XVI. The Croonian Lecture.—*Experiments on the Brain of Monkeys* (Second Series).

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Communicated by Dr. Sanderson, *V.P.R.S.*

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In a former memoir presented to the Royal Society the author described the results of electrical irritation of localized regions of the brain of monkeys. This memoir contains the details of experiments relating chiefly to the ablation or destruction of these localized centres, with the view of determining the significance, as regards motion and sensation, of the phenomena resulting from electrical stimulation, and for the purpose of ascertaining the function of those parts which give no external response to irritation. No originality is claimed either for the idea or method of carrying out these experiments.

The plan chiefly followed in the destruction of localized regions in the hemispheres was the application of the cautery, either in the form of a red-hot iron, or of the galvanic cautery, or of Bruce's blowpipe cautery, according to special necessities or conditions. The advantage of this method is that destruction of the grey matter can be caused rapidly and effectually, without risk of hæmorrhage or interference with the integrity of surrounding parts. By the same method a part can be severed from the hemispheres without risk of hæmorrhage.

The details of observation are given in full as the best method of indicating the course of events following each operation and the data on which the conclusions are based.

Extirpation of the Frontal Lobes.

It has already been stated that the antero-frontal regions of the hemispheres give no response to electrical stimulation. Only one exception to this statement is to be made (see Exp. I.), viz. that in one case irritation of these regions caused the eyes to be turned to one or other side, according as the electrodes were placed on the opposite hemisphere.

Experiment I.

December 2nd, 1873.—A very lively, active, and intelligent monkey was placed under the influence of chloroform, and the frontal extremities of both hemispheres exposed as far back as the anterior extremity of the supero-frontal sulcus (fig. 1), the infero-frontal regions being exposed to a corresponding extent. On electrical irritation of the upper surface of these regions the eyes were occasionally turned to the opposite side. No results could be observed to follow application of the electrodes to the orbital region.

The exposed portions of the hemispheres were in this instance divided rapidly by

means of a scalpel, and the cut surface touched with perchloride of iron to still the hæmorrhage.

The operation was completed at 4.40 P.M.

When the chloroform stupor had passed off, which occurred in a few minutes, the animal sat up, but nodded off to sleep, opening its eyes faintly when a noise was made.

5 P.M. Eagerly drank some sweet tea held to its lips, but immediately went to sleep when it was withdrawn. Took a piece of bread and butter held before its face and began to eat, but after a bite or two went to sleep, holding the bread in its hand. When it was awakened by cold air blown in its face, at which it expressed annoyance, it woke up and began to eat again greedily.

5.15 P.M. The scalp was sewn up. The animal retained sensation. After the operation the animal took some food and again went to sleep.

December 3rd.—The animal is alive and well. Eats and drinks spontaneously, but frequently subsides into a doze while eating. Is constantly tending to sleep when it is not kept awake by external stimuli. It pays little or no attention to any thing going on around unless stimuli are applied to it directly. Formerly it used to exhibit the utmost curiosity in every thing going on around it. A lighted match held before its face caused it to exhibit some curiosity. Touched it several times; each time showing signs of pain and rubbing its fingers vigorously. Formerly the sight of fire used to cause it to run away.

December 4th.—The animal remains in much the same state, sitting quietly, feeling the wound, which is oozing, and licking its hand. Occasionally it runs hither and thither in the cage in an aimless manner. Often subsides into a dozing state, but is easily roused by sounds, touch, &c. Eats and drinks of its own accord in a mechanical way, frequently going to sleep the while.

Retains all its senses and muscular power.

Gives evidence of sight by shrinking and holding its hands to protect its head when threatened with a stick. Whatever is placed in its hand is mechanically raised to its mouth.

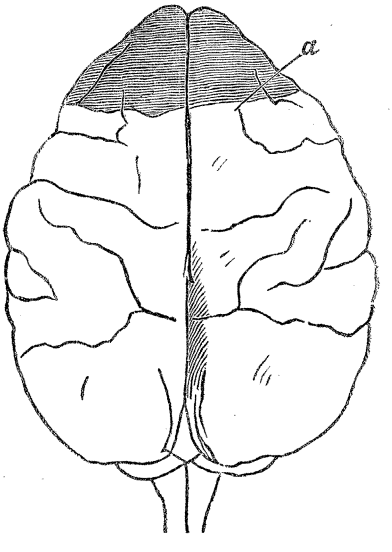
December 5th.—The condition is in all essential respects unaltered. Another monkey was placed in the cage beside it. Of this it took little or no notice. Formerly it took the greatest interest in examining any companion placed beside it.

The continual sleepiness continues.

The animal died from exhaustion on the 7th without having exhibited any further symptoms.

Post mortem Examination.—The frontal lobes were

Fig. 1.



Upper view of the hemispheres of the monkey. The shaded part in the frontal lobes indicates the extent to which the brain was destroyed in Experiment I. *a*=the supero-frontal sulcus.

found to have been removed by a line corresponding to that described and indicated in fig. 1.

The cut surface had fungated and was protruding through the openings in the skull. The rest of the brain had a normal appearance.

Experiment II.

January 13*th*, 1875.—A mischievous, good-tempered, and intelligent monkey was placed under the influence of chloroform, and the frontal lobes exposed on both sides. By means of the wire cautery the lobes were severed by a transverse line cutting across the anterior extremity of the supero-frontal sulcus. The division was carried down to the orbital surface, and the severed portion of brain removed.

The operation was finished at 4 P.M.

4.15 P.M. The animal drank some tea held to its lips, but lay quiet and had not yet attempted to get up.

5 P.M. Now moves about, which it does rather unsteadily, but evidently sees where it is going, as it avoids obstacles in its path.

5.45 P.M. Sits quietly with its head down when undisturbed, and makes scraping movements with both hands. Expresses great annoyance when its face is blown on. Tobacco-smoke held to its nostrils caused it to start back and run away.

7 P.M. Sits with its head down, engaged in picking at imaginary objects in front of it. Can find its way in and out of its cage when roused to action. Turns its head round and looks when called to, giving full evidence of its sense of hearing.

8.10 P.M. Run out of its cage when the door was opened. Runs about and jumps on furniture when roused. Otherwise, when left to itself, it sits down and picks at imaginary objects on the floor. Took a piece of apple offered to it and ate it.

11.15 P.M. Ran about the room when let out of its cage, occasionally stopping to pick up things lying on the floor, and turning round to look when called to. Climbed up a chair and then relapsed into its usual position with its head down, and began to pick away with both hands at nothing.

January 14*th*.—10 A.M. When taken out of its cage wandered restlessly around the room. Took a little food offered to it, and then capsized the dish. When placed in its cage picked up some pieces of bread, and sat and ate them contentedly; then rose and marched round and round. After this subsided into a dreamy-like doze, and then after a few minutes began its picking and scraping movements.

11 A.M. Is busily engaged picking up pieces of bread lying in its cage, carefully scraping and eating them. Runs about the cage occasionally in a restless manner, and then subsides into its quiet attitude, picking and scraping among the straw &c. in its cage.

5.30 P.M. When let out it ran about the room for some time, jumping on chairs &c., and then after sitting still for a few minutes, picking as usual, started up and ran about again in the same aimless manner.

Took some food offered to it, but after eating a little set to work to scatter it all about.

10.15 P.M. Is found clinging to its cage with hands and feet, apparently asleep, and takes no notice of my approach.

January 15th.—10.30 A.M. This morning when taken out seemed unwilling to move about. When roused and pushed, seemed to walk somewhat unsteadily, and as if its limbs were clogged.

Thinking that the motor centres were becoming involved in softening, I chloroformed the animal to death.

Post mortem Examination.—On examination of the brain it was found that the frontal lobes had been cut off on both sides according to the line indicated, viz. in a line passing transversely through the anterior extremities of the supero-frontal sulci. The plane of section sloped somewhat from above downwards, leaving the posterior half of the orbital surface uninjured.

The cut surface was projecting so as to protrude through the openings in the skull and reach the under surface of the scalp.

Some degree of softening had extended from the edges of section on both sides to the proximity of the antero-parietal sulcus, but slightly more on the left than on the right side (see figs. 2 & 3). The rest of the brain was round in appearance. The olfactory bulb and tract on both sides had escaped injury.

Fig. 2.

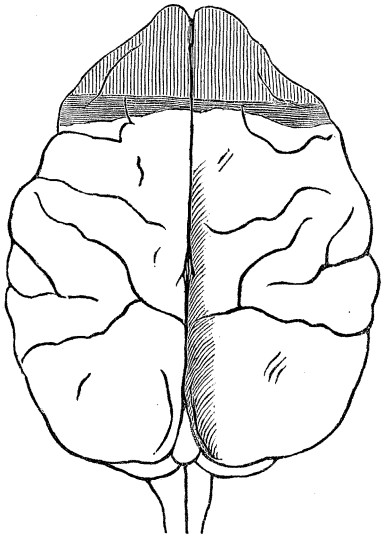
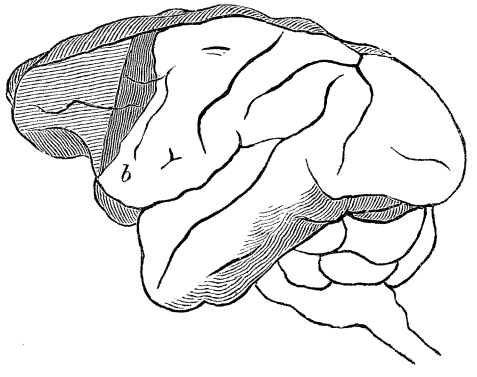


Fig. 3.



Figs. 2 & 3 represent the upper surface of both hemispheres and side view of the left hemisphere of the brain of the monkey. The line cutting across the frontal regions at the anterior extremity of the supero-frontal sulci indicates the line of section of the lobes in Experiment II. The parallel lines indicate the extent of brain-substance removed. The shading posterior to the line indicates the extent to which softening had advanced. *b* = the antero-parietal sulcus (HUXLEY).

Experiment III.

March 16*th*, 1875.—The frontal lobes of both hemispheres were exposed in a small active and intelligent monkey, and by means of white-hot wires the frontal lobes were severed from the rest of the hemispheres by a line passing approximately through the anterior extremity of the supero-frontal sulcus on each side. The division, however, was slightly further back on the left than on the right side. The operation was completed at 1 P.M.

A few minutes after being let loose it sat up, and seeing a piece of cotton-wool lying before it, took it up and began tearing it with its teeth. Offered a piece of apple, it seized it and ate it.

1.15 P.M. Walks about the room pretty steadily. There is no affection of its muscular power nor of sensation; it sees where it goes, turns its head when called to, and smells and eats fruit offered to it.

6 P.M. Animal is found sitting quietly in its cage. It used to be very discontented at being shut up, and kept up a continual whining. Offered some fruit, it smelt it and ate it. When let out of the cage it ran about the room, giving full evidence of the retention of all its special senses and powers of motion.

7 P.M. Sits in the cage diligently occupied in examining and picking its hands and feet and woollen jacket.

Has rather a stolid look, and makes no attempt to move away when a hand is put out to lay hold of it.

Formerly it was very timid and disliked being touched.

8 P.M. Eagerly drank some sweet tea.

When let out of its cage it walked about a little, and then sat down and went on with its usual employment of examining and picking at its hands, feet, and coat.

9.30 P.M. Found sitting in same position at the same employment. Takes no notice of whether the room is suddenly lightened or darkened, but goes on with its occupation all the same.

11.30 P.M. Found asleep on its perch. On the gas being turned up and the animal awakened, it began to examine its hands &c. as before. The cat happening to come into the room caused it to give a shriek and appear terrified.

March 17*th*.—8.30 A.M. Ate some breakfast; came out of its cage when the door was opened, and marched about the room. An hour or two afterwards another monkey was placed in the cage beside it. Its companion examined it with curiosity, but it sat quietly and made no sign of interest. Gradually sidled up to it, however, and sat hugging it, enjoying the warmth of contact.

2 P.M. When let out of its cage it ran about a little followed by its companion. After a few minutes sat down in a corner and began to examine and pick its hands, feet, and tail. Makes no resistance when its companion pulls it about rather roughly and examines its head.

5.30 P.M. Condition remains as before. Frequently gets a tug and a bite from its companion, who seems annoyed at its occasional restless movements.

Later in the evening when examined it exhibited no new symptoms.

March 18*th*.—10.30 A.M. Remains as before. Sensation and voluntary motion are unimpaired. Eats and drinks heartily, finding its own food in the cage.

When the door of its cage is opened it comes out and runs about, and then settles down quietly in a corner. Allows itself to be touched and taken hold of, which its companion resents very much. Has lost its former timidity and shyness. Pays no attention to any thing going on around, but sits picking its hands and feet unless directly disturbed, when it gets up and runs about.

8 P.M. Remains in same condition. Eats and drinks heartily.

March 19*th*.—10 A.M. Ate breakfast heartily. When taken out of its cage it ran about the room in a wild manner, jumping on furniture. Gives a little grunt of recognition when called to by name. After running about it subsided into a dull stupid-like state, scratching its sides occasionally or the edges of the wound, which would seem to itch. The wound looks tolerably dry and healthy.

Later it sat down by the fire close to its companion, but occasionally got up and made some restless movements, whereupon it got a tug or bite from its companion, who seemed to lose patience with its waywardness.

5 P.M. Found in a dozing state, but woke up and drank some tea and ate some bread and butter, after which it again subsided into a dozing condition.

March 20*th*.—9 A.M. Ate and drank. There is no difference observable as regards sensation or voluntary motion. During the day sat quietly except when roused, when it would get up and run about wildly for a few minutes and then subside into its sleepy condition.

5.30 P.M. Gave a screech when the cat was brought into the room, but after a short interval walked up to it half in terror and half showing fight.

Continued much the same as before during the rest of the day.

March 21*st*.—11 A.M. Ate some breakfast, but appears much less active than before. Inclined to climb about along the inside of its cage.

When taken out it ran about a little and then sat down, clinging to some object. Sees and hears as before, and other senses seem unimpaired. A few minutes after it had been let out of its cage it returned, and began climbing restlessly on the sides of its cage, occasionally resting quietly with its eyes closed as in sleep.

1 P.M. Was found climbing restlessly along the inside of the cage. Pays no attention to its companion, and does not seek to sit beside it as usual. Utters a short grunt when called to. When taken out and placed before the fire it sat perfectly still with its head bent. On being disturbed by the movements of its companion it would get up and run about a little.

It was observed that its movements were less free than before, and that it walked as if its limbs were clogged.

2 P.M. Was found sprawling against the wall of the room in a corner as if it wished to climb.

When set to move about it picked up things lying on the floor, smelt them, and occasionally put them in its mouth. Eats and drinks as usual.

5.30 P.M. In attempting to drink some tea, of which it was very fond, its head was observed to shake so that it could scarcely hold its lips to the fluid. When its head was held steady it drank with avidity.

Fig. 4.

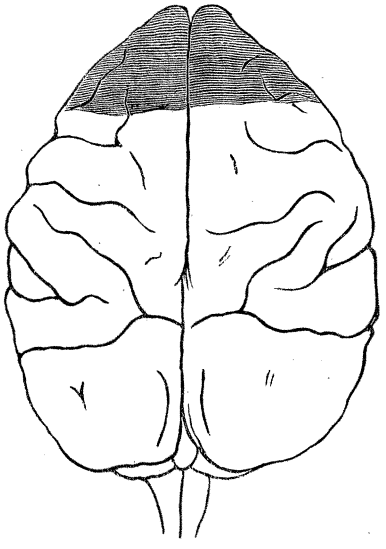


Fig. 5.

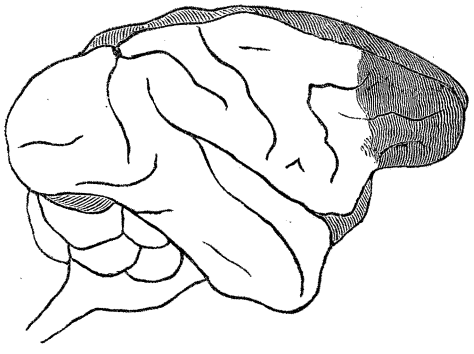


Fig. 6.

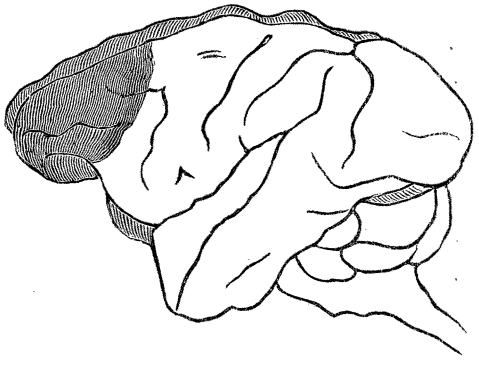


Fig. 4 represents the upper surface of the hemispheres, fig. 5 the right, and fig. 6 the left hemisphere of the brain of the monkey. The shaded parts in the frontal lobes in all the figures indicate the extent of destruction of the brain-substance in Experiment III.

This paralysis agitans was taken as an implication of motor centres, and therefore the animal was chloroformed to death to prevent complications.

