# NEW STUDIES ON THE FOLDING OF THE VISUAL CORTEX AND THE SIGNIFICANCE OF THE OCCIPITAL SULCI IN THE HUMAN BRAIN.

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This is an abstract of one section of a communication dealing with the mode of folding of the visual cortex in the Primates, read before the Anatomical Society of Great Britain and Ireland in Belfast on 1st June 1906. The other subjects considered in that communication—(*a*) the arrangement of the area striata in the Apes, Lemurs, and other Mammalia; (*b*) the asymmetry of the occipital region of the cerebrum in Man and its effect upon the cranium; and (*c*) the variations in the occipital sulci—are being published elsewhere as separate papers.

This work is a sequel to that published in the *Records of the Egyptian Government School of Medicine* (1) two years ago.

If a coronal section be made through the occipital region (about 1 centimetre behind the fossa parieto-occipitalis) of a *perfectly fresh* human cerebral hemisphere—preferably the *left* hemisphere of a man (or woman) between the ages of thirty or forty years, examined within six hours after death—one can recognise (in most cases) with the unaided eye no less than eight strips of cortex each of which differs from the areas adjoining it in texture, coloration, the nature and mode of distribution of the intracortical matter, and, in some cases, also in thickness. If the brain be anæmic or that of a child or youth, it is impossible to recognise many of the distinctive features of the various regions. But in most cases the contrasts that are apparent to the naked eye in fresh sections of the brain of a non-anæmic adult are much more pronounced than those exhibited in sections stained by such a selective method as that of Weigert; and the process of mapping out the areas is simpler and gives much more exactly defined boundaries than can be obtained by the laborious reconstruction from serial sections stained by Nissl's method. Not only are the contrasts in the naked-eye method greater, but for other reasons the advantages of this procedure *for a purely topographical survey* are immeasurably greater than those of the alternative methods. In the process of mapping out any given area one can deal with a large piece of brain, and by making incisions with a scalpel at right angles to its borders can trace its edge

exactly, however irregular its outline may be, while still retaining intact the actual tissue of the region to be mapped; whereas by other methods not only must the area be cut up into sections, but in many of the slices the cortex will be cut so obliquely that it becomes impossible to determine the exact spot where the change in structure takes place. Much more important than this is the consideration that, by means of the macroscopic examination of fresh material, it is possible to obtain results (at least as accurate, if not more so) from at least two hundred specimens in the same time that it takes to examine one by the histological method. In this field of investigation this is a factor of the utmost importance, because there is such a wide range of variability that conclusions drawn from the study of one or even a dozen specimens, however complete the examination may have been, are liable to mislead. The process of folding of such a plastic material as the cerebral cortex does not always occur with mathematical precision along definite lines or in reference to fixed anatomical landmarks, so that it is often necessary to examine a very large number of specimens before we are able to determine the causal relationship between a furrow and the distribution of a cortical area.

The accompanying diagram (fig. 1) of a coronal section through the occipital region is intended to represent the causal relationship that exists between a large series of sulci and the distribution of various localised cortical areas: it is based upon the examination of nearly two hundred hemispheres. Although it is rare to find in one specimen every furrow exhibiting such a definite relationship to the edges or the axes of the various areas as this diagram exhibits, such cases do occur. This drawing in fact represents an actual section, and is diagrammatic only in the mode of representation of the texture of the cortical areas. It is quite common for the edge of an area, such as is represented in the diagram, stopping exactly in the floor of a sulcus, to cross the bottom of the furrow into the other wall for a few millimetres, or in other cases to stop before it reaches the floor. But when we consider how plastic a material the cerebral cortex is and how complex are the factors that exert an influence on it during its expansion, the wonder is, not that the coincidence of a sulcus and the boundary line between two areas should not be mathematically exact in every case, but that it should ever occur; and especially that this exact relationship should be found so often.

In these notes I shall not discuss the variations in the arrangement of sulci and the different modes in which the cortex may be packed in different brains. I shall devote a special memoir to the discussion of these matters: but in passing I may remark that the range of variation in the human occipital region is extraordinarily wide. At present I am simply

concerned with the consideration of the anatomical localisation of three cortical areas in the occipital region and the causal relationship of their distribution to a large series of sulci.

