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Cerebellar Functions

BY
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FIRST PART

EXPOSITION OF FACTS

CHAPTER I

ANATOMY OF THE CEREBELLUM

I. The Architecture of the Cerebellum

The cerebellum is an unpaired median symmetrical organ, situated, in man, below the *cerebral hemispheres* which cover it entirely, behind the *corpora quadrigemini,* and above the *pons Varolii* and the *medulla oblongata* in which it makes a deep groove or concavity and which it overlaps largely on the sides.

With its furrowed and lamellated appearance it is related to all the other parts of the central nervous system in which, by volume, it occupies the second place; it is but a misnomer to call it the "little brain" or "Kleinhirn" as do the Germans as this name is neither justified by morphology, histology nor physiology.

The cortex of the cerebellum or the cerebellar mantle, which is demonstrated by a simple macroscopic examination, constitutes but one portion of the organ; a series of longitudinal or sagittal sections gives immediately an important idea of its architecture. From the surface towards the interior one can distinguish: (1) the cerebellar cortex; (2) a thick layer of white matter; (3) collections of gray matter or central gray nuclei. In man there are four of these nuclei for each half of the organ, the *corpus rhomboideum* or cerebellar olive also called the *corpus dentatum,* the *nucleus fastigii,* the *nucleus globulosus* and the *nucleus em-*

boliformis (Fig. 3). Certainly the cortex and the nuclei have, as we shall see further on, very intimate relations with one another, but their configuration and their structure is so dissimilar that they must be looked upon as distinct organs. This should be the same with the cerebellum as with the cerebrum. In each cerebral hemisphere does not one distinguish—as well from the point of view of structure as of function—the cortex and the central nuclei? All the more reason to do the same for the cerebellum in which the cortex is so distinctly differentiated from the rest by its external appearance as well as by its histological structure.

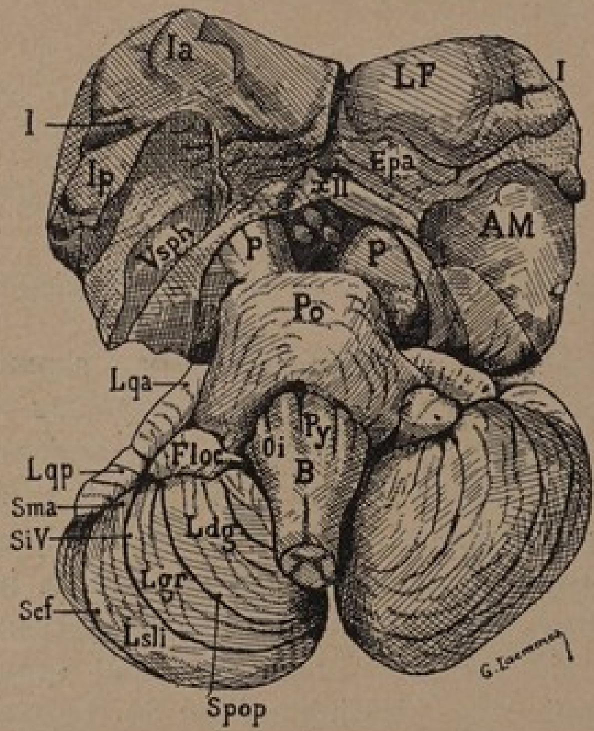

FIG. I. Section of Meynert. Inferior surface of the cerebellum. (After a photograph.)

AM, anterior wall; *B*, medulla; *Cv*, hemispheres of the cerebellum; *Epa*, anterior perforated space; *Fe* bundle of Férré; *Floc*, flocculus; *I*, insula; *i*, fissure of the insula; *Ia*, anterior convolutions of the insula; *Ip*, posterior convolution of the insula; *LF*, frontal lobe; *LT*, temporal lobe; *Lc*, central lobe; *Ldg*, digastric lobe; *Lgr*, lobus gracilis.