Post mortem Examination.—On removal of the scalp the brain was found protruding on each frontal region, the herniæ reaching the under surface of the scalp. The sur-

faces were suppurating slightly. The edges of the bone looked healthy, and there was no œdema of the scalp or surrounding parts.

The dura mater was of normal appearance, and stripped readily from the surface of the hemispheres, which looked somewhat "wet" but otherwise normal.

On removal of the brain the base and cranial nerves were all found intact. The olfactory tracts and bulbs had escaped injury, though the bulbs were slightly covered with pus.

On opening the ventricles slight excess of fluid was found in them, but the ganglia were quite normal in appearance. The anterior cornua of the ventricles had not been penetrated.

The abnormal appearances were entirely confined to the frontal lobes. The hernial prolongations were of the size of the openings in the frontal bone, and were bounded by a sharp line somewhat congested, indicating the line of section of the lobes.

In the right hemisphere the line of section struck the anterior extremity of the supero-frontal sulcus, and sloping somewhat downwards and forwards had struck the orbital surface in a plane anterior to the superior line of section.

In the left hemisphere the line of section was situated slightly posterior to that on the right, cutting across the supero-frontal sulcus, and sloping forwards like the right. The posterior half of the orbital surface was intact on both sides.

The softening at the margins of the section did not extend into the antero-parietal sulcus.

There was some softening between the lips of the longitudinal fissure at the base, but this did not extend beyond the perpendicular plane of section.

The septum lucidum was uninjured.

The rest of the brain was intact.

An analysis of these three experiments elicits, with individual differences, certain common and fundamental facts. They show conclusively that an animal deprived of its frontal lobes retains all its powers of voluntary motion unimpaired, and that it continues to see, hear, smell, and taste, and to perceive and localize tactile impressions as before. It retains its instincts of self-preservation, retains its appetites, and continues to seek its food. It is also capable of exhibiting various emotions. The result, therefore, is almost negative, and the removal of a part of the brain which gives no external response to electric stimulation exercises no striking positive effect; and yet the facts seem to warrant the conclusion that a decided change is produced in the animal's character and disposition. For this operation I selected the most active, lively, and intelligent animals which I could obtain. To one seeing the animals after the removal of their frontal lobes little effect might be perceptible, and beyond some dulness and inactivity they might seem fairly up to the average of monkey intelligence. They seemed to me, after having studied their character carefully before and after the operation, to have undergone a great change. While conscious of sensory impressions, and retaining voluntary power, they, instead of being actively interested in their surroundings, ceased to exhibit

any interest in aught beyond their own immediate sensations, paid no attention to, or looked vacantly and indifferently at, what formerly would have excited intense curiosity, sat stupidly quiet or went to sleep, varying this with restless and purposeless wanderings to and fro, and generally appeared to have lost the faculty of intelligent and attentive observation.

Perhaps this condition may be attributed to the constitutional disturbance excited by the operative procedure alone; but the effects of this are capable in a great degree of elimination; and in the record of subsequent experiments it will be seen that after operations of equal severity marked differences are observable according to the part of the brain which was destroyed. The animals seem to bear the operation with comparatively little constitutional disturbance; and this is testified by the fact that they continue to eat and drink heartily within a few hours, and often less, after a large portion of the brain has been removed.

The phenomena occurring towards the latter end of the periods of observation are more to be regarded as signs of constitutional disturbance, and as indications of the advance of inflammatory softening or morbid process into other cerebral regions. The spasmodic motor affections, as well as the paretic condition seen in regard to certain movements, are to be explained by the implication of motor centres, the nature and position of which will be illustrated in the next series of experiments.

Destruction of Motor Areas—Regions of the Fissure of Rolando.

In my former Memoir I have related the results of electrical irritation of regions situated in the immediate neighbourhood of the fissure of Rolando, which show that certain definite and purposive movements of the hand, foot, arm, leg, face, and mouth result from the electrical stimulus applied to individual areas capable of more or less exact localization. The experiments next to be related have reference to the effect of destruction of these centres, collectively and individually, on the power of voluntary motion.

Experiment IV.

June 18*th*, 1873.—The right hemisphere of a monkey had been partially exposed and experimented on for the purpose of localizing the regions of electric stimulation.

The part exposed included the ascending parietal and postero-parietal convolutions, the ascending frontal, and the posterior extremities of the three frontal convolutions. After having been under experimentation for eight hours the animal recovered sufficiently to sit up and take food. The wound was sewn up, and the animal placed in its cage.

June 19*th*.—The animal is apparently as well as ever, eating and drinking heartily, and as lively and intelligent as before. No change was perceptible during the whole of this day.

June 20*th*.—The wound was oozing, and the animal was less active; but there was

no diminution of sensation or voluntary motion. It closely watched flies buzzing about, and frequently made attempts to catch them.

Towards the afternoon it began to suffer from choreic spasms of the left angle of the mouth and of the left hand. There was no loss of consciousness. The animal was apparently annoyed by the spasmodic action of its mouth, and frequently endeavoured to still them by holding its mouth with the other hand.

Towards the close of the day the spasms frequently repeated, became more intense, and exhibited an epileptiform nature, the convulsions of the left side of the body becoming general.

This state continued till

June 23*rd*.—Left hemiplegia had manifested itself. The angle of the mouth was drawn to the right, the left cheek-pouch was flaccid and full of food, there was almost total paralysis of the left arm, and partial paralysis of the left leg. The pupils were equal, and there was no paralysis of the left eyelids apparently. The animal still maintained an intelligent aspect, but seemed disinclined to move on account of the powerlessness of its left side.

June 24*th*.—Hemiplegia is complete on the left side, hand, foot, and face. The animal moved by means of its left limbs, dragging the right after it.

The animal died from exhaustion on the 27th.

Post mortem Examination.—The whole of the exposed part of the brain was in a state of softening and suppuration, projecting through the opening of the skull.

The extent is indicated in figure 7.

Fig. 7.

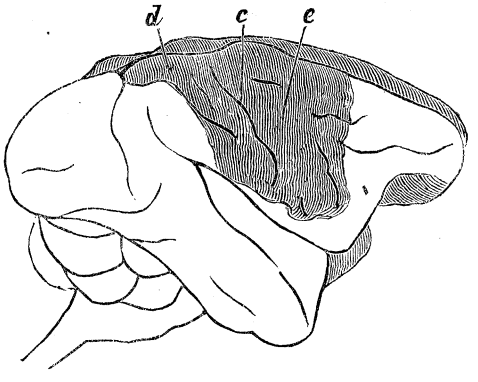


Fig. 7 represents the right hemisphere of the brain of the monkey. The shaded part indicates the extent of destruction of the grey matter in Experiment IV.

c = the fissure of Rolando.

d = the postero-parietal lobule or upper end of the ascending parietal convolution.

e = the ascending frontal convolution.

The brain otherwise was normal. The softening was confined to the surface of the hemisphere, and did not extend to the ganglia, which were normal.

In this experiment we have a general affection of the whole of the motor region of the right hemisphere, beginning with inflammatory irritation, which showed itself in choreic spasms passing into general epileptiform convulsions, and ending ultimately, as softening advanced, in complete left hemiplegia.

This result followed destruction of the cortical motor centres alone.

Experiment V.

January 5*th*, 1875.—A macaque of large size was placed under the influence of chloroform, and the ascending frontal, ascending parietal, and postero-parietal convolutions of the left hemisphere exposed.

Electrical irritation was applied, and the movements already related as following

stimulation of these regions produced. The animal was allowed to recover consciousness completely at 5 P.M. It remained for two hours as well as before to all appearance.

At 7 P.M. by means of the blowpipe cautery the surface of the postero-parietal lobule (foot-centre), of the ascending parietal (hand and wrist centre), with a small portion of the upper extremity of the ascending frontal convolution (arm and leg centres) were destroyed.

Though the animal was quite conscious it expressed no sign of pain or uneasiness during the process. Once during the passage of the cautery along the ascending parietal convolution a partial closure of the fist occurred, seeming as if the heat had caused in some degree the same effect as the electric stimulus.

On being set free the animal jumped away, but staggered and fell over on its right side. It was observed that when the animal moved, it did so by the aid of the left arm and left leg, dragging the right leg on the floor. When it rested, the right leg was seen to straddle outwards, as if the power of adduction had been lost. There was no muscular resistance to the free movement of the ankle in any direction, but there was resistance to forcible extension of the leg. The right arm was kept flexed at the elbow, but the wrist dropped and the hand hung flaccid. There was no resistance offered to flexion and extension of the wrist, but decided muscular resistance to straightening the arm. The animal made no use of its right hand to grasp, or in progression, but it retained the power of flexing the right forearm.

The sensibility of the right side was unimpaired, as judged by the expression of pain and annoyance when the limbs were pricked or pinched.

The great difficulty it experienced in walking, or sitting steadily upright, caused the animal to growl in annoyance each time it staggered.

Otherwise the animal was well, and ate and drank as before within an hour after the operation.

The animal was then subjected to an experiment for destruction of the angular gyrus (see Exp. VIII.), and its further history and the results of the post mortem examination are detailed under Exp. VIII.

This experiment demonstrates very conclusively that the destruction of cortical centres, irritation of which by the electric stimulus gave rise to very definite movements of the hand and foot, caused motor paralysis of the same movements and of none other; and, as will be found, the paralysis remained permanent up till the time of death.

Experiment VI.

February 26th, 1875.—A monkey was chloroformed, and the left hemisphere was exposed on the region which former experiments had indicated as the centre for the biceps (*f*, fig. 8). By electrical irritation the region was accurately defined, and the grey matter destroyed by means of the blowpipe cautery. The animal was conscious, and lay perfectly quiet during the operation, though unbound. When placed on the floor the animal sat very unsteadily; and the cause of this was seen to be that the right

arm hung by the right side in a state of flaccid extension. When urged to move it used the left limbs and the right leg as before, but had lost the power of flexing the right arm. In trying to walk, it frequently fell over on its right side.

An hour after the operation the paralytic condition of the right forearm remained very marked; the loss of voluntary power was confined to the same action as was excited by the electric stimulus.

The animal died from an overdose of chloroform when about to be subjected to a further operation.

Post mortem Examination.—The only lesion in the brain was a cauterized spot of the size of a threepenny bit, corresponding to the bicipital centre in the ascending frontal convolution (see fig. 8).

Fig. 8.

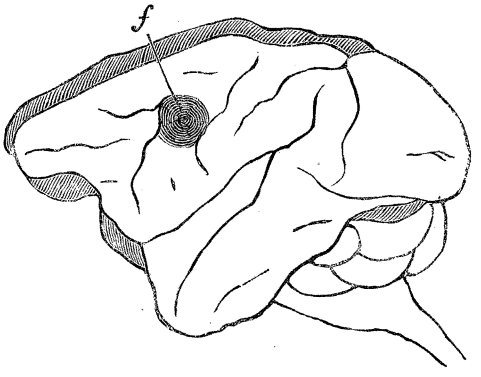


Fig. 8 represents the left hemisphere of the brain of the monkey.

The shaded spot on the ascending frontal convolution marked by the letter *f* indicates the extent to which the grey matter of the surface had been destroyed in Experiment VI.

These three experiments, besides others where the same regions became involved indirectly as the result of other experiments*, afford a simple and conclusive proof that the movements which are excited by the application of the electrodes to the surface of the hemispheres in these regions are due to excitation of the grey matter of the cortex, seeing that destruction of these same areas causes paralysis of the same movements, while sensation remains unaffected†.

In the first experiment the more or less complete destruction of the cortex in the region of the fissure of Rolando caused complete hemiplegia on the opposite side of the body, affecting all the unilateral movements capable of being called into play by the electric irritation. In the next two, only those movements were paralyzed which had their special centres destroyed in the cortex of the opposite hemisphere.

* See Experiments VII. and X.

† I am aware that the conclusion here stated, and which seems to me well established by the above facts, apparently stands in diametric contradiction to the conclusions which Hermann ('Archiv für Physiologie,' Band x. Hefte 2 & 3, p. 77) has arrived at from a few similar experiments on the motor centres of the brain of dogs. He concludes that because dogs ultimately recover completely from such disturbances of motor functions as are at first caused by the ablation of cortical centres, these centres cannot be motor in the true sense of the term. Experiments on dogs, however, are not strictly comparable with experiments on monkeys; and the relative subordination and association of lower centres in different animals is a fact which ought to be carefully considered. The explanation I have elsewhere given ('West Riding Reports,' vol. iii.) of how associated movements, such as those of the limbs of dogs, can still be carried out through the associated action of lower centres so long as the cortical centres of the other hemisphere are intact, is quite in harmony with the facts Hermann gives, and is further demonstrated by the complete paralysis of *voluntary* motion which follows the destruction of corresponding regions in both hemispheres in these animals.

Experiments relating to the Localization of Sensory Perception.*

Certain movements of the eyes, ears, and nostrils, obtained by stimulation of certain convolutions already described, led me to regard them as the external manifestations of sensations thus subjectively aroused; and the following experiments were directed to test the truth of this hypothesis, and to determine to what extent sensory localization in the brain might be possible.

Destruction of the Angular Gyrus.

As already related, electric stimulation of this convolution caused movement of the eyeballs to the opposite side, with a direction upwards or downwards, according as the anterior or posterior division was stimulated, and frequently the pupils contracted and the animal tended to close the eyes.

Experiment VII.

November 18*th*, 1873.—The angular gyrus of the left hemisphere of a monkey was exposed, and after electric irritation, causing the movements already described, the whole of this convolution, with the upper part of the superior temporo-sphenoidal convolution situated between the two limbs, was seared and destroyed with the galvanic cautery (see fig. 9). The left eye was then securely sealed up with plaster, and the animal left to recover from its chloroform stupor.

Fig. 9.

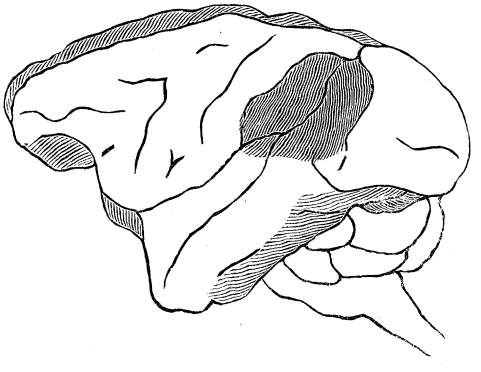


Fig. 9 represents the left hemisphere of the brain of the monkey.

The shading which occupies the whole of the angular gyrus and the upper angle of the superior temporo-sphenoidal convolution indicates the extent to which the grey matter was cauterized in Experiment VII.

A few minutes after it began to struggle a little, as if endeavouring to rise, but was unable to get on its legs. Half an hour after it sat up, and began to grope about cautiously, but made no efforts at progression. It made no sign when a light was approximated to its eye. It did not flinch when lifted up and its face brought quite up to the light.

It had retained its sensation as regards hearing and touch, starting if a noise was made, and expressing annoyance if it was pinched.

When placed in its cage beside two other monkeys, it clung to the bars of the cage, and took no notice of its companions. It would not stir from the position it assumed. A little later sat down in its cage, with its head covered with its hands.

An hour having elapsed, it was taken from the cage and the left eye unbandaged.

Immediately on this being done, it looked around, and seeing the door of the cage open, ran nimbly and made its way among its companions.

* By this term, as also by the term "sensation" which I sometimes use, I wish to signify the fact of conscious discrimination of impressions as distinct from the mere sensory impressions themselves.

When taken out again, and the door shut, it ran back, looking at its companions, and desirous to gain admittance.

When held up to the light it flinched and averted its head.

The transition after the bandage was removed was of a striking character, and indicated an evident restoration of sight which had been lost.

Next day (Nov. 19) the animal looked perfectly well, running about, eating and drinking as usual.

An experiment was then made with the view of ascertaining whether the blindness of the right eye had continued. The left eye was again bandaged up as before, and the animal placed on the floor. It immediately ran up to the cage, and putting its hand through the bars into a dish of water began to lap it.

Sight had therefore returned, notwithstanding the destruction of the angular gyrus on the left side.

The animal died on Nov. 24 from suppuration and necrosis of the skull, having also become paralyzed on the right hand.

Post mortem Examination.—The angular gyrus and the ascending parietal convolutions were softened, and the hemisphere fungating from the orifice in the skull. The abnormal appearances were confined to the surface of the hemisphere. No drawing was made of the exact extent of the softening; but the paralysis of the right hand coincided with the destruction of the ascending parietal convolution. This experiment served to show that destruction of the angular gyrus resulted in blindness of the opposite eye, and that this loss of visual perception was only of temporary duration, compensation having been effected within a period of twenty-four hours.

Experiment VIII.

January 5th, 1875.—The subject of this experiment was the same monkey spoken of under the head of Exp. V.

Two hours after the destruction of the motor centres alluded to, the animal was again chloroformed, and the angular gyrus clearly exposed, the left eye closed with plaster, and the animal allowed to recover.

On returning to consciousness it followed my movements with its right eye, and indicated its sense of hearing by turning its head and looking when called to. Took some fruit offered to it in its left hand, and sat contentedly eating it. It seemed disinclined to move on account of the motor paralysis of its right side.

It sat with the right leg doubled up under it, and resting the internal malleolus on the floor. Sometimes it supported the right hand with the left. Expressed annoyance when pinched. The animal having thus recovered from the operation of exposure of the brain, it was taken and the angular gyrus carefully destroyed by means of the cautery, no more than two hours having elapsed since the first operation.

