles. Upon this primitive brain swellings are developed in connexion with the senses of sight and smell. The sense of smell seems first of early importance, probably for selection between nutritious or poisonous foods or as a means of safety.

Fishes.

In fishes we find the visual organs well developed and varying in importance with the necessity in the species for more or less perfect sight: optic lobes and tracts, an optic chiasma and infundibulum, a third, fourth, and lateral ventricles and corpora geniculata underneath the optic thalamus. These often vary conversely in importance with the olfactory region, which is enlarged when smell is the more needed function. In all fishes the optic nerve crosses over from either eye to the optic lobe on the opposite side of the brain each quite separately, usually one above the other, though one nerve may pass through a slit in the opposite one, or the fibres may interlace, but without association.

Amphibians.

In amphibians the brain is usually of low type but rather large. In the proteus, which is practically blind, the optic lobes are scarcely recognisable, but in the frog they are large and form the broadest part of the brain.

Reptilia.

In the reptilia the brain is long and narrow, it has become much increased in size and is well differentiated, and we get a very definite cerebral cortex. The three mantles of the brain exist as found in mammals: (1) the basal pallium or pyriform; (2) the marginal pallium or hippocampal; and (3) the neopallium or higher cortex (brain proper).

Birds.

The brain in birds is broad and highly developed, enlarged chiefly by the size of the corpora striata. All the structures upon which sight depends are very well developed. The thalamus and optic lobes are highly organised, and there are even present small temporal and occipital lobes. In birds the optic chiasma is single and complete and crosses over the infundibulum. The bundles of fibres from the optic nerves interlace and alternate, but those of each nerve completely decussate to the opposite side of the brain. The optic tracts pass round the optic thalami and show well-developed geniculate bodies. Vision is as a rule panoramic and monocular, one eye for the object on its own side. The fowl sees its food one eye at a time. In birds of prey, where rapid co-ordination between the seeing and capturing their prey is essential, the optic lobes are very strongly developed. The owls and hawks, whose eyes look forward, probably possess a considerable field of binocular vision, but possibly all the fibres from each optic nerve cross to the opposite side of the brain; none go direct to the same side. Their vision is binocular, but not stereoscopic, for which direct as well as decussating fibres are required.

Mammalia.

The *Non-placental mammals* have a smooth cerebral cortex, the halves linked together by two commissures, the anterior or ventral and the dorsal or hippocampal (*d*, *v*). There is no corpus callosum.

In the *Monotremata* there is a poor sense of sight, the eyes and optic tracts are very small, the geniculate bodies are absent and there is no splenial fissure.

In the *Marsupials* the brain becomes more highly organised. On the medial surface of the hemispheres there appears a sulcus which runs horizontally behind and parallel with the hippocampal. This is the calcarine, or splenial, about which the cortical substratum for vision is placed; it is one of the earliest and most constant fissures of the brain, and it can already be shown to form the calcar avis in the ventricle. A genual and a rostral sulcus also show on the medial surface of the hemisphere, although no corpus callosum as yet exists.

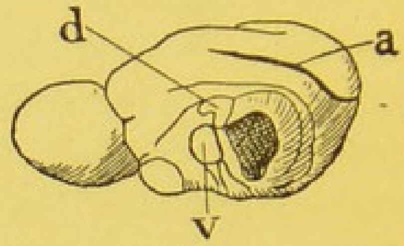

FIG. 1.
MEDIAL SURFACE OF BRAIN.
a—Calcarine Fissure.
d—Dorsal. *v*—Ventral.

When we reach the *Placental mammals* a real corpus callosum becomes developed in addition to the two commissures mentioned.

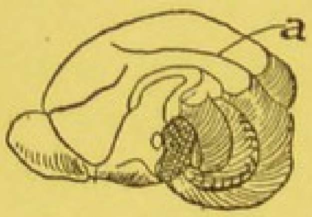

FIG. 2.
MEDIAL SURFACE OF BRAIN,
SHEWING CORPUS CALLOSUM.
a—Calcarine Fissure.

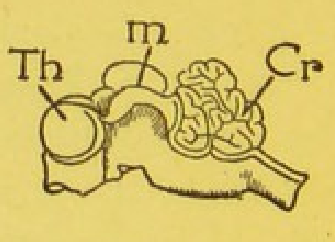

FIG. 3.
MEDIAL SECTION OF BRAIN.
Cr—Cerebellum. *M*—Mid-brain.
Th—Thalamencephalon.

Insectivora.

In the flying lemur the sulci on the brain become more marked; the most definite is a deep calcarine sulcus running horizontally forward, almost the whole length of the medial surface of the hemisphere; there are also very large anterior quadrigeminal bodies between a well-marked thalamencephalon and cerebellum. (Fig. 3.)

Rodents.

In the many families of rodents the brain is large, but there is a peculiar absence of sulci, especially on the medial aspect of the brain, and the calcarine fissure is rarely seen, or at any rate is only slightly developed. But the squirrel requires very accurate sight, and he has large optic nerves and very developed anterior quadrigeminal bodies. The rabbit and the hare probably possess a very acute sense of hearing. They live to avoid being captured, for escape, rather than defence. Their eyes are placed so much on the side of the head that each carries an enormous range over its field of vision on that side, and they can see laterally and behind almost as well as in front. This wide panoramic vision cannot well be associated with any great binocular effort; nearly all the optic nerve fibres decussate.

Edentata.