This conception is however not only anatomical but physiological as well; there will be occasion to investigate whether there are differences observed between the symptoms which are produced by the simple destruction of the cortex in animals and man, and those produced by the total destruction of the organ (both cortex and central gray nuclei), between the phenomena produced by the excitation of the cortex and of those which follow the irritation of the central nuclei. To sum up, the cerebellar cortex is an organ and the central gray nuclei are other organs; there exist relations, both anatomical and physiological, between the two, but nevertheless they enjoy an independence sufficiently marked to consider them as distinct organs.

The cerebellum is formed of a median or central part, the vermis or median lobe, and of two lateral parts, the lateral lobes or hemispheres.

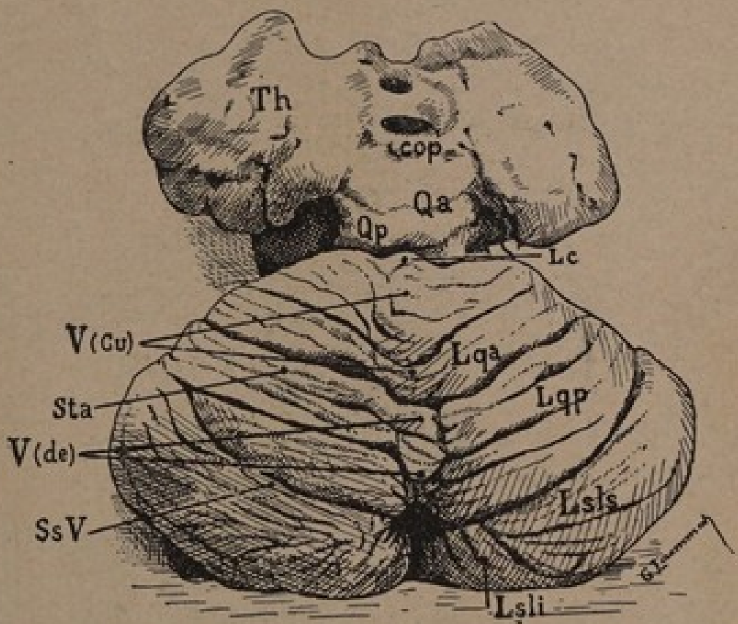

FIG. 2. Section of Meynert. Superior surface of the cerebellum. *Lqa*, anterior quadrilateral lobe; *Lqp*, posterior quadrilateral lobe; *Lsli*, inferior semi-lunar lobe; *Lsls*, superior semi-lunar lobe; *NA*, nucleus amygdalus; *P*, foot of the peduncle; *pFL*, falciform fold of Broca; *Scf*, circumferential fissure of Vicq d'Azyr; *SiV*, inferior fissure; *Sma*, anterior marginal groove; *SsV*, superior fissure; *Sta*, anterior transverse fissure; *Vcu*, culmen; *Vde*, declive; *Vsph*, sphenoidal ventricle; *XII*, optic chasm.

The vermis in the animal series is the most constant part of the cerebellum; it alone exists in the inferior vertebrates (fishes, reptiles), and also in the great majority of birds. It is only in the mammalia that the lateral lobes, rudimentary in certain types of birds, compare in their development with the vermis. Edinger, from the point of view of phylogenetic evolution, joins the vermis and the flocculus under the name of paleocerebellum; the lateral lobes which appear later form the neocerebellum.

In man the limits between the hemispheres and the vermis on the superior surface are somewhat indistinct; this is not so on the inferior surface, where the pyramids are clearly separated from the hemispheres on each side by a deep groove. The superior surface of the vermis is called the superior vermis and the inferior surface the inferior vermis.