When let loose, it moved about a little when nudged, but would not move of its own accord. When forced to move, it avoided obstacles as if it still saw. On exami-

nation it was found that the bandage had slipped, and that the left eye was partially open. On this defect being remedied, it put up its left hand, and tried to pull the bandage from the eye. On this being prevented, it sat still and would not move. When pushed and forced to move on, it ran its head against every thing in its way.

When removed into another room it sat still with its head bent, and would not stir. Would not come when called to.

When taken back and placed beside its cage it still refused to move, and grunted annoyance if disturbed, or rushed with its head against any thing in its way. After it had remained for an hour in this condition the bandage was removed from its left eye. On this being done, it began to look around, and on being called to by name, ran to me and tried to climb on to my knee as it had used to do. This it did on three separate occasions.

The difference in its attitude after the bandage was removed was as striking as in Exp. VII., and indicated restoration of sight.

January 6th.—On account of the paralytic condition of its right side, and the suppuration going on in its wound, it was chloroformed to death.

Post mortem Examination.—The postero-parietal lobule, ascending parietal, and upper part of the ascending frontal convolutions, with the angular gyrus were softened and disorganized (see fig. 10). The rest of the brain was quite normal in appearance.

Fig. 10.

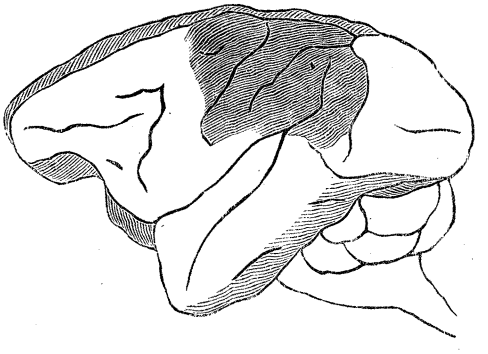


Fig. 10 represents the left hemisphere of the brain of the monkey, the shaded part indicating the extent to which the surface was destroyed in Experiment VIII.

Experiment IX.

April 7th, 1875.—This animal was used for an experiment on the superior temporo-sphenoidal convolutions on both sides. These were exposed; but previous to their destruction the angular gyrus was exposed on the left side for the purpose of demonstration of the effects of destruction of this convolution to Dr. BURDON SANDERSON and Dr. LAUDER BRUNTON. At 3.30 P.M. the angular gyrus was exposed, and its surface destroyed accurately by means of the blowpipe cautery.

The left eye was securely closed by means of plaster, and the animal placed on the floor.

After a few minutes it began to move about, which it did very irregularly, sometimes going backwards, and occasionally turning round and round.

4.20 P.M. The animal is more lively, but sprawls about on the floor, and does not make any regular progression. Drank some tea held to its lips.

4.55 P.M. Answers with a grunt, or makes mouths when called to. Sprawls about on the floor or goes backwards. When placed close to the door of its cage makes no

attempt to enter or seek its companion, who calls for it anxiously. When urged to move, it ran against obstacles held in its path.

It was adjudged to be blind.

5 P.M. The bandage was now removed from the left eye. After a few moments of apparent stupor and unwillingness to move, it ran when touched, avoided obstacles which formerly it had run against, and made its way to its cage and jumped up beside its companion.

The animal had evidently recovered its sight.

On this being established it was again placed under chloroform, and the superior temporo-sphenoidal convolution was destroyed in both hemispheres. The results will be recorded subsequently (see Exp. XV. p. 461).

Next day (April 8) at 12 noon it was taken out of its cage, and the left eye bandaged up as before, much against the animal's will. When let loose it made a spring at me, and then galloped away into the other room and made for its cage. Followed its companion out of the cage a short time after, and found its way in again and jumped on the perch. Retired from the perch when I approached making mouths.

Vision therefore had returned in the right eye.

The subsequent history and post mortem examination of this animal will be found on p. 461 *et seq.* under the head of Exp. XV.

This experiment completely confirms the former two as to the fact of blindness being caused in one eye on the destruction of the angular gyrus of the opposite hemisphere.

The important fact noted in Exp. VII. is also confirmed, viz. that within a very short period visual perception becomes again possible with the same eye, notwithstanding the lesion.

The next experiment relates to the effects of destruction of the angular gyrus on both sides.

Experiment X.

January 8th, 1875.—The angular gyrus was exposed accurately and clearly in both hemispheres of a monkey, and the animal allowed to recover from its chloroform-stupor 2.45 P.M.

At 3 P.M the animal had almost recovered, but was somewhat unsteady. Looks around, and turns its head when called to, and makes mouths as before.

3.30 P.M. When taken away from the fire before which it had been sitting, it ran back to its position, looking back at me, making grimaces and mouths.

It drank with avidity some sweet tea, of which it was exccedingly fond on all occasions. When the dish was removed to the other side of the room away from the fire, it ran to it and drank it up.

When a light was flashed before its eyes, it turned away its head and tried to conceal its face in its hands.

4 P.M. The animal having completely recovered from the operation, and being in full

possession of all its powers, it was taken and the angular gyrus destroyed on both sides by means of the cautery.

The operation was finished at 4.35.

The animal when placed on the floor uttered a cry and looked about in a scared manner.

Pricked up its ears and cried when called to.

Sat up quite steadily, but would not move.

The pupils reacted to light.

4.55 P.M. A light flashed before its eyes caused it to wince and erect its head. When placed beside the fire it sat up, enjoying the heat.

When removed from the fire it lay down, and would not move from its position even when nudged.

Turned its head sharply when called to by name.

When taken hold of clung violently to me, in terror at being placed down again.

When placed beside the fire sat contentedly enjoying the heat. Made no sign of perception when the room was suddenly darkened and lightened.

5.30 P.M. Sits quietly by the fire. A piece of apple dropped beside its hand caused it to lay hold of it, and after smelling eat it. When taken away from the fire and placed on a chair, lay down and refused to stir.

There is no paralysis of motion or sensation unless of sight; and this is difficult to ascertain beyond all doubt, as no crucial test seems applicable.

8 P.M. The question of sight was decided in the following manner. A dish of sweet tea, of which it was fond, was placed to its lips, whereupon it drank greedily, keeping its mouth in the dish as it was lowered; but on the dish being withdrawn from immediate contact and placed on the floor quite under its nose, the animal was unable to find it, though exhibiting a desire to do so. This was repeated several times with the same result. On the dish being raised to its lips it drank eagerly, and followed it with its mouth immersed until every drop was exhausted, the dish being drawn along the floor for some feet.

January 9th.—11 A.M. The animal is alive and well, and retains its muscular power and senses, except sight. It eats and drinks with avidity whatever is brought up to its mouth, but is unable to find its food when it is removed from immediate contact.

Will not move from its place, but remains quite still with its eyes open. The pupils are equal and active. An object waved in front of its eyes causes wincing only if closely approximated to the eyes.

A threatened blow with a stick causes no reaction, unless when brought almost in contact with its eyes.

The left wrist seemed slightly dropped, and not used like the other. With this exception all the voluntary movements were unimpaired.

To avoid the complication of extension of softening to other regions, the animal was killed with chloroform at 12 noon.

Post mortem Examination.—Slight suppuration existed at the margins of the wound and under the scalp; and there was some œdema of the cellular tissue over the orbits. The skull was deficient in the region of the parietal eminences.

The brain-surface corresponding to this opening was slightly elevated above the rest.

The surface of the brain was everywhere normal, except in the region of the angular gyri.

The surface of these convolutions was destroyed on both sides. Slight softening extended about a line into the adjoining margin of the occipital lobe on both sides, slightly more on the left than on the right (see figs. 11, 12).

Fig. 11.

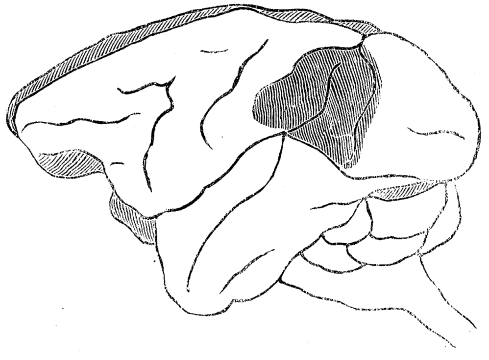
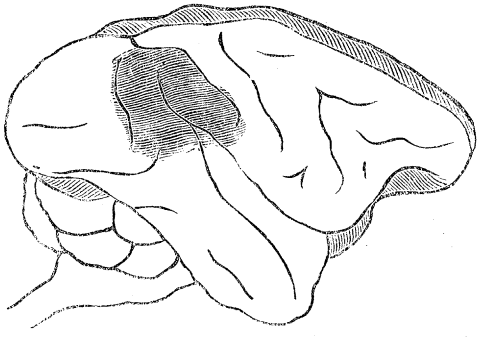


Fig. 12.



Figs. 11 & 12 represent the left and right hemispheres of the monkey respectively. The shaded portions indicate the extent of destruction of the surface of the hemispheres in Experiment X.

The lower part of the ascending parietal convolution of the right side was also slightly involved.

The base of the brain, the ganglia, and the optic tracts were uninjured.

This experiment completely confirms the other three as to the effect of destruction of the angular gyrus or the power of visual perception.

The slight affection of the left wrist is explained by slight invasion of the right ascending parietal convolution by the process of softening.

These four experiments demonstrate conclusively that unilateral blindness of a complete character results from destruction of the angular gyrus of the opposite hemisphere, and that this unilateral blindness is only of temporary duration, provided the angular gyrus of the other hemisphere remains intact; while permanent blindness results from the destruction of the angular gyrus in both hemispheres. Further proof of this will be found in Experiment XXI.

The loss of visual perception is the only result of this lesion, the other senses and the powers of voluntary motion being retained so long as the lesion remains confined to the angular gyrus itself.

By the term visual perception I wish to indicate the consciousness of visual impressions, and to distinguish this from mere impressions on the optical apparatus and reactions which are only of a reflex nature, such as the sudden start which an animal really

blind in the sense in which I use the term may make when a light is flashed before its eyes.

Retinal impressions and reflex actions resulting from these are left unaffected by the lesion which abolishes the perception of visual impressions.

Effects of Lesions of the Temporo-sphenoidal Lobe.

The experiments recorded under this heading relate to more or less general, as well as limited, lesions of the convolutions of this lobe. As it is difficult to reach and localize lesions in the individual convolutions, the exact effects of the destruction of any one part have to be arrived at in a great measure by a process of exclusion, besides that of direct experiment on each separate region.

The effects of electrical stimulation have been already recorded.

Irritation of the superior temporo-sphenoidal convolution always gave very definite results, viz. pricking of the opposite ear, opening of the eyes and dilatation of the pupil, with turning of the head and eyes to the opposite side.

That these phenomena were the indications of excitation of subjective auditory sensations seemed probable, both from experiments on monkeys and other animals.

Stimulation of the posterior division of the third external convolution in cats, dogs, and jackals is usually followed by sudden pricking of the opposite ear. In rodents a similar effect results from stimulation of an homologous region.

A very marked effect I observed in the case of a wild jackal, on stimulation of the posterior division of the third external convolution. The animal suddenly started, pricking up both ears, and would have bounded off the table had it not been securely fixed.

The phenomena were just such as would have resulted from a sudden alarm. A similar result I observed in a rabbit on which I was experimenting.

That the movements resulting from irritation of the superior temporo-sphenoidal convolution in monkeys resemble those caused by a sudden sound is seen by the following experiment:—

A monkey was placed on a table, and a loud whistle made close to its ear. Immediately the ear became pricked up, the animal turned its head to the same side, opening its eyes widely, while the pupils were observed to be dilated. The dilatation of the pupils was not observed in every case when the experiment was repeated, but the other phenomena were the same.

The effect of irritation of the lower end of the uncinate convolution (subiculum cornu ammonis), viz. torsion and closure of the nostril of the same side, is evidently to be taken as the indication of excitation of subjective olfactory sensations, and is precisely similar to the effect of irritating the olfactory bulb itself, as I have ascertained by direct experiment.

The following experiments serve to demonstrate the accuracy of the views at which I had arrived.

Experiment XI.

December 10*th*, 1873.—The left hemisphere of a monkey was exposed in the regions of the ascending parietal convolution, the postero-parietal lobule, the angular gyrus, and the upper part of the superior and middle temporo-sphenoidal convolutions.

After experimentation by means of electric irritation on these regions, the temporo-sphenoidal lobe was deeply divided with the galvano-cautery in a line nearly coinciding with the direction of the lower temporal fissure (see fig. 13), and the substance of the superior temporo-sphenoidal and middle temporo-sphenoidal convolutions destroyed and scooped out throughout their upper two thirds approximately.

After the operation the animal retained sight, and apparently heard as before, as judged by its reaction to sounds.

The condition as to smell and taste is exceedingly difficult to determine accurately.

As to smell, there is hardly any odour, pure and simple, which will cause distinct manifestation of olfactory sensation in a monkey; and one must study the habits of the animal carefully, or employ some volatile substance which will cause reaction. These, however, such as ammonic and acetic acid, act conjointly on the nerves of common sensation and on the special nerve of smell. I have found, however, by careful experimentation on a patient who had lost both taste and smell as the result of a blow on the head, that ammonic and acetic acid, and particularly the latter, cause much less reaction than they do when both systems of nerves are intact.

Confirmations of this will be found among the experiments narrated.

The reaction to acetic acid, which I frequently used to test the sensibility of the nostrils, is only a comparative test, and reaction caused by it, when applied to the nostril, is not to be regarded as an indication of smell; but the absence of reaction would show that the sensibility of the nostrils had been entirely lost; while a less reaction in one nostril as compared with the other would fairly indicate some abnormal condition of the nostril, the exact cause of which is capable perhaps of explanation by other facts.

In this case the reaction to the vapour of acetic acid was distinctly less in the left nostril than in the right. (The left nostril is, as will be noted, the same side as the lesion in the hemisphere.)

As to taste, no exact experiment was made. The right side of the tongue was touched with a rod dipped in perchloride of iron; but, owing to the nature of the substance and the diffusion in the mouth, nothing could be ascertained accurately, though I thought that there seemed to be less immediate reaction on the right side than on the left.

The animal had not lost its appetite, for it drank milk and ate some food offered to it.

Hearing, as was noted, did not seem affected, as the animal reacted as usual to sounds, turning its head, &c.

As the animal had, however, its left ear and right hemisphere intact, I plugged up the left ear securely by means of cotton-wool, in order to ascertain whether it heard in reality only with the right.

On this being done, sounds which formerly caused the animal to prick its ear and look round, failed to cause any reaction or excite its attention.

Sounds made by concussion caused the animal to look round, as well as the making of any sound which likewise attracted its attention by sight.

Whether, therefore, the animal heard or not, it gave no sign of such sensations being aroused.

It was also found that reaction to pricking and pinching was considerably less on the right than on the left side, though not completely abolished.

The animal died next day in a comatose condition.

Post mortem Examination.—The injury to the brain involved the convolutions to the extent described.

The division was carried down to the hippocampus, which, however, was not severed; and the lower part of the uncinate convolution and of the temporo-sphenoidal convolutions still remained, though almost severed from the rest of the temporo-sphenoidal lobe.

This experiment only gave partial indications of impairment of certain senses, particularly of hearing and smell, and in some degree of tactile sensation, and is chiefly important in relation to the other experiments to be described.

Fig. 13.

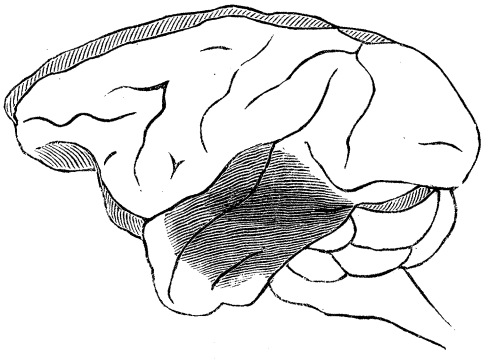


Fig. 13 represents the left hemisphere, and the shaded part indicates the seat of lesion in Experiment XI. The deep shading in the centre is intended to represent the part at which the temporo-sphenoidal lobe was deeply divided transversely almost as far as the hippocampus major. The lighter shading represents the extent to which the surface of the convolutions was destroyed.

Experiment XII.

January 27th, 1875.—The left hemisphere of a lively and intelligent monkey was exposed by a trephine opening in the region of the annectent gyrus connecting the posterior limb of the angular gyrus with the occipital lobe, and the upper part of the superior and middle temporo-sphenoidal convolutions further exposed by the bone-forceps.

With the cautery the convolutions exposed were thoroughly cauterized and the grey matter destroyed scooped out, while the cautery was directed horizontally inwards, so as to divide the lobe transversely as far as possible, taking care to avoid sinking it so deeply as to injure the crus. (See fig. 14, where the darkest part of the shading indicates the region of the greatest depth.)

The operation was completed at 4 P.M.

After a few minutes the animal recovered from its stupor, and began to look around.

Endeavoured to get up, but staggered towards the right side. Gradually recovered its equilibrium.

On being placed on a chair it gave evident proof of its retention of sight by jumping on to the table, and running to a dish containing milk, and drinking up the contents.