In edentata the occipital region of the brain is large, and on the medial surface shows the calcarine sulcus

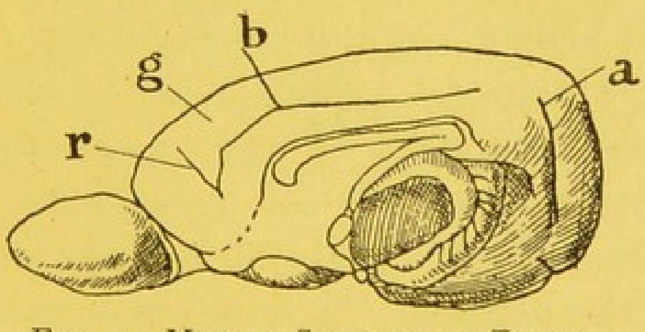

FIG. 4.—MEDIAL SURFACE OF BRAIN.
a—Calcarine Fissure. *b*—Intercalary.

pushed backward by development of the anterior and upper parts of the brain, and becoming vertical, as in the ant-eater, instead of passing horizontally forward. (Fig. 4.)

Carnivora.

In the carnivora the brain proper is highly developed ; it passes forward over the olfactory bulb and backward over

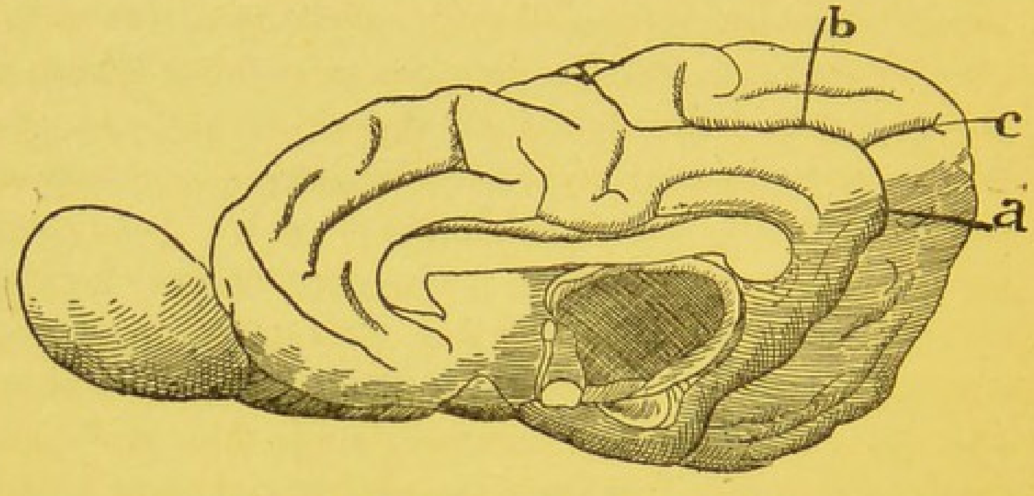

FIG. 5.—MEDIAL SURFACE OF BRAIN.
a—Calcarine Fissure. *b*—Intercalary. *c*—Retro-calcarine.

the cerebellum. There is a very high degree of binocular vision. In the fruit-eating carnivora the eyes are at the side of the head and they possess only a limited convergence. But in the felidæ and others the eyes are set forward and the pupil is very active ; these animals require good distant vision, often when the light is dull, and they also need very reliable closer sight and a most perfect co-ordination of the eyes with the fore limb, by which they catch their prey. In the optic chiasma there are considerable direct as well as decussating fibres. There is a deep calcarine sulcus which with the intercalary shuts off a posterior lobe from the rest of the brain. In some species there appear secondary fissures, running out of the calcarine or even a definite retrocalcarine.

Ungulata.

The ungulata are large animals and they need a large brain, but the medial area is very simple. There is no high specialisation in the calcarine fissure ; it is large and placed behind the splenium. It joins the intercalary and this the genual, showing a complex splenial or a form of cingular arc. The eyes are usually placed on the side of the head and separated by the forehead or nose. There is a wide area of periscopic sight, but they only have a limited amount of convergence and binocular vision. In the horse about one-sixth of the fibres do not decussate, but pass direct.

In periscopic vision each eye is responsible for the field on its own side, and as this is represented on the opposite side of the brain all the optic nerve fibres must decussate. The nerve of the left eye concerned with the left field terminates in the right optic lobe of the brain. When the eyes tend to converge and give slight binocular vision a part of the nasal side of each field is overlapped. The super-imposed parts have crossed to the opposite side of the middle line. The extreme temporal side of the retina of the right eye is now concerned with the left field of vision, and the fibres that represent this left field must go to the right side of the brain. As the eyes turn more forward more and more of the nasal fields overlap, and more and more direct fibres are required from the temporal side of the retina.

In perfect stereoscopic vision both visual axes must be turned towards the object looked at ; the whole of each nasal field is carried across the middle line, and there is almost a complete overlapping of the fields of the two eyes; and, what is more important, the central objects seen by the macula of each eye overlap and blend in the brain.

The acuity of the macula depends on the delicate association of each cone (7,000 or 8,000 in number), with bipolar nerves and ganglion relay centres. Through fibres in each optic nerve they may become connected with the decussating and direct portions of each optic tract, and be widely distributed on the visual cortex of both cerebral hemispheres. Or if there is a localised macular area in the brain, it is probably especially well supplied with blood, and has a great resisting and recuperative power, but no such area has as yet been demonstrated.

Lindsay Johnson says that a true macula is only found in man and the true monkeys. It would perhaps be more accurate to say with him, that parallel vision with complete convergence is only found in animals that have a macula lutea.

Monkeys.

In the monkeys the calcarine sulcus becomes the centre of further developments. In the aye-aye and lemurs it is somewhat vertical, but in the tamarin, one of the anthropoid apes, and the marmoset, a long single sulcus is prolonged horizontally far back into an elongated occipital lobe, which measures nearly half of the brain. In the squirrel monkey (Fig. 6) almost half the hemisphere lies behind the splenium. In this large occipital lobe the calcarine sulcus terminates in a wide-shaped bifurcation (Fig. 6), and several other compensatory calcarine sulci are developed. The collateral runs forward on its ventral side, and from its dorsal runs up a parieto occipital sulcus close behind the intraparietal.