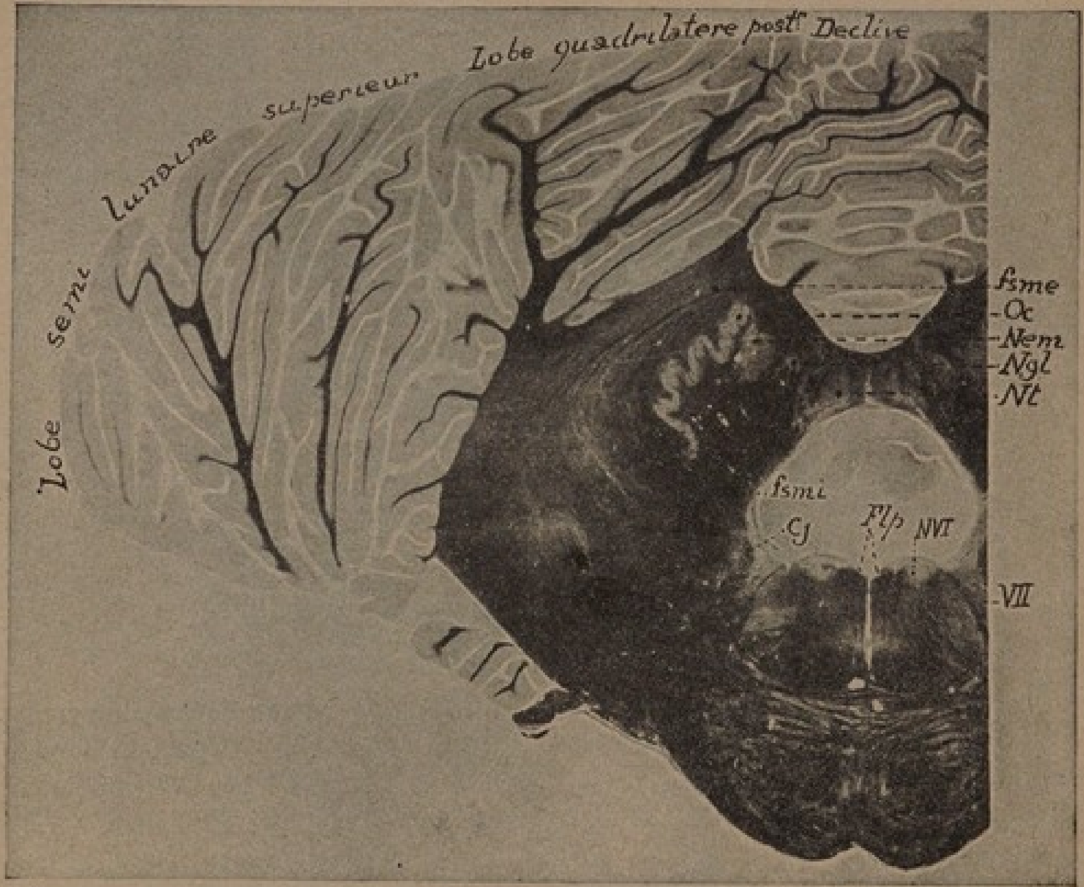

FIG. 3. Photograph of a section of the pons and the cerebellum of man. (Stained Wiegert-Pal.)

Cj, juxta-restiform body; *Flp*, posterior longitudinal bundle; *fsme*, *fsmi*, arcuate fibers, external, internal; *Nem*, embolus; *Ngl*, globulus; *Nt*, nucleus fastigii; *Oc*, cerebellar olive; *Pci*, inferior cerebellar peduncle; *Pcm*, middle cerebellar peduncle; *NVI*, nucleus of sixth nerve; *VII*, facial.

In animals they are respectively the posterior and anterior vermis. A detailed description of the fissures and lobes does not come within the scope of this work. It is only necessary to remember that the cerebellum is divided by several deep fissures into lobes; these are divided by less pronounced fissures into lobules and these in their turn into lamellæ. The fissures of the vermis are less deep than of the lateral hemispheres, nevertheless there is an apparent continuity between the lamellæ of the cerebellar hemispheres and those of the vermis, so that each lobe comprised between two deep fissures may be considered as being formed of a vermian and two hemispheric parts. This conception, however, is purely anatomical, for physiologically it seems preferable not to confound the hemispheres and the vermis.

M. and Mme. Dejerine distinguish five primordial lobes in the cerebellum of man: (1) superior lobe or lobe of the principal mass of the vermis; (2) posterior lobe, or lobe of the transverse lobule; (3) inferior lobe or lobe of the pyramid; (4) infero-internal lobe, or lobe of the uvula; (5) infero-anterior lobe or lobe of the nodule.

