DEGENERATIONS RESULTING FROM LESIONS OF THE CORTEX OF THE TEMPORAL LOBE.

By W. H. THOMPSON, M.D., *Dunville Professor of Physiology, Queen's College, Belfast.* (PLATES XVIII., XIX.)

THE investigation from which the following results have been obtained was begun as far back as the year 1892, in the Physiological Department of University College, London, under the guidance of Professor E. A. Schäfer. It was subsequently continued in the Physiological Laboratory of this College, where most of the work has, in fact, been carried out. The completion of the research has, however, been delayed by several interruptions.

Two preliminary communications dealing with some of the results obtained were made in 1892, one before the Pathological Society of London, the other before the Section of Anatomy and Physiology of the Royal Academy of Medicine, Dublin. A more detailed account was given at the meeting of the British Medical Association in Montreal in 1897.

OBJECTS OF THE RESEARCH.

At the time this inquiry was undertaken, much controversy existed concerning the seat of the cortical representation of the sense of hearing. Ferrier, Munk, and Schäfer, proceeding chiefly from the immediate results of extirpation of portions of the cortex of the temporal and occipital lobes, had all arrived at different, and in many respects contradictory views, regarding the precise region in which this sense is represented. Ferrier, as is well known, had located it in the upper end of the superior temporal convolution. Munk's auditory sphere, on the other hand, embraced portions of both temporal and occipital lobes; while Schäfer, without assigning the sensation to any special part of the cortex, came to the conclusion that destruction of Ferrier's auditory centre, or even complete removal of the

whole temporal lobe, did not impair the animal's sense of hearing.

Meanwhile the question had been attacked in another way. The experiments of Baginski,[1] who followed the degenerations resulting from destruction of the cochlea in rabbits, together with the researches of Flechsig and Bechterew,[2] who employed the now well known embryological method of the former investigator, showed that the auditory nerve of one side is brought into connection with the posterior tubercle of the corpus quadrigeminum, and with the internal geniculate body of the opposite side, by means of the contralateral fillet.

Prior to this, *V. Monakow*,[3] who extirpated definite regions of the cortex of the brain in new-born animals, and afterwards followed the tracts of arrested development which resulted from these operations, had come to the conclusion that fibres from the ventral part of the temporal lobe end, some in the corpus geniculatum internum, others in the posterior tubercle of the quadrigeminate body, and still others, pass directly down into the fillet.

The difficulties attendant upon the accurate tracing of conducting paths within the brain prevented these results from being finally accepted as conclusive, and since their publication many investigators have engaged in work more or less intimately connected with this field.

Held,[4] who employed the newly introduced method of Marchi for showing degenerated tracts, was enabled to fully confirm the observations of Flechsig and Bechterew regarding the central connections of the auditory nerve. Von Monakow, who likewise carried out an investigation on this part of the subject, has also arrived at results which, in the main, agree with those of Flechsig, Bechterew, and Held. He takes a different view,

[1] Baginski, B., "Ueber d. Urspr. und centr. Verlauf d. Nerv. acust. d. Kaninchens," *Virch. Archiv*, 105, s. 28–46.

[2] Flechsig, P. (with Bechterew), "Zur Lehre. v. centr. Verlauf d. Sinnes-Nerv," *Neurol. Centr.*, No. 23, s. 545–551.

[3] V. Monakow, "Ueber einige durch extirp. circumscr. Hirnrind-Reg. bedingt Entwickelungshemm. d. Kaninch-Gehirns," *Archiv f. Psych.*, xii. 1, 141; also xii., s. 535–549.

[4] Held, "Die cent. Bahnen des Nerv. acust. bei d. Katze," *Archiv f. Anat. u. Physiol.*, Anat. Abt., 1891.

however, regarding the paths which the connecting fibres pursue in one part of their course, when passing from the auditory nuclei to the above-mentioned ganglia.

Results also obtained by Zacher[1] from an examination of four brains with more or less extensive softening, contain the following conclusions which bear upon this subject. First, that the corpus geniculatum internum is directly connected with the two upper convolutions of the temporal lobe, to which it stands in the same relation that the external geniculate body bears to the occipital lobe. Second, that fibres from the temporal lobe descend through the outer fourth of the *pes pedunculi* as far as the upper part of the pons.

These results though, as we shall see, in themselves perfectly correct, did not, however, do away with the necessity for further investigation, especially of an experimental nature, and accordingly the following research was undertaken.

Methods employed.

Monkeys and marmosets were exclusively employed. Of the former, Macacus rhesus, Macacus sinicus, and Callithrix personata; of the latter, the common marmoset (Hapale Jacchus) were used.

After being anæsthetised, the temporal lobe was exposed by trephining, and a portion of the cortex removed down to the white centre. This was effected by means of a small Volkmann's scoop after the area had been circumscribed by a shallow incision. The whole operation was performed aseptically; after the cranial cavity had been opened, however, no fluid was employed for contact with the brain other than sterilised normal salt solution. The size and situation of the removed areas varied. Some were confined to Ferrier's auditory centre (apex of superior temporal convolution), but for the most part they involved a considerably greater extent of cortex. The posterior part of the temporal lobe was throughout avoided, so as to escape possible injury to the occipital cortex. Fig. 1 and Plate XVIII.

[1] Zacher, "Beitr. z. Kenntn. d. Faserverlaufs in d. Pes Pedunc., sowie über die cort. Bezieh. d. Corp. Genic. Int.," *Arch. f. Psych.*, xxii., s. 654-698 (1891).

a, *b*, *c*, *d*, represent the areas removed in certain of the experiments.

In most of the experiments the motor area was not exposed and was never actually injured in any way.

