these centres, "responsive" movements. Ferrier accepted this distinction and suggested three groups of reactive functions: the kentro-kinetic or excito-motor function of the spinal cord; the æsthetico-kinetic function of the mid-brain and cerebellum; and the noetico-kinetic function of the cerebral hemispheres. In this way, he endeavors to avoid the use of the term sensation in connection with the complicated movements of the midbrain, defining the æsthetico-kinetic reaction as one unaccompanied by consciousness. The various investigations of this initial period of physiological experimentation tended, when the results were analyzed and judiciously interpreted, to restrict all conscious functioning to the cortex of the cerebral hemispheres.

Flourens' researches had been indeed epoch-making, so far as they concerned the establishment of the specific capacities of the portions of the nervous system below the cerebral hemispheres. So thoroughgoing were his methods, so painstaking his researches, and so full of insight his conclusions, that the doctrine of the equivalence of all portions of the cerebral hemispheres long held sway, even against sound pathological evidence, and according to Ferrier became in consequence answerable for many erroneous notions in cerebral physiology and pathology. Schiff went so far in advocacy of Flourens' conclusions that he set aside the testimony of pathologists, which made for the specificity of parts of the cerebral hemispheres, as the opinions of "mere practical physicians." Those who localized specific areas over the cerebral convolutions were also often slightingly referred to as phrenologists.

And yet sound pathological evidence had steadily been accumulating which pointed to this specialization of cerebral function. Bouillaud, in 1825, from experiments on animals and from the facts of clinical research, was led to maintain that lesion of the anterior lobes was more particularly responsible for loss of speech, and that special motor centres are situated in the cerebrum, the destruction of which is responsible for paralysis. Limited lesions of the cerebral hemispheres, he reports, give rise to limited paralysis which would not be the case if the cerebral hemispheres did not contain a multiplicity of differentiated centres for the conduction of motor impulses. With prophetic insight he remarks: "I am well aware that the preceding propositions appear at variance with the results of experiments upon animals. It is certain that after ablation of the cerebral hemispheres an animal may walk, run, move its jaws, eyes, eyelids, etc.; and it is not less certain that an alteration of the cerebral hemisphere in man gives rise to paralysis, more or less complete, of voluntary motion on the opposite side of the body. Can we refute the one set of facts by the other? No, certainly not, for facts equally positive are not susceptible of refutation. A time will come when new light will dispel the apparent contradiction which exists between them."

The credit of having first indicated the motor function of certain regions of the cortex, and of giving a rational explanation of the phenomena of unilateral cerebral convulsions, belongs to Hughlings Jackson. Experimental physiology had apparently demonstrated that neither electricity nor any other customary stimulus of nerves and nerve centres was capable of exciting movement when applied directly to the surface of the brain. It was, therefore, inferred that centres below the cerebral hemispheres were alone capable of initiating movements, and that the cerebral convolutions exercised restrictedly a psychical function. Against this view, Jackson contended that the cortex did not transmit an "influence" to some distant motor region, but was itself motor and capable of motor discharge by irritation.

A much more dramatic discovery added force to the arguments of those who opposed the finality of the conclusions of the experimental physiologists. This was a contribution to the pathology of the cerebral hemispheres presented by Broca in 1861 and followed by corroborative evidence presented in a second contribution in 1865. In these clinico-pathological observations, Broca demonstrated that the cause of the disorder of speech known as aphasia, which had previously been symptomatically investigated by Lordat as early as 1820, Bouillaud (1825), Jackson (1829), Dax (1836), and others, was a lesion of the posterior third of the inferior frontal convolution. Analysis of the two cases first reported by Broca showed the lesion to be in the left cerebral hemisphere, which he at first regarded as accidental. Reports of similar cases by Voissan (1862), Broca (1864), and Seguin (1867), who had collected two hundred and seventy-two cases of right hemiplegia with aphasia, led to the conclusion that the speech centre was located in the inferior frontal convolution of the left hemisphere only. Broca himself, an anthropologist of note, offered, as an explanation, the fact that the great majority of humanity are right-handed, in consequence of which the left hemisphere contains the centres for the exquisitely coordinated movements which subserve speech, as well as those for the finer adjustments of movements executed by the more motile hand. Bastian (1869) was the first to recognize the relationship of defective auditory perception to speech production. Ogle (1871) distinguished aphasia from agraphia. Broadbent first pointed out in 1872 the condition which is known as "word-blindness." The investigations of Wernicke, which began in 1874, furnished the basis for the conception of sensory aphasia, and for the recognition of three varieties of aphasia: visual, auditory, and motor. He showed that a lesion of the first temporal convolution produced auditory aphasia, and maintained that the most typical aphasia can occur with lesion of other parts of the brain than Broca's convolution. Contributions of importance, leading on to a better understanding of aphasia, were made by Trousseau and Hughlings Jackson. Finally, Kussmaul, in 1877, in the article on Aphasia in "Ziemssen's Encyclopedia," introduced the terms "word-deafness" and "word-blindness," and fixed the concept of aphasia in a form which it retained substantially until the time of Déjerine.

About this time Fritsch and Hitzig, in 1870, changed entirely the attitude of experimental physiologists by their discovery that the application of the galvanic current to the cerebral surface of the brain of dogs gave rise to movements on the opposite side of the body. The result of these investigations was to show that certain portions of the convexity of the cerebrum are motor, while other portions are non-motor. The original experiments located five motor areas in the cerebrum of the dog: a centre for the muscles of the neck in the middle of the prefrontal gyrus at the place where its surface falls off steep; a centre for the extensor and adductor of the fore limb at the outermost end of the postfrontal gyrus in the region near the end of the frontal fissure; a centre for the bending and rotation of the same limb a little farther back; a centre for the hind limb in the postfrontal gyrus, but toward the median line of the hemisphere and back of the preceding two centres; and a facial centre in the middle part of the gyrus lying above the fissure of Sylvius (see Fig. 892). Points lying between these, when stimulated, produced contractions of the muscles of the back, tail, and abdomen, but circumscribed areas for these muscles could not be ascertained. The motor areas lie, therefore, to the front and the non-motor areas behind. By using weak currents, the movements are localized to definite groups of muscles of the opposite side of the body, while stronger currents ap-

FIG. 892.—Cortical Areas in the Dog. (After Fritsch and Hitzig.) Δ, Muscles of the neck; ⸸, extension and adduction of the fore-limb; +, flexion and rotation of fore-limb, #, hind-limb; O˙, facial area.

plied to the same or closely adjoining areas stimulate other muscles or even muscles of the same side. When the left cortical centre for the fore limb was excised, there followed a clumsiness of the right fore limb, the right foot (but never the left) easily slipping. Although no movement was quite destroyed, the right foot was adducted somewhat weakly and was often planted on the back instead of on the sole. Sensibility of the skin was not noticeably changed. These and later experiments substantiated the conclusion of the investigators that certain motor functions, probably all, are to be assigned to circumscribed areas of the cortex.