Each of these lobes comprises a vermian and a hemispheric portion. The superior lobe is divided into four secondary lobes. The lobe of the lingula, central lobe, lobe of the culmen and lobe of the declive. The lobe of the lingula is represented in the vermis by the lingula and in the hemispheres by the frenulæ of the lingula; in the same way the central lobe comprises the central lobule and the alæ of the central lobule. The lobe of the culmen, the culmen and the anterior portion of the quadrilateral lobe; the lobe of the declive represents the declivus and the posterior portion of the quadrilateral lobe.

The posterior lobe is subdivided into the superior lobe of the transverse lamellæ (folium cacuminis in the vermis and superior semilunar lobe in the hemispheres), and the lobe of the inferior transverse lamellæ (tuber valvulæ in the vermis and the inferior semilunar lobe and the lobus gracilis in the hemispheres), the inferior lobe or lobe of the pyramid comprises the pyramid in the vermis and the digastric lobe in the hemispheres.

The infero-internal lobe or the lobe of the uvula is formed by the uvula in the vermis, and the tonsils in the hemispheres.

Finally the infero-anterior lobe or lobe of the nodule is represented in the vermis by the nodule and in the hemispheres by the flocculus.

The figures 1 and 2 represent the superior and inferior surfaces of the cerebellum in man.

The nomenclature of the lobes and fissures is purely anatomical. The theory of cerebellar localization, which is of very recent date, does not up to the present repose upon a basis of facts sufficiently demonstrable.

II. Histology of the Cerebellum

In the solution of a physiological problem of this order one cannot omit a consideration of the structure of the cerebellum and more particularly the knowledge that has been acquired of the connections which unite the nerve elements or different groups of cells one with another. The results obtained by staining with silver chromate by Golgi and Ramon y Cajal are of primary importance from this viewpoint (Figs. 4 and 5).

Structure of the Cortex.—Each lobe of the cortex is divided into lobules and lamellæ. The whole histology of the cortex is thus based upon that of a lamella. Each lamella is divided from the surface to the interior into: (1) the molecular layer; (2) the granular layer and (3) the white substance.

The molecular layer is occupied by star-shaped cells of two kinds, large and small. The small cells, more superficial, have the form and properties of the majority of multipolar cells. The large cells for the most part lie deeper. The axis-cylinder of the large star-shaped cells is derived from the body of the cell and takes an antero-posterior direction; after a long course it approaches a Purkinje cell around which it arborizes and forms a sort of basket or envelope (Kölliker), but before this it gives off at regular intervals collaterals which arborize in the same manner around other Purkinje cells. Each star-shaped cell of the molecular layer has thus, dependent upon it, a large number of Purkinje cells. At the limits of the molecular layer and the granular layer there are found a large number of the Purkinje cells: the largest in size of the elements of the cortex, and considered from the physiological point of view as playing the most active part.

The Purkinje cells are notable for their rich protoplasmic expansions which run through the whole thickness of the molecular layer. The body is voluminous and spherical or ovoid, it is continuous with one or two large protoplasmic arborizations upon which all the others are implanted. These protoplasmic arborizations or dendrites are covered with thorny projections which are perpendicularly inserted; they terminate freely. The axis cylinder is directed towards the interior, at first to the granular layer and then to the white substance, it gives off one or two collaterals which mount to the molecular layer where they end.