The wounds in every instance healed by first intention, and the animals were allowed to live for periods varying from nine to twenty-one days. They were then painlessly killed by an

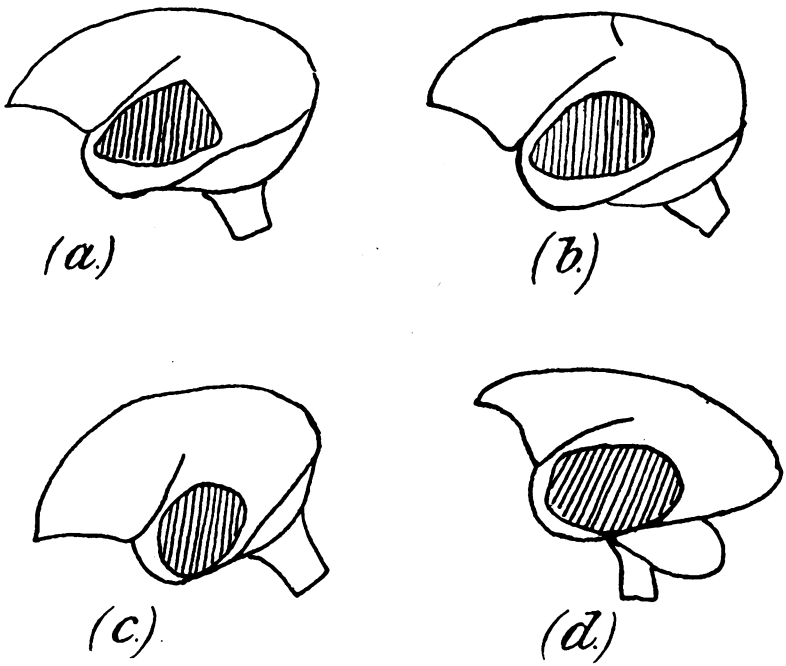

FIG. 1.—Showing tracings of lesions from four of the marmoset brains, viz., marmosets 5, 6, 7, 8.

overdose of chloroform, and the brains and spinal cords hardened in Müller's fluid. Subsequently thin slices were stained in Marchi's solution, and cut in celloidin.

In some of the experiments, instead of actual removal of a portion of cortex, a subcortical lesion was made, and the piece left *in situ*. The results of these differed in no way from those furnished by the more usual method of removal. Control experiments, in which the surface was merely exposed, were also performed. In all, the results of experiments upon thirty brains

were investigated, fifteen of which were monkeys and a like number marmoset brains. Through these, sections were made in various directions, horizontal, coronal, and oblique. Before cutting, photographs or tracings of the lesions, or both, were made.

Results obtained.

Degenerated fibres were ascertained to exist in the following tracts and fibres:—

1. *Association Fibres.*—In the first instance short association fibres connecting the removed area with adjacent convolutions or portions of cortex were found degenerated. But, in addition, longer association tracts were also found to present the same change. One of these was the *inferior longitudinal fasciculus* conveying degenerated fibres into the occipital lobe (see *d. 2*, figs. 3 and 4). The other conveyed similar fibres to the parietal lobe—*parieto-temporal fasciculus.*

These results are confirmed by recent observations of *Pusateri*,[1] who found degenerations in these tracts after removal of portions of Munk's auditory sphere in cats.

It must, I think, therefore be unquestionably accepted that the inferior longitudinal fasciculus is mainly, if not wholly, an association link between the occipital and temporal lobes. This, the usually accepted view, has recently been contested by *Flechsig*,[2] who regards it as a projection bundle, descending from the occipital lobe. It has, however, on the other hand, received confirmation from researches by *Sachs*[3] into degenerations following softening of circumscribed areas of the cortex.

2. *Commissural Fibres*:—(*a*) *Corpus callosum.*—In every case degenerated fibres were traced over the ventricular cavity towards the corpus callosum, across the posterior half of which they passed to reach the opposite side (see *d. 5*, fig. 1). In this commissure, they were found mostly to occupy the lower half of the vertical section. Having gained the opposite side,

[1] Pusateri, E., "Contrib. allo studio del origine dell fascio pedunc. di Türck e del fascio long. infer," *Il Pisani*, s. 141–154.

[2] Flechsig, P., "Die Localisation d. geistigen Vorgänge, insbesond. der Sinnes-Empfindungen d. Menschen," Leipz., 1896.

[3] Sachs, H., "Ueber Flechsig's Verstand-Centren," *Archiv. f. Mik. Anat.*, B. 48, pp. 550–572.

a number were seen to bend downwards and radiate into the cortex of the opposite temporal lobe. Some fibres turned forwards into the internal capsule. These will be referred to later.

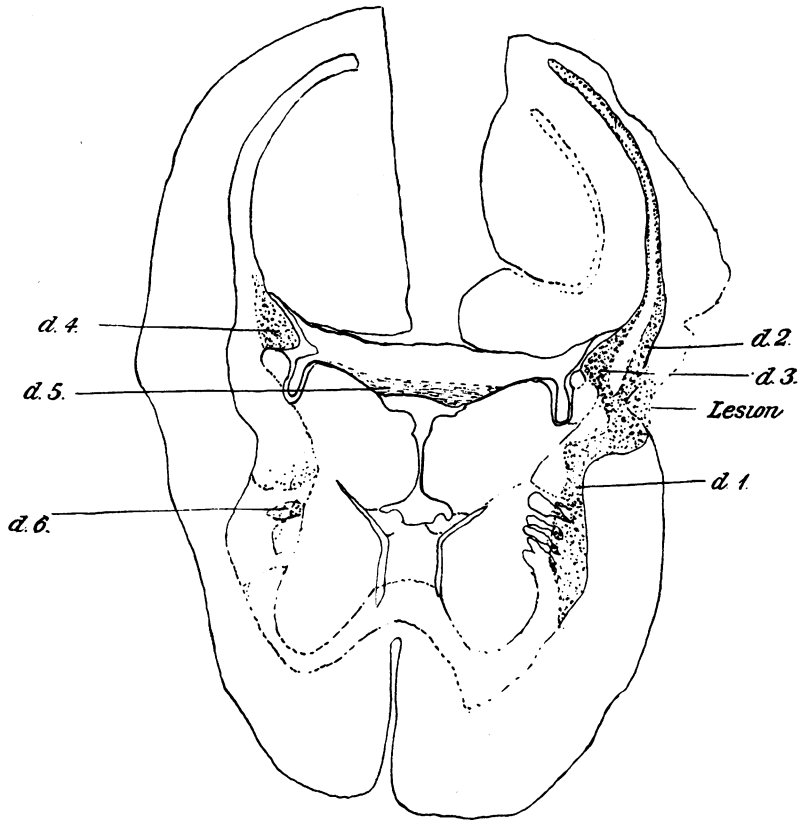

FIG. 3.—Horizontal section through the brain of marmoset 6 at the level of the upper part of the internal capsule, showing sites of degeneration.

d. 1, internal capsule, side of lesion.
d. 2, inferior longitudinal fasciculus.
d. 3, tapetum, side of lesion.
d. 4, tapetum, opposite side.
d. 5, corpus callosum.
d. 6, internal capsule, opposite side to lesion.