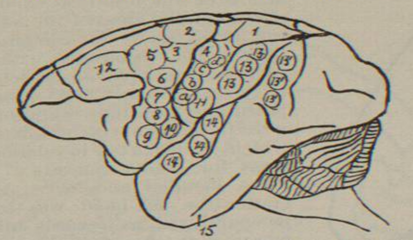

FIG. 893.—Cortical Areas in Monkey. (Ferrier.) 1. Forward movement of leg; 2, the same, and toward middle line of body; 3, the same, with movement of the tail; 4, retraction and adduction of arm; 5, extension of arm; *a*, *b*, *c*, *d*, movements of fingers; 6, flexion and supination of arm; 7, lifting and retraction of angle of mouth; lifting of upper and sinking of lower lip; 9, opening of mouth, with protruding of tongue; 10, the same, with retraction of tongue; 11, retraction of angle of mouth and turning of head away from stimulated side; 12, opening of eyes, dilatation of pupils, head and eyes turned away from stimulated side; 13, turning eyes away from stimulated side and down; 13′, the same, and up; 14, the same, and same movement of head, expansion of pupils, pricking of opposite ear; 15, lifting of lips and corner of nostril on stimulated side.

Ferrier, in 1873, and later in 1876 reported the discovery of numerous centres of electrical irritation on the cerebral hemispheres of the monkey. These were found, as reference to Fig. 893 will show, to lie close together about the Rolandic fissure in the central convolutions. Even after it had become generally accepted that the effect of these weak currents was not due to the conduction of the electrical stimulus to lower motor areas, but was the effect of the direct stimulation of gray matter in the cortex, which was thus proved to exercise a determining influence over the pathways of motor conduction, it still remained a matter of doubt as to the degree to which the specialized functions of muscle groups may be localized in the cerebral cortex. Some experimenters claim that minute areas, at first excitable, after a time cease to be so. Others report that a displacement of the excitable points may take place. Exner distinguishes between absolute and relative motor fields, the former being those wherein lesions are always followed by impaired motion, the latter being such as sometimes give rise to impaired motion and sometimes not. Panneth found that a number of minute areas or spots could be detected as lying in a larger excitable zone.

Although the investigations of Fritsch and Hitzig demonstrated the connection of the Rolandic convolutions with voluntary movements, the interpretation of their functioning remained uncertain for some time. Even at the present day, it is possible to find charts of the distribution of functions over the cerebral hemispheres, based upon the erroneous interpretation of Hitzig's results. Ferrier was above all others responsible for drawing a sharp line of demarcation between the purely motor centres and the sensory centres. According to this view the Rolandic convolutions are centres for the emission of motor stimuli only, their excitation perhaps giving rise to no consciousness whatever. The so-called motor areas are supposed to receive directly no afferent sensory stimuli, but to be physiologically stimulated from other portions of the cortex. Ferrier accordingly located tactile sensibility in the limbic lobe, particularly in the hippocampal convolution. He denied that such sensibility was interfered with by ablation of parts of the motor convolutions. A better understanding is chiefly due to Munk, though in second degree to the labors of Goltz and to the criticisms of Bastian.

Munk made a much more extensive series of extirpations of areas in the brains of dogs and monkeys than previous investigators had done. These led him to the conclusion that the occipital lobes are connected with the sense of sight, the temporal lobes with that of hearing. On removal of the area A_1 (Fig. 894) in a dog's brain on both sides, and examining the animal some days after the operation, he observed a peculiar disturbance of the sense of sight, without injury to any other sensory or motor function. The dog moves with perfect freedom without striking any obstacle, and when such are put around him, he eludes them by crawling under or jumping over them. But the sight of dogs or men, whom he had before greeted joyfully, now leaves him perfectly cold. However hunger and thirst may cause him to move about, he no longer seeks the accustomed place for his food, and will even pass it by as long as he does not smell it. A light held to his eye no longer causes him to blink, nor does the sight of the whip, which formerly drove him into the corner, produce any effect upon him. He had been trained to give his paw when a hand was held out, now he will not give it unless ordered to. "By the extirpation, the dog has become psychically blind, *i.e.*, he has lost the sight-presentations which he possessed, his memory pictures of former sight perceptions, so that he neither knows nor recognizes anything he sees." But the dog does see, and gradually forms a new store of sight memories. Munk further states that no matter how long the dog is kept alive, he never regains any of his former sight-memories, except by renewal of the experience. Complete removal of both sight areas, he asserts, causes total and permanent "cortical blindness"; if only one side be destroyed, hemiopia results.

In the same manner extirpation of a limited area in each temporal lobe produced what Munk calls "psychic deafness," a condition much like the so-called "word-deafness" in the human subject. The dog hears perfectly, but no longer understands words to which he had before been trained. Gradually, however, the dog learns how to hear. In the so-called motor zone the results are no less striking. In opposition to his predecessors, Munk maintains that the motor disturbances are always accompanied by sensory disturbances, which consist in the loss of the most complex feelings, the sense of position, of pressure, muscular sense, etc. He concludes that the paralysis is the result of the loss of motor

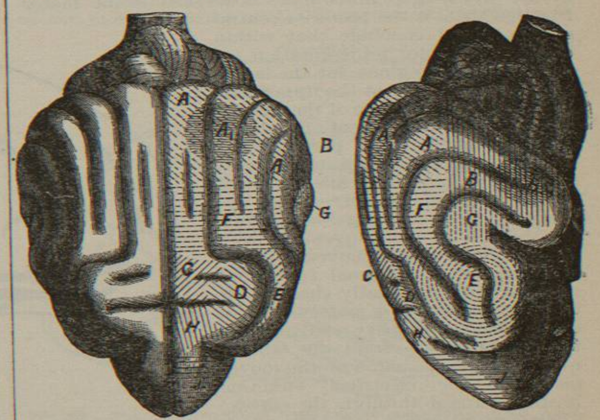

FIG. 894.—Cortical Areas in the Dog. (After Munk.) AA, sight area; B, hearing; C, feeling of hind limb; D, of fore limb; E, of the head; F, of protecting apparatus of eye; G, of the ear; H, of the neck; J, of the trunk.

memories, and calls the motor zone the "area of feeling." Within this area (Fig. 894) are seven subareas, those for the fore and hind limbs, head, eyes, ears, neck, and body. The rapidity of restitution of function, when one of these areas is removed, depends upon the extent of the lesion; if it is all removed the defect is a permanent one. In the monkey's brain Munk obtained essentially the same results.