In this section (fig. 1) not only are both walls of the sulcus calcarinus (the posterior calcarine fissure of Cunningham—the sulcus retrocalcarinus (*mihi*), defined as the "sulcus intrastriatus mesialis," (5)) formed entirely of area striata (*i.e.* cortex containing the stria of Gennari—the line of

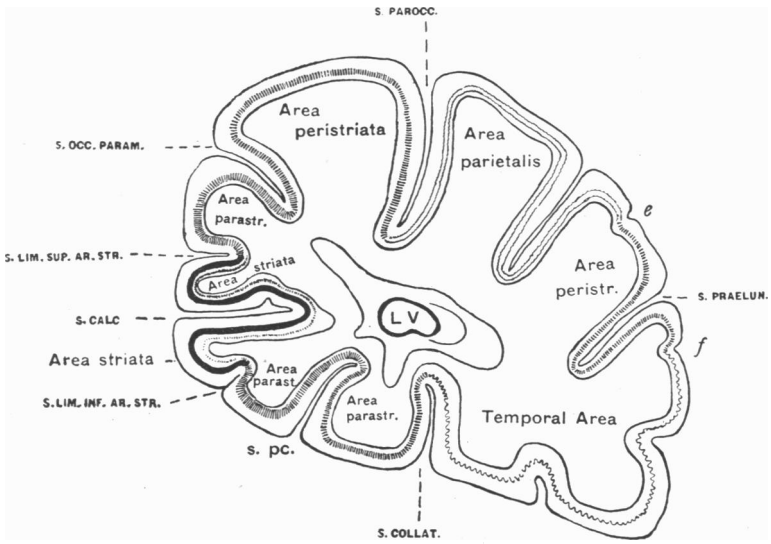


FIG. 1.—A diagram to represent the distribution of the different cortical areas in a coronal section through the left hemisphere of an Egyptian man one centimetre behind the fossa parieto-occipitalis.

*L. V.*, posterior cornu of lateral ventricle; *s. calc.*, posterior calcarine sulcus; *s. lim. sup. ar. str.*, sulcus cunei (s. limitans superior areæ striatæ); *s. lim. inf. ar. str.*, sulcus lingualis (sulcus limitans inferior areæ striatæ); *s. pc.*, sulcus paracollateralis; *s. parocc.*, sulcus paroccipitalis (sulcus intraparietalis); *s. prælun.*, sulcus occipitalis lateralis of Eberstaller (s. prælunatus); *e* and *f*, sulci limitantes areæ peristriatæ.

Vicq d'Azyr), but part of the cuneus above it (see also fig. 2) and part of the lingual convolution below it are also formed of area striata. The dorsal boundary of the area striata in the cuneus is the furrow (figs. 1 and 2, *s. lim. sup. ar. str.*), which Retzius (2, p. 137) has called "sulcus sagittalis inferior cunei," a term which might with advantage be shortened to sulcus cunei. It is one of the two furrows which Wilder (6, p. 189) has called "intracuneal." In a previous memoir (5), I have defined this furrow as the "sulcus limitans superior areæ striatæ."

The ventral boundary of the area striata in the lingual gyrus is the

furrow (figs. 1 and 2, *s. lim. inf. ar. str.*) which Retzius has distinguished by the name "sulcus sagittalis gyri lingualis." In shortening this name to "sulcus lingualis," I shall at the same time define it as the sulcus limitans inferior areæ striatæ. In the lingual gyrus there may be two sulci or only one: in the latter case the furrow may be a sulcus limitans areæ striatæ or a sulcus limitans inferior areæ parastriatæ (fig. 1, *s. pc.*, and fig. 2, *s. paracollateralis*). Retzius's term does not distinguish between

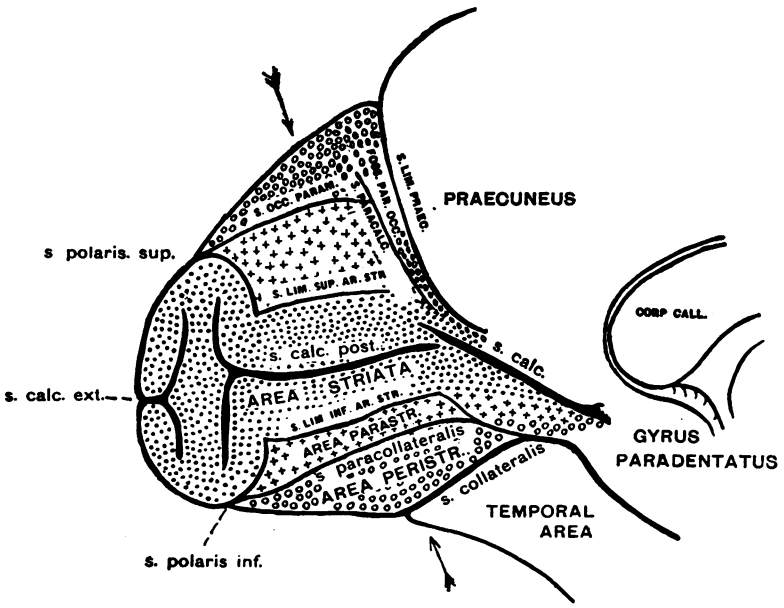


FIG. 2.—Diagram to illustrate the distribution of the cortical areas on the mesial surface of the occipital region of the left hemisphere.