But fibres of another set were also traceable from the seat of the lesion *towards* the region of the corpus callosum at its hinder part. Here they entered the bundle of fibres known as the

tapetum (see *d. 3*, fig. 3), and at once separated into two groups. One of these remained on the side proximal to the lesion, and passed back into the occipital lobe, forming a layer immediately outside the posterior horn of the lateral ventricle. The other crossed over in the corpus callosum, and was found in the tapetum of the opposite side, along which its fibres were traced backwards and downwards into the occipital lobe, forming here also a layer placed closely external to the posterior horn (see *d. 4*, fig. 4), and internal to the so-called optic radiations of the white centre. In this way a communication is established between a given area of temporal cortex and the surfaces of both occipital lobes.

Some light is also thrown upon the constitution of the tapetum, concerning which a good deal of difference of opinion exists amongst cerebral investigators. *Wernicke*[1] believed it to be a set of fibres passing from the corpus callosum into the internal capsule. *Dejerine*,[2] however, identifies it with the *occipito-frontal fasciculus* of *Forel*[3] and *Onufrowicz*; but, while denying that it receives any fibres from the corpus callosum, or contributes any to the internal capsule, he admits that it is made up of fibres from two different sources. Where the second set of fibres originates, Dejerine does not state. *Mingazzini*[4] corroborates the view that the tapetum contains two sets of fibres, one of which belongs to the fasciculus occipito-frontalis; the other is furnished by the corpus callosum. *Dotto* and *Pusateri*[5] have also found that the corpus callosum contributes fibres to the tapetum. My own results fully substantiate this latter view, and further show at least one source from which the callosal fibres come. They do not lend any support to the belief that fibres of the tapetum descend into the internal capsule.

(*b*) *Anterior Commissure.*—In all cases where the lesion of the

[1] Wernicke, *Lehrbuch d. Gehirnkrankheiten*, Leipzig, 1881.

[2] Dejerine, J., *Anatomie des Centres Nerveux*, Tome 1, p. 760, Paris, 1895.

[3] Forel, "Fall von Mangel d. Balkens in einem Idiotenhirn," Tagebl. d. 54. Versamml. deutsch. Naturforsch. u. Aertzte in Salzburg, 1881.

[4] Mingazzini, G., "Osservaz. Anat. intorn al corpo callose e ad alcuno formaz. che con esso hanno rapporto," *Ricerch. lab. di Anat. Norm. Univ. Roma.*, vol. vii. pp. 5–28.

[5] Dotto and Pusateri, "Sul decorso delle fibr. del corp. callos. e del psalterium," *Rivist. di patol. Nerv e ment.*, ii. 2, 1897.

temporal cortex was extensive, marked degeneration was found in the anterior commissure. Here the fibres occupied the inferior half of its vertical section (pars corticalis) (see *d. 3*, fig.

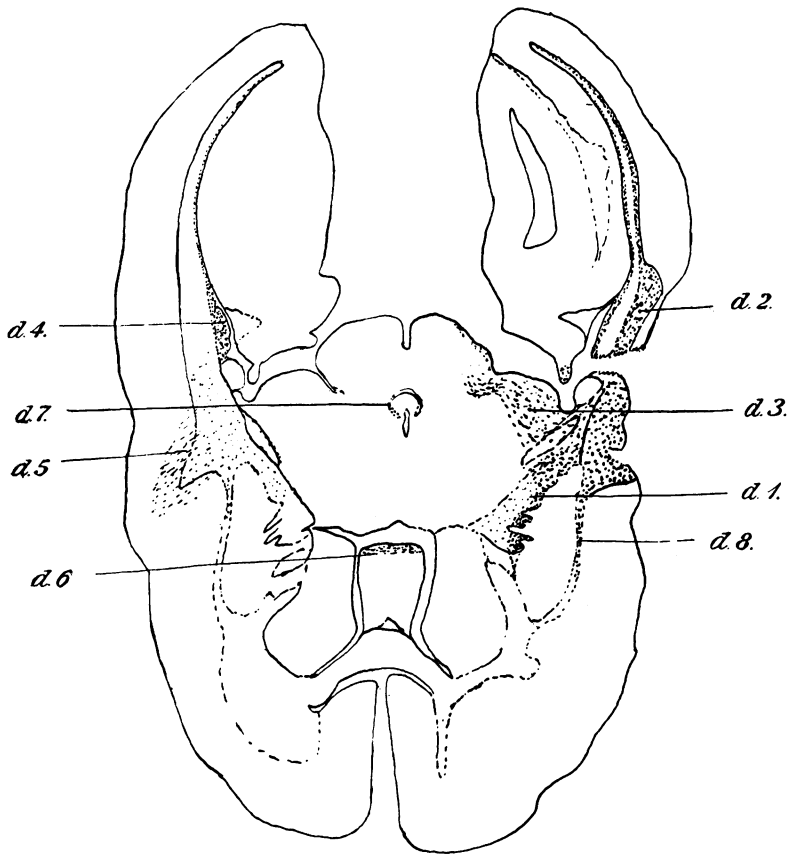

FIG. 4.—Horizontal section from same brain as fig. 3 at a lower level.

d. 1, *d. 2*, *d. 4*, as in fig. 3.
d. 6, degenerations extending out into opposite temporal lobe.
d. 7, in posterior commissure.
d. 8, in external capsule.

5), and passed across to the opposite side, where they bent outwards and backwards, to end in the lower and front part of the cortex of the temporal lobe. To reach the anterior commissure, these degenerated fibres coursed from the seat of lesion, along the external capsule (see *d. 8*, fig. 4). But all of those found in

the external capsule did not enter the anterior commissure. Many descended to the anterior and lower part of the temporal cortex on the side of the lesion. Through the external capsule and anterior commissure another bilateral connection is thus established between the cortex of the temporal lobe and both hemispheres, comparable to that formed in a posterior direction by the fibres of the tapetum.