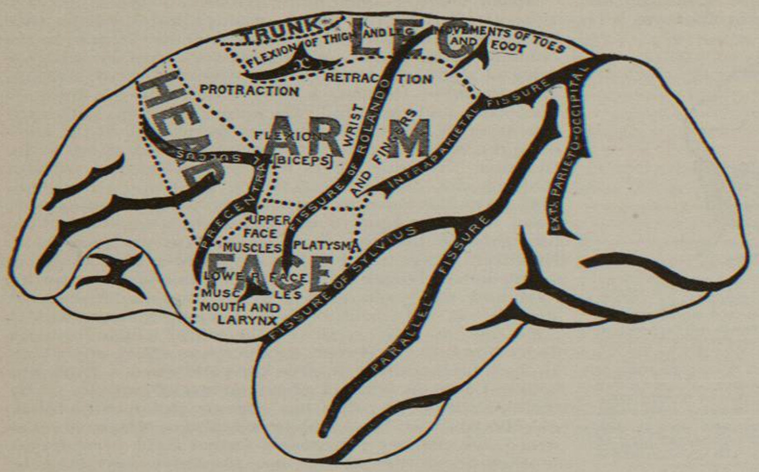

FIG. 895.—The Distribution of Motor Areas Over the External Surface of the Cerebral Hemispheres of the Monkey's Brain. (After Horsley and Schäfer, from Barker.)

A summary of the results of Beevor, Horsley, and Schäfer (1887–1894) will serve best to indicate the present status of knowledge as to the exact representation of different movements over the Rolandic convolutions of the monkey and orangoutang, which stand nearest to man in biological relationship. The anterior central gyrus, they find, is much more concerned in the motor function than is the posterior central gyrus. They conclude that within the area of motor representation for the limbs, the regions for the larger joints are generally at the upper part of the area, while those of the smaller joints and more differentiated movements are at the lower part. Movements of extension are represented in the upper part, while those of flexion are in the lower. There appeared to be no absolute line separating the area of one movement from that of another, each movement having a centre of maximal functional representation gradually shading off into the surrounding cortex. They distinguished a primary result of electrical stimulation from the subsequent epileptoid march of the movements as the electrical stimulus became diffused through the cortex. Their general scheme of motor representation is diagrammatically summarized in Figs. 895 and 896. The results from ablations of areas of the cortex were quite in accord with their findings by the physiological method. Suggestive is the report that muscular movements of each individual segment are much more fully represented in the cortex of the ourang than in that of the monkey. It seems a general law that the higher the animal the more definite is the area of representation not only of individual segments, but of individual movements belonging to one segment. This would suggest a still more specific motor representation in the human brain.

The subdivisions of the motor area in man have been ascertained from a large number of carefully reported cases and autopsies, and from the electrical excitation of circumscribed areas of the cortex during its exposure for cerebral operations. The exactness with which such localizations can be determined is remarkable. In 1888 Keen extirpated the focal representation of the wrist in the right cerebral hemisphere which he had fixed in relation to the areas for the movements of the elbows, shoulder, and face. After operation the left hand was found to be paralyzed as regards all movements of the fingers and wrist. The elbow was weak, but the shoulder and face were entirely unaffected.

The distribution of specific motor areas over the cortex of the human cerebrum is presented in Figs. 897 and 898. The following summary is based upon those of Mills and Gordinier, omitting details which in some cases are still doubtful. As shown in the diagrams, the specific leg area occupies the upper third of the two Rolandic convolutions, the arm area the middle third, and the face area the lower third. The trunk muscles are represented on the median surface of these two convolutions, the paracentral lobule. The leg area extends over the posterior part of the paracentral lobule and the upper anterior part of the superior parietal lobule; it occupies a greater antero-posterior surface than does the area of the arm or face. The movements of the thigh, knee, leg, foot, and toes are ranged in order from the front backward. The arm area is subdivided from above downward into centres for the movement of the shoulder, elbow, hand, and fingers. The movements of the shoulder are also represented in the anterior part of the paracentral lobule. The subdivisions of the face area contain from above downward the movements of the orbicularis palpebrarum and oc-

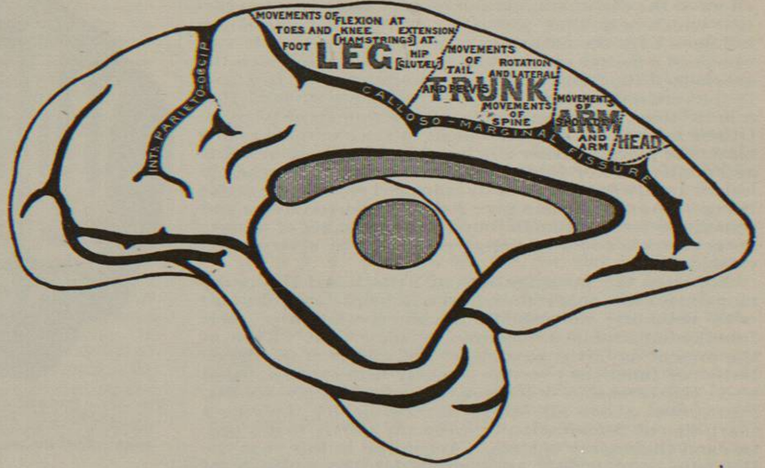

FIG. 896.—The Distribution of Motor Areas Over the Median Surface of the Cerebral Hemispheres of the Monkey's Brain. (After Horsley and Schäfer, from Barker.)

cipito-frontalis, the mouth, lips, tongue, pharynx, and larynx. The platysmal movements, according to Mills, are probably represented in the posterior part, and the larynx and pharynx in the anterior part. Movements of the head and eyes are probably represented in the posterior part of the first and second convolutions adjacent to the ascending frontal and on the median surface of the first frontal convolution. Those movements of the body which are always bilaterally innervated appear to have bilateral representation, so that an injury of one hemisphere, *e.g.*, of the laryngeal centre, fails to produce paralysis. Those movements, on the other hand, which may take place on one side of the body only, are represented in the assigned area of the opposite hemisphere only.