The two arrows indicate the plane of the section shown in fig. 1. The area striata is represented by dots; the area parastriata by crosses; the area peristriata by circles.

these two furrows. In introducing the term "sulcus lingualis," I wish to give it more precision by applying it definitely to the former sulcus, and shall call the latter "sulcus paracollateralis."

If the sulci cunei et lingualis be traced backward, it will be found that in many cases (fig. 2) these furrows each join a semicircular sulcus, which Bolton has called "polar" (7, p. 171). Adopting this term, I shall distinguish these furrows as the sulci polaris superior et inferior respectively. The distinction between the cuneal and the polar furrows is one which is peculiarly characteristic of the occipital region. The polar sulci belong to the same type as the sulci lunatus, occipitalis inferior, and sometimes the

parieto-occipital fossa; the area striata extends as far as the lip of all these furrows without entering into the formation of their walls; in the case of the cuneal and lingual sulci the area striata extends into the furrow and stops in its floor (fig. 1). The former type of sulcus may be succinctly defined as "operculatus" and the latter as a "sulcus limitans." The sulcus calcarinus posterior belongs to yet a third group—axial furrows, formed by the infolding of one cortical area (fig. 1).

The area striata usually extends on to the lateral surface of the hemisphere and is folded axially to form the sulcus calcarinus externus of Cunningham (fig. 3, *s. calc.*), which I have defined in an earlier memoir

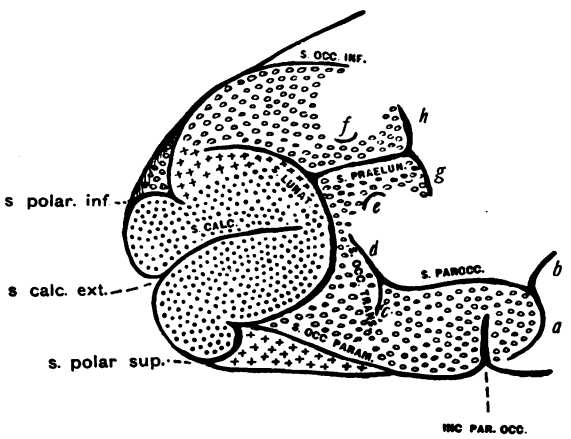


FIG. 3.—Diagram representing a dorso-lateral view of the occipital region of the same hemisphere.

(5) as the sulcus intrastriatus lateralis. In my earlier memoirs I have called this furrow by various other names—"sulcus occipitalis lateralis" and "sulcus occipitalis superior," which I now definitely discard in favour of Cunningham's term, "external calcarine," which so happily suggests the exact analogy between this sulcus on the lateral surface (fig. 3, *s. calc.*) and the posterior calcarine on the mesial surface (fig. 2, *s. calc. post.*). The accessory intrastriate sulci, which often surround the external calcarine sulcus, have been omitted from this diagram (fig. 3) because they are of no morphological importance. When it happens that the V-shaped accessory intrastriate sulcus, that is often present surrounding the external calcarine, parallel to, *i.e.* concentric with, the sulcus lunatus, is placed around the edge of the area striata, the coincidence is fortuitous and has no causal relationship; for in most cases where such a V-shaped sulcus is present the

area striata extends beyond it and ceases either exactly at or close to the caudal lip of the sulcus lunatus (fig. 3).