In the macacus we have the higher organisation of the old-world monkeys. The smell organs are well seen, but

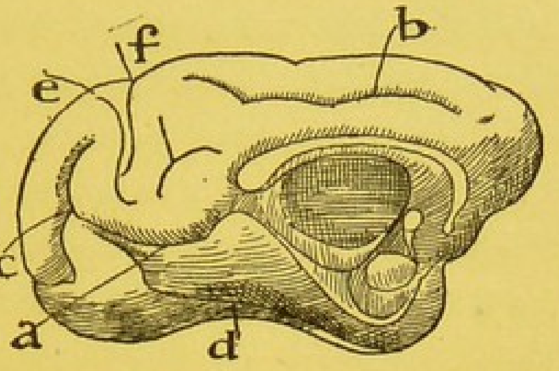

FIG. 6.—MEDIAL SURFACE OF BRAIN.

a—Calcarine Fissure. *b*—Intercalary. *c*—Retro-calcarine. *d*—Collateral. *e*—Parieto-occipital. *f*—Intraparietal.

diminishing. The long bifid retrocalcarine sulcus, the callosal and the parieto-occipital, with the intraparietal sulci, are well developed, and the general conformation of the brain, especially in the occipital lobe, closely resembles that seen in man.

THE VISUAL PATH IN MAN.

The optic chiasma has very important relations with the third ventricle and with the structures adjoining it ; and lesions involving this ventricle would be likely to cause visual symptoms.

The lamina cinerea, the very vascular "anterior perforated substance," and the tuber cinereum are in important relations with the optic chiasma, and bitemporal defects of the visual fields might be expected to arise from many directions. In some cases of primary optic atrophy

I have seen a narrowing of the nasal fields which I have taken to be due to some error in the anterior perforated space.

Acromegaly seems undoubtedly to depend on a diseased condition of the pituitary body, and the close relationship of the latter with the chiasma accounts for the early onset of bitemporal hemianopsia. Conditions of hemianopsia due to implication of the chiasma may, however, be very marked without any symptoms of acromegaly, and therefore presumably without implication of the pituitary body.

The fibres in the chiasma are "decussating," "direct," and "intercerebral." Special "interretinal" fibres probably do not exist. The "intercerebral" are not found in the optic nerve; they join together the two medial geniculate bodies as the commissure of Gudden, which can be separated from the optic chiasma, and are probably concerned with the sense of hearing.

In all vertebrata below mammals, and in some higher mammals, the optic nerve fibres are said all to decussate in the chiasma. In the higher mammals and in man the decussation is certainly incomplete. A portion of fibres pass direct from the temporal side of the retina to the same side of the brain.

The more perfect the degree of binocular vision the larger the bundle of direct fibres. In man the decussating fibres are about three-fifths of the whole, the other two-fifths pass directly from the temporal retina to the same side of the brain.

The chiasma is connected with the brain by the optic tracts. They wind round the cerebral peduncles, each dividing into a medial and lateral root.

The *medial* root is small; it contains the intercerebral fibres of the chiasma, and it ends in the medial geniculate body, the brachium inferius and the lower colliculus of the corpora quadrigemina—all these are concerned with hearing.

The fibres from the retina all run along the large *lateral* root of the optic tract. The right tract carries the direct fibres from the temporal side of the right retina, and the decussating fibres from the nasal side of the left retina; and the left tract takes the fibres from the left lateral sides of each retina. So that the fields of vision are represented by the tract on the opposite side of the brain, just as they are in the lower orders when all the fibres decussate.

It may reasonably be suggested that about 80 per cent. of the retinal fibres pass through the lateral geniculate body, the other 20 per cent. mostly go to the nucleus of the pulvinar of the optic thalamus. A few pass to the superior colliculus of the corpora quadrigemina; the connexion is made through the brachium superius which runs under the pulvinar; these fibres are afferent tracts for the pupil reflexes from the retina. The brachium also carries corticifugal fibres from the occipital lobes and the optic radiations, to the corpora quadrigemina and thence to the oculo-motor nerve centres. The geniculate fibres are directly associated with vision. Those that pass through the pulvinar (which is closely allied in structure and probably in function to the geniculate body) do not go with the others to the calcarine area. They pass independently to other centres, and have no doubt some special function connected with sight; some of them probably go to the neighbourhood of the angular gyrus. Degeneration of the pulvinar, if the geniculate bodies are intact, does not produce hemianopsia. The upper half of the external geniculate body seems to correspond with the upper quadrant of the retina.

The axis processes from the optic tracts and lateral geniculate bodies traverse the posterior end of the internal capsule at the junction of its superior and inferior laminæ behind the lenticular body, and then pass directly backward as the optic radiations towards the occipital lobe. They run along the outer wall, roof, and floor of the posterior horn of the lateral ventricle, and end in the nervous felt-work of the occipital cortex along the calcarine fissure. The occipito-thalamic radiations consist chiefly of "corticipetal fibres" for sight, but "corticifugal fibres" also pass along them through the superior brachium to the quadrigemina colliculus, and thence to the oculo-motor nerves. By Campbell these corticifugal fibres are thought to be the axones of Meynert giant cells in the occipital cortex.

If the visual region of the occipital cortex is removed on one side the lateral geniculate body of the same side undergoes atrophy, particularly in the cells. The pulvinar does not seem much altered. If the eyes are extirpated the tract undergoes atrophy in the grey matter between the cells, but the cells themselves are not affected. Lesions of the retina cause degeneration in the intercellular grey matter of the geniculate body, which is mainly composed of ramifications of the retinal fibres.