There is distinct reaction on both sides when a hot iron is applied to the skin. The animal starts, and rubs vigorously the part touched.

The extent of its hearing and smell were not ascertained at this time.

January 28th.—10 A.M. The animal is alive and well. Ate its breakfast as usual.

Can walk and jump about, and sees distinctly, as it puts out its hand and lays hold of objects before it.

In order to ascertain its condition as to hearing and smell, the right nostril and the left ear were tightly stopped with cotton-wool.

When offered a piece of apple it hesitated eating it, placing it to its nostrils over and over again, apparently as if it had difficulty in smelling.

Does not pay any attention when a noise is made, such as formerly caused it to respond actively.

Tactile sensation seemed unimpaired on both sides.

5 P.M. The left side of the scalp has become œdematous. The left eye is partially closed by œdema of the eyelids. Eats heartily.

Took a piece of apple offered it in its *left* hand.

On testing the right side by means of the hot iron there was a marked diminution of reaction on the ear, hand, and foot of the right side, as compared with the left.

Sight continues unimpaired. Smell and hearing are considered as impaired; smell on the left, and hearing on the right. It is difficult to ascertain by any crucial test whether they are gone on these sides.

January 29th.—10 A.M. The eyelids are œdematous. Ate some breakfast. When taken out of its cage sat still, unwilling to move. Takes every thing offered to it in its left hand. The animal drinks out of a dish, holding its head sideways, keeping the left side of its lips in contact with the fluid.

On testing with the hot iron there is very marked diminution of reaction over the whole of the right side of the body as compared with the left.

There is no loss of muscular resistance in the limbs of the right side. They do not hang flaccid as in motor paralysis. There is no facial distortion.

The limbs are occasionally moved, but they are not used by the animal in grasping or progression.

The foot and hand are frequently rested on the floor in irregular and what otherwise would be uncomfortable and unnatural positions.

The animal occasionally scratches its left side with its left hand. Occasionally utters a discontented grunt. Retains its intelligent look, and takes notice of what is going on around it.

It was killed with chloroform at 11.15.

Post mortem Examination.—The scalp was œdematous and the wound suppurating. From the opening in the skull a hernia cerebri of the diameter of a walnut was observed.

With the exception of this appearance on the surface, the brain otherwise was perfectly normal in appearance.

The fungus was attached to the superior temporo-sphenoidal convolution along two thirds of its extent.

The lower end of this and also of the middle temporo-sphenoidal convolution were not broken down externally, but they were much congested.

The rest of the lobe was completely broken up. The lesion extended inwards, so as to appear on the inner surface of the temporo-sphenoidal lobe, leaving only a continuity of a narrow band between the lower and upper end of the uncinate gyrus (see fig. 15).

The hippocampus was much softened.

The occipital lobe was intact, as also the optic thalamus.

The olfactory tract and bulb were uninjured, as also the crura, corpora quadrigemina, and corpus striatum.

This experiment is another link in the chain of evidence pointing to the association of hearing and smell with integrity of the temporo-sphenoidal lobe—hearing on the opposite and smell on the same side. The hypothetical seats of these, the superior temporo-sphenoidal for hearing and the subiculum cornu ammonis for smell, were either disintegrated or cut off by the lesion described. Though the effect is not regarded as conclusive proof of this association, it will be seen to derive importance from conjunction with other experiments to be related. At the same time, however, the fact is again noted that tactile sensation was almost completely abolished on the right side. This effect was subsequent to the phenomena just observed, and apparently advanced with the process of softening inwards towards the hippocampus and uncinate convolution.

Fig. 14.

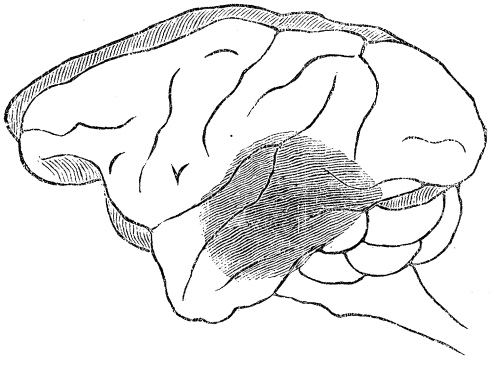


Fig. 14 represents by the shaded part the extent of the lesion as seen on the outer aspect of the left hemisphere in Experiment XII. The dark shading in the centre indicates the part at which the lobe was deeply injured.

Fig. 15.

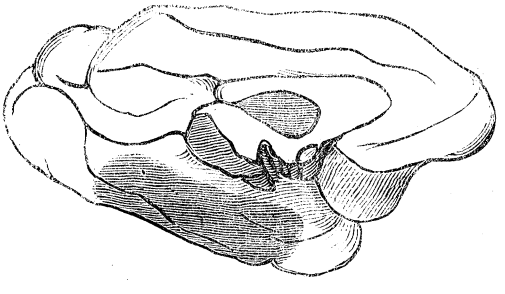


Fig. 15 represents the extent of the lesion, as seen on the inner aspect of the temporo-sphenoidal lobe.

Experiment XIII.

February 2nd, 1875.—The brain of a monkey was exposed by trephining over the

region of the annectent gyrus passing from the posterior limb of the angular gyrus into the occipital lobe on both sides.

By means of hot wires the temporo-sphenoidal lobe was divided transversely in this region, care being taken to avoid crossing the fissure of Sylvius, and also to avoid the crura and optic tracts.

The wires were also directed downwards and forwards, so as to break up the lobe as far as possible in the interior. This was carried out much more completely on the left than on the right side.

The operation was completed at 4 P.M.

4.30 P.M. The animal has recovered from its chloroform stupor, and moves about rather unsteadily.

It evidently retained its sight, as it directed its course to the fireplace, where it sat down to warm itself.

5 P.M. Drank a dish of tea offered to it. It sits still with its head bent on the floor, and seems disinclined to move. It has no muscular paralysis, and can hold on by both feet and hands. Sits, however, very unsteadily when perched on the back of a chair. Gives no sign of hearing when called to, as it used.

There is distinct reaction to the application of a hot iron to any part of its body, though there seems somewhat less reaction on the right side as compared with the left.

11.30 P.M. Is more lively, and looks about intelligently, and seems to walk somewhat more steadily.

February 3rd.—10.30 A.M. The animal was found sitting quietly with its head bent. On being roused and offered some milk, it drank a very little, but kept moving its lips about in the liquid, without continuing to drink.

Made no response when a loud sound was made close to its cage.

When taken out of its cage it moved only when nudged, and then made its way to the fire, where it sat down, holding on to the fender, enjoying the heat.

When tested with the hot iron there was found to be very decided diminution of sensation on the right side, on ears, hands, and feet.

There was no muscular flaccidity of the limbs or distortion of the face. A shrill sound made close to its ear caused it to start somewhat.

1 P.M. The animal was fed with milk, as it did not seem inclined to eat of its own accord.

Made no sign of reaction when acetic acid was held before its nostrils or placed in its mouth.

7 P.M. When acetic acid was placed within its nostrils it appeared to suffer from irritation, and at last a kind of sneeze was effected.

With the left hand it tried to clear away the offending matter from its left nostril, but made only a kind of attempt with the right hand to the right nostril, not succeeding in localizing the seat of irritation. Opened its eyes slightly when loudly called.

It uses its left hand more than the right in laying hold of any thing. Formerly it used the right chiefly.

It is very easily knocked over by a push when it is sitting, often falling quite supine.

It was again fed, as it does not seem able to feed itself.

8 P.M. The eyelids are somewhat œdematous, more so on the right than on the left.

The animal sits leaning its weight chiefly on the left arm and leg. When knocked over, which is done by a slight push, it recovers itself chiefly with the left arm and leg. The right leg, when it sits, is sometimes doubled up, and rests on its outer side. It makes no use of its right arm for any voluntary movement. The left arm and leg are moved cautiously. Muscular resistance continues in all four limbs. There is no facial distortion.

On being tested with a red-hot iron there was entire absence of reaction on the right side. The left side seems to react somewhat less than before.

The animal, in struggling when acetic acid was placed in its nostrils, moved all four limbs, but it fell repeatedly while trying to get rid of the irritation.

At 9 P.M. the animal was killed with chloroform.

Post mortem Examination.—The skull was deficient below the parietal eminences, and the brain-substance was protruding slightly from the orifices in the skull. The dura mater stripped readily from the brain, but underneath it there was found a thin layer of extravasation over the region of the right temporo-sphenoidal lobe.

In the left hemisphere (see fig. 17) there was a surface corresponding to the trephine-

Fig. 16.

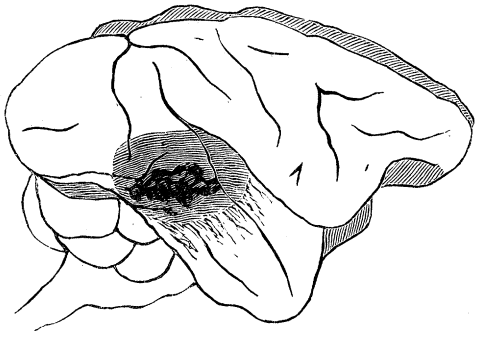


Fig. 16 represents the right hemisphere, and the shaded part the extent of superficial injury in Experiment XIII. The dark shading in the centre indicates the point of greatest depth of the lesion. The dotted lines indicate the extent of internal softening of the medullary matter.

Fig. 17.

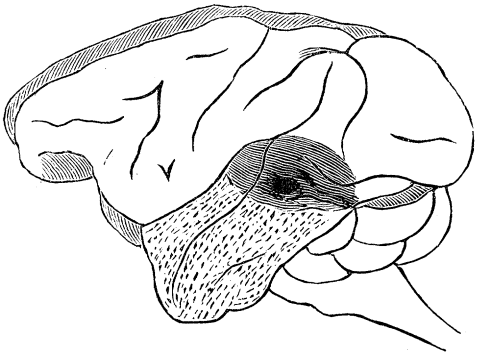


Fig. 17 represents the left hemisphere, and the shading the extent of superficial lesion in Experiment XIII. The deep shading in the centre indicates the line of deep transverse section, and the dotted lines indicate the extent of internal softening of the interior of the lobe.

opening of about the size of a shilling, somewhat elevated above the surrounding surface. The middle of this was deeply excavated, and the division extended from behind the

fissure of Sylvius below the inferior occipital fissure to the edge of the uncinate convolution on the internal aspect.

In the right hemisphere the fungating mass occupied about the same extent as in the left, but extended somewhat further backward into the occipital lobe.

The temporo-sphenoidal lobe was not divided to the same extent transversely; but a deep excavation occupied the centre of the fungating surface, and corresponded to the level of the upper end of the middle temporo-sphenoidal convolution (fig. 16). The internal aspect of the temporo-sphenoidal lobe was of normal appearance.

The rest of the brain was normal.

On examination after the brain had been hardened in spirit for 20 hours, it was found that in the left hemisphere the transverse division extended almost to the hippocampus. The whole of the interior of the lobe below this point was reduced to a pulp, the softening extending to some extent between the lips of the fissure of Sylvius, and affecting the surface of the island of Reil to a slight extent.

The grey matter of the lower half of the temporo-sphenoidal convolutions and of the uncinate gyrus formed a sort of shell, enclosing softened medullary substance. The hippocampus was disorganized as far as the subiculum cornu ammonis. The optic thalamus was not injured.

In the right hemisphere the excavation extended to the extraventricular surface of the optic thalamus, but the hippocampus and fornix could still be seen of normal or almost normal appearance. The internal or medullary surface of the superior and middle temporo-sphenoidal convolutions was softened to a slight extent below the point of greatest depth of the wound on the hemisphere. The subiculum and the lower ends of these convolutions are not injured externally.

In this experiment the results as regards hearing were such as to indicate abolition, or at least considerable impairment, of reaction to stimuli which in the ordinary conditions are responded to actively. So far, therefore, the theory that this is dependent on the destruction of the superior temporo-sphenoidal convolution holds good, for this convolution was divided or disintegrated almost completely on both sides.

The reaction to acetic acid in the nostrils is not to be taken as a sign of the retention of true smell, for it in all probability was more due to irritation of nerves of common sensation.

The reaction, however, was decidedly diminished, and was not caused when the vapour was held only before the nostrils.

The absence of reaction on the tongue points to impairment of the sensation of taste, and perhaps the want of desire to eat may have its explanation in loss of this faculty.

The experiment, however, is not regarded as conclusive, and is to be taken in connexion with other facts. It is brought out more clearly than before that the loss of tactile sensation coincides with lesion of the hippocampus and hippocampal convolution. This region was quite destroyed on the left side, and loss of tactile sensation was observed on the opposite side; while on the left side tactile sensation apparently

continued good, the hippocampus and uncinate gyrus remaining intact, or at least not presenting any marked abnormality on the right hemisphere.

Experiment XIV.

March 9th, 1873.—The brain of a monkey was exposed on both sides in the region of the upper part of the superior and middle temporo-sphenoidal convolutions, and red-hot wires were passed from this point downwards and forwards, with the intention of breaking up the grey matter on the outer aspect of the lobes as far as the subiculum cornu ammonis. Owing to hæmorrhage from the left, the destruction was made more deeply than intended into the lobe in attempts to check it. The operation was completed at 3.30.

4.15 P.M. Is recovering from its stupor, and moves when disturbed.

4.25 P.M. Begins to sit up, but seems to have some difficulty in using its right limbs.

4.40 P.M. Tactile sensation seems gone on the right side. There is no reaction to the application of a hot iron to the right hand or foot, but slight on the ear. The same heat causes violent reaction on the left side.

The animal has not yet sought to move about.

4.50 P.M. Neither aloes nor citric acid caused any reaction when placed on the tongue.

Acetic acid caused no reaction when held befor the nostrils.

Tactile sensation, as indicated by reaction, is unimpaired on the left side, but there is no reaction on the right side to hot iron or pinching.

Acetic acid caused no reaction when placed on the tongue.

No reaction to the application of a hot iron to the right side of the tongue, and little, if any, on the left.

The animal sits up, supporting itself with its left hand and foot chiefly. Makes no use of its right hand, but clings firmly with its left hand when about to be placed on the floor after being taken up.

5.10 P.M. Acetic acid placed within the right nostril caused no reaction and no lacrymation. Placed within the left nostril caused no torsion on turning away the head, but caused a copious flow of tears from the left eye.

5.40 P.M. Aloes nor acetic acid applied to the tongue caused any reaction.

The animal is perfectly conscious; though it sits still, and is disinclined to move.

It gives no signs of hearing when a noise is made beside its cage.

Cutaneous sensibility of the left side remains intact; apparently is quite gone on the right. The animal was placed in its cage, where it lay half asleep, but immediately roused itself when the left hand was touched.

6 P.M. While lying asleep in its cage with the tongue showing between the teeth, acetic acid was applied to the top of the tongue. No reaction of any kind ensued. Applied to the left nostril no movement resulted.

A hot wire applied to the tip of the tongue caused no reaction. The same stimulus

applied to the left hand caused a sudden start, opening of the eyes, and withdrawal of the hand.

The left side of the lip and face retained sensibility.

8 P.M. A faint reaction ensued on the application of the hot iron to the right foot.

The same stimulus applied to the hand caused no reaction. The tongue remained absolutely insensible. The left side of the body gives active reaction.

9 P.M. I repeated these tests in presence of Dr. LAUDER BRUNTON. The absolute want of reaction on the right side with the exception of slight reaction of the right foot, the retention of sensibility as indicated by reaction on the left side, the absolute insensibility of the tongue to stimuli of any kind, the entire want of reaction to acetic acid placed in the right nostril, and the copious lacrymation of the left eye when it was introduced into the left nostril were confirmed in his presence.

Desirous to avoid further complication after this demonstration, I killed the animal with chloroform.

Post mortem Examination.—The brain, except at the points to be described, was everywhere normal. The base of the brain and the cranial nerves were intact. The fifth and the Gasserian ganglion on both sides were specially examined and found intact.

In the left hemisphere there was a wound with blackened edges, of the extent seen in fig. 18, occupying the upper part of the superior and middle temporo-sphenoidal

Fig. 18.

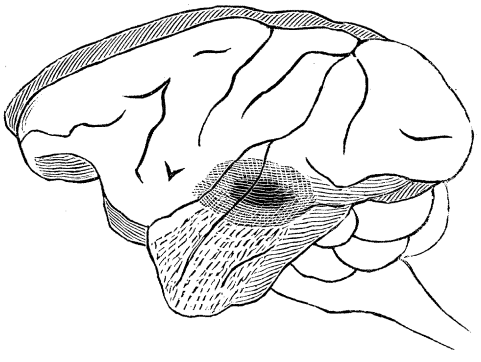


Fig. 18 represents the left hemisphere, and the shading the extent of the lesion in Experiment XIV. The deep shading in the centre indicates the point of deepest excavation, and the dotted lines proceeding downwards and forwards are intended to represent the extent of internal disintegration of the lobe.

Fig. 19.