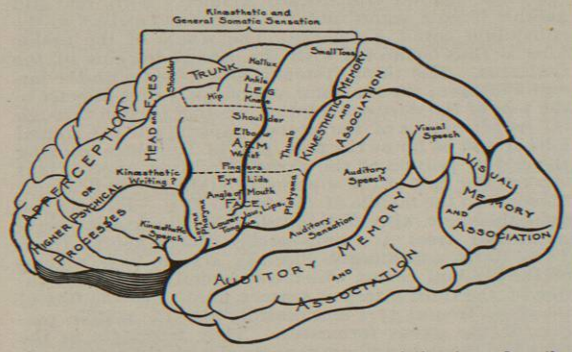

FIG. 897.—The Distribution of Sensory and Association Areas Over the External Surface of the Cerebral Hemispheres. The diagram shows: 1, The area of kinæsthetic and general somatic sensation, occupying the central convolutions and portions of adjacent convolutions. (This is usually called the motor area. It is both an emissive or motor and a receptive or sensory area. The localization of the subdivided sensorimotor areas is indicated in the diagram.) 2, the area of auditory sensation, occupying the middle portion of the superior convolution and adjacent portions of the transverse convolutions of the temporal lobe; 3, the area of association of the first order, occupying the occipital lobe, the second and third temporal convolutions, a portion of the superior temporal convolution, the insula, and the posterior parietal convolutions; 4, the area of association of the second order, or the zone of language, occupying the angular gyrus, the upper portion of the superior temporal convolution, the posterior third of the inferior frontal convolution (restricted to a single hemisphere, most frequently the left); 5, the area of association of the third order, the area of apperception, occupying the prefrontal regions of the frontal lobes.

To Munk, in the opinion of the writer, belongs the credit of offering a satisfactory interpretation of the relation between the motor and sensory functions of the cortex and between psychical disturbance and the loss of simple sensation. From this point on, I shall merely summarize the views of different authorities with respect to various cortical functions, considering first in order the sensory areas, and next the areas of higher psychical activity. The excitable motor area is a "feeling sphere," according to Munk, because it receives afferent stimulations which excite the cortical cells to give rise to sensations and ideas of bodily movement. Cortical stimulation, otherwise than through the afferent tracts, may awaken memories or ideas of such movements. Fritsch and Hitzig had indeed referred to the Rolandic convolutions as the area of the muscular sense. For a long time, however, sensations of the muscle sense were understood to be due to the efferent stimulus of the cells in that region. This notion gave rise to the theory of an "innervation feeling" or "sense," a theory which Wundt did not entirely give up until the appearance of the third edition of the "Physiologische Psychologie" in 1887. It is now accepted that the activity of purely motor cells of efferent conduction in the Rolandic region (probably the large pyramidal cells) is unaccompanied by consciousness; that sensations or feelings of bodily movement are primarily due to the activity of sensory cells of the same region which receive stimulation from the sensory conduction paths comprising the median fillet and posterior columns of the cord. Bastian made the valuable proposition to call these areas "kinæsthetic" areas or areas of "kinæsthetic sensation." Goltz's results were in many ways contradictory of both Munk's and Ferrier's, but this contradiction is to a great extent limited to details, and in the main his work is confirmatory of the trend of the results as indicated in this paper. Although he contended that it is not possible permanently to paralyze any muscle, he distinguishes between fine and coarse adaptations, and shows that although a dog's paw is not paralyzed as an organ of locomotion by the destruction of the cortex, it yet remains permanently paralyzed for all those actions in which it is employed as a hand.

The testimony of experimental physiologists, including in addition to those mentioned above Luciani, Horsley, and Mott, points unequivocally to the so-called motor area and immediately adjacent convolutions as the centre of kinæsthetic sensation and of touch, pressure, heat, cold, and pain sensation as well. For this reason the convolutions of motor function are designated in Figs. 897 and 898 as areas of kinæsthetic and general somatic sensation. Confirmatory are also the pathological findings of Gowers, Westphal, Seguin, Dana, and Starr. Dana's twenty-five cases, four of his own with twenty-one others, all prove that lesions of the central convolution are attended by partial or complete loss of tactile, temperature, pain, and muscular senses in the limbs of the opposite side of the body. Starr, after thirty cases of cerebral operations consisting of excisions of parts of the motor area, thinks that it is clearly determined that the tactile centres are situated in the Rolandic area, especially in the postcentral gyrus. Redlich, from an analysis of twenty cases of lesions confined to the parietal lobe, states positively that these lobes are the centres for muscle sense. Nothnagel, Luciani, Seppelli, and Flechsig long ago asserted that the parietal lobes were concerned in the reception of muscle sense impressions and possibly of the other forms of general sensation. Many pathologists whose opinions justly carry great weight are opponents of the view here represented. Among these, Mills is most worthy of mention as still contending for the restrictedly motorial function of the excitable areas of the Rolandic convolution and for a distinct representation of cutaneous and muscular sensations in the adjacent postero-parietal convolutions, precuneus and gyrus fornicatus. In support of this view

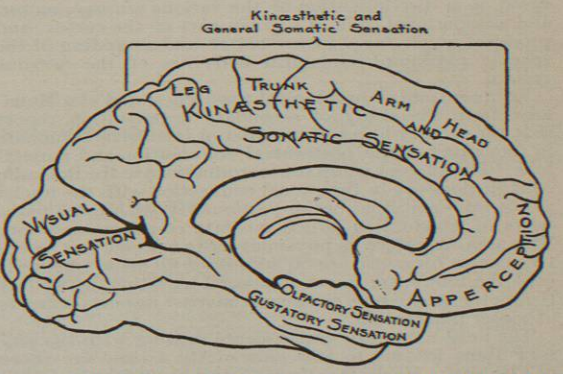

FIG. 898.—The Distribution of Sensory and Association Areas Over the Median Surface of the Cerebral Hemispheres. The diagram presents: 1, The area of kinæsthetic and general somatic sensation, occupying portions of the parietal and frontal lobes; 2, the areas of visual sensation in the convolutions adjacent to the calcarine fissure; 3, the areas of olfactory and gustatory sensation in the uncinate gyrus and adjacent cortex; 4, the area of association of the third order, or area of apperception, in the prefrontal convolutions of the frontal lobes. The portions of the parietal and temporal lobes to which no special function is assigned in the diagram are association areas of the first order.

he maintains that innumerable cases have been reported of lesions of the motor cortex without impairment of sensibility. He also cites his own experience with that of others which shows that surgical excision of the Rolandic cortex is not necessarily followed by any sensory impairment.