The visual path has its anterior neurons running from the retinal elements to arborise in the cells of the external geniculate bodies, and from them the posterior neurons run on to nerve cells in the occipital cortex in and around the calcarine fissure. It is therefore not the retinal fibres, but the fibres of the external geniculate body that are projected upon the occipital lobe.

Development.

In the third month the "hemisphere vesicle" becomes indented, forming three primary fissures, the choroidal, the Sylvian, and the hippocampal. The hippocampal begins near the frontal pole, and extends back until it bends outwards, downwards, forwards, and inwards, into the middle horn of the lateral ventricle forming the hippocampus; at its posterior part it gives off behind two branches the calcarine and the occipito-parietal, of which the latter is only temporary, while the former is permanent and produces the calcar avis. During the sixth month, among other secondary sulci the permanent occipito-parietal is formed; and also the collateral fissure, which is the only true secondary fissure and forms the eminentia collateralis.

The Visual Cortex.

The calcarine fissure, which in man commences a short distance behind and below the splenium, was first well described by Cunningham. It consists of an anterior part or "stem," the "true calcarine fissure," which protrudes into the posterior horn of the lateral ventricle as the "calcar avis." The fissure as it passes backwards appears to bifurcate into the posterior or "retrocalcarine" and the occipito-parietal fissures; really, however, the latter is separated by the annectant cuneal gyrus, and the former by the deep anterior annectant cuneo-lingual gyrus. The posterior calcarine itself also seems to bifurcate behind into an upper and lower vertical fissure, the "fissura extrema" or "terminalis," but it is really separated from them by the posterior annectant cuneo-lingual gyrus.

If sections are made through the cortex of the occipital lobe there is seen running across the calcarine fissures, and parallel to the grey matter which covers the surface of the lobe, a well-marked easily seen white line. The line is due to the presence of a special plexus of nerve fibre running in the cortex and traceable for a considerable distance within its deeper surface. This is known as the *line of Gennari*. Elliot Smith has most carefully described its distributions: it stops abruptly and can be readily traced, and the area over which it passes can be easily identified. It runs in the grey substance of the occipital lobe following the sulci and convolutions, and by means of its presence the area concerned in vision can be accurately mapped out. Though it appears as a line in sections of the brain, it is really, of course, a layer of special tissue, which forms part of the thickness of the cerebral grey matter, and lies half-way between the surface of the brain and the underlying white matter. At the retrocalcarine fissure it is seen to line the hollow and both sides of the sulcus, and it reaches upward on the cuneal gyrus, and downward on the lingual gyrus, as far as the two small sulci which run nearly parallel to the retrocalcarine, namely the "sulcus limitans superior" above, and the "sulcus limitans inferior" below; these meet together in the pole of the occipital lobe, and bound the area striata at that part. It is only prolonged a little to the posterior lateral surface of the hemisphere around the tip of the occipital lobe. Here it is strictly bounded by the sulcus lunatus which is itself free of the striate tissue. The area of cortex which it involves is called by Elliot Smith the "area striata." This is the "visuo-sensory" area of Bolton, Campbell, and others. The "primordial visual area" of Flechsig.

The structures concerned have been most carefully examined by Campbell, who finds that the special lamination included in the line of Gennari shows its largest dimensions at the forked termination of the posterior calcarine fissure which it surrounds, just reaching the pole of the occipital lobe, and as the length of one or other limb of the fork may be greater or less the extent of the striate tissue will also increase or diminish, not only in length, but in breadth and substance. It spreads forward, bounding the retro-calcarine above and below, involving the cuneo-lingual gyri at either end of that fissure. It spreads chiefly below, occupying the lingual gyrus, and it passes forward half-way along the lower border of the true calcarine fissure. Above it is well marked at the back of the cuneus, but anteriorly at the angle where the occipito-parietal sulcus leaves the calcarine it has gradually ceased to exist, and it is not found in the cuneal portion of the annectant gyrus at that part. The occipito-parietal sulcus is quite free of it, so is the gyrus fornicatus. There is no striate tissue along the upper margin of the calcarine proper. Both Campbell and Elliot Smith insist that it is only found along the lower margin. On the other hand, the retrocalcarine is extensively and completely surrounded by the stria Gennari both in man and the anthropoid apes, and this must be a very important part of the visual cortex area. Elliot Smith proposes to call it the medial intrastriate sulcus.

Visuo-Sensory Area.

On microscopic examination special arrangement of cell structure is found in the visuo-sensory area. The line of Gennari is seen to be composed of a dense network of fibres of fine calibre mingled with some larger fibres which run horizontally and obliquely. There is marked consolidation in the line of Gennari, below it a pale stained area, with the termination of the optic fibres. The external layers of large pyramids usual in the brain are replaced by a layer of curious large triangular or quadrilateral shaped stellate cells, which are practically distinctive of this region, and found chiefly along the calcarine fissure ; they have strong processes of considerable length, which pass horizontally, some of them run obliquely in the fibre plexus.

In the deeper parts of the calcarine cortex the internal layer of large pyramids is modified by the presence of a layer of pyramidal cells, the solitary cells of Meynert, another important distinctive feature of the calcarine cortex.

Visuo-Psychic Area.

Outside the visuo-sensory area is a border about 2 cm. in width—the visuo-psychic area. It covers the cuneus above, but not the occipito-parietal fissure nor the upper edge of the true calcarine, though it occupies its lower border almost in its whole length. It passes over the back part of the collateral fissure and round the occipital lobe, rejoining the cuneus above. The gyrus fornicatus does not seem to be a part of the substratum of vision.

The visuo-psychic region shows peculiarities in the histological structure ; fine fibres are numerous, but they are not collected together as in the line of Gennari, nor is there the pallid zone underlying it.