(*c*) *Fornix.*—In a small number of the brains examined,

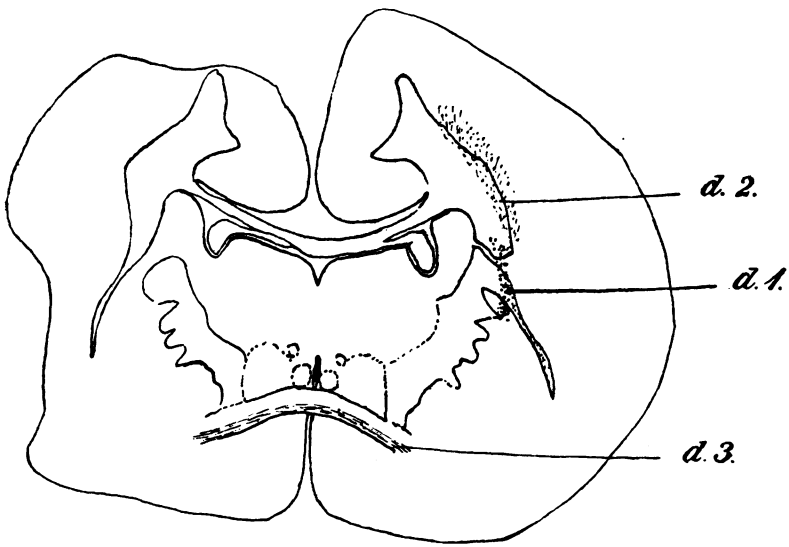

FIG. 5.—Vertical section through anterior part of brain of marmoset 7, showing sites of degeneration.

d. 1, internal capsule.
d. 2, parieto-temporal fasciculus.
d. 3, anterior commissure.

degenerated fibres were detected in the body of the fornix (see *d. 6*, fig. 4). They probably belonged to the set of fibres described by authors under the name of fasciculus pericavitarius medialis. They were traced forwards to the anterior end of the fornix, but neither their exact source of origin nor termination could be definitely determined.

(*d*) *Posterior Commissure.*—Some degenerated fibres were found in nearly all cases in the posterior commissure. Reference to these will again be made.

3. *Projection Fibres*: (*a*) *Retro-Lenticular Group.*—The largest group of degenerated fibres was in all cases traceable from the seat of injury through the corona radiata towards the internal capsule (see *d. 1*, fig. 3). On entering this system of fibres, the majority were found to occupy the retro-lenticular segment of its posterior limb, some extending slightly forwards, however, between the posterior end of the lenticular nucleus and the optic thalamus. Certain of these fibres were seen to reach the capsule

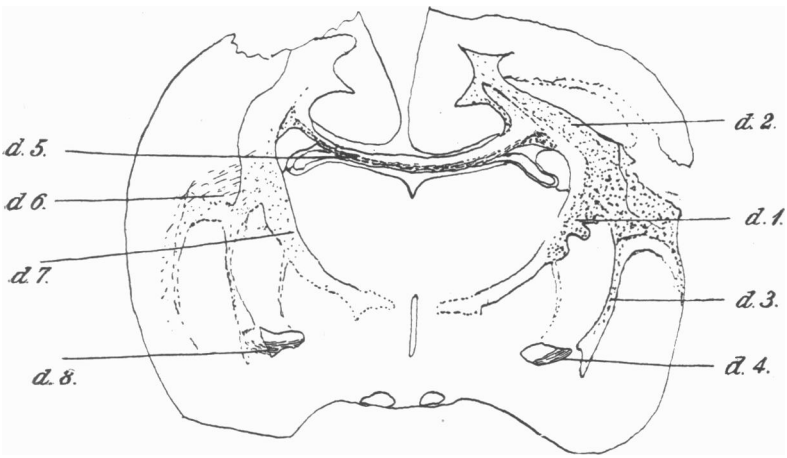

FIG. 6.—Vertical section through brain of marmoset 7, posterior to fig. 5.

d. 1 and *d. 2*, as in fig. 5.
d. 3, external capsule.
d. 4 and *8*, anterior commissure.
d. 5, corpus callosum.
d. 6, degenerations extending into opposite temporal lobe.
d. 7, opposite internal capsule.

by piercing the back part of the lenticular nucleus. These, no doubt, correspond to the bundle which *Flechsig*[1] has recently described in the brain of an eight months fœtus, and which passes from the internal geniculate body to the anterior transverse temporal gyri perforating the putamen in its course. This bundle was medullated before those of the fillet, which are contributed to the posterior corpora quadrigemina.

The above retro-lenticular group descended with the capsular fibres, and was found to be distributed in the following ways.

[1] Flechsig, P., "Zur Anatomie des vord. Sehhugelstiels des Cingulum u. der Acusticus-Bahn," *Neurol. Centralb.*, xvi. 7, p. 290.

Many of its fibres entered the optic thalamus (see *d. 3*, fig. 4), and of these some were not traceable further. Others traversed this body, and appeared near the surface at a sulcus external to the anterior corpus quadrigeminum [1] (see fig. 4). Some of these latter entered the anterior tubercle ; the remainder were continued backwards to enter the posterior tubercle of the corpora quadrigemina. Still others were continued into the internal

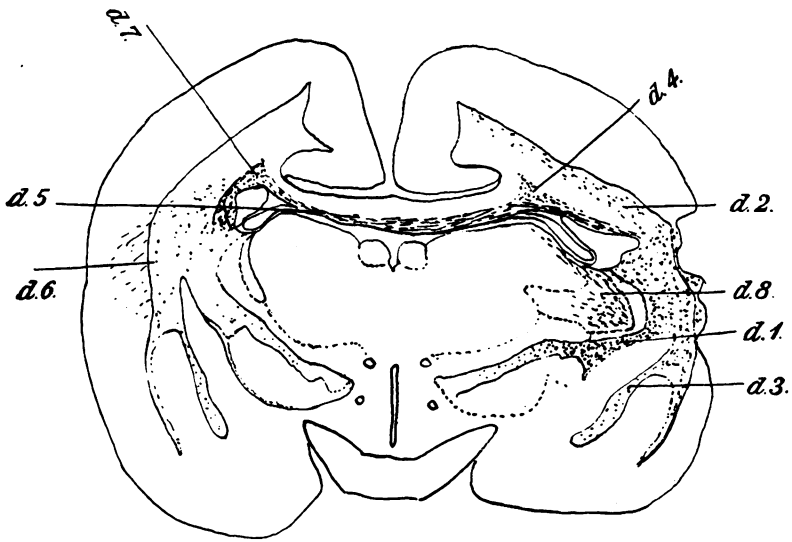

FIG. 7.—Vertical section through same brain as figs. 5 and 6 but posterior to fig. 6.

d. 1, *d. 2*, *d. 3*, *d. 5*, and *d. 6*, same as in fig. 6.
d. 4 and *d. 7*, degenerations in tapetum.
d. 8, degeneration extending into optic thalamus.

geniculate body. These are probably identical with the similar fibres found by Boyce after removal of one hemisphere. Boyce considers, however, that they end chiefly on the side opposite to the lesion. In my experiments this was not so, unless one regards those in the posterior commissure as belonging to the same system (*vide infra*). My observations under this heading in the main therefore confirm and extend those of numerous observers. In addition to the names already quoted, may be

[1] *Cf.* Boyce, "Contrib. to the Study of: I. Some of the Decussating Tracts of the Mid- and Inter-brain ; II. of the Pyramidal System in the Mesenceph. and Bulb," *Phil. Trans.*, ser. B., vol. clxxxviii. pp. 218, 219.

mentioned those of *Dejerine*,[1] and of *Ferrier* and *Turner*,[2] whose publications have appeared since the present research was undertaken.