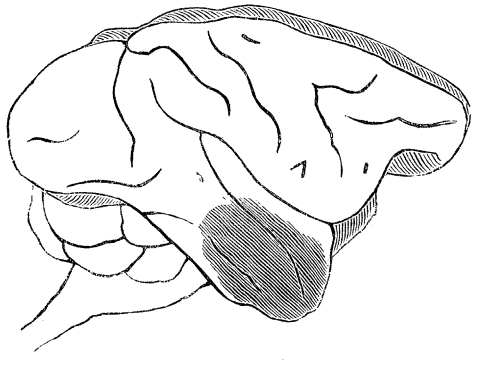


Fig. 19 represents the extent of lesion in the right hemisphere in Experiment XIV. The shading indicates the extent to which the grey matter was destroyed.

convolutions. The middle of this was excavated, and the lesion was continued into the interior of the lobe, the whole of which was converted into a softened mass, enclosed by a shell of grey matter on the outer and inner aspect of the lobe. The hippocampus was injured at a point opposite the wound, and was softened throughout below this. There was some blackened effusion within the lips of the fissure of Sylvius and covering the surface of the island of Reil, which, however, was of normal consistence,

and easily separable from the convolutions overlapping it. The lower part of the ascending frontal convolution was slightly softened and congested.

In the right hemisphere the surface of the lower half of the temporo-sphenoidal convolutions was quite disintegrated and blackened (fig. 19). The subiculum cornu ammonis was broken up. The softening did not extend to the fissure of Sylvius. The internal aspect of the lobe, the hippocampus, and uncinate convolution were normal, except at the subiculum, as already described. No other injury existed in any part of the brain.

This experiment was followed by results of a very remarkable character.

There was absence of reaction to stimuli of smell, taste, hearing, and of tactile reaction on the right side (almost complete).

As regards the loss of tactile sensibility, we have again the apparent connexion of this with destruction of the hippocampal region.

On both sides the subiculum cornu ammonis was broken down, and on both sides there was absence of any reaction indicating olfactory sensation.

A peculiarity, however, existed in the comparative reaction of each nostril to the effect of acetic acid. In the left nostril, *i. e.* the side on which tactile sensibility remained, acetic acid caused a copious flow of tears from the left eye, while in the right nostril no effect of any kind was produced. This is evidently to be ascribed to the abolition of common sensibility as well as of true smell from the right nostril. The lacrymation was the indication of the reflex excitation of the lacrymal gland through the medium of tactile sensibility, which still continued unimpaired on the left side. The absence of motor reaction, however, was an interesting fact, and serves to show how much of the reaction caused by a pungent vapour applied to the nostril is dependent on the integrity of true olfactory sensibility.

As regards taste, the results indicated its entire abolition. But not only taste, as such, but also the tactile sensibility of the tongue seemed to have been destroyed. This was noted as a remarkable phenomenon, and the tests were frequently repeated in order that no fallacy might be allowed to remain. Not only on the right side of the tongue, but also on the left, was this absence of reaction noted. The centres for the tactile sensibility of the tongue on the left side seemed to have been destroyed along with those of special sense, a fact apparently indicating their close anatomical relation in the hemisphere. The following experiments serve to narrow the boundaries of the lesions causing these various results as regards hearing and tactile sensation.

Experiment XV.

April 7th, 1875.—The subject of this experiment was the same monkey used for Exp. IX.

After the animal had quite recovered from the effect of destruction of the angular gyrus on the left side, it was again chloroformed, and the superior temporo-sphenoidal

convolution was destroyed on both sides throughout the greater part of its extent, by means of the blowpipe cautery passed along the surface.

An hour after the operation (6.30 P.M.) it still staggered while walking, and looked only half awake. Made no sign when a whistle was made close to its ear or when called loudly.

Acute sensibility existed on both sides, as determined by the application of a hot iron. It rubbed vigorously the parts touched.

Aloes and citric acid placed on the tongue caused great annoyance and movements of the mouth and tongue to expel the offending substance. The animal also ground its teeth, and then got up and ran about the room, grinding its teeth, and annoyed at the unpleasant sensation in its mouth.

Acetic acid held before its nostrils caused it to start and sneeze and rub its nose.

When not disturbed sat quietly with its head down.

8.30 P.M. Found asleep in its cage. Made no sign of perception till I laid hold of it, when it started with a shriek. Looked up and ran to a dish of water and drank.

Again, on trying to rouse its attention, it did not look up when a loud sound was made, though its companion looked terrified.

12.30 A.M. A loud sound made in the immediate vicinity of its cage caused a slight start.

April 8th.—10 A.M. Animal alive and active, and jumped out of its cage when the door was opened. Sight was good, and tactile sensation unimpaired. Various experiments were made to ascertain the existence or not of hearing; but it was difficult to devise a test, as the animal was continually on the alert; and it was not easy to make a sound without in any way attracting its attention by sight. The following method was tried. While the animal was sitting quietly by the fire, I retired to the other room, and while watching through the chink of the half-shut door called loudly, whistled, knocked on the door, tinkled glass, &c., without ever causing it to look round or give any sign of having heard. I then cautiously approached the animal, and not till it saw me did it give any sign of consciousness of my presence.

When the same experiment was repeated, while the monkey and its companion were quietly seated by the fire enjoying the heat, it gave no sign of hearing, while its companion started with alarm, and came with curiosity to ascertain the cause of the sound. At 12 (noon) the test of sight, related under Exp. IX., was made.

8 P.M. In presence of Dr. BURDON SANDERSON I repeated the various tests with the view of eliciting signs of hearing. To all it remained without response. It seemed unconscious of my presence when speaking close to its ear, and only started when it caught sight of me.

April 9th.—The animal was found weak and prostrate, and was killed with chloroform.

Post mortem Examination.—There was a considerable amount of pus underneath the scalp and below the detached surface of the left temporal muscle. Pus was found beneath the dura mater continuous with the collection beneath the muscle. The surface of the brain was otherwise intact, except at the points to be described.

In the left hemisphere the brain-surface corresponding to the opening in the skull to the extent indicated by the dotted line in fig. 20 was elevated above the rest and congested. The surface of the angular gyrus and of the superior temporo-sphenoidal convolution was disorganized to the extent seen in the figure. The lower part of the shading indicates medullary softening, caused by passing a hot wire into the substance.

In the right hemisphere (fig. 21) a similar dotted line indicates the extent of the

Fig. 20.

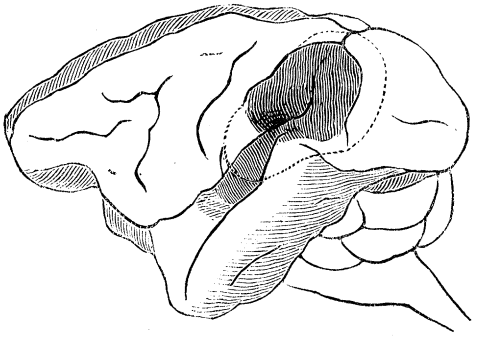


Fig. 20 represents by the shading the extent of destruction of the grey matter of the left hemisphere in Exp. XV. The dotted line indicates the extent of surface exposed by removal of the bone and dura mater.

Fig. 21.

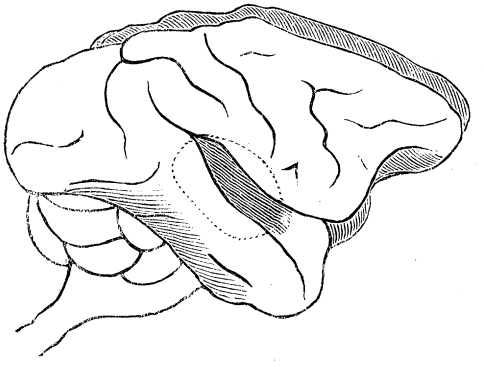


Fig. 21 represents the extent of the lesion in the right hemisphere in Exp. XV.

The dotted line has the same signification as in last figure.

opening of the skull, and the extent of congestion and hernia of the surface of the brain. The hernia was only slightly elevated above the rest of the hemisphere. The lesion was accurately circumscribed.

The grey matter on the surface of the superior temporo-sphenoidal convolution was destroyed throughout the upper two thirds of its extent (*i. e.* the extent which reacts to electrical stimulation).

The base of the brain, ganglia, and cranial nerves were intact.

This experiment (besides confirming the fact of loss of sight by destruction of the angular gyrus) serves to localize the effects as to hearing, which were observed to result from extensive lesions of the temporo-sphenoidal lobe. It is obviously more difficult to ascertain the presence or absence of the sense of hearing in the lower animals than in man, on account of the difficulty of distinguishing between reflex action and true sensory perception.

In the above experiments, involving destruction of the superior temporo-sphenoidal convolution, it will be seen that, with the exception of an occasional start to a shrill sound, in general there was an abolition of reaction to sounds which in normal conditions are sufficient to excite active attention, and this while the animals were on the alert and in full possession of their other senses.

If this absence of reaction, except where it might well be the result of reflex action,

following the destruction of this region of the brain, be taken with the phenomena resulting from electrical stimulation of the same part, we have, it appears to me, as satisfactory proof as it is possible to obtain from the lower animals, that the sense of hearing is localized on the superior temporo-sphenoidal convolution.

Having thus eliminated the result of destruction of this convolution from the complex effects caused by more extensive lesions of the temporo-sphenoidal lobe, I proceed to describe experiments tending to fix more definitely the seat of tactile perception.

Several experiments have already been detailed, which rendered it more than probable that the loss of tactile sensation was dependent on lesion of the hippocampus major or uncinate convolution, or both.

Experiments were devised for the purpose of destroying this region without injury to the rest of the temporo-sphenoidal lobe. To effect this seems almost impossible, considering its deep-seated and concealed position in the internal aspect of the hemisphere.

The method I at last resolved to pursue was to endeavour to reach this from the occipital region by passing heated wires through the posterior aspect of the occipital lobe in the direction of the hippocampus. I had first ascertained the negative effects of destruction of the occipital lobe. These will be related subsequently.

Having made repeated experiments on the dead brain, so as to acquire knowledge of the direction and extent to which the cautery should be pushed, I proceeded to experiment on the living animal.

My first attempts were not quite successful, as will be seen, but ultimately my efforts were rewarded with success.

Experiment XVI.

February 5th, 1875.—This, though not successful as regards the object intended, yet presents some interesting phenomena. The left occipital lobe was exposed posteriorly, and penetrated at the posterior extremity of the superior occipital fissure by means of hot wires, which were directed with a view to follow the inner aspect of the temporo-sphenoidal lobe. There was no hæmorrhage from the sinus. During the operation the animal was observed to make sighing respiration. The operation was finished at 4.30 P.M.

The animal lay in a state of stupor for more than an hour, only making slight movements when disturbed, and then with its left limbs.

7 P.M. The animal lies quiet, but indicates consciousness by grunting discontentedly when moved. Struggles with its limbs, chiefly the left, but occasionally with the right.

On testing the cutaneous sensibility with the hot iron, reaction was decisive over the whole of the left side, but quite abolished on the right. The animal occasionally opened its right eye, but the left remained permanently closed. The animal passed into a state of coma, and was found dead at 11.30 P.M.

Post mortem Examination (next morning).—It was found that the cautery, as indicated by the blackened sinus, had penetrated the occipital lobe at the point mentioned, where a round hole was situated, and on emerging had ploughed a furrow on the upper

end of the uncinate gyrus, but then leaving the inner aspect of the temporo-sphenoidal lobe, had ploughed off the left tubercles of the corpora quadrigemina, then penetrating the middle of the left optic thalamus had passed inwards and emerged at the longitudinal fissure on its basilar aspect. The corpus striatum was uninjured, as the wire had penetrated to the inside of this ganglion.

There was no effusion into the skull, and, beyond the injury narrated, the rest of the brain had not been injured. The optic tract of the left side had of course been destroyed along with the left tubercles of the corpora quadrigemina, and the anterior extremity of the sinus was situated just in front of the optic commissure.

In this the loss of sensation on the opposite side coincided with destruction of the left optic thalamus and the injury to the *tegmentum cruris*.

The ptosis of the left eye indicated the destruction of the nucleus of the third nerve, situated just below the region of the lesion in the corpora quadrigemina. As the optic thalamus was destroyed along with part of the uncinate convolution, this experiment of course does not warrant any conclusion as to the effect of destruction of this convolution itself.

As regards the optic thalamus, and the effect of its destruction, see also Exp. XIX.

The following experiment is a repetition of the last, and was only partially successful.

Experiment XVII.

February 9th, 1875.—The left occipital lobe of a monkey was exposed as in last experiment, and hot wires were pushed through the tip of the occipital lobe in a direction downwards and outwards, approximately in the direction of the hippocampus major. There was no hæmorrhage of any extent.

The operation was completed at 3.15 P.M. The animal was already conscious before the wound was dressed. It was freed and laid before the fire.

3.30 P.M. Lies by the fire breathing quietly. Pupils equal, and both eyes open. Utters a grunt of recognition when called to, and also begins to move its tail and right hand.

Gets up, but sits unsteadily, inclining to fall over on its right side. Reaction to hot iron distinct on both sides of the body.

3.50 P.M. Retains sight unimpaired. Can now sit up more steadily and walk without falling. Took a piece of apple offered to it in its right hand and ate it.

5 P.M. Took some tea, and ate some fruit. While sitting before the fire accidentally touched the bar of the grate, on which it manifested a lively sense of pain, and rubbed the part. The animal seems to retain all its senses and muscular power unimpaired.

9 P.M. Continues as before. Clings with right as well as left hand to its cage when laid hold of.

When offered any thing to eat, it now uses its *left* hand, whereas formerly it almost invariably employed the right. There is a distinct reaction to heat on the right side.

February 10th.—10 A.M. Remains as before. Eats and drinks heartily. Sees and hears perfectly. Reaction to hot iron still continues on both sides.

No difference observed in the animal when again tested at 7 P.M.

February 11*th*.—10 A.M. The animal looks much as before. The wound is suppurating freely. Can see and hear, and move about. Takes every thing offered to it in its left hand. Reaction to hot iron still continues on both sides. A sore on its right foot seems to cause it great trouble, as it is continually biting and scratching it.

February 12*th*.—10 A.M. The animal ate and drank as before. There appeared to be slight twitching of the right side of the body. Reaction to heat still observed on both sides.

10.45 A.M. The animal had again a return of the twitching of its right side. The animal was quite conscious, and did not fall. After a few minutes the animal walked back to the fire, whence it had been removed for observation. It was now seen to drag its right limbs somewhat.

11.40 A.M. In climbing in its cage seems to have great hesitation in using the right hand. When taken out had a slight return of the twitching. When it had ceased some food was placed in its right hand. Failed to grasp it, but took it with its left hand, raised it to its mouth and ate.

4 P.M. Still continues to drag its right limbs in walking, and cannot grasp with the right hand. There is marked diminution of reaction on the right side, as compared with the left, when a hot iron was applied.

After this there was a return of the spasmodic twitching of the right side.

In the interval of the fits the right leg was again tested with the hot iron, and reaction seemed to have entirely disappeared, while reaction was active when the stimulus was applied to the left.

Towards evening the animal began to exhibit symptoms of basilar meningitis, suffering from frequent convulsive seizures. It became comatose, and died in convulsions on February 13.

Post mortem Examination (February 13th, 10.30 A.M.).—The exposed posterior extremity of the left occipital lobe was fungating. The dura mater stripped easily from the surface of the brain; but the vessels of the pia mater were injected on the left hemisphere, particularly on the postero-parietal region.

The course of the wire was easily traced by the sinus it had caused, and by a line joining the points of entrance and exit. After penetrating the occipital lobe it had ploughed a furrow on the upper extremity of the uncinate gyrus (see fig. 22), and then, instead of following the inner aspect of the temporo-sphenoidal lobe, had made its way horizontally outwards through the lobe, and emerged on the outer aspect at the extremity of the superior temporo-sphenoidal fissure (see fig. 23). On examination of the brain after hardening in spirit, it was found that softening had extended from the track of the wire, and that the hippocampus was in great measure softened down and disorganized.

In addition to these appearances there were signs of inflammation of the membranes at the base of the brain, on the pons. and anterior surface of the medulla. The left

optic tract was adherent to the hippocampal convolution. The dura mater in the left sphenoidal fossa, and on the left petrous bone, and on the basilar process had a yellowish

Fig. 22.

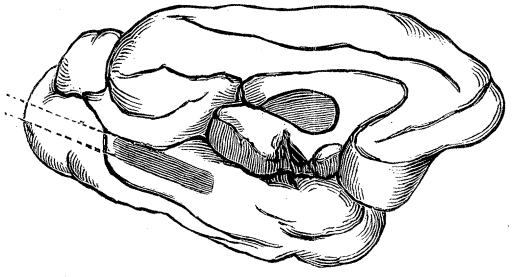


Fig. 22 represents the lesion of the uncinate gyrus and the direction of the sinus caused by the cautery in Exp. XVII.

Fig. 23.

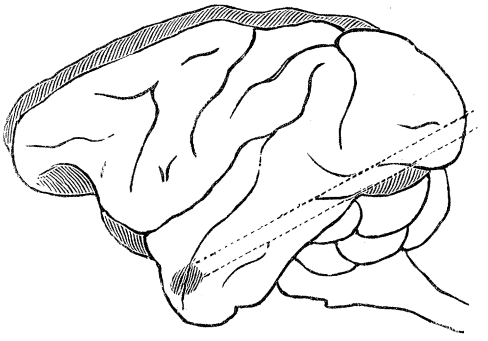


Fig. 23 represents the outer surface of the same hemisphere, and the dotted lines indicate the track of the cautery in Exp. XVII. The black dot at the extremity of the upper temp.-sph. fissure indicates the point at which the track terminated externally.

aspect. The inflammation appeared to have spread from the point in the left sphenoidal fossa where the cautery had emerged from the brain. The optic thalamus and other ganglia were normal, except perhaps slight extension of the inflammation up the left optic tract to the left nates and testes.

