THE SIGNIFICANCE OF THE CORTEX CONSIDERED
IN CONNECTION WITH A REPORT UPON A DOG
FROM WHICH THE ENTIRE CEREBRUM HAD
BEEN REMOVED BY PROF. GOLTZ.¹

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Thanks to the kindness of Professor Goltz, of Strassburg, I have been placed in possession of most valuable material for cerebral anatomy—none other than the brains of a large number of dogs from which a larger or smaller portion of the cerebrum had been removed.

The anatomical investigation of these brains requires a long time and it is still far from completion. Nevertheless I shall report at present upon a part of the results which have been obtained from the study of the brain of that widely known dog from which Professor Goltz succeeded, by a method hitherto unapproached, in removing the entire cerebrum. This dog, which survived the last operation more than eighteen months, was doubtless known to many of you. The unparalleled success of the operation, the possibility of studying an animal entirely deprived of cerebrum so many months after the disappearance of all irritative phenomena, the valuable observations which have been made upon the animal, and which Professor Goltz has published in his *Abhandlung über die Verrichtungen des Grosshirns*, VII. (*Plüger's Archiv*. Bd. LI.) all these have awakened much interest in the anatomical results. Added to this is the interest which such a preparation has in virtue of its manifold secondary degeneration phenomena for those who realize upon how slender footing our knowledge of the fibre tracts of the diencephalon now stands.

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I may at once remark that this "dog without cerebrum, Goltz" actually proves, on anatomical investigation, to possess scarcely a trace of the cerebrum. This dog was able during its lifetime to employ its limbs in walking, running and standing, he perceived tactile irritation of all parts of the body and could be awakened from a deep sleep by these excitements or loud noises. He possessed a distinct sensation of the position of his members and could unquestionably be incited to adaptive activity by such sensory stimuli. Nor was he totally blind, though it could not be proven that he was so affected by visual sensations as to modify the position or movements of the body. It was evident that hunger and gustatory sensations remained. The animal was profoundly imbecile and it was impossible to enter into any sort of personal relation to him. No expressions of joy or fear escaped him. In restless and unvarying round he ran in his cage. With the exception of the gradual reacquirement of the power to feed himself, he never learned anything. However often an act may have been repeated, as, for example, his daily removal from his cage for feeding during eighteen months, it produced no evidence of acquired experience; each time, no matter how hungry, he snapped and bit angrily. Every trace of methodical activity was lost. The dog was capable of a variety of vocal expressions. His spontaneous acts, which were numerous enough, exhibited no trace of reflection or the slightest evidence of experience.

The most remarkable deficiency resulting from the removal of the cerebrum was the suppression of all expressions which betray understanding, memory, reflection, and intelligence in the animal. On the other hand those faculties remained intact which may be exercised without these functions, such as a certain degree of motor power, sensation and general irritability.

And now, gentlemen, a glance at the charts¹ and preparations will show that, caudad of the great injury which has removed the entire cerebrum and somewhat injured the thalamus,

¹ The illustrations will appear at the proper time with the extended publication of the results of the study of the operated dog brains.

in the region of the corpora quadrigemina only slight divergence from the normal conditions are observable at first sight.

In this section of spinal cord you will detect nothing to distinguish it from a section from a normal dog, and it is only after close inspection that you will discover that a few fibres are absent from dorso-lateral columns and that the whole pyramidal tract, which is not very strongly developed in the dog at best, is affected by secondary degeneration on both sides. Even in these sections of the medulla and quadrigemina no one would discover without careful study that farther forward such an enormous region of the ventral nervous system had been injured. From these observations we might conclude that the spinal cord and the ganglia and fibres in the medulla and mid-brain are distinct centres which possess a high degree of anatomical independence of those parts of the brain lying farther cephalad. The functions which they subserve, motor co-ordination, receptivity to sense impressions, were not so seriously affected in this dog. The opinion which might be formed on anatomical grounds, that an animal which retains only these centres intact could, in case of necessity, get on with them alone, has become certainty through the evidence afforded by eighteen months' observation of this dog. I shall discuss this point more in detail later.

Glance, in the next place, at the illustrations of sections through the forebrain. These were prepared by drawing the outline of the sections through the fragments of brain of the operated dog and projecting sections from the same level of normal dog brains. The projection distance was so adjusted that the two outlines were made to correspond and thus artificial figures of two equal brains were produced.

It appears that almost the entire forebrain has been removed in an extraordinarily skilful and complete manner. Cephalad both the frontal lobes are absent, together with a part of the striatum and the callosum and corpus fornicis. On the right side a part of the internal capsule is retained with the body of the striatum but on the left side only traces of these re-

main. The precommissure, the olfactory fibres of which should be visible at this point, has completely disappeared.