It is interesting to note, at this stage, the existence of degenerated fibres in the posterior commissure (see *d. 5*, fig. 8). These turned immediately downwards towards the dorsal grey nuclei of the mesencephalon. They were no doubt continued from the capsular set of fibres, and would thus supply the cross link for

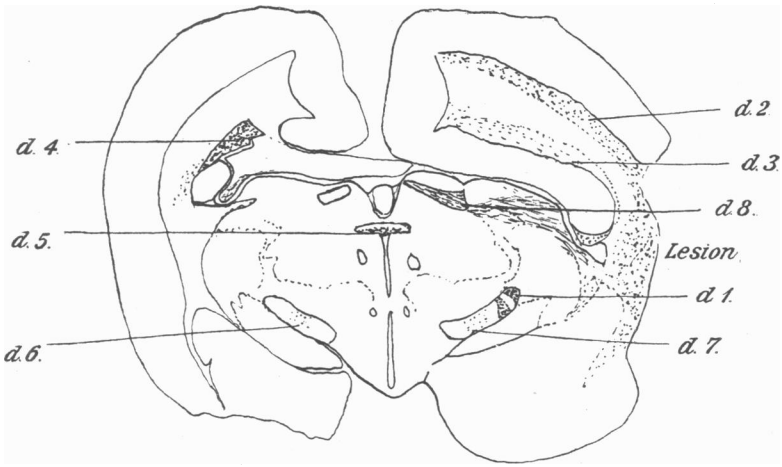

FIG. 8.—Vertical section through same brain as figs. 5, 6, and 7, but posterior to fig. 7, showing degenerations in—

d. 1, posterior part of internal capsule (subthalamic region).
d. 2, inferior longitudinal fasciculus.
d. 3, extending from tapetum into occipital lobe.
d. 4, tapetum of opposite side.
d. 5, posterior commissure.
d. 6 and *7*, scattered through middle parts of internal capsules.
d. 8, traversing optic thalamus to reach corpora quadrigemina.

a bilateral termination of the sets of fibres with which we are now dealing. That such bilateral method is the general plan of connection between a given portion of the cortex and other masses of grey matter I have little doubt.

Lastly, a very definite fasciculus continued downwards in the internal capsule, traversing the subthalamic segment of this

[1] Dejerine, J., "Sur l'origine cort. et trajet intra-céréb. des fibres de l'etage inf. ou pied du pédoncle cerebrale," *Mém. de la Soc. de Biol.*, t. 5, pp. 193–206.

[2] Ferrier and Turner, W. A., "An Experim. Research upon Cerebro-cortical afferent and efferent Tracts," *Proc. Roy. Soc.*, lxxii. p. 1.

tract (see *d. 1*, fig. 7), and from thence passed into the outer part of the pes pedunculi. In the subthalamic region the degenerated fibres were found to occupy the posterior part, distributed amongst certain of the bundles of fibres into which the system is here subdivided (see *d. 1*, fig 8), but leaving others wholly free. These latter, which no doubt for the most part represent the projection system of the occipital lobe, were not always the most posteriorly situated. Quite a common arrangement was to find a small degenerated bundle hindmost of all; then one or more large bundles in which the fibres were normal; and in front of these the main set of degenerated fibres. The method of distribution was, however, subject to variation, and leads one to believe that the relative position of the various bundles at this situation is not absolutely constant.

The existence of a definite tract in the outer part of the pes pedunculi, descending from the temporal lobe, has been abundantly confirmed by many observers in recent as well as former years. Amongst later workers may be mentioned *Dejerine*,[1] *Van Gehuchten*,[2] *Ferrier* and *Turner*,[3] *Pusateri*,[4] and *Gerwier*,[5] all of whom describe this tract. *Van Brero*[6] stands alone in denying its existence. Nearly all of the authors mentioned consider that the bundle in question contains fibres from the temporal lobe only. Gerwier, on the other hand, assigns to it fibres from the occipital cortex as well. This view I can substantiate, both from the fact that amongst the degenerated fibres, numerous normal ones are found, and also from the results of experiments which I made on the occipital cortex in conjunction with *Dr Cecil Shaw*,[7] and published some years ago.

[1] Dejerine, J. *op. cit.*

[2] Van Gehuchten, "Contrib. a l'étude du faisc. pyram.," *Journ. de Neurol. et d'Hypnol.*, B. 1, pp. 336–345; also 355–364.

[3] Ferrier and Turner, W. A., *op. cit.*

[4] Pusateri, E., "Contrib. allo studio dell' orig. del fascio pedunc. di Türck e del fascio long inf.," *Il Pisani*, s. 141–154.

[5] Gerwier (Herwer), A. W., "Ueber die Endigung. in d. Hirnrinde des lat. Bündels an. d. Basis d. Pedunc. cereb.," Ueberschau über *Psych. Neurol. u. experim. Psych.*, H. 3, s. 222. (Ref. in *Centr. f. Nervhkde.*, 21. Jahrg., N.F., ix. 106, p. 687.)

[6] Van Brero, P. C. J., "La Termin. cort du faisc. latéral pédonculaire," *Nouv. Iconogr. de la Salpêtriere*, Année 9, No. 4, pp. 206–222.

[7] Shaw, C., and Thompson, W. H., "Desc. Degenerns. from Lesions of the Cortex of the Occipital Lobe in Monkeys," *Brit. Med. Journ.*, 1896, vol. ii. p. 630.