The external layer of large pyramids reappears, and none of the peculiar stellate cells remain; but, on the other hand, some of the pyramids are much enlarged into giant cells, with several roots below and one very long drawn-out process above. These cells are the most characteristic elements of the layer. The large cells of Meynert are not found. The very great number both of cells and of fine fibres in this area suggests a high degree of functional activity, and through it are probably transferred the impulses received from the parts around the calcarine to further districts in the brain in which the higher attributes of sight are located.

Dr. F. W. Mott, in his interesting Bowman Lecture on the progressive development of the visual cortex, shows how the width and complication in structure of the cortex gradually increases as we ascend the animal series and how the special cells become more necessary. Thus, in the hedgehog, in addition to polymorph and small stellate cells, are found occasional large pyramids. In the rabbit there is a line of Gennari, large stellate cells, and branching pyramids. Ungulates have a well-marked line of Gennari and numerous solitary cells of Meynert. In the cat there are numerous cells of Meynert, but the most striking feature is the depth of the pyramidal layer; these pyramids are also well developed in the cervical region of the cord, and Mott suggests that they lie along the volitional path of the executive faculty which is exercised through the fore limb and with the help of binocular vision. The depth of the pyramidal layer increases after birth. Dr. Mott considers that the progressive development of the pyramidal layer in the visual cortex of mammals is associated with an increase in the perfection of binocular vision.

Flechsig has shown by preparations of the fœtal brain how the development of different parts of the visual area takes place. He considers that as there are many degrees of functions, so the nerve fibres develop as they are required—the sensory found at birth, the motor found soon after birth, or as needed, and the associated, which gradually develop more and more.

Thus, at birth only a portion of the fibres in the optico-thalamic radiations have acquired their myelin investment. All those that have done so come from the lateral geniculate bodies, and they go direct to the calcarine fissure. Those fibres that come from the pulvinar appear to be medullated later in life and to pass outside the immediate limits of the calcarine area. Medullation of the fibres in the cortical areas occurs at different times.

Thus an infant very soon sees light, but does not show that it sees an object held in front of it for some weeks, while it takes him as many months to turn his eyes to follow an object held at his side, or to stretch out his hand to get it. It is obvious that the highly co-ordinated work that depends on sight is constantly needing the further development of new cells and of association fibres throughout life, and they are far more easily acquired in early life.

The visuo-sensory area along the calcarine fissure is the primary station in each hemisphere for the reception of impressions coming from the retina through the lateral geniculate bodies. Around it is the visuo-psychic area to which these impressions are transferred, this occupies the rest of the surface of the occipital lobe, its functions are to elaborate and to interpret. If part of the visuo-psychic area is primarily diseased, there is likely to be a partial hemianopsia complicated by slight peculiarities of vision more or less indefinite, some difficulty in memory of words, some form of letter, word, or mind blindness.

When the fibres that go to the temporal region are affected, there may be word deafness, or loss of power of the musical faculty, to recall names, or to read aloud. The psychic cells are associated with the psychic motor centre, where the impressions or information gained by sight are transferred for purposes of thought, speech, or action, and these are further connected with the emissive motor, by which speech and writing are affected ; the centres for these latter acts lie adjoining those for the simple movement of the lips and hand. The various parts of the visual cortex are connected by short association fibres almost infinite in their distributions.

Adjoining the occipital lobe and continuous with its lateral portion is the *angular gyrus*, which appears to be a higher visual centre of some importance, probably developed mainly in the left hemisphere. The angular gyrus might be readily associated with the primary visual areas by means of fibres running through the occipital lobe, or with the pulvinar or elsewhere by association fibres.

The central sulcus of each hemisphere separates the motor area (frontal) in front from the sensory area (parietal) behind. The intraparietal sulcus runs upward almost parallel behind the central (inferior and superior post-central) ; it then turns horizontally backwards parallel to the upper margin of the hemisphere, and terminates in the occipital lobe behind. It separates the post-central region of common sensation and the superior parieto-occipital gyri from the supramarginal and angular gyri ; these two latter are probably the centres for the recognition of higher, more elaborate forms of sensation and of sight and hearing.

In cases of visual hallucination the angular gyrus is perhaps usually but not always affected. The supramarginal may be the seat of mischief, or the posterior parietal lobule. A case in which a scar after injury over the region of the angular gyrus on the right side was associated with epileptiform attacks on the left side, which were preceded by an aura of bright red flashes of light and followed by visual hallucinations, Mr. Gould trephined over the region of the scar and cured the patient.

In a case of Macewen's, in which injury to the side of the head had produced melancholy and homicidal impulses, there was no damage to the outer part of the skull excepting a slight depression behind the angular process of the frontal, which seemed hardly to account for the symptoms ; no motor phenomena were present. It transpired that directly after the accident, and for some time afterwards, the patient had suffered from psychical blindness. The skull was trephined over the angular gyrus, and a portion of the lateral table was found pressing upon the posterior portion of the supramarginal convolution, a corner of it embedded in the brain. This was removed, with relief to his mental condition.

More distant regions are connected with visual areas by long association fibres, some of which are arranged in well-defined bundles.

The most important of these are :—

The perpendicular fasciculus connects the superior occipital and parietal gyri above with the inferior occipital and fusiform below and with the temporal.

The superior longitudinal fasciculus joins the frontal lobe with the occipital, parietal and temporal, and, Mott believes, through the large pyramidal cells of the visuo-psychic area.

The inferior longitudinal runs along the outer wall of the posterior and inferior horns of the lateral ventricle, and connects the occipital cortex with the temporal lobe: it probably associates sight with hearing, though the fibres may be for projection rather than for association, Many fibres connect the neighbourhood of the calcarine with the angular or marginal gyri, and interference with these fibres might produce typical abnormalities in sight and hearing.

The fasciculus occipito-frontalis runs below the corpus callosum external to the lateral ventricle, and connects the convex surface of the occipital lobe with many parts of the frontal. The *splenium* is the commissure of the occipital lobes, and connects one visual area with the opposite occipital cortex.