The true sulcus calcarinus (fig. 2, *s. calc.*)—the stem or anterior calcarine fissure of Cunningham—is a sulcus præstriatus, *i.e.* a sulcus limitans anterior areæ striatæ in *most* human brains. In other words, the area striata forms its caudal (ventral) wall only and stops in the floor of the sulcus. When the gyrus cunei is reached, the area striata crosses the floor of the furrow and extends exactly as far as the crest of the small gyrus: as the latter rises to the surface of the cuneus the edge of the area striata

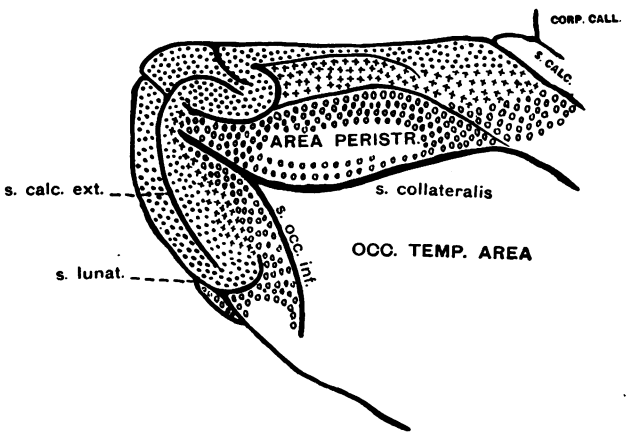


FIG. 4.—Tentorial aspect of the same.

continues to maintain this same relationship. It occasionally happens that the area striata extends to the caudal lip of the fossa parieto-occipitalis in the whole of this furrow's extent. In such cases the parieto-occipital fossa falls into the class of "sulci operculati," whereas in most instances it is a complex furrow of the class of "sulci limitantes."

## THE AREA PARASTRIATA AND ITS LIMITING SULCI.

At the bottom of the sulci cunei et lingualis the cortex containing the stria Gennari comes to an abrupt end (fig. 1) and gives place to a cortical strip presenting very different features, which I shall distinguish as the "area parastriata." Neither Bolton nor Campbell has drawn any distinction between this area and that which I shall next describe under the name "area peristriata": the two regions are included by them in the "psycho-visual area" of Bolton.

Brodmann (9), however, clearly distinguishes these two areas on the mesial surface of the hemisphere of a *Cercopithecus*: but I cannot harmonise his map of the lateral distribution of these areas with my own results. The area parastriata is represented by Brodmann's "occipitaltypus" (typus 18), the histological features of which he has defined on page 190 of his memoir (9) and represented in Tafel 9. He refers to a description of this area in the human brain by Oskar Vogt (*Journal f. Psychologie und Neurologie*, Bd. ii., Taf. 10, fig. 2), which is not accessible to me.

In sections of the fresh human brain this cortical area is distinguished by the absence of any definite line of Baillarger, but the inner half of the cortex is characterised by a diffuse paleness which merges into the general medullary mass of the hemisphere with only a very faintly marked and quite indefinite layer of grey matter intervening between them.

It is limited above by the sulcus paramesialis (figs. 1 and 2, *s. occ. parum.*). This is the sulcus sagittalis superior cunei of Retzius (2, p. 137), but I retain my own term because it is more appropriate. The sulcus in question is often not in the cuneus but on the dorsal surface of the hemisphere. It may be defined as the sulcus limitans superior areæ parastriatæ.

There is sometimes a sulcus limitans inferior areæ parastriatæ in the gyrus lingualis, which I shall call "sulcus paracollateralis" (fig. 1, *s. pc.*, and fig. 2).

Posteriorly the area parastriata is often buried in the polar sulci and laterally in the sulcus lunatus—although a small part of it may be exposed near the edge of this furrow (fig. 3).

Anteriorly the edge of the area parastriata is buried in the fossa parieto-occipitalis, and the most caudal of the three furrows in this fossa—the sulcus paracalcarinus of my earlier memoirs—becomes the sulcus limitans anterior areæ parastriatæ (fig. 2).

## The Area Peristriata and the Furrows related to it.

Beyond the ring of parastriate area the diffuse paleness of the inner half of the cortex gives place to a definite band of Baillarger not quite so narrow or dense as the stria of Gennari but almost as distinct. Unlike the condition seen in the parastriate cortex, there is a definite band of grey matter separating the intracortical white band from the general medulla in this region, which I shall call "area peristriata." It seems to be identical with the region which Brodmann calls "præoccipitaltypus" (typus 19) in the brain of *Cercopithecus* (9, p. 191).

It is impossible to recognise from Campbell's account of the locality

from which his sample of "visuo-psychic" cortex was obtained whether it was para- or peri-striate, because "a section of the superior occipital gyrus, midway between the top of the parieto-occipital fissure and the posterior extremity of the hemisphere" (8, p. 312), or "2 cm. anterior to the tip of the lobe" (p. 310), are quite inadequate as topographical directions, when it is recalled that the area striata may stop at the "tip of the lobe" or extend as much as 4 cm. beyond it. The histological features of his visuo-psychic area (plate xi., fig. 2) seem to resemble most those of my parastriate area.