The fibres of this bundle when traced downwards were seen to enter a group of cells in the pons, situated external to the pyramidal bundles, and on the side of the lesion. The majority ended here, but some were found crossing in the trapezium to effect a connection, no doubt, with the corresponding group of

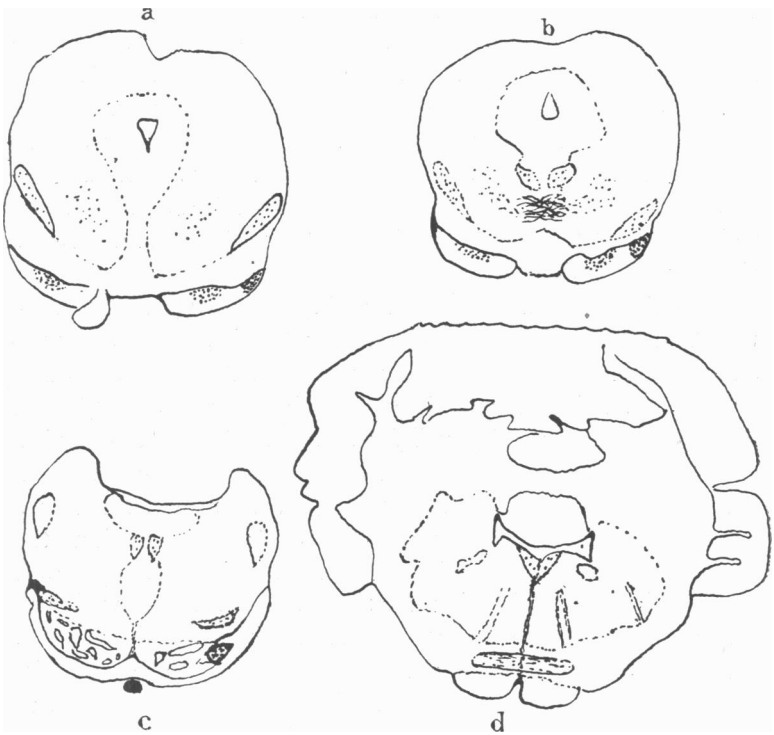

Fig. 9.—Dorso-ventral sections through mid-brain of same marmoset as preceding four figures, and through upper part of medulla of marmoset 9.

(*a.*) through upper part of crura.
(*b.*) through lower part of same.
(*c.*) through pons varolii.
(*d.*) through upper part of medulla of marmoset 9.

the opposite side. Thus, at this stage, a bilateral communication is again established. Gerwier[1] also describes degenerated fibres crossing in the transverse bundles of the pons after lesions of the temporal cortex.

(*b*) *Scattered Capsular Fibres.*—To return to the internal

[1] Gerwier, *op. cit.*

capsule, the degenerated fibres described were not the only ones found in this structure. Others were scattered throughout the whole of its posterior segment. A similar distribution of degenerated fibres was found in the internal capsule on the side opposite to the lesion. There can be little doubt, therefore, that these latter crossed over in the corpus callosum, which, as we have seen, contained such fibres throughout the whole of its posterior half. Bilaterally degenerated fibres situated in both internal capsules were also described by *Shaw* and *myself*, *loc. cit.*, after lesions of the cortex of the occipital lobe.

On tracing these fibres downwards they were found to diminish in number, and no doubt, as *Hamilton*[1] as well as *Ferrier* and *Turner*[2] state, by the contribution of some to the optic thalami.

Others were continued on into both peduncles, where they occupied the middle regions of the crustæ (see *d. 6* and *d. 7*, fig. 8). From here many were seen to enter the substantia nigra and terminate there. Such a mode of ending of pedal fibres has been observed by many investigators, and has recently been confirmed by *Dejerine* and *Long*.[3] It was also described by *Shaw* and *myself*,[4] in connection with similar fibres, degenerating after lesions of the occipital cortex. *Muratoff*,[5] *Rothmann*,[6] and *Boyce*[7] have also observed fibres leaving the pyramidal system in the mesencephalon and passing towards the tegmentum. The remainder of these fibres were followed in gradually reducing numbers as low as the pons, beyond which they could not with certainty be traced. These latter, no doubt, ended at different levels in ventral grey matter on their way downwards. It will be noticed that this system also furnishes bilateral connections between a given cortical area and the grey matter of the basal ganglia on the one hand, as well as that of ventral aspect of the mesencephalon on the other.

[1] Hamilton, D. J., "On the Corpus Callosum in the Embryo," *Brain*, 1885, p. 145; also "The Corpus Callosum in the adult Human Brain," *Journ. of Anat. and Physiol.*, vol. xix. pp. 385–414.

[2] Ferrier and Turner, W. A., *op. cit.*

[3] Dejerine, J. E., and Long, E., "Sur quelq. degener. second du tronc encephde l'homme, etc.," *Compt. Rend. de la Soc. de Biol.*, 30 Juillet 1898.

[4] Shaw, C., and Thompson, W. H., *op. cit.*

[5] Muratoff, *Arch. f. Anat. u. Physiol.*, 1893.

[6] Rothmann, *Neurol. Centralbl.*, June 1896.

[7] Boyce, *op. cit.*

The view that the corpus callosum contains other than direct commissural fibres, which was first set forth by *Hamilton*,[1] received much opposition. It has, however, been confirmed by the experiments of *Bianchi* and *d'Abundo*,[2] in connection with cortical localisation; by those of *Shaw* and *myself* on the occipital lobe; and also by those of *Ferrier* and *Turner*,[3] on cortical afferent and efferent tracts. Finally, *Dotto* and *Pusateri*[4] also support this view. These workers divided the corpus callosum at its hinder part in cats, and as a result were able to trace degenerated fibres downwards through the capsules into the mid-brain, and thence on into the medulla. Some were even followed into the spinal cord.

The liability to injury of adjacent parts of the motor cortex, which such experiments involve, has been pointed out by *Dejerine*,[5] and he attributes the degenerations which are traceable downwards to such cause.

I can confirm the statements of *Dejerine* with regard to the liability to injury, but I would point out that such possibility did not arise in the present series of experiments, nor did it in those of *Ferrier* and *Turner*.

These descending callosal fibres can hardly be regarded as "projection fibres" in the ordinary acceptance of this term. They are more to be considered as contra-lateral association fibres, a view which would equally apply to all of the fibres composing the corpus callosum.

Mid-brain.—Besides the degenerated fibres already mentioned as being found in the mid-brain, others also occurred in both fillets. These were detected in the highest sections made through the crura, and were even more numerous here than in sections lower down. They could not, therefore, have wandered in from other crural tracts, possessing such fibres, and must consequently have descended from the internal capsules.

[1] Hamilton, D. J., *op. cit.*

[2] Bianchi, L., e d'Abundo, G., "La degeneraz. speriment. nel cervello e nel' midollo spinale, etc.," *La Psychiatria*, 1886; also, "Die in das Gehirn u. Rückenmark herabsteig. Experim. Degener. als Beitrag z. Lehre v. cereb. Lokalisation," *Neurol. Centralbl.* v. 17, 1886.