The occipito-thalamic radiation contains two sets of fibres. The centripetal run towards the occipital cortex to produce vision ; and centrifugal impulses are transferred by it from the cortex to the lower parts of the brain to assist the sight by causing movements of the eyes.

Visual reflexes.

The pupil reflex passes through the lower centres, corpora quadrigemina and third nerve ; it is quite unconscious and does not reach the cortex of the brain. But pupil movements are also controlled by impulses centrifugal from the visual cortex which pass through the brachium superius to the quadrigemina.

Many of the simpler and most constant movements that occur in association with sight are automatic, practically reflex, such as involuntary movements starting from the occipital lobes, as in blinking of the eyes, looking towards a sudden light, or to moving objects. Wide movements of the head and limbs are constantly necessary—such as in the avoidance of obstacles—and become visual reflexes of varying complexity. For them associated fibres run from the visual cortex to the motor centres from which the movements emanate; some of these tracts are in such constant co-operation that the associated movements become a part of compound reflex action gradually evolved by constant use.

Eye movements intimately associated with the most complex mental activities are many of them involuntary and unconscious; consciousness is alone concerned with the result affected—sleight of hand, billiards, etc.

The visual centres are undoubtedly reached by other afferent impulses than through the eyeball and retina alone. Pupil action and accommodation and muscle sense produced by movements of the eyes in any direction, or in convergence, cause simple impulses towards the brain. Visual judgments also largely depend on impressions from the sense of touch, and as almost every movement of the body is guided by sight, the associations around sight are very wide indeed.

When the sight is lost from defects in the eyeball or optic nerve, almost all other impulses from hearing, touch, muscle balance, etc., are effectual in stimulating a healthy visual cortex, and they become increased in influence to the help of faulty sight. But defect in the visual brain is a much more serious matter, and if the sensory area is damaged by disease, some part of the psychic area is likely to be affected with it.

We cannot overrate our obligations to Ferrier for his early experimental research work on the brain and for drawing attention to the importance of the angular gyrus and of the neighbourhood of the occipital lobe in visual processes, nor to Schäfer, Horsley, and others.

Bolton examined in serial sections the occipital lobe in five cases of old-standing blindness and in one case of anophthalmos. In all he found changes in the cortical area throughout the line of Gennari with marked atrophy of the fibres and of the cells, especially of the large stellate cells. The line was much diminished in thickness, but not absent (perhaps from the presence of fibres running from the occipital lobe through the splenium to the opposite side of the brain).

A very important paper published by Dr. Turnbull in *Brain*, 1904, on "Bilateral Loss of Post-central Cortex," described with great detail a case of bilateral cystic degeneration of the occipital lobes and of the neighbouring cortical areas on both sides of the brain, and the consequent absence or deterioration of the optic radiations and optic tracts with the structures associated with them in the sense of sight.

The patient died at 24 years of age, from severe burns, in the London Hospital, January, 1903, under Mr. Moullin. As a baby she was noticed not to follow anything with her eyes; she simply stared straight ahead with them. They were fine perfect working eyes, and did not squint. She was taken to Moorfields, and found to be quite blind. The notes then made were, unfortunately, not available after her death.

She was very peculiar and of uncertain temper. Her power of hearing, taste, and smell were very good. She could speak with a limited degree of intelligence. Her powers of locomotion and her common sensations were very imperfect. She never showed signs of seeing anything, never examined anything with her eyes, never watched objects moving about the room.

After death the brain was removed and most carefully investigated. About the posterior third of each hemisphere was found to form a cyst with thinned walls. The cavity included the pole posterior horn of the lateral ventricle and part of the middle horn. The cortex involved was that of the occipital lobes (excepting a small portion of the lingual lobule), the cuneus, and the angular gyrus. The proper structure of this wide area of the visual cortex and its surroundings was completely destroyed.

The posterior part of the corpus callosum was much reduced in size, and the splenium was represented by a mere cord.

(The splenium is the commissure for the occipital lobes, and sends into each a large mass of fibres known as the forceps major, while the tapetum spreads from it over the lateral ventricle. Déjerine had shown that fibres pass in the splenium from the posterior portion of the medial surface of the hemispheres, from the occipital pole, from the cuneus, and the lingual and fusiform convolutions ; and Ferrier also found that fibres pass from the lateral surfaces, the external occipital convolutions, and from the angular gyrus to the splenium.)

There was no trace of the fibres of the optic radiation, and the retrolentiform portion of the internal capsule from which they pass was extremely atrophied or almost absent. The optic chiasma in front was small and flattened out by pressure from the distended dropsical third ventricle.

The optic nerves and tracts were small. (The small middle root of the optic tract was present ; it passes to the medial geniculate body, and by the brachium inferius to the inferior colliculus of the corpora quadrigemina, and is concerned in hearing.)

The lateral root of the optic tract was very small, and the lateral geniculate body through which most of the fibres pass was very much atrophied; no fibres could be traced into it from the retina nor from the brain. The other 20 per cent. fibres of the lateral root were much better defined: they passed upwards to the pulvinar, and to the superior quadrigeminal body. The pulvinar was only very slightly deficient behind, otherwise the optic thalamus seemed well developed, as were also the quadrigeminal bodies, though somewhat compressed. (Though concerned in vision these parts are not directly associated with the visual area in conveying impulses for the primary sensation of sight.)

Evidence from Post-mortem Examinations.

A very large number of cases of varying types of hemianopsia have been investigated, but the deductions drawn between the faulty area of vision involved and the precise locality of the disease found in the occipital lobe after death are not by any means conclusive or uniform.

Many forms of pathological mischief have caused the changes in the brain tissues. Hemorrhage, gumma, tubercle, softening from embolism or thrombosis, abscess, tumour, etc.