The results of histological investigation of the structural elements of the cortex in the main confirm the view that the functions of the Rolandic cortex are only in part motor. At least four layers of the cortex are distinguished—a superficial layer rich in small cells and tangential fibres, a layer of small and a layer of large pyramidal cells, and a deeper layer of polygonal cells which are supposed to give rise to short and long associational neuraxones. Only the pyramidal cells, perhaps only the very large pyramidal cells, are supposed to give rise to the projection neuraxones of efferent or cortico-fugal conduction—*i.e.*, those fibres which pass in groups functionally related through the internal capsule to the crura cerebri, to terminate about the motor cells of the cranial nerves of the same, but chiefly of the opposite side, or to continue on through the pyramids and, a portion crossed and a portion uncrossed, to terminate about the motor cells in the anterior horn of the cord, partly on the same and partly on the opposite side. The path of these projection neurones has been made out by the stimulation methods of Beevor and Horsley, Burdon Sanderson, Franck, and Pitres, and by the studies of resultant degeneration, first initiated by Türck in 1851, and subsequently extended by Bouchard, Charcot, Pierret, Nothnagel, von Monakow, Marchi, Hoche. The excision of limited areas of the motor cortex gives rise to secondary degenerations also; these have been studied by von Gudden, von Monakow, Franck, Pitres, Moueli, Marchi, Algeri, Muratoff, Mellus and Langley, and Sherrington. The true motor cells are so situated that they may be stimulated to activity by the constituent cells of the proximate cortex, by associational and commissural neuraxones from remote parts of the cortex, or by the neuraxones of afferent conduction which terminate, perhaps, in all four layers of the cortex. Cajal has presented a scheme of intercortical relation, and has constructed an elaborate theory of the neuronal mechanism of association, ideation, and attention. Problematic as this scheme remains, it indicates a new line of speculation as to cerebral functions, based on a discrimination of the various sensory, motor, and associational cells of a given part of the cortex, and promises much for a future better understanding of the specific psycho-physiological activities of the nervous system.

Edinger from embryological researches, and von Monakow from the study of secondary degeneration, report that the sensory fibres of the fillet or lemniscus terminate in the cortex of the postcentral convolution and parietal lobe. The afferent neuraxone terminations in the Rolandic convolutions are in functional connection with the nuclei of the mid- and hind-brain, particularly with those pathways of conduction which mediate common sensation. This area, therefore, is physiologically a sensory or receptive centre for cortico-petal stimuli of all sense tracts except the four sense tracts of special sensation, as well as the motor or emissive centre of the most important tracts of motor innervation.

The most extensive experiments dealing with the sensory fibres leading to this part of the cortex are those of Flechsig. He divides these cortico-petal fibres—which pass together through the internal capsule and which are the indirect continuations of the dorsal roots of the cerebral and spinal nerves—into three groups or systems, distinguished by the fact that they put on their myelin sheath at different periods. The first group becomes medullated at the beginning of the ninth fœtal month. It occupies the posterior part of the internal capsule and, in its upper half, the area immediately behind the fibres of the pyramidal tract. These fibres are distributed exclusively to the cortex of the two central gyri, which are thus the first regions of the cortex to become connected by means of medullated fibres with the sensory apparatus of the body (see Figs. 900 and 901). The second group receives its myelin about a month later than the first group. These fibres are distributed to the central gyri, the lobulus paracentralis, and the foot of the superior frontal gyrus. Another portion is distributed to the gyrus fornicatus along its whole length. The posterior bundles run toward Ammon's horn, and still another bundle enters into the uncus and arrives at the subiculum cornu Ammonis. The whole of the limbic lobe is thus connected with the lateral nucleus of the thalamus. The third system is also joined with the lateral nucleus of the thalamus and one part runs directly to the foot of the third convolution, another portion through the pars frontalis of the internal capsule into the frontal lobe almost as far as the pole, part of the fibres reaching the middle portion of the gyrus fornicatus, another part the anterior half of the superior frontal gyri, while single fibres go to the middle of the frontal gyri. Edinger and von Monakow also distinguish from the cortico-fugal pyramidal tract a fronto-cerebro-cortico-pontal tract. These fibres, according to Flechsig, arise in those regions of the cerebral cortex which correspond to the distribution of the third group of sensory fibres, *i.e.*, the feet of the three frontal gyri and possibly also the middle portion of the gyrus fornicatus. They terminate in the nuclei of the pons and are concerned with the movements of bilaterally innervated muscles, such as those of the eyes, neck, and trunk. The motor impulses concerned in the speech movements may also, he believes, be carried by these fibres, though according to Barker there is a good deal of evidence that the speech path is separate and distinct.

Results indicating the cortical localization of the area of vision have from the first been consistent in prescribing its limits to the occipital lobes and adjacent parieto-temporal convolutions. The location within these limits has been differently assigned; thus Hitzig to gyri in the posterior lobes of the dog, while Ferrier has persistently contended for the angular gyrus. Munk's careful and critical investigations prepared the way for an understanding of the relation of the different parts of the visual area. He distinguished between psychical blindness and the simple loss of vision proper, and found different areas giving rise to these diverse conditions. He interpreted the area of simple or primary vision to be the cortical projection field of the retina, whereas adjacent areas added those memory images which made visual impressions intelligible. Despite conflicting evidence, it is fairly well established that the primary visual areas of the cerebral hemispheres are situated in the neighborhood of the cuneus, and that the calcarine fissure bears about the same relation to visual stimulation as the Rolandic fissure does to somæsthetic stimuli. This statement refers, however, only to retinal stimulations, which constitute in reality only a very small part of those sensory stimuli which are essential for the maintenance of complete vision. Henschen proposes for this area the name of calcarine retina, and suggests, from an examination of clinico-pathological evidence, that the upper lip of the calcarine fissure of one hemisphere is the projection field of the lower quadrants of the visual fields of the homonymous halves of both retinæ, and that the lower lip has a corresponding connection with the upper visual fields. Henschen also assigned the cortical representation of the central portion of the retina to the anterior part of the calcarine fissure and of the peripheral portions of the retina to the posterior part. The macula seems from many results to have a separate and distinct representation and to be represented for each eye in both cortices, whereas the symmetrical halves of each retina are represented in the hemisphere of the same side only.