[3] Ferrier and Turner, *op. cit.*

[4] Dotto e Pusateri, "Sul de corso delle fibre del Corp. Callos. e del Psalterium," *Riv. di patol. nervement*, pp. 69–70.

[5] Dejerine, J., *Anatomie des Centres Nerveux*, Paris, 1895, p. 765.

Further, from the fact that the numbers were about equal on both sides from the first, I take it that those of the contralateral bundle must have crossed over in the corpus callosum.

The existence of fibres directly connecting the cortex with the mid-brain, through the medium of the internal capsule, has been shown by numerous observers. It was first stated by *V. Gudden*,[1] and has since been confirmed by *Flechsig*[2] and *V. Monakow*.[3] *V. Monakow* found such fibres descending from the occipital lobe, and entering both upper and lower fillets. The fibres in my own experiments also occupied both these, though they chiefly lay in the upper fillet.

Bechterew,[4] *Edinger*,[5] *Obersteiner* and *Hill*,[6] *Hösel*,[7] *Ferrier* and *Turner*[8] also adopt the view of cortico-mesencephalic fibres.

The fibres thus found in both fillets were never very numerous. They were traceable as low as the pons, diminishing on their way downwards, and no doubt ended in tegmental grey matter at successively lower levels, probably furnishing cortical connections with the nuclei of sensory cranial nerves.

Thus throughout the whole chain of communicating links, a bilateral plan of connection seems to be followed. One would almost *a priori* expect this. Moreover, it is interesting to note that this system of 'sensory' communications has its homologue in the mode of termination of motor paths, as *Muratoff*,[9] *Sherrington*,[10] and *Mellus*[11] have all shown. These observers have

[1] V. Gudden, *Gesammelte Abhandlungen.*

[2] Flechsig, "Zur Anat. u. Entwick. Geschicht. d. Leitungs-B. i. Grossh. d. Menschen," *Arch. f. Anat. u. Physiol.*, Anat. Abth., 1881, 12–75.

[3] Monakow, "Experim. Beiträge z. Kenntn. d. Pyramiden u. Schleifenbahn Referat," *Neurol. Centralbl.* 1883, s. 197–198; also *Ibid.*, 1885, s. 265–268; also *Deutsche med. Wochenschr.*, xi., s. 79.

[4] Bechterew, "Untersuchungen u. die Schleifenschicht," *Verh. d. konigl. sachs. Gesellsch. d. Wissensch. z. Leipzig*, 1885, i., ii., s. 241–244.

[5] Edinger, *Vorlesungen über d. Bau d. Nerv. Centralorg.*, s. 415 6ste Aufl. Leipz. 1900.

[6] Obersteiner and Hill, *Anat. of the Cent. Nerv. Organs* (Lond. 1890), p. 252.

[7] Hösel, "Beiträge z. Anat. d. Schleifen," *Neurol. Centralbl.*, 1894, pp. 546–549.

[8] Ferrier and Turner, *op. cit.*

[9] Muratoff, "Secund. Degener: nach Zerstörung d. Motor-Sphäre des Gehirns, etc.," *Archiv f. Anat.*, 1893, s. 97.

[10] Sherrington, "Note on Experim. Degener. of Pyramidal Tract.," *Lancet*, i., 1894, p. 265.

[11] Mellus, "Prelim. Note on Bilat. Degener. in the Sp. Cord of Monkey (*Macacus sinicus*)," *Proc. Roy. Soc. Lond.*, lv. (1894), p. 208.

found that the portion of the pyramidal tract destined for the lateral column when it reaches the medulla, and rises dorsally prior to decussation, divides into two portions; a larger which crosses over into the lateral column of the opposite half of the spinal cord, and a smaller which is continued on into the lateral column of its own side. It is, I should venture to say, quite likely that the direct pyramidal bundle also ends bilaterally. Further, the manner in which the optic tract terminates in both retinæ is not without interest to call to mind in this connection.

Since I have no doubt that the same rule applies to other areas of cortex than those of the temporal lobe, one might therefore formulate *a law of bilateral connection between a given portion of cortex, and all the more distantly situated masses of grey matter with which it is associated.*

Before concluding, I have to thank Dr Cecil Shaw for kindly making the photographs for me.

Summary of Results.

I. *Degeneration was detected in the following sets of fibres:*— (1) In short association, fibres passing to neighbouring parts of the cortex. (2) In longer association bundles, viz., inferior longitudinal fasciculus, and parieto-temporal fasciculus, leading to occipital and parietal lobes respectively. (3) In the tapetum, some of these fibres passed back into the occipital lobe on the side of the lesion; others crossed over in the corpus callosum to the tapetum of the opposite side, by which they were likewise conveyed backwards and downwards into the occipital lobe. (4) In the external capsule, some being distributed to the anterior and lower part of the cerebrum, others crossing over in the anterior commissure to the opposite temporal lobe. (5) In the corpus callosum, one set leading to the opposite temporal cortex, another descending in internal capsule. (6) In the internal capsule, the main bundle of descending degeneration occupying the retro-lenticular segment of the posterior limb on the side of the lesion. Its fibres were distributed in the first instance to the back part of the optic thalamus, the corpus geniculatum internum, and to both corpora quadrigemina. An additional set descended