The secondary area involved around the actual lesion is in many of them very wide and irregular, and even when thrombosis or embolism of the calcarine artery or its branches have taken place, the district affected is more or less wide in extent, and changes are produced, not only in parts of the visual cortex, but in the underlying fibres of the optic radiations and in the neighbouring tissues.

A lesion involving the occipito-thalamic radiation anywhere between the passage of the optic fibres from the retrolenticular portion of the internal capsule, or from the lateral geniculate body to the centres in the visual cortex, would produce a hemianopsia varying in degree and permanence according to the position of the fibres involved and the nature of the lesion.

Several cases have been published where the mischief has been limited to some part of the optic radiation, without implication of the cortex. The radiation fibres, without being the primary seat of lesion, may become affected from without, and a hemianopsia may result by their secondary implications where no part of the visual cortex or tracts is itself affected. *But in cases of uncomplicated hemianopsia some primary damage on the medial aspect of the occipital lobe in the neighbourhood of the calcarine fissure has usually been found.*

Sequin collected 40 cases of hemianopsia in which autopsies had been made, and 5 traumatic cases which showed circumscribed lesions in the occipital lobe, cuneus, and neighbourhood; all had hemianopsia, with other symptoms of various detail according to complications. He estimated that the visual cortex centre was on the medial aspect of the occipital lobe.

Dr. Merrell in 1884 published the case of a man aged 57. The fundi and optic discs were normal; central vision good, for his age; perfect reaction of the pupils. But there was hemianopsia of the left side, complete in the lower quadrants and in the periphery of the quadrants above. He was nervous and irritable, otherwise the definite defect was a weakness of memory for names. In 1886 he died, and there was found a well localized atrophy of the cerebral convolutions on the medial surface of the R, involving the lower half of the cuneus, bounded below by the calcarine fissure and in front by the occipito-parietal. The white matter underneath the damaged cortex was softened to a depth of about one-third of an inch. No other part of the brain or visual tract was found to be defective.

Henschen insists that the primary half-vision centre is along the lips and depth of the calcarine fissure, especially of its anterior two-thirds. He considers that the upper and lower quadrants in the visual field (lower and upper parts of the retina) are associated with the structures that occupy the ventral and dorsal areas respectively of the calcarine fissure. The dorsal part of the visual cortex, the cuneal lobe, and dorsal portions of the optic radiations are concerned with the lower quadrants of the field of vision, while the upper quadrants of the visual field are associated with the lingual and fusiform lobes, and the ventral boundary of the calcarine fissure and the optic radiations associated with them.

In a case of complete hemianopsia under his care there was found in the opposite occipital lobe softening produced by thrombosis. It was confined to the cortex along the calcarine fissure, lying deep in it, and giving rise to slight secondary degeneration of the optic fibres beneath.

Wilbrand states that the lower lip of the calcarine corresponds with the upper quadrants of the visual fields.

Hun's Case (*Amer. Jour. Med. Sci., January,* 1887).

A man, aged 57, was suddenly seized with slight cerebral symptoms. The fields of vision showed a complete left lower quadrant bilateral hemianopsia, the upper left quadrant being also slightly narrowed at the periphery, the charts of vision did not alter for nearly two years. . . . Then he died. There was found on the medial surface of the occipital lobe on the right side a localized atrophy involving the lower third of the cuneus, bounded below by the calcarine fissure, and in front by the parieto-occipital.

In other cases such definite division cannot be made out. A thoroughly reliable case of quadrantic hemianopsia was published by Drs. Beevor and Collier.

A patient, aged 55, was under their observation for nearly two years during which his illness lasted. Careful perimetric observations were repeatedly taken, and after death a most thorough examination and exhaustive report was made of the brain structures. His only general symptoms were numbing of the left hand and arm, severe recurring occipital headache and faulty eyesight, and at long intervals two or three fits. The optic discs were pallid, and there was some sclerosis of the retinal arteries.

His central vision was $\frac{6}{9}$ in either eye; he was completely blind in the upper left quadrant of both visual fields, with some general narrowing of the fields. For two months or so before he died his health failed rapidly and his sight got worse.

There was found occlusion of the right posterior calcarine artery, with destruction of the visual cortex involving the whole depth of the calcarine fissure, together with the right lingual lobe and the fusiform lobe below it.

The optic radiation was not involved in the necrosis. So far we should expect the defect that was actually found in the visual field.

But there was in addition damage to the lower third of the cuneal gyrus and the adjoining retrocalcarine fissure; this latter area, if Henschen's view is correct, should have caused defect in the lower quadrants of the visual field, which in this case were only slightly implicated. Mott, on examining the sections, found a patch of healthy striate cortex along the upper lip of the calcarine and in the adjoining surface of the cuneus which he thought accounted for the retention of vision in the lower fields.

Again, by far the greater part of the disease lay in and around the lingual lobe, but the defective field area is not confined to the upper quadrants; it shows definite narrowing of the lower fields as well. Besides, it would seem possible that the upper part of the cortical lesion came later in the disease, after the patient was too ill for further perimetric testing, and when possibly the lower quadrant of the field had become defective from the cuneal disease above. The cortex lining the calcarine fissure was necrotic, and yet the menianopsia was not complete. Can the calcarine, then, be looked upon as the primary half-vision centre? For there was not complete hemianopsia in this case. We must admit the importance of considering, not only the amount of mischief done in the cortex, but also the extent to which the radiation fibres are affected. For, as the author suggests, there may be considerable overlapping in the cortical supply of the various parts of the retina, and considerable power of compensation for local damage in the cortex limiting the lesion.