On the mesial surface of the hemisphere the area peristriata occupies the floor of the fossa parieto-occipitalis, and extends as far as the anterior sulcus buried in that depression, which I have called sulcus limitans "præcunei." So that this furrow might also be defined as the sulcus limitans anterior areæ peristriatæ (fig. 2).

When the paramesial sulcus is found on the mesial surface (fig. 2, *s. occ. param.*), a strip of peristriate cortex occupies the upper part of that surface, as well as the dorsal edge of the hemisphere. Thence it extends as far outward as that portion of the intraparietal sulcus of Turner which Wilder has called "paroccipital." As this is a natural subdivision of the large composite sulcus—intraparietal—and is genetically distinct from the remainder, it is convenient to use Wilder's term. The paroccipital may be defined as the "sulcus limitans dorsalis areæ peristriatæ"; whereas the rest of the intraparietal is the limiting sulcus separating the two parietal lobules.

It is interesting to observe that whereas the main stem (fig. 3, *s. parocc.*) and its mesial cephalic (fig. 3, *a*) and lateral caudal (*d*) branches are essential parts of the limiting furrow, the lateral cephalic (*b*) and the mesial caudal (*c*) branches are morphologically unimportant furrows, being apparently mere kinks resulting from the mechanical conditions incidental to the bending of the cortex at these points. Like the mesial part (*c*) of the transverse occipital furrow (*s. occ. trans.*), the incisura parieto-occipitalis is also merely an indentation in the area peristriata, probably due to the mere mechanical inbending of the floor of the fossa parieto-occipitalis between its two limiting sulci.

A considerable part of the area peristriata is often hidden under cover of the operculated caudal lip of the sulcus lunatus, but a process always stretches out toward the auditory centre (but without reaching it), and this usually becomes folded longitudinally to form an axial sulcus, which in former memoirs I have called the sulcus prælunatus (fig. 3, *s. prælun.*). This furrow usually ends anteriorly in a T-shaped piece (fig. 3, *g* and *h*), the vertical part of which forms an anterior limiting sulcus of the area peristriata. Small additional limiting furrows (fig. 3, *e* and *f*) are often

found at the margins of the peristriate area. I have elsewhere (1, plate A, figs. 2 and 3) published photographs of a brain almost exactly similar to that represented in the diagram (fig. 3). The ventral limit of the peristriate cortex on the lateral side is the sulcus occipitalis inferior (fig. 3, *s. occ. inf.*), just as the sulcus collateralis forms its inferior boundary mesially (figs. 2 and 4).

As there may in some cases be doubt as to the identity of the collateral sulcus (see on this subject Zuckerkandl, 3), I may state that the sulcus limitans inferior areæ peristriatæ mesialis is precisely that part of the furrow which indents the ventricular wall to form the eminentia collateralis.

At the bottom of the paroccipital sulcus the area peristriata becomes continuous with the great parietal association area of Flechsig (fig. 1), and on the tentorial surface in the floor of the collateral sulcus it becomes continuous with the temporal (or temporo-occipital) association area. Stretching forward so as to separate the caudal ends of these two areas, we find the process of peristriate cortex which becomes folded to form the prelunate sulcus. There can be little doubt that this patch of cortex is identical with the "area 12" of Flechsig, which he calls the "gyrus subangularis" (10).

Nor can there be any question that the sulcus prælunatus is anything else than Eberstaller's "sulcus occipitalis lateralis." The latter term has been applied to various other totally distinct furrows. Zuckerkandl has justly criticised my error of confusing this furrow and the sulcus lunatus (4, p. 237), yet in the same memoir (4, fig. 7, p. 228) he himself has labelled the lower part of the sulcus lunatus "S. occipitalis lateralis"; and in other memoirs he has applied the latter term to the sulcus occipitalis inferior in the apes (11, fig. 11, p. 47). To these two undoubted mistakes there is yet a third error in identification to be mentioned. I was misled by a statement made by Retzius (2, p. 136) into the belief that Cunningham regarded his external calcarine and Eberstaller's lateral occipital sulci as identical, and used the latter term for the external calcarine in my part of the Catalogue of the Brains in the Museum of the Royal College of Surgeons. I now recognise (as I have stated in previous publications) that I was quite unjustified in this belief.

As there can be no question that the sulcus that I have called "prælunatus" is identical with Eberstaller's "occipitalis lateralis," the former term may be discarded.

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