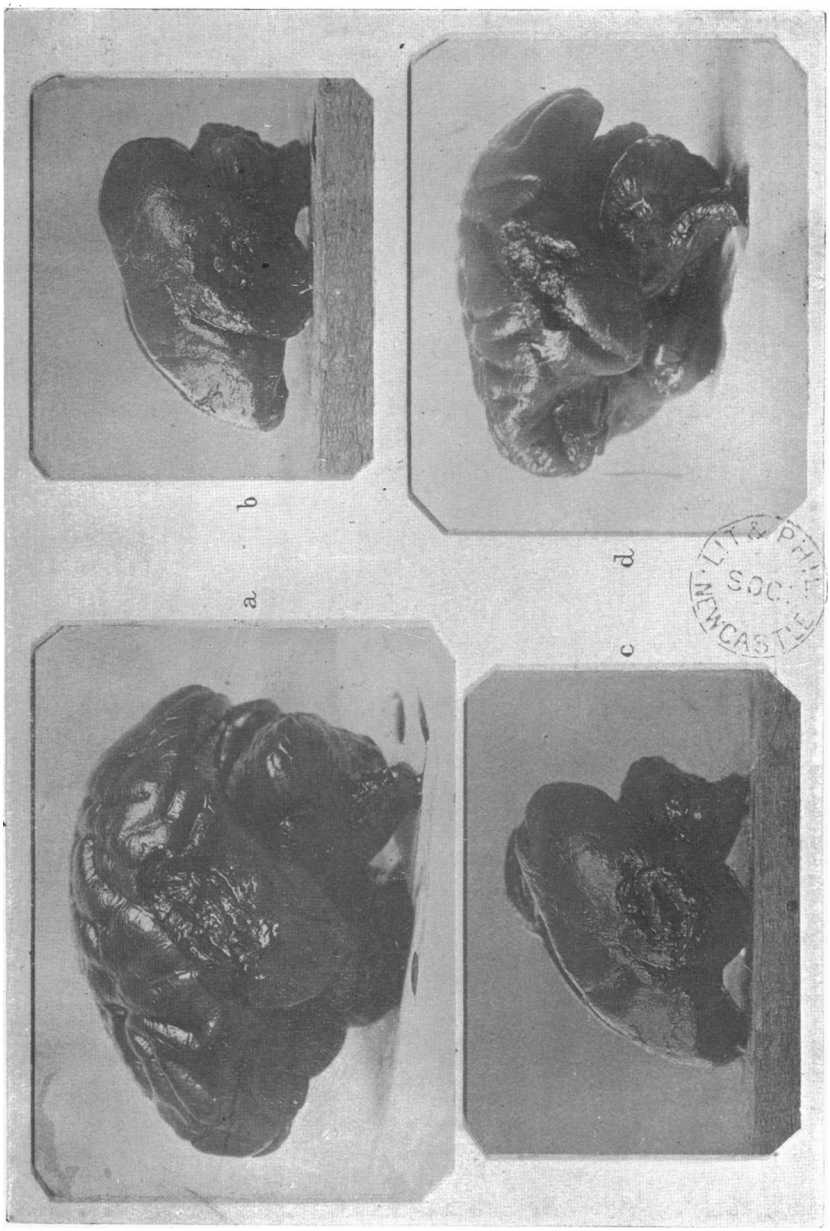

PLATE XVIII.—Photographic representations of the lesions from four experiments—(a) monkey ix. ; (b) marmoset xv. ; (c) marmoset x. ; (d) monkey xii.

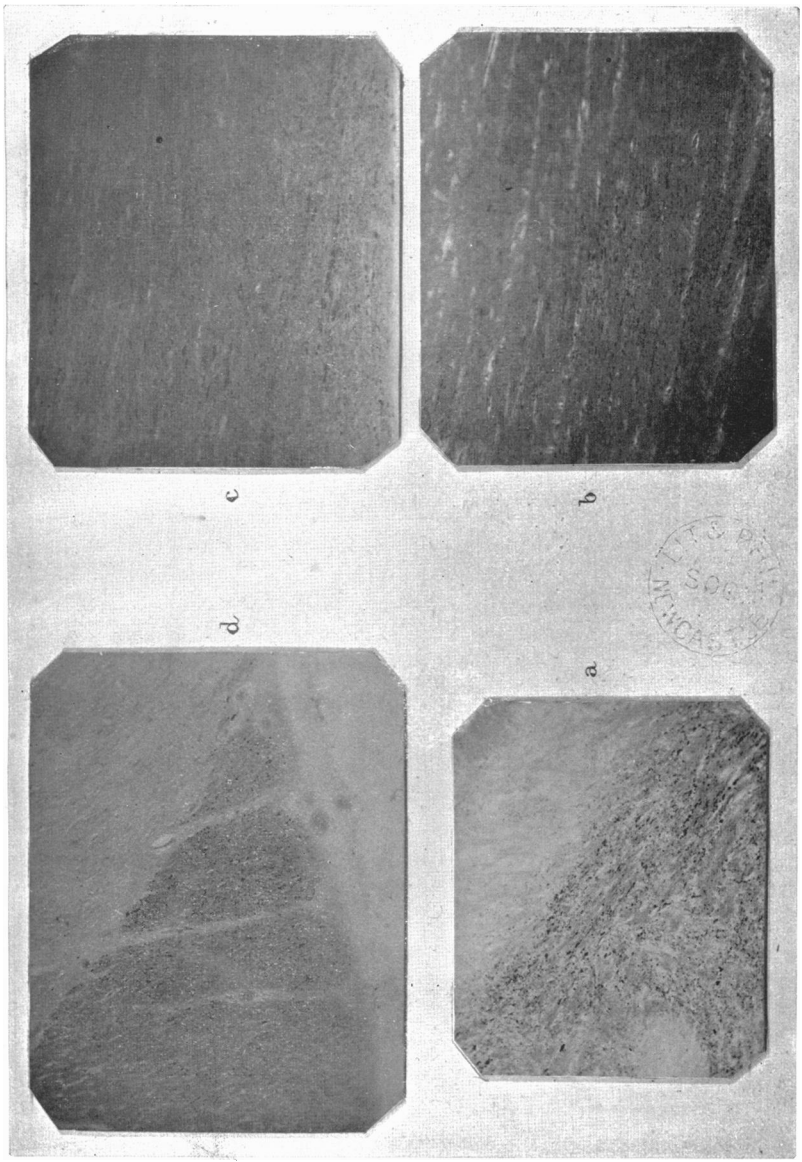

PLATE XIX.—Photographs of degenerations taken from (a) internal capsule post. part. (marm. vi.); (b) anterior commissure, monk. ix.; (c) external part of left pes pedunculi, monk. ix.; (c) corpus callosum, monk. ix.

into the outer fifth of the pes pedunculi, reaching as low as the pons, where it terminated bilaterally. Other scattered degenerations were seen in the greater part of the posterior limbs of both capsules. These were traced into corresponding parts of the peduncles, and on into the pons. Fibres from this source were contributed to the optic thalami, the substantia nigra, and mesencephalic grey matter. (7) Lastly, in both fillets, crossing from the internal capsules, and gradually disappearing in the mid-brain.

II. *A law of bilateral association seems to prevail in the communications established between a given area of cortex and all other distantly situated masses of grey matter with which it is directly connected, whether subserving 'motor' or 'sensory' functions.*

N.B.—The expenses of this research have been defrayed by grants from the Royal Society and Royal Irish Academy. Thanks are, in addition, due to the latter Society, in whose Proceedings the paper also appears, for the kind loan of the illustration blocks.