It seems to me probable that the centre for complete hemianopsia lies more anteriorly in the optic radiation near the calcarine proper, rather than in the post-calcarine, which was the sulcus here implicated, or else that the optic radiations must be involved when the hemianopsia is complete; and I suggest that the further forward towards the splenium the mischief is the greater the number of fibres likely to be involved and the wider the hemianopsia, while the more posterior the lesion the more numerous the subdivisions of the artery, and the more localized the area of faulty blood supply is likely to be and the smaller the defect in the field.

Many cases are not so well defined as these, but a quadrant defect more or less complete in the fields of vision is not infrequent. The defect may be only slight and partial, or it may approach towards a complete hemianopsia by implication of the adjoining vertical quadrant, or it may be irregular.

It must be admitted that the sense of sight is an extremely complicated physiological process, especially in man, while the lesions made by *pathological changes* are very rarely sufficiently localized to provide for a fine subdivision of physiological values of the different portions of the visual area. But we have ample data from *post-mortem* examinations to be certain on general lines that the visual field is primarily represented on the medial surface of the occipital lobe along the calcarine fissure. Moreover, it is proved that the area of cortex above or below the fissure respectively represents the lower and upper quadrants of the visual field.

In Foster's case of bilateral hemianopsia there was symmetrical damage of the medial surface of both occipital lobes, and fibres internal to and below the lateral ventricle, including the inferior longitudinal bundle, were found to be destroyed. The apex of the cuneus and hinder end of the calcarine towards the pole were left intact. In this case the central macular vision was maintained.

The most important means for localizing mischief to the sight is the use of the perimeter to ascertain the condition of the visual field and any defects that may be present in it. From the position of the defect in the fields may be deduced the locality of the visual area in the brain that is diseased, particularly in its relation to the calcarine and retro-calcarine sulci.

It is certain that hemianopsia may occur without being necessarily an early symptom of further brain trouble. I have seen a number of patients who with more or less defect in the visual fields have been able to do useful work apparently without discomfort, and who have remained without any other evidence of disease for many years.

The common cause in localized cases is, I expect, thrombus or embolism of some twig of the calcarine artery. The onset is usually sudden, the patient has slight brain disturbance for some days, and then recovers. The probably tiny obstructed area undergoes atrophy and causes the patient no discomfort except his loss of localized visual field.

But hemianopsia may be a part of a spreading lesion, the first symptom of a thrombosis which will lead to a progressive softening, or of a commencing tumour, which causes pressure upon some part of the visual cortex or radiations, or upon the optic tract. Increase in the size of the morbid growth will probably cause increased defect in the visual field, as well as more vascularization or swelling in the optic nerve.

Trephining, made safe by antiseptics, may be necessary in primary injuries, for fracture, abscesses, hemorrhage, and discharging cortical areas in epilepsy. Cysts may be relieved and old gummata removed. Cases of tumour will die if not interfered with, and though some may be malignant and too deep for removal, still others may be on the surface and more easy than might have been expected, while, on the other hand, necropsy may show that operation by decompression would have saved the patient or his sight.

For the study of the blood supply to the brain structures concerned in vision I would refer to the splendid work of Dr. Beevor, *Phil. Trans. Roy. Soc. Lond.*, 1908.

A simple summary may here be given. The optic chiasma and nerves are supplied by the posterior communicating and the anterior cerebral arteries. The anterior choroidal artery, which ends in the choroidal plexus of the lateral ventricle, supplies the optic tract, the posterior portion of the internal capsule, especially its retrolenticular fibres, and the origin of the optic radiations. The chief artery for supply, however, is the posterior cerebral; it assists in forming the choroidal plexus, it supplies the corpora geniculata, the corpora quadrigemina, the pulvinar, the fornix and the splenium, with the anterior portion of the optic radiations, though not quite up to their origin.

The medial surface of the occipital lobe is entirely supplied by the posterior cerebral, which terminates in two branches, the occipito-parietal and the calcarine; they go to the lingual and cuneate gyri, the fusiform and gyrus quadratus, the pole of the occipital lobe and other parts of the visual cortex. The outer surface of the occipital lobe with the angular and supramarginal gyri are supplied by the middle cerebral. There is a very free anastomosis between these vessels, so that a faulty circulation due to embolism of one artery should be readily restored by means of the other.

The posterior part of the radiations are supplied according to their proximity to the cerebral cortex, the dorsal and outer layers by the middle cerebral artery, the inner and ventral layers by the posterior cerebral.

This Lecture, with a very few emendations, is printed as it was written for delivery; but I cannot reproduce here most of the diagrams that I used.

BIBLIOGRAPHY.

Elliot Smith, *Catalogue Roy. Coll. Surgeons, Museum,* "Physiology," vol. ii., 1902; *The Occipital Region: Studies in the Morphology of the Human Brain,* Cairo, 1904; *Journ. of Anat. and Phys.*; *Trans. Linn. Soc.*, etc.; *Anat. Anzeiger*, xxiv. 16.

Campbell, "Localization of Cerebral Function," *Proc. Roy. Soc.*, lxxii.

Henschen, *Centre cortical de la vision.*

Bolton, "Histological Localization of Visual Area in Human Cerebral Cortex," *Phil. Trans.*, 1900.

Beevor and Collier, "A Contribution to the Study of the Cortical Localization of Vision," *Brain*, 1904.

Wilfrid Harris, "Binocular and Stereoscopic Vision," *Brain*, 1904.

Mickle, *Journ. Med. Soc.*, 1881–2.

Mott, *Trans. Oph. Soc.*, vol. xxv.

Swanzy, *Trans. Oph. Soc.*, vol. ix.

Turnbull, *Brain*, 1904.

Sequin, *Journ. Nerv. and Ment.*, 1886.

Parsons, Arris and Gale Lectures, 1904.

Beevor, "Distribution of Arteries supplying the Human Brain," *Phil. Trans. Roy. Soc. Lond.*, 1902.

Lindsay Johnson, *Proc. Zool. Soc.*, 1897.

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