Cajal has shown that the fibres of the macula retained their individuality as far as the basal ganglia. It is denied, however, by von Monakow and others, that there is a distinct cortical area for the macula. He believes that it is represented in perhaps all portions of the occipital lobe constituting the visual area, even in the posterior part of the angular gyrus Examination of the results

of pathological findings indicates the possibility of much individual variation both at the centres and along the conduction pathways. There can be little doubt that the cuneus (see Fig. 898, page 305) is the cortical centre of primary visual sensation, and that regions which ontogenically acquire the associational capacity of complex visual perception involving the visual memories of past experience, spread out over the convex surface of the occipital lobes and perhaps to adjacent lobes, certainly to the angular gyrus (see Fig. 897). Kinæsthetic stimuli from the muscles of the eyes are important elements in visual perception; whether these are conducted to the visual area also does not appear; it is probable, however, that sensations of eye movements are associated in this area with the light sensations due to retinal stimulation. This conclusion seems the more necessary since, according to Rámon y Cajal, Engleman, von Monakow, von Gehuchten, Kölliker, and Held, the centrifugal fibres start in the axis-cylinder processes of the pyramidal cells of the cortex and arborize in the superficial gray matter of the anterior corpora quadrigemina. Proccesses from these ganglia terminate in the nervous feltwork of the retina and are in functional connection with the motor nuclei of the ocular and other nerves supplying the facial muscles. The connection of the cortex with these subcortical ganglia suggests that the oculomotor functions of the occipital lobe are exercised centrifugally via the optic radiation, as maintained by Munk and Sherrington (see Fig. 899). Thus through these centrifugal neurones the retina, the ocular reflexes, and facial instinctive movements may be under the influence of the occipital cortex. Of the basal nuclei, *i.e.*, thalamus, external geniculate body, anterior corpora quadrigemina, connected with the visual function, the external geniculate body alone seems to be in direct relation to retinal stimuli. Lesion of this ganglion inevitably causes hemianopsia, and its destruction is followed by atrophy of the inferior portion of the bundle of Gratiolet. The pulvinar of the thalamus, on the other hand, may atrophy without producing hemianopsia if the geniculate body be intact. Lesion of the pulvinar and anterior corpora quadrigemina may, nevertheless, produce important modifications of vision. These ganglia appear to be centres of visual reflexes, such as winking, avoiding of obstacles, etc., the retinal reflex of contraction of the pupils to light, and perhaps even of acquired visual reflexes, such as the flight from a whip, etc. The expression of the emotions of involuntary origin appears to have its origin in the thalamus. The loss of the emotional involuntary reflex, at all events, may follow upon a lesion of this subcortical ganglion.

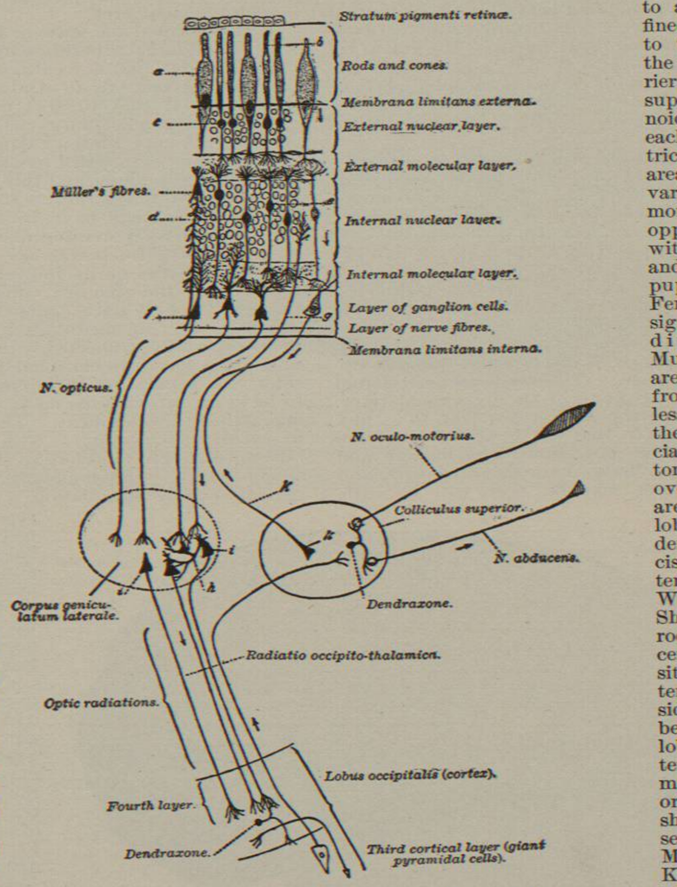

FIG. 899.—Diagram of the Visual Conduction Paths. (After von Monakow, from Barker.) *a*, *b*, *c*, Rods and cones of the retina; *d*, *e*, bipolar cells; *f*, large multipolar ganglion cells, giving rise to axones of the optic nerve; *g*, centrifugal axone of a neurone, the cell body of which is situated in the anterior corpora quarigemina (colliculus superior), its terminal dendritic processes being situated in the retina; *h*, Golgi cell of type *II*, in the lateral geniculate body; *i*, neurone connecting the lateral geniculate body with the occipital lobe, its axone running in the optic radiation of Gratiolet. The centripetal and centrifugal courses of the visual impulses are indicated by the arrows.

As in the case of cortical visual representation, the localization of the sense of audition has been restricted by almost all observers to a region of well-defined limits, in this case to the convolutions of the temporal lobe. Ferrier's results point to the superior temporo-sphenoidal convolution on each side, because electrical excitation of this area on either side invariably produced in the monkey retraction of the opposite ear associated with opening of the eyes and dilatation of the pupils; these movements Ferrier regarded as a significant index of auditory perception. Munk distinguished an area of greater intensity from adjacent regions of less intensity, both in the temporal lobes. Luciani considers the auditory sphere to extend over the whole cortical area of the temporal lobe. Pathological evidence has with equal decisiveness pointed to the temporal lobe. Bastian, Wernicke, Friedländer, Shaw, and Mills leave no room for doubt that the centres for hearing are situated in the superior temporal gyrus of each side. Each ear seems to be represented in both lobes, as both superior temporal gyri in man must be destroyed in order that total deafness shall ensue. The researches of Flechsig, von Monakow, Held, von Kölliker, Rámon y Cajal, and Florence Sabin have shown the anatomical relations of the cochlear branch of the auditory nerve, which alone is concerned in hearing, with the various basal nuclei, the chief of which are the trapezoid nucleus, the superior olive, the posterior corpora quadrigemina, the median geniculate nucleus, and the nucleus lemnisci lateralis. The fibre tracts connecting these various nuclei furnish an anatomical basis for more than one pathway of partial decussation. These fibres are also connected with the anterior corpora quadrigemina and with the motor nuclei of the cranial nerves, thus constituting a basal organ for automatic movements of the head, and perhaps of the trunk, in response to auditory stimulation. It is not deemed advisable to present the several parts of the complicated pathway of afferent conduction, as these have been made out by various investigators. It will suffice to mention that the collected fibres from these various nuclei pass as the lateral fillet, according to Flechsig in two separate bundles, to the internal capsule, and go transversely through the same in two separate bundles to the transverse gyri of the temporal lobe. The one bundle ascends near the external capsule and arrives from behind and above into the auditory sense area. The other runs for some distance along with the occipito-thalamic radiations, and passes around the fossa Sylvii from behind and below into the temporal lobe itself, close by the second and third temporal gyri, to reach the transverse temporal gyrus. The exact extent of the sense region, according to Flechsig, corresponds to the two transverse gyri of the temporal lobe, particularly the anterior and that portion of the superior temporal immediately adjacent (see Figs. 900 and 901, on pages 308 and 309).