Notice that the inner capsule, even in the first section, contains quite a number of medullated fibres. These, therefore, must have their origin not in cells of the cortex but in structures lying farther caudad. The next section shows that the caudatus is relatively well preserved on the right side while on the left only insignificant fragments remain. A trace of the cortex belonging to the trigonum olfactorium lies ventrad of the head of the striatum on the brain base. The lentiformis is almost completely removed with the hemispheres. Farther caudad, in region of the commissura media, the thalamus is present on both sides but all its niduli are atrophied to a marked extent. Only a much atrophied internal capsule, not a trace of hemispheres, no fornix and only the fragments of an ammonshorn of one side remained. The uncus of the parietal lobe is retained because the operator wished to preserve the optic nerve. In this he was successful on the right side but on the left side the section passed a little too far mesad and also removed the corpus geniculatum laterale. Thus the optic nerve of that side is atrophied although intact on the other side. Behind the sections here figured all the thalamus ganglia are present and send their fibres caudad quite like those of a normal brain. In spite of the enormous injury in the forebrain region, the tegmental region and mesencephalon gradually appear, sections passing through which are but slightly distinguishable from those of a normal midbrain. The farther caudad one goes the fewer tracts are affected till, as already remarked, in the cord the only defect is the absence of the pyramidal tracts.

I have thus far scarcely taken into consideration tracts secondarily degenerated, in part because these relations lie outside the range of this lecture, and in part because the investigation is as yet incomplete. Our present purpose is to indicate the extent of the destruction due to the operation.

I again summarize the results. Of the entire cerebrum, aside from the remnants of the right Ammonshorn, there remains not a trace except a strongly atrophied uncus of the parietal

lobe, which is reduced to a mere membrane. The incision on the right side passes laterad of the capsule leaving the thalamus ganglia and opticus intact, while on the left side the genicululum externum, optic nerve, the ganglion of the lattice layer, and a part of the ventral thalamus nidulus were also removed. The left optic nerve remains visible only in the form of a thread of nonmedullated fibres. Of the ganglia of the mesencephalon, cerebellum, etc. all are intact.

This dog which, as you see, had lost almost the entire cerebrum, possessed the greater part of those faculties which for a time we have been led to believe emanated essentially from the cerebrum. The experiments of Goltz, which have removed so large a mass of brain substance, have always produced great interest. But the results of these operations, which he described in his usual masterly manner, seemed to many to contradict the results of the majority of the physiologists who have employed stimulation and extirpation. In other words, a distinct contradiction was thought to exist between the results of localization and those produced by Goltz. Here, however, we must be content with the facts. It is possible to explain that, on one hand, a slight injury of cortex in man or the ape produces evident symptoms or lameness, motor insufficiency, etc., that we may diagnose the spot and treat it successfully, and that, on the other hand, this dog, and many others operated upon by Goltz, gave evidence of no marked motor disturbances.

I am convinced that the facts which comparative anatomy has taught us are well adapted to throw a strong light upon the significance of the cortex and cerebrum and to explain the contradictions which so many find between the results of stimulation of the cortex and its total extirpation.

There is a large class of animals which are totally devoid of a cortex and the fibres originating there. It is the group of bony fishes [Teleostei.] In this group the brain "begins", *sit venia verbo*, with the axial ganglion, corpus striatum, as indicated in the drawing. The thalamus ganglia are relatively insignificant, it is only when we reach the mesencephalon that great cell and fibre masses appear. I may add that these do not differ in es-

sentials of arrangement from those with which we are familiar in the mammals and man. No one would assume that the cortexless fish is lame or without sensation or blind, yet it lacks those tracts which in higher animals conduct from the first termini of the motor, sensory and cranial nerves to the cortex. The sole conclusion which is warranted is that the first stations of these nerves suffice to exert those functions which we recognize as characteristic of the central organs.

As one ascends the scale there is added (I use the word "added" purposely) to the structures already existing a cortex. We are able to clearly distinguish the cortex from all other parts of the brain (by the form and arrangements of the cells) since we possess the Golgi method. Such cells appear first in an irregular and sporadic manner in the amphibia. In the reptilia we find a well-defined, regularly arranged cortex clothing the mantle. From it arise a few fibres which connect the mantle with the deeper centres. Even among the mammals the cortex is, as well known, exceedingly variable in its extent. Its amount in rodents and many other mammals seems quite small when compared with that of the thalamus and mid-brain ganglia. It is not until the higher mammals are reached that the cortical layer of the cerebrum gradually acquires its extensive development which, through the magnitude of the connections which it contains and especially the radiations which pass to the thalamus, produces the familiar convolutions. The cortex is, therefore, not a necessary element in the concept of a vertebrate brain, it is of gradual development and continues to increase in size in the group of mammals itself.

The latest to develop is that part of the cortex which, with its radiations, is called the frontal lobe. In the carnivora it is still very small, and even in the ape it has relatively slight development, while in the anthropoids, those apes which most nearly approach man, there are remarkable differences between the frontal lobe and that of the lowest races of men. The rate of development is not the same for all parts of the cortex. Those parts of the cortex pertaining to the olfactory sense, the marginal gyre and ammonshorn, may attain an enormous develop-

ment in those animals which depend much on this sense, while in the case of the apes and man these parts occupy a subordinate place.