This experiment became complicated by the results of basilar inflammation, but it is possible to trace the course of the phenomena.

The cautery, as determined by the points of entrance and exit, seems, after ploughing along the upper end of the uncinate gyrus, just to have missed the hippocampus and descending pillar of the fornix. At first the effects were negative or nearly so; but gradually the animal began to exhibit failing sensation, as indicated by the diminution of reaction to tactile impressions and inability to use the right hand, until ultimately sensation became to all appearance abolished, or nearly so, on the right side. This would coincide with the advance of softening into the hippocampus, as was found to be the case after death.

Whether the spasmodic affection of the right side is to be attributed to sensory irritation excited by the progress of inflammatory softening is a question; but it had also a possible origin in the basilar inflammation which, extending from the left sphenoidal fossa, naturally would affect the left half of the pons and medulla first, and show its effect by convulsive action of the opposite side of the body in the first instance.

This complication renders it difficult to estimate the exact effect of the lesion in the temporo-sphenoidal lobe; but the difference observed in the reaction of the two sides to the hot iron strongly confirms the view that this was dependent on the lesion of the hippocampus in the left hemisphere.

The following experiment serves to confirm this view.

Experiment XVIII.

March 2nd, 1875.—A large monkey of the baboon type was chosen for this experiment. As it seemed to be usually left-handed, the right hemisphere was operated on.

The right occipital lobe having been exposed, hot irons were passed through the posterior aspect of the lobe in the direction of the hippocampal gyrus.

There was no hæmorrhage of any moment.

The operation was completed at 3.15 P.M.

3.20 P.M. The animal lies by the fire, having recovered consciousness, and moves its limbs, but has not yet attempted to get up.

3.25 P.M. When moved it opened its eyes, whence it was concluded that the crus cerebri had not been injured.

While lying by the fire scratched its right leg with its right hand. Does not move its left arm or left leg, whether laid on its right or left side.

3.35 P.M. There is no reaction to a hot iron on the left side. The same stimulus causes active manifestation of pain and rubbing when applied to the right side.

3.45 P.M. Begins to sit up and look about.

Moves only the limbs of the right side, and in sitting up occasionally falls over on its back.

The test of the hot iron was again applied.

On the right side the slightest touch caused active reaction, and caused the animal to rub the part touched. Applied to the left foot, the iron was kept in contact several seconds without causing the slightest reaction, but when kept up longer a slight retraction was caused. The same result was obtained on the left hand and the right ear.

Pinching of the right hand and right foot caused violent reaction and slight cry. No effect followed the strongest pinching of the left hand and foot. The left ear gave slight reaction to pinching.

4 P.M. The animal is sitting up and looking about. Grunts when called to. Occasionally falls over. Recovers itself by the aid of its right limbs. It can draw the legs together, but the left foot is generally allowed to straddle outwards and rest on the internal malleolus. The left arm is kept motionless in a semiflexed condition. Muscular resistance continues.

4.15 P.M. When offered food it took it with the right hand, and raised it to its mouth.

Occasionally moves its left arm and leg while sitting still, but does not use them to grasp or in progression.

The reaction to the hot iron is still persistent on the right, but gone on the left side.

The animal was occasionally seen to give a jerk of its head and grind its teeth, which I attributed to some irritation of the fifth nerves, probably caused by inflammation of the dura mater in the neighbourhood of the Gasserian ganglion, set up by contact of the cautery.

4.30 P.M. The reaction to heat was again tried. A hot iron is allowed to remain in contact with the right side without causing any reaction, except when kept so long as to burn the part, while the slightest contact with the right side causes violent reaction and active rubbing of the part. This was observed on the ear, hand, and foot.

There is no facial distortion.

5.45 P.M. On being placed in its cage the animal mounted its perch with difficulty, and sat unsteadily with its head down. On turning its body a little the left leg slipped off the perch. The animal, in recovering itself, clutched hold of the bars of the cage with its right hand, and though the left was placed on the bars no grasp was made with it. Aided by its teeth and the right hand, it ultimately regained its equilibrium, and dragged up its left leg, after having fairly got hold of the perch with its right.

Sits now holding on firmly to the perch with the right foot.

After this, on the animal shutting its eyes and going to sleep, the left foot frequently slipped off, causing sudden grasping with the right hand on the cage until it recovered its equilibrium.

8 P.M. The anæsthesia of the left side being again firmly established, and the animal being otherwise well and apparently in possession of all its other senses, the animal was killed with chloroform, in order to avoid complication by the extension of the lesion.

Post mortem Examination.—The exposed surface of the right occipital lobe was slightly congested. The surface of the brain, except at the point of entry of the cautery, was everywhere else normal. There was no effusion within the skull. There was injection of the vessels of the dura mater in the right sphenoidal fossa and over the region of the Gasserian ganglion, extending from an inflamed spot with which the point of the wire had come in contact.

The base of the brain and cranial nerves were normal in appearance. The crura, the corpora quadrigemina, the optic thalami, corpora striata, pons, and medulla were uninjured and normal in appearance.

The cerebellum was just grazed on its right upper lobe, where the cautery had come in contact with the tentorium in its course.

The track of the cautery was clearly traceable. It had penetrated the right occipital lobe just at the posterior extremity of the superior occipital sulcus. Here there was a round hole with blackened edges, about a quarter of an inch in diameter.

Emerging on the under surface of the lobe, the track appeared as a deep furrow, commencing at the posterior termination of the calcarine fissure, and running along the uncinate gyrus for about an inch. Thence following a concealed course below the surface of the uncinate convolution, which yielded to pressure, it emerged at the tip of the temporo-sphenoidal lobe on the orbital aspect of the lower end of the superior temporo-sphenoidal convolution, two lines external to the subiculum cornu ammonis. On cross section of the lobe it was found that the cautery had ploughed along the hippocampus major.

The track of the cautery was followed with precision by the discoloration caused.

This experiment indicates with precision the region in the temporo-sphenoidal whose destruction is followed by impairment or total abolition of tactile sensation.

In the various cases in which this result followed extensive lesion of the temporo-sphenoidal lobe, it was found that the hippocampus major and the hippocampal convolution were more or less extensively involved. The destruction of these convolutions alone, as shown by this experiment, abolishes tactile sensation alone.

Fig. 24.

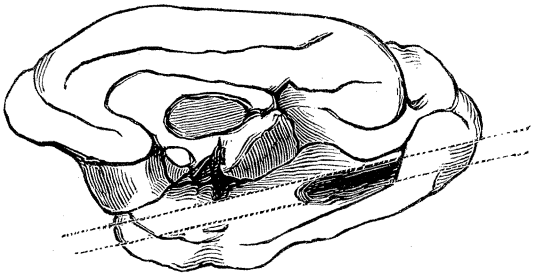


Fig. 24 represents by the shading the external extent of the lesion in the uncinate convolution, and the dotted lines the track of the sinus caused by the cautery in Experiment XVIII.

To ascertain the existence or absence of this sense is surrounded with some difficulty, owing to the fact that reflex reaction may simulate the appearance of tactile sensation, properly so called. The mere fact of reaction to a stimulus is no proof of the existence of sensation.

The entire absence of reaction, however, observed in some of the preceding experiments, where the hippocampal region was completely destroyed, is a strong proof of the abolition of sensation, when it is considered that reaction was lively and marked on the opposite side of the body at the same time.

But the loss of tactile sensation is even more conclusively indicated by the fact that monkeys in whom the hippocampal region was destroyed ceased to use the opposite limbs for the purposes of prehension or the exercise of the faculty of touch.

To react to tactile stimuli may signify reflex action or tactile sensation, or both; *to touch* necessarily implies the possession of the power of tactile perception.

The condition of the limbs in these cases was such as to simulate motor paralysis; and it is well known that Sir CHARLES BELL mistook the immobility of the side of the face resulting from anæsthesia caused by division of sensory branches of the fifth for real motor paralysis. It was pointed out by MAYO that, owing to the loss of tactile sensation, an animal has no indication for the regulation and adaptation of its muscular movements, and hence ceases to make them. That anæsthesia, and not motor paralysis, existed on the side opposite the destruction of the hippocampus, is shown by the fact that a certain degree of voluntary motion was retained. The animal (Exp. XVIII.) whose leg was anæsthetic could replace it on the perch, though it continually tended to slip off when the animal withdrew its attention from it.

There was no muscular flaccidity as in true motor paralysis, nor was there any appearance of facial distortion, such as would have been produced by motor paralysis of one side.

It is impossible to differentiate between lesion of the hippocampus itself and of the hippocampal or uncinate convolution. A lesion involving the hippocampus necessarily involves the medullary aspect of the uncinate convolution, and it is impossible to destroy the uncinate convolution without injuring the hippocampus.

In the above-mentioned experiments both these convolutions were more or less conjointly involved.

Owing to this difficulty, I shall speak of the two together as the "hippocampal fold," and regard this as the seat of tactile perception.

We are now in a position to differentiate the various effects on sensation caused by general destruction of the temporo-sphenoidal lobe.

As regards hearing, separate evidence is given in Experiment XV. of the localization of this faculty in the superior temporo-sphenoidal convolution.

The absence of reaction to the usual auditory stimuli, combined with the effects of stimulation of this convolution, afford evidence of the strongest possible character of the localization of this sense.

The localization of smell is no less clearly indicated. Anatomically, the connexion between the olfactory tract and the subiculum cornu ammonis, though less evident in man, is clear in the monkey, and very apparent in the lower animals.

The effects of irritation of this region are very constant and characteristic, and are of the same nature as direct irritation of the nostril or of the olfactory bulb itself.

Destruction of this region causes abolition or diminution of reaction to stimuli on the same side as the lesion.

Taken together, these facts establish the localization of the sense of smell in the subiculum, or tip of the temporo-sphenoidal lobe.

As to the sense of taste, the positive indications are less distinct than those of smell or hearing.

Yet the phenomena occasionally observed on stimulation of the lower part of the middle temporo-sphenoidal convolution, viz. movements of the lips and cheek-pouches, may be taken in connexion with lesions affecting this region, and accompanied by loss of reaction to stimuli of taste, to afford evidence of no weak character for the localization of taste in or near this region.

That the centres of gastatory and olfactory perception are closely related to each other anatomically is rendered probable by the fact, often observed, of loss of taste and smell following severe blows on the head, and particularly of the vertex. It is not at all likely that one and the same cause should simultaneously directly affect all the nerves which are involved in the sensations of smell and taste; but it is easy to understand that a *contre-coup* might readily affect the integrity and functional activity of the lower end of the temporo-sphenoidal lobe, in which the above experiments serve to localize the central seats of these faculties.

We have thus accounted for the senses of sight, hearing, taste, smell, and touch, and given evidence for the localization of each and all of these in the central convolutions.

Whether they are all integrated in the optic thalamus is a subject on which the experiments I have yet made do not furnish sufficient evidence; but the following experiment serves to prove that, in regard to tactile sensation, this is the case.

Destruction of the Optic Thalamus.

Experiment XIX.

February 12*th*, 1875.—The left hemisphere was exposed by a trephine-opening in the region of the pli de passage from the posterior division of the angular gyrus to the occipital lobe.

With a small trocar and cannula (after the method adopted by NOTHNAGEL in his experiments on rabbits) the anterior extremity of the annectent gyrus was perforated horizontally in the direction which experiments on the dead brain had taught me to reach and destroy the optic thalamus.

After withdrawal of the trocar, a stilette with expanding wings was passed through the cannula, and rotated so as to break up the parts with which it should come in contact.

There was some hæmorrhage from the cannula.

The operation was completed at 5.30 P.M.

5.50 P.M. The animal now is sitting up, leaning towards the right side. Makes some movements with its left limbs.

7 P.M. The animal looks quite active and intelligent. Can move about pretty freely, but seems weak on the right side. Does not use the right hand in taking hold of any thing presented to it. A hot iron applied to the right hand caused the animal to wince and rub the part touched.

8 P.M. Animal can move about. Took a piece of apple offered to it in its left hand, and held it to its mouth with both hands. Sight and other senses do not seem affected.

8.45 P.M. A bandage was placed on the left eye in order to ascertain the condition as to vision on the right. The bandage could not be maintained, as the animal bounced about, knocking its head against furniture, and tearing at the bandage till it got it off. Owing to this the condition as to sight could not be definitely tested, though the running against obstacles seemed to indicate affection of sight in the right eye.

February 13*th*.—11 A.M. The animal is much in the same condition as yesterday. Uses all four limbs in walking, but the movements of the right are made with caution and hesitation; nor does it use the right hand in grasping, taking every thing offered to it with the left.

3 P.M. Thinking that the optic thalamus had been only partially destroyed, I passed a hot wire in the track of the cannula, so as to completely traverse the optic thalamus, the distance &c. being carefully calculated from the result of experiments on the dead brain.

Before the animal recovered from chloroform the left eye was bandaged, and the animal laid before the fire.

3.10 P.M. The animal, while lying before the fire, begins to make some movements with its left limbs. The right remain motionless. The right eye was open, and the pupil dilated.

Active reaction followed the application of a hot wire to the left side, hand, foot, and ear.

No reaction followed application of the iron to the same points on the right side.

3.24 P.M. Begins to move about, turning towards the right side. When placed on the back of a chair the animal clung tenaciously with the left hand and foot, but did not grasp with the right.

The right side is completely anæsthetic. The animal, though keeping its right eye open, apparently does not see, as it runs its head against obstacles in its way. When placed on a chair it tumbled off, with its eye open. Muscular resistance is considerable in the limbs of the right side. There is no trace of facial distortion.

3.40 P.M. Can flex and extend the right leg. Does so when lying down and in trying to get up. Does not move the right limbs in walking, but drags them after the left. Turns about aimlessly, and knocks its head against furniture &c. Sometimes goes backwards. There is no reaction on the right side, but active on the left to hot iron.

3.55 P.M. The animal was placed on the floor, and surrounded by a circle of battery-jars. It turned round and round, knocking its head against them, and apparently unable to find its way out between them.

The bandage was then removed from the left eye. The animal still remained quiet for a few minutes. When placed on the back of a chair, it quickly found its way down. When placed beside its cage it looked about and then went in. Sight was therefore improved or restored since the removal of the bandage.

5 P.M. The animal was observed to flex the right arm and partially close the fist while it was sitting still. Entire abolition of reaction still continues in right. After some minutes the animal seemed to be animated by all its former vivacity. Ate and drank heartily. Makes active movements, turning round and round frequently to the left, using its left limbs only.

At 5.30 P.M. the animal was chloroformed to death, so that the exact seat of the lesion might be ascertained.

Post mortem Examination.—From the opening in the skull below the parietal eminence there was a hernia cerebri involving the upper part of the middle temporo-sphenoidal, annectent gyrus, and lower part of the angular, and upper end of the superior temporo-sphenoidal convolution (see fig. 25).

In the centre of this was an opening, almost circular, with softened edges, indicating the point of entrance of the cannula. The surface and base of the brain were everywhere else normal. The cranial nerves were intact.

Fig. 25.

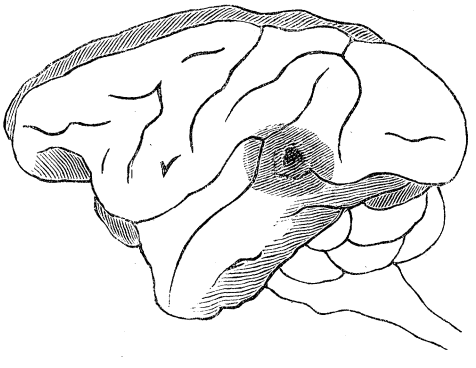


Fig. 25 represents by the shading the area of superficial injury of the left hemisphere of the monkey in Experiment XIX. The dark central shading indicates the orifice of the wound leading into the optic thalamus.

On opening the ventricles they were found free from effusion. The left optic thalamus was disorganized.

The track of the hot iron was easily traced by its blackened appearance. It had passed horizontally almost in the centre of the ventricular aspect of the ganglion, a line or so beneath the surface, and completely traversing the left thalamus, had just crossed the third ventricle and made a slight indentation on the opposite right thalamus.

Besides this wound there was another lacerated surface situated more towards the extraventricular aspect of the thalamus. This had been caused by the spring stilette, which, as it had been conjectured, had not penetrated the body of the ganglion. Round this discoloured laceration softening had extended somewhat, but had not quite invaded the body of the thalamus. The anterior and posterior extremities of the thalamus were almost of normal appearance. The intervening portion was quite broken up.

The corpora striata and corpora quadrigemina were uninjured. The crura cerebri were intact.

In this experiment the lesion was confined to the optic thalamus, or as far as can be effected by such a method of experimentation.