The giant pyramidal cells, which are believed to give origin to the cortico-fugal projection tracts, seem to be absent in this region. Flechsig nevertheless maintains that the temporo-cortico-cerebro-pontal path begins here. The axones of this bundle of fibres, usually but mistakenly called Türck's bundle, pass down, through the anterior portion of the occipital part of the internal capsule, to the lateral region of the base of the cerebral peduncles; thence they go into the pons, terminating perhaps in the nuclei of that region. Flechsig is inclined to think that this temporal path represents a mode of connection, by way of the brachium pontis, of one cerebral with the opposite cerebellar hemisphere. The fibres are medullated at a later period than the fibres of the pyramidal tract; Von Monakow and Déjerine also report on this tract Déjerine believes, however, that the bundle arises from the whole temporal lobe, but chiefly the median and inferior convolutions. Whatever the origin, course, and termination of this tract may be, there can be little doubt as to its existence. The evidence seems to point to the middle part of the superior temporal convolution as the primary cortical auditory area (see Fig. 897, page 305), while the areas for more complex auditory perceptions are located in the upper part of the second and third convolutions toward the angular gyrus, and perhaps extend downward over the fourth and fifth temporal convolutions also, a region in which Mills places a centre for the hearing of words—the so-called "naming" or "idea" centre.

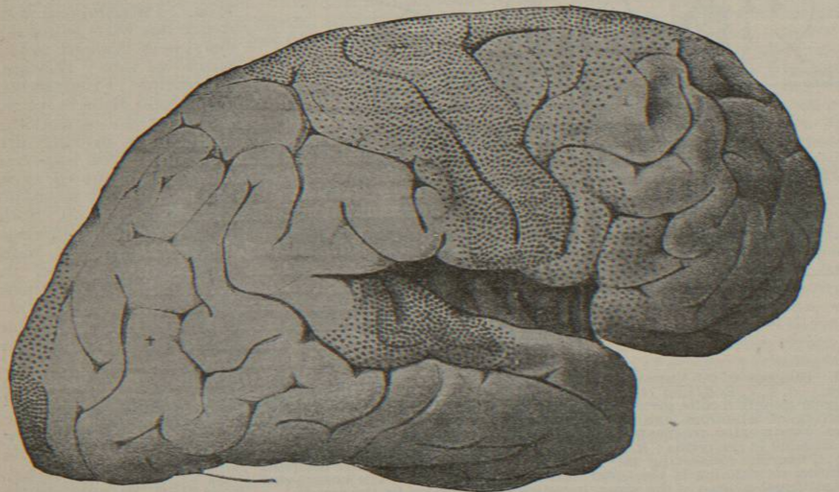

FIG. 900.—The Sense Areas and Association Areas on the External Surface of the Right Cerebral Hemisphere. (From Flechsig.) The closely dotted areas about the central fissure, on the middle part of the superior temporal convolution, and in the posterior part of the occipital lobe, indicate respectively the primary areas of general somatic sensation, of auditory and of visual sensation. The regions not marked with the dots are: 1, The posterior association areas in the parietal, occipital, and temporal lobes; 2, the middle association area in the insula; 3, the anterior association area in the frontal lobe. As the thickly dotted regions shade off into the unmarked regions, so the primary sense areas are continued into adjacent portions of the association areas, presenting a gradual transition from the simpler to the more complex functions.

The vestibular branch of the auditory nerve is connected with nuclei which are in anatomical relation with the cerebellum and with the median fillet; thus stimuli from this branch may pass to the somæsthetic area of the cerebral hemispheres.

Ferrier located the sense of taste and smell in the subiculum and in neighboring portions of the lower temporal convolution. Munk localized smell in the gyrus hippocampus. According to Andriezen, the cortical regions which receive the olfactory projection fibres are (1) the region of the genu of the gyrus fornicatus; (2) the septum lucidum; (3) the inferior extremities of the hippocampal and uncinate gyri. Hill looks upon the fornix as one of the conduction paths, and this is certainly in accord with the relation of that structure to the terminal cortical areas just named. Cases have been reported by Ogle, Jackson, Hamilton, Worcester, and others, in which impairment or loss of smell was associated with lesions of the gyrus uncinatus or its immediate vicinity. According to Flechsig, the olfactory conduction path in the fore-brain is the first path connected with the special sense organs to become medullated. Turner grouped the regions especially connected with the sense of smell in 1865 under the term rhinencephalon. His and Edinger consider this separation of the parts concerned with smell to be in accord with the facts of embryological and phylogenetical development. The rhinencephalon is rich in neurones connecting it with the basal ganglia; these lower centres are therefore so situated as to be able to respond reflexly or anatomically to all forms of general or special sensory stimulation. The gyrus hippocampus, especially the uncus, appears to be established as the cortical sensory area for olfactory stimulation. The cortical area for the sense of taste is probably located adjacent to the area for that of smell, perhaps occupying in part a portion of the fourth temporal convolution. Turner (1897) in reviewing the subject finds disagreement among investigators as to the peripheral gustatory neurones and almost complete ignorance as to the central neurones. Bechterew has presented a scheme of taste conduction paths. Peripherally these involve the fifth and ninth nerves in the region of the fourth ventricle, where they are associated with the motor nuclei of the fifth, seventh, and ninth nerves. The limited knowledge pointing to a definite location of taste sensation is in accord with the relative unimportance of this sensation and with its close association to the sensations of smell, of touch, and of temperature.