It is not necessary to rehearse in this circle the evidence that the cortex with its numerous cells and fibre tracts is essentially the bearer of the psychical functions. Comparative anatomy and Goltz's experiments show that its existence is not necessary for the so-called lower functions which take place without constant intervention of the intelligence and were formerly called instinctive. Schrader, by his experiments on doves and lizards has obtained results like those I reached on an anatomical basis and the experiments of Steiner have not offered any contradiction.

If the cortex is non-essential for the above functions, it by no means follows that it has no influence upon them, and at this point the results obtained by experimenters who have employed localization, offer a valuable supplement. It must be assumed that, in fact, a chart of the surface of the brain may be constructed, a chart which indicates at which points stimuli may be applied to produce a specific motor or sensory reaction upon the deeper centres. There is no contradiction between the two experimental tendencies, but one supplements the other. Goltz, however, shows that the removal of the cortex and its connections deprives the animal of the organ for all those functions which make possible the higher psychical manifestations, such as intelligence and reflection.

In progressive paralysis of insanity we meet clinically and anatomically a disease from focal beginnings which gradually destroys the cortex. The final result is just what Goltz obtained operatively, the patient becomes deeply imbecile. Naturally the symptomatic complex is greatly modified in man, who has become accustomed in his activities to permit the coöperation of memory and reflection to a very great extent. Thus man bears cortical injuries much worse than animals and reacts from injuries which would hardly permanently affect a dog at all, to the extent of complete obliteration of function. Moreover the clinical symptoms of paralysis, so far as these questions are

concerned, are much complicated by the fact that, in the course of the disease, spinal cord symptoms usually appear.

The new-born child has but few connections of the first centres with the cortex. The optic radiations do not develop until weeks after birth. In spite of this, however, it may be easily proven that the child sees well, but there appears for a time no evidence of comprehension of what is seen, as in the decorticated dog, nor of the power to practically apply what is seen. These appear only after the development of the optic radiation permits the cooperation of the cortex. But a man who in later life loses the occipital lobe of both sides no longer has the capacity to see, like the dog or the child, with the deeper centres. I have the record of a man who suddenly became completely blind. He lived for years without being able to see in the slightest degree. In the autopsy I found bilateral softening of the two occipital lobes, probably as a result of embolism.

The cortex plays a more important part and becomes more indispensable the higher we ascend in the animal scale. This is the explanation of the divergent results of the experimenters. It is not only possible but very probable that the destruction of the occipital lobes would have a very different effect on vision in the ape than in the dog or rabbit.

Since we have discovered that the cortex is something which has gradually been added to the rest of the brain in the animal series and that it serves the higher faculties of psychical life, such as intelligence, experience, and reflection, it is not of slight moment to enquire what sensations are localized in the small cortex which first appears in amphibians, or still better, in reptiles. It is only within the last months that I have reached a solution of this problem. It proves that the cortex of these animals is connected by a strong system of fibers almost exclusively with the olfactory apparatus. The phylogenetically oldest cortex serves the olfactory sense and has, even thus early, certain peculiarities which permit us to consider it closely related to the Ammonshorn. The conclusion which is self-evidently to be drawn is that the first of the higher psychological functions which makes its appearance in the animal kingdom is

that which has to do with the memory and evolution of olfactory sensations (For particulars see *Anatomischer Anzeiger*, 1893, 10.)

I present not only the preparations from the dog operated on by Goltz but also a series from a normal dog and finally a number of sections of the brain of the giant turtle, *Chelone midas*, which clearly show the connection of the oldest cortex with the olfactory lobes.

CONTRIBUTIONS TO THE COMPARATIVE MORPHOLOGY OF THE CENTRAL NERVOUS SYSTEM.

II.—Topography and Histology of the Brain of Certain Reptiles.

(Continued from Vol. I. p. 37.)

By C. L. HERRICK.

Additional remarks upon the cerebrum. The *olfactory tuber* is large in nearly all reptiles. In some cases, as we have shown elsewhere, the tuber is carried forward by the growth of the skull and separated from the cerebrum, as in fishes. This is true in the alligator, giving rise to the mistaken idea that the peduncles are the olfactory nerves (Rabl-Rückard and Wiedersheim). In serpents the tuber retains its direct connection with the hemisphere but it is greatly expanded, with a laterally divergent terminal bulb. The ventricle extends nearly to the end. It would appear that there are two distinct portions of the pero. The longitudinal sections of black snake brain (Plate VII., Figs. 1-3.) show that at the very tip there is a mass of isolated pero which is the source of the olfactory nerve proper, while the nerve to the large Jacobson's organ is derived from fibres from the mesal olfactory fossa. The real configuration of the tuber is best seen from the horizontal section (Plate VII., Fig. 4.) It will be seen that serpents have developed to an enormous extent the structure we have described as the olfac-