This result, and the result of Experiment XVI., show that complete disorganization of the optic thalamus in monkeys abolishes cutaneous sensation on the opposite side. (As I am restricting my conclusions to monkeys, I do not here stay to discuss in detail the results of NOTHNAGEL'S experiments on rabbits (VIRCHOW'S Archiv, 1874, p. 201), which lead him to apparently contradictory conclusions. I will merely remark, on the ground of experiment, that NOTHNAGEL, in my opinion, is not warranted in asserting that true sensation continues in rabbits after total destruction of the optic thalami. Reaction to tactile stimuli, in all respects resembling sensory, such as springing forward when the tail is pinched, or uttering screams, still continues to be manifested by these animals after complete removal of the hemispheres.)

The retention of reaction to stimulation in the first instance in this experiment may have been due partly to reflex action, partly to the retention of sensation; but that sensation was impaired was evidenced by the fact that the animal ceased to use its right limbs as before for the purposes of prehension and touch. Here also, as in destruction of the hippocampal fold, there was apparent muscular paralysis—but not so in reality, as the animal could still move the limbs in some degree, and the muscles retained their tonicity and resistance.

The interference with vision may have been due to the proximity of the lesion to the angular gyrus and its medullary connexions, as much as to the lesion of the optic thalamus, and therefore no definite conclusion is built on this fact. With regard to the circular movements of the animal which were occasionally made, the body seemed to go to the right or left according as the left arm was adducted or abducted.

The next experiments relate to the effects resulting from destruction or complete removal of the occipital lobes.

It has before been stated that the occipital lobes do not give any external response to the electric stimulus.

Destruction of the Occipital Lobes.

Experiment XX.

November 21*st*, 1873.—The occipital lobes were exposed on both sides in an active and intelligent monkey.

By means of the galvano-cautery the upper surface of the exposed lobes was disorganized as far back as their posterior extremity, while the left was further almost severed from the rest of the brain by carrying the cautery perpendicularly downwards towards the tentorium. It was not removed, however.

The operation was completed at 6 P.M.

6.15 P.M. The animal sat up spontaneously, which it did in a very unsteady manner, and kept its head bent on the chest. Some milk was poured down its throat. Gave evidence of retention of sight.

6.25 P.M. Moves about a little, looking about. Shows signs of pain and annoyance when its tail is pinched. Grunts discontentedly when nudged and made to move.

8 P.M. Made to swallow some more food. When placed in the cage beside the other monkeys it sat with its head bent, grunting when disturbed by them, and screaming when they began roughly to examine its head.

Being obliged to be absent from London for a few days, I found on my return that the animal had survived till the 25th. During the whole period it had maintained its dejected and melancholy attitude, paying no attention to its surroundings, and had shown no desire to eat or drink.

After death the occipital lobes were found disorganized, while the rest of the brain was uninjured. The stomach and intestines were completely empty. The other viscera were normal. No drawing was made of the brain.

In this case it might be supposed that the effects were merely due to the severity of the operation; but a review of the foregoing experiments will serve to indicate that experiments involving quite as serious surgical operations were not followed by the same depression, the animals still retaining their appetite, and eating and drinking as before.

The results as regards motion and sensation were negative; and the only effect which could be noted was the general depression, and the abolition of the animal's appetite.

Experiment XXI.

January 16*th*, 1875.—The occipital lobes of a monkey were exposed on both sides, and the dura mater removed from both. Owing to the rupture of a venous sinus on the right side, cotton-wool, soaked in perchloride of iron, had to be used to stanch the hæmorrhage, and there was reason to fear that it had in some degree injured the brain.

At 4 P.M. the left occipital lobe was separated from the hemisphere by means of

white-hot wires passed perpendicularly downwards close to the sulcus, separating this lobe from the angular gyrus.

4.35 P.M. The animal was let loose and laid down. After a few minutes it attempted to sit up, and uttered a croaking sort of sound.

5 P.M. Moves about the room rather unsteadily, occasionally uttering a short cry. Turns its head when called.

7 P.M. The animal appears to be blind. When placed on the back of a chair it would not move, though the chair was shaken, and the animal evidently felt uncomfortable. A piece of apple was held before it. It smelt it, and wished to lay hold of it, but made futile grasps after it. It could not find the way into the cage when placed close to the door.

8 P.M. It had been intended also to remove the right occipital lobe; but owing to the uncertainty as to the cause of the blindness, it was thought advisable to leave the right side undisturbed, so that if the blindness were due to affection of the left angular gyrus during the process of removing the left occipital lobe, time should be allowed for compensation. The wound was therefore sewed up and dressed.

The animal, when placed on the floor, wished to return to me, but could not find its way.

January 17th, 10 A.M.—The animal refuses to eat. Drank some water in which its mouth was forcibly immersed. When taken out of its cage it is seen to retain its muscular power, but gropes about on the floor. The pupils are equal and of medium size, and react sluggishly to light.

1 P.M. Tries to climb up whatever it comes in contact with. Likes to be taken up and caressed, but cannot find its way. Still continues blind.

An ophthalmoscopic examination was attempted, but could not be carried out, on account of the animal's restlessness.

January 18th.—10 A.M. The animal looks somewhat more lively today. Ate a fig and drank some water, but refused other food. Still continues blind, and moves about in a groping manner.

At 10.30 A.M. the animal was killed with chloroform, in order to ascertain the cause of the blindness.

Post mortem Examination.—The wound was suppurating freely.

The cut surface of the left occipital lobe was found projecting almost to the orifice in the skull.

The exposed surface of the right occipital lobe was soft and pulpy. There was slight extravasation on the surface of the dura mater on the right parietal region, caused by the rupture of the sinus above alluded to.

The left occipital lobe had been cut off by a line passing perpendicularly through its junction with the left angular gyrus (see fig. 26).

The angular gyrus was softened all along its posterior division, and just beyond the curve (see fig. 28).

The right occipital lobe, besides being softened on its upper aspect, was discoloured and covered by a layer of extravasation, which likewise covered the right nates. The nates themselves were, however, uninjured, and of normal consistence.

Fig. 26.

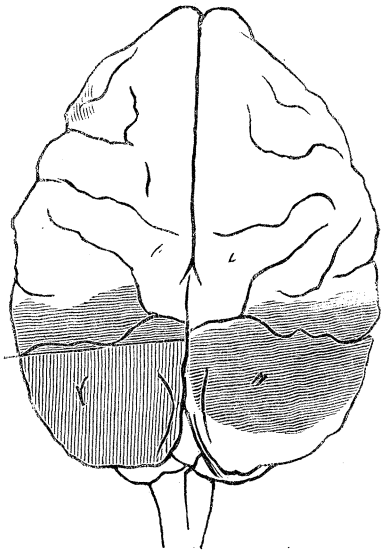


Fig. 26 represents by shading the extent of softening on both hemispheres of the monkey in Experiment XXI. The transverse line on the left occipital lobe is the line of section, and the part marked by paralle lines is the part entirely removed.

Fig 27.

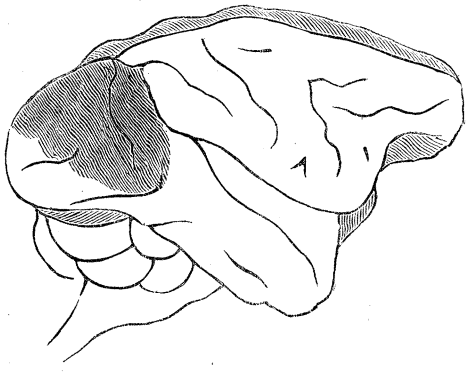


Fig. 27 represents the extent of softening in the right hemisphere of the monkey in Experiment XXI.

Fig. 28.

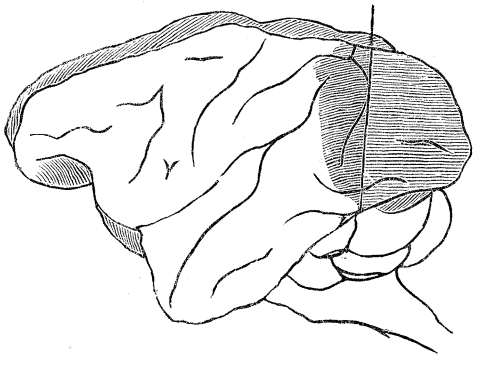


Fig. 28 represents by the perpendicular line the line of section of the occipital lobe. The part marked by parallel lines was cut off. The shading indicates the extent of lesion of the surface.

The posterior limb of the right angular gyrus was softened and discoloured yellow, owing to the contact with the cotton-wool soaked with perchloride of iron which had pressed on this part of the right hemisphere. The posterior extremity of the right occipital lobe was normal in appearance, both on its upper and under surface (see fig. 27).

The optic tracts and cranial nerves were intact.

The upper part of the tentorium cerebelli on the left side was covered with pus, and

the cerebellar surface beneath was yellowish in colour, but not softened. No other lesion existed in the brain.

This experiment was unsuccessful in so far as the object of localizing the lesion in the occipital lobes was concerned, but is a valuable confirmation of the results obtained by former experiments on the angular gyri. In this experiment, besides the complete removal of the left occipital lobe and extensive injury to the right, the angular gyrus was deeply involved on both sides, not throughout, however. The lesion was, however, extensive enough to produce total blindness; and it further illustrates the fact that when the angular gyrus is destroyed on both sides no compensation of visual perception occurs.

Beyond the fact of loss of sight, which is to be attributed to the lesion of the angular gyri, the lesions of the occipital lobes were in a great measure negative, the animal retaining its muscular powers, and apparently other senses, and still exhibiting, though to a less extent than before, its desire for food.

Experiment XXII.

January 22*nd*, 1875.—The occipital lobes were exposed on both sides in a monkey, and the surface exposed destroyed by the cautery, which was also passed deeply into the interior of the lobes, in order to cause as much disorganization as possible. Care was taken not to injure the angular gyri.

The operation was completed at 3.30 P.M.

4.10 P.M. The animal after lying in a state of stupor till now begins to move, but staggers a good deal. The eyes are open and the pupils dilated.

It indicates consciousness by turning its head when called to.

4.45 P.M. Sits quietly with its head down on its chest. It drank a little tea in which its mouth was kept immersed. Turned fiercely round on its tail being pinched.

5.45 P.M. Gives emphatic evidence of sight. Ran away when I approached it, carefully avoiding obstacles. Seeing its cage door open, it entered and mounted on its perch, carefully avoiding the cat which had taken up its quarters there.

Tried to escape my hand when I offered to lay hold of it, but picked up a raisin which I had left on the perch.

8 P.M. When not disturbed sits quietly with its head bent on its chest. Easily roused.

Does not take any food or drink offered to it.

12 midnight. Is sound asleep on its perch. Has not eaten any of the food left in the cage.

January 23*rd*.—10 A.M. Animal found sitting in the cage with the head bent as before. Drank a little milk held up to its lips. When removed from the cage walked about somewhat unsteadily, and then sat down as before. The eyes are partially closed from œdema of the eyelids. Sight continues. Made for a warm corner by the fire. Wakes up and grunts when called to. There is no loss of motion or sensation as far as can be seen.

3 P.M. Still continues sitting as before. When disturbed moves very unwillingly and apparently with great caution, as if its sight were impaired, occasionally knocking its head against obstacles. Drank some water, but would not eat.

9 P.M. The animal remains as when last seen. Has taken no food.

January 24th.—11 A.M. Found lying prostrate in the cage. Killed with chloroform.

Post mortem Examination.—The exposed surface of the occipital lobes on their superior and lateral aspect was soft and pulpy and suppurating. The extent is marked by the shading in figures 29, 30, 31. The softening extended deeply into the interior, but did not affect the under or inner aspect of the lobes.

The angular gyrus on both sides was of normal consistence, but the grey matter had a yellowish tint in the posterior half.

There was no effusion into the lateral ventricles.

The rest of the brain was quite normal.

Fig. 29.

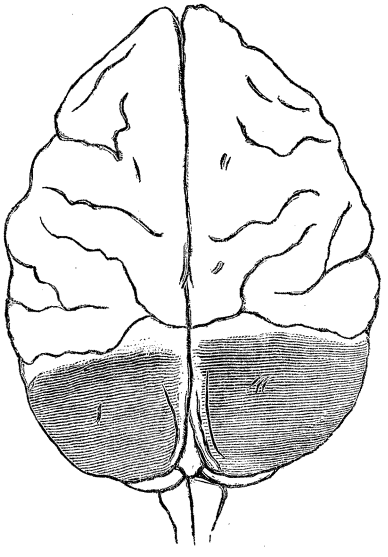


Fig. 29 represents by the shading the extent of destruction of the grey matter of the occipital lobes in Exp. XXII.

Fig. 30.

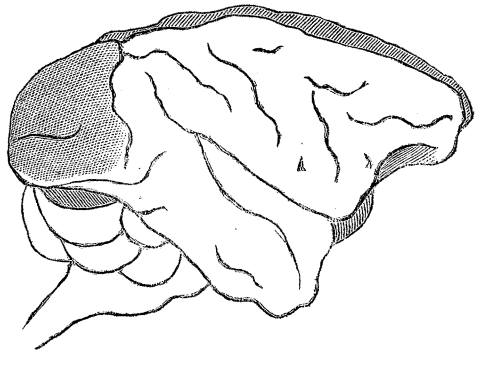


Fig. 30 indicates the extent of softening in the right occipital lobe in Exp. XXII.

Fig. 31.

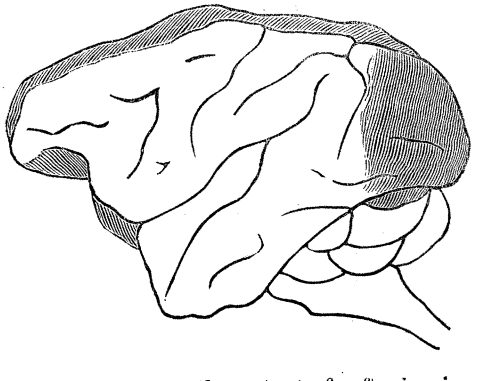


Fig. 31 indicates the extent of softening in the left occipital lobe in Exp. XXII.

In this experiment the results as regards sensation and voluntary motion were entirely negative. Sight became affected later; and this can be accounted for by the proximity of the angular gyrus to the lesion, and the commencement of pathological change in its substance. Nothing further was to be observed, except the dull dejection and melancholy attitude of the animal and its persistent refusal of food.

Experiment XXIII.

March 10*th*, 1875.—The occipital lobes were exposed in a small and rather weakly monkey, and the lobes severed by perpendicular section with hot wires about a quarter of an inch posterior to the parieto-occipital fissure, so as to avoid all interference with the angular gyrus. The operation was completed at 4.30 P.M., the animal having by the time the wound was dressed almost completely regained consciousness.

4.45 P.M. Begins to move about in rather a staggering manner, but exhibiting no muscular paralysis.

4.55 P.M. Can see quite well, as it avoids obstacles, and when removed regains its place by the fire. Twitches its ear and turns its head when called to, or a noise made. Can sit quite steadily.

7 P.M. Sits still looking about vacantly. Will only move when nudged. Tactile sensation is unimpaired. Sight and hearing continue. Withdrew its head sharply when acetic acid was held before its nose. Made movements of tongue and mouth, as if to expel it when colocynth was placed in its mouth. Circulation and respiration regular and normal.

The animal has refused food and drink.

7.45 P.M. Drank a few teaspoonfuls of tea held up to its lips, and accidentally placing its hand in the dish stooped and drank up the contents.

When left to itself, takes up a position with its head bent on its chest and covered with its hands.

8.45 P.M. Remains as before. Refuses to eat or drink. When a dish of milk was held before it in such a manner that it could not hold its head down without immersing its mouth in the liquid, it sipped a little but wished to avert its head.

9.40 P.M. Reaction to taste again tried with aloes, and again discomfort manifested. Turned away its head when assafœtida was held before its nostrils. Active reaction to acetic acid. Smelt at its hand on which some assafœtida had been spilt.

12 midnight. Lies asleep in cage breathing quietly. Easily roused by a touch on its hand, which caused it to open its eyes. Animal weak.

March 11*th*.—9.30 A.M. Found dead in its cage and rigid, death having occurred in the night.

Post mortem Examination.—The brain was everywhere normal except in the region of the occipital lobes. The occipital lobes had been completely divided and removed on both sides, but more on the right than on the left. The parts removed are indicated in figures 32, 33, 34 by the shading.

The lungs were normal, of pinkish colour. The heart was dilated, and its cavities full. The stomach contained a few coagula of milk which it had swallowed. The other viscera presented no abnormal appearance.

There was therefore nothing to account for death in the animal except the prostration consequent on the operation in an animal of weakly constitution.

The only facts, therefore, which can be relied on as proved by this experiment are the negative results as regards the individual senses and the powers of motion. The abolition of appetite was not absolute, but nearly so. The occipital lobes were not entirely removed, as will be seen by the figures.

Fig. 32.

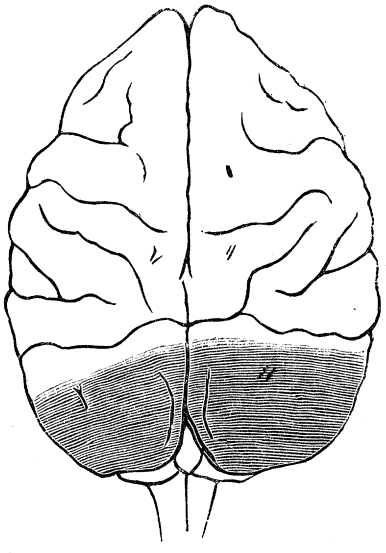


Fig. 32 indicates by the shading the extent of removal of the occipital lobes in Exp. XXIII.