The primary centres of sensation occupy only about one-third of the superficial surface of the cerebral hemispheres (see Figs. 897, 898, 900, and 901). These physiologically are higher sensorimotor centres superimposed upon the lower basal centres, and enable the organism which possesses them to act in response to stimuli

with more complicated coordination than would be possible with the basal and other lower centres alone. In Figs. 900 and 901 the central portion of each sensory area is indicated by the more numerous dots which represent, according to Flechsig, their richer supply of cortico-petal fibres, while the less frequent dots represent the portion in which these fibres are less numerous. The remaining two-thirds of the cerebral area, unmarked with dots, are not provided with projection fibres either afferent or efferent. The white matter of all these cortical regions, with the exception perhaps of that beneath the angular gyrus, becomes medullated considerably later than that of the sense centres, so that even in children three months old the former are sharply distinguishable from the latter by their poverty of myelin. Flechsig finds, however, that medullated paths gradually grow out from the sense centres into these non-medullated regions. Further, between the individual gyri of the non-medullated regions, bands of association fibres gradually ripen, connecting the individual gyri with others near them and also with gyri at a distance. These areas Flechsig designates association areas; through these alone one sensory area is indirectly connected with another. The association areas are therefore centres whose cells are superimposed upon those of lower primary sensory areas, supplying a mechanism for the higher co-ordinations which are most representative of the intelligent as well as of the conscious life of the organism. He designates as the posterior association area that part which includes the precuneus, all the parietal gyrus, except the postcentral gyrus, part of the gyrus lingualis, the fusiform gyrus, and the middle and inferior temporal gyrus, as well as all portions of the occipital gyrus not concerned in the visual sense area. This association region is therefore situated midway between the visual, the somæsthetic, and the auditory sense areas, and is indeed not remote from the olfactory and gustatory areas. The middle association area is constituted by the island of Reil, surrounded by the somæsthetic area, the auditory area, and the olfactory area, from all of which bands of fibres run into it. The prefrontal convolutions constitute the anterior association area, which is chiefly connected with the somæsthetic area and the olfactory sense area.

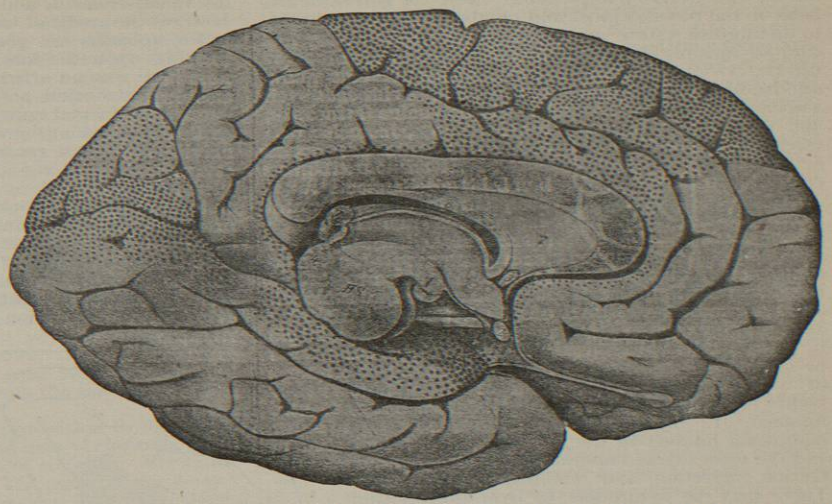

FIG. 901.—The Sense Areas and Association Areas on the Median Surface of the Left Cerebral Hemisphere. (From Flechsig.) The closely dotted regions in the anterior portion of the parietal and posterior portion of the frontal lobes, about the calcarine fissure, and in the hippocampal and uncinate gyri, indicate respectively the primary sense areas of general somatic sensation, of visual sensation, and of gustatory and olfactory sensation. The regions not marked with dots are: 1, The posterior association area in the precuneus and temporal lobe; 2, the anterior association area in the frontal lobe.

The facts advanced by Flechsig are admitted in part, but contested in part also. Thus von Monakow asserts that projection fibres go to nearly all parts of the cortex, though he, as well as all others, admits that some parts receive fewer by far than others, the frontal lobe especially receiving few, if any. Some also deny that association tracts connect the sensory areas only indirectly through the association areas. These tracts have been made out in some instances with much precision. The polymorphous cells of the fourth layer and of the pyramidal layers are admitted to give origin to the fibres that either separately or as constituents of well-defined tracts unite in functional relationship the cortices of separated convolutions.

By means of the corpus callosum the gyri in one hemisphere are connected with those in the opposite hemisphere. Of short association fibres there are five different bundles that have been made out in the occipital lobes alone. In the frontal lobes, fewer distinct bundles of association fibres have been made out, although Déjerine has described the source of several. In the temporal lobe and insula, similar bundles have been described but no definite tracts have been ascertained. The long association tracts that have been described are, according to Barker: (1) the cingulum, which belongs to the rhinencephalon; (2) fasciculus longitudinalis superioris, connecting the frontal and occipital lobes; (3) fasciculus longitudinalis inferioris, uniting the occipital and temporal lobes; it is suggested that this may be the bundle connecting the visual sense area with the auditory sense area; (4) fasciculus uncinatus, which extends between the uncus and the basal portion of the frontal lobe, and which may be an association tract of the rhinencephalon; (5) the tapetum, which is held by some to be a portion of the fasciculus longitudinalis superioris. According to Déjerine, it arises in the whole cortex of the frontal lobe, and, passing through the tapetum, its fibres are distributed to the lateral surface and inferior border of the lobus occipitalis.

These results seem to establish a direct connection between the various sense centres, as well as the indirect connection through the association areas as proposed by Flechsig. Whether Flechsig be right or wrong in this, whether subsequent research shall substantiate or disprove the anatomical connections and relationships indicated by the report of his results of the embryological method, it seems to the writer that Flechsig's psycho-physiological interpretation of the functions of the association areas is in the main incontestibly sound in psychology, and accordant with the trend of conclusions drawn from multifarious experimental and clinical investigations.

It has already been pointed out that most authorities distinguish between sensory disturbances and perceptual disturbances. Loss of memory and of higher sense perception have generally been attributed to regions which lie from the direction of the auditory, visual and somæsthetic areas toward the angular gyrus. It is immaterial whether psychical blindness, deafness, etc., are due to a loss of memory images or to an ataxia of sense perception. It seems clear that the nearer a lesion lies to the calcarine fissure, the Rolandic fissure, or the middle part of the