Fig. 33.

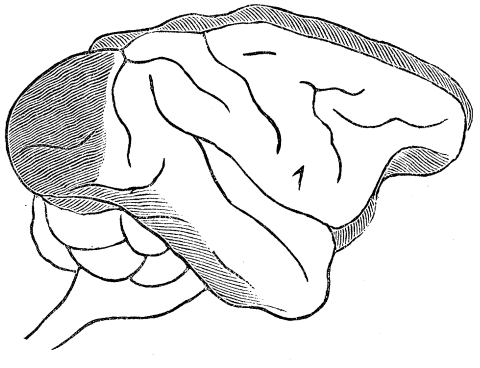


Fig. 33 indicates the extent of removal of the right occipital lobe in Exp. XXIII.

Fig. 34.

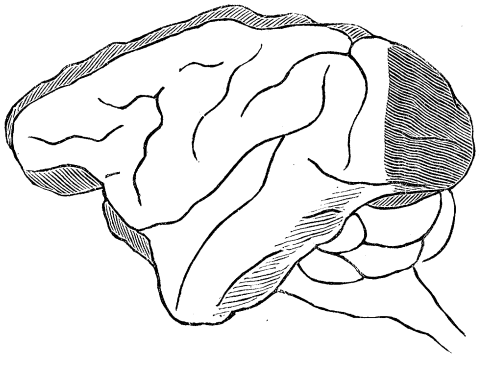


Fig. 34 indicates the extent of removal of the left occipital lobe in Exp. XXIII.

Experiment XXIV.

March 18*th*, 1875.—The occipital lobes were exposed in a large and strong macaque, lively and active, but of rather a timid disposition and unwilling to be handled. With

hot wires the lobes were divided and removed by a line somewhat in advance of the anterior extremity of the superior occipital sulcus, but the exact line was doubtful. The left section sloped posteriorly, the right was almost perpendicular to the tentorium.

There was very little hæmorrhage, and the operation was rapidly completed at 11.30 A.M., the animal being almost conscious during the dressing of its wound.

11.45 A.M. The animal has been lying quietly looking about, but has not moved. While this note was being written the animal sat up spontaneously, but feeling weak and unsteady lay down again. Turned its head and looked when called by name. Got up and tried to walk, but staggered and fell.

12.10 P.M. Oscillates while sitting up and totters when it tries to walk.

Sits near the fire, rubbing its nose and ears when they become too hot. Followed its companion with its eyes, but cannot succeed in walking steadily to join it.

12.20 P.M. On my approaching it and making a threatening grimace at it, it turned away making mouths at me as usual. A few minutes after ran away when I approached it, moving now almost quite steadily.

7 P.M. Can move about freely; but there seems to be some confusion or defect of vision, as the animal puts out its hand to reach things without appreciating distance. Can see its way, however, tolerably well. Smells at various kinds of food offered to it, but refuses to eat. Refused tea, of which it formerly was very fond. Objects to being disturbed, and sits hugging its companion, which it occasionally salutes with a tug or a bite when it does not sit quiet.

March 19th.—10 A.M. Refused all food. Looks rather dejected, but otherwise is well, retaining its muscular powers and sensation unimpaired, with the exception of slight defect in vision, as above noticed.

The wound looks healthy, and the animal vigorous.

11.15 A.M. Licked at a piece of orange offered it, but will not eat any thing else. Frequently treats its companion to a rough shake or bite.

5 P.M. Still refuses to eat or drink. Has taken nothing since the operation but the piece of orange.

March 20th.—9 A.M. Still refuses food or drink. Sits quietly and takes little or no interest in its companion, which runs about.

Otherwise there is no change in the symptoms, as to motion or sensation.

7 P.M. Drank eagerly a large quantity of water. Refused all kind of food.

March 21st.—11 A.M. The animal is well and in seemingly good health. The wound is oozing only slightly at one part, the greater part having healed up.

Came out of the cage when the door was opened and walked to the fire, before which it sat down with a contented grunt. Still refuses to eat.

1 P.M. Greedily accepted and ate a piece of orange, which is the only thing it seems to have any desire for. Incidentally it was observed to seize hold of its companion (a male) and make the movements of coitus. This occurred twice. (The testicles existed, but the penis had been amputated.)

2 P.M. Drank water, but refused food.

7 P.M. Again eagerly drank cold water. Does not exhibit any desire to eat the food, of which there is a plentiful supply in the cage. Goes occasionally and takes a draught of water. It was once at this time observed to nibble a crust of bread, but further did not manifest any sign of hunger.

March 22*nd*.—10 A.M. Looks very dejected, sitting quietly in a corner of the cage. Took a little water held up to its mouth, but would not eat.

7 P.M. For the first time since the operation has exhibited a distinct desire to eat by accepting and eating a piece of bread and then drinking largely of water. This was at the end of the fifth day. Otherwise the animal is as before.

8 P.M. Refused its former beverage tea, of which it used to be fond. Sits dejectedly in a corner of the cage, feeling its head and licking its hand occasionally. The wound looks well, only oozing slightly.

11 P.M. Again offered food, but refused all the food the other monkeys seemed to enjoy. At last, on being offered a cold potato, it took it in its hands, smelt it carefully, and then, as if suddenly struck by a new idea, began to eat with great gusto.

March 23*rd*.—The animal looks well and less dejected than before. Walked out of the cage when the door was opened. Retains its muscular power and senses as before. Ate and drank several times during the day. Seems to have recovered its appetite for its former food.

March 24*th*.—The animal continues well and took its breakfast as usual.

Today it was placed in a hamper and taken to the country, to be under my observation during a short absence from London.

April 10*th*.—Since last observation the animal has continued well. The wound gradually healed up completely. The animal retained its appetite, eating and drinking heartily. With the exception of the defect of vision, seen particularly in the want of appreciation of distance, the animal had recovered perfectly to all appearance. It would be difficult to say what alteration in its disposition had occurred, yet it looked duller and less active than it used to be.

It had, however, entirely recovered from the effect of the operation, and was used for another experiment to be recorded next (see Exp. XXV.).

This experiment is remarkable as being the only successful case I have observed of recovery taking place after removal of a large portion of the skull and a considerable quantity of the brain-substance.

The history of the animal offers some interesting features, and is a further illustration of the entirely negative effect as regards motion and sensation of destruction of the occipital lobes. The only exception was with reference to vision, which continued impaired throughout. In the other cases when vision was lost or impaired, it was found on post mortem examination that the angular gyrus was more or less affected. In this case also, as will be seen from the post mortem examination (p. 486), the angular gyrus was again the seat of lesion.

This animal exhibited less of that dejection and depression which characterized the other animals similarly operated on.

It is difficult to single out any one positive result of the destruction of this part of the brain, except the remarkable aversion to food which was observed almost invariably. This may be regarded as due to the constitutional disturbance consequent on such severe mutilation; but if so, it will be difficult to account for the fact that equally severe mutilation of the frontal lobes and other parts of the brain caused little or no impairment of the appetite for food.

I am disposed to think, therefore, that the aversion to food stands in causal relation to the destruction of the occipital lobes as such, and that these lobes are somehow related to the systemic sensations. The other animals did not live long enough to decide as to whether this condition should remain permanent; but in experiment XXIV. the animal, otherwise exceptional, after remaining without food for a period of five days, again recovered its appetite and continued to eat as before.

Thirst did not seem to have been affected to the same extent as the appetite for food.

If the systemic sensation of hunger has its seat in the occipital lobes, it is difficult to account for the restoration of this appetite after these lobes have been removed. Yet it is possible that compensation may have occurred by association with other senses, such as of taste and smell. This is offered as a possible explanation; but it must be admitted that neither the electrical irritation of the occipital lobes nor their destruction suffice to indicate clearly the functions which these lobes perform.

It would appear from experiment XXIV. that their destruction does not abolish the sexual appetite. The exhibition of this appetite may perhaps have been due to irritation of some centre in proximity to the seat of lesion. Some interesting speculations might be made with reference to these results; but as my object in this paper has been to restrict myself to conclusions directly deducible from my experiments, to enter on such would be foreign to the subject.

The following experiment is interesting, and one perhaps not often capable of repetition.

Conjoint removal of Frontal and Occipital Lobes.

Experiment XXV.

April 10th, 1875.—The monkey which had had its occipital lobes removed on March 18th (exp. XXIV.), *i. e.* twenty-three days previously, and which had apparently quite recovered, was placed under the influence of chloroform, and the frontal lobes removed on both sides by a line approximately traversing the anterior extremity of the supero-frontal sulcus.

The operation was completed at 12 noon.

The animal had regained consciousness before the wound had been quite dressed.

12.10 P.M. On being let loose and placed on the floor, it sat up and began to move about in a tottering manner. When it shook itself it fell over on its side.

12.20 P.M. Is sitting up somewhat unsteadily and gnawing at whatever comes within

its reach. Occasionally suddenly puts out its hand, and frequently rubs its nostrils as if there were some source of irritation in them.

It gives complete evidence of retaining hearing.

2 P.M. Runs away when I approach. Is not quite steady in its movements. Can find its way into its cage as before when taken out. Sight continues as formerly.

2.30 P.M. Drank some water and ate some fruit. Sits on its perch occupied in feeling its head and licking its hand. Seems much less timid than before; does not seek to move off its perch when about to be laid hold of, but resists and offers to bite. When not disturbed sits in a dreamy sort of state, taking no notice of any thing.

4 P.M. Found sitting in the same position as when last seen, with its head bent. Looks vacantly, and does not seem to mind an attempt to lay hold of it. When seized it resisted, and attempted to bite, exhibiting great anger.

Ate some food offered to it. When removed from the cage it walked about restlessly and without seeming to have any purpose. Ran away on being approached, but did not as usual make for its cage.

12 midnight. The animal sits still and is evidently feverish, the head being swollen and hands and feet hot.

April 11*th*.—11 A.M. Found asleep in a corner of the cage. When removed it subsides into a deep sleep and nearly falls over, but recovers itself suddenly. There is no motor paralysis, and sensation is unaffected.

This state continued during the day, and towards night the animal fell into a state of semistupor, and did not seem able to support itself on its legs, sprawling about occasionally when disturbed. No convulsions were observed.

April 12*th*.—The animal was found dead in its cage at 10 A.M. partially rigid, so that death must have occurred some hours before.

Post mortem Examination.—The scalp was œdematous, and there was a considerable amount of pus oozing from the wound. The skull was deficient over the region of the frontal and occipital lobes. The brain-substance at the occipital openings was adherent by adventitious membranes to the under surface of the scalp. The left looked of normal colour and not congested. The right was congested, and appeared as if it had received a contusion from a fall.

From the frontal openings there protruded two livid herniæ cerebri. On removal of the dura mater, a layer of pus was found coating its under surface. This was not adherent to the brain-substance, from which it stripped entirely.

The brain-substance had normal colour and consistence.

The roof of the orbit was also covered with pus, which extended as a thick layer into the sphenoidal fossæ, but was easily detachable and of recent formation.

The base of the brain and cranial nerves were free from signs of inflammation. There were traces of inflammation and some degree of suppuration between the longitudinal fissure at the occipital region and over the tentorium cerebelli. These were to all appearance of older formation than those in the anterior part of the skull. The cerebellum had a normal appearance.

After the brain had been hardened in spirit, it was found that the frontal lobes had been removed by a line crossing the anterior extremity of the supero-frontal sulcus on both sides. The plane of section sloped somewhat forwards, and the under surface of the orbital region remained where it conceals the olfactory tracts and bulbs. The cut surface bulged considerably and the edges of the section were softened nearly as far back as the antero-parietal sulcus on both sides (see figures 35, 36, 37). The edges were raised, and the vessels were injected for some distance posterior to the cut surface.

Fig. 35.

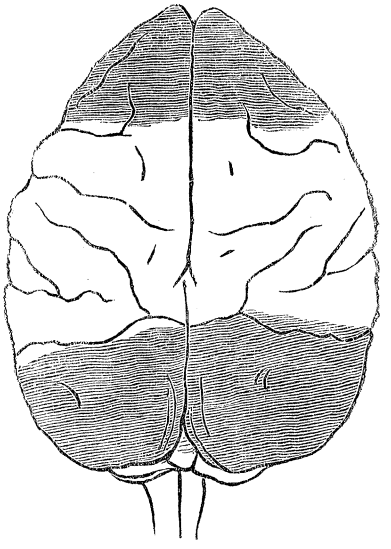


Fig. 35 represents by shading the extent of destruction of the frontal and occipital regions in Exps. XXIV. & XXV.

Fig. 36.

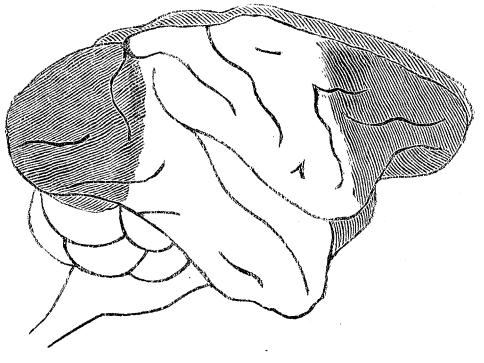


Fig. 36 represents by shading the extent of destruction of the right hemisphere in Exps. XXIV. & XXV.

Fig. 37.

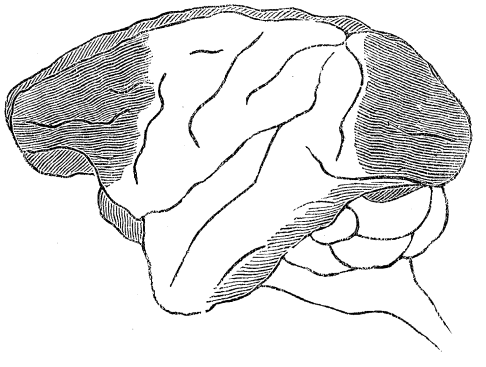


Fig. 37 represents by shading the extent of destruction of the left hemisphere in Exps. XXIV. & XXV.

The occipital lobes had been removed almost completely. On the left side the hemisphere became rounded off just behind the posterior limb of the angular gyrus, which was intact. On the right side the posterior limb of the angular gyrus was ragged and torn, and formed part of the edge of the plane of section (see fig. 36).

With the exception of the injection of the vessels of the pia mater behind the frontal section, the rest of the brain had a normal aspect.

The most important fact demonstrated by this experiment is that the conjoint removal of the frontal and occipital lobes exercises no effect on the powers of voluntary motion or of sensory perception.

The results of the post mortem examination indicate that the phenomena of the second day are not to be regarded as the effect of the removal of the frontal lobes as such, but as due to the inflammatory complications which resulted in death.

But the fact that for many hours after the operation the animal continued to retain its powers of sensation and of volition, proves that these faculties are independent of the frontal and occipital lobes, and that they are associated with those parts of the brain which, by other experiments, I have shown to be specially related to sensation and motion.

What the positive effects were, as distinguished from the merely negative, it would be difficult to state in exact terms. They are quite in accordance with experiments already related as to the effect of destruction of the frontal lobes.

Without entering further into the psychological aspects of these results, I would sum up the conclusions which seem to me to be legitimately deducible from them as follows:—

(1) Ablation of the frontal regions of the brain which give no reaction to electrical irritation is without effect on the powers of sensation or voluntary motion, but causes marked impairment of intelligence and of the faculty of attentive observation.

(2) Destruction of the grey matter of the convolutions bounding the fissure of Rolando causes paralysis of voluntary motion on the opposite side of the body, sensation remaining unaffected, while lesions circumscribed to special areas in these convolutions, previously localized by the author, cause paralysis of voluntary motion limited to the muscular actions excited by electrical stimulation of the same parts.

(3) Destruction of the angular gyrus (pli courbe) causes blindness of the opposite eye, the other senses and voluntary motion remaining unaffected. This blindness is only of temporary duration, provided the angular gyrus of the other hemisphere remains intact. When both are destroyed the loss of visual perception is total and permanent.

(4) The effects of electrical stimulation and the results of destruction of the superior temporo-sphenoidal convolution indicate that this region is the centre of auditory perception.

(5) Destruction of the hippocampus major and hippocampal convolution abolishes the sense of touch on the opposite side of the body.

(6) The sense of smell has its centre in the subiculum cornu ammonis or tip of the uncinate convolution on the same side.

(7) The sense of taste is localized in a region in close anatomical relation to the centre of smell, and is abolished by lesion of the lower part of the temporo-sphenoidal lobe.

(8) Destruction of the optic thalamus causes complete anæsthesia of the opposite side of the body.

(9) Destruction of the occipital lobes produces no effect on the special senses, nor on the powers of voluntary motion, but is followed by a state of depression and refusal of food not to be accounted for by mere constitutional disturbance consequent on the operation. The function of these lobes is regarded as obscure, but considered as being in some way related to the systemic sensations. Their destruction does not abolish the sexual appetite.

(10) After removal both of the frontal and occipital lobes an animal still retains its faculties of special sense and the powers of voluntary motion.