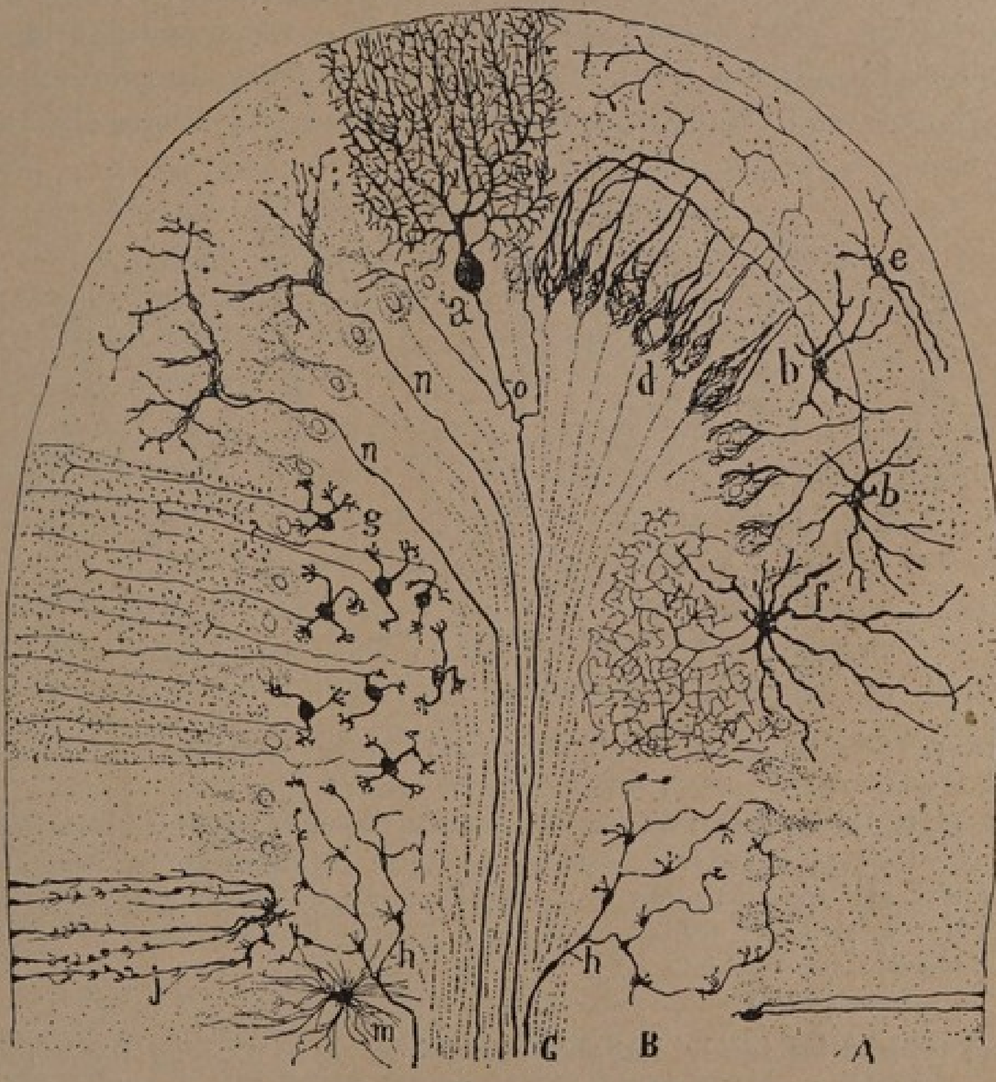

FIG. 4. Semi-schematic transverse section of a cerebellar convolution in a mammal. (After Ramon y Cajal.)

A, molecular zone; *B*, granular zone; *C*, zone of the white substance; *a*, Purkinje cell, front view; *b*, small star-shaped cells of the molecular layer; *d*, final descending arborizations which surround the cells of Purkinje; *e*, star-shaped superficial cells; *f*, large star-shaped cells of the granular layer; *g*, granules with their ascending axis-cylinders bifurcated at T; *h*, mossy fibers; *j*, neuroglia cell with branches; *m*, neuroglia cell of the granular layer; *n*, climbing fibers; *o*, ascending collaterals from the axis-cylinders of the Purkinje cells.

The Purkinje cells contain a number of large chromatic granules and are traversed by numerous neurofibrillæ.

The granular layer is almost entirely composed of an agglomeration of small cellular elements of a spheroidal shape. Each one possesses protoplasmic prolongations and an axis-cylinder prolongation. The protoplasmic prolongations are few in number (three or four), thin, short, and terminate by a slight arborization. The axis-cylinder mounts into the molecular layer and divides in the form of a T, into two horizontal branches; each of these runs through the molecular layer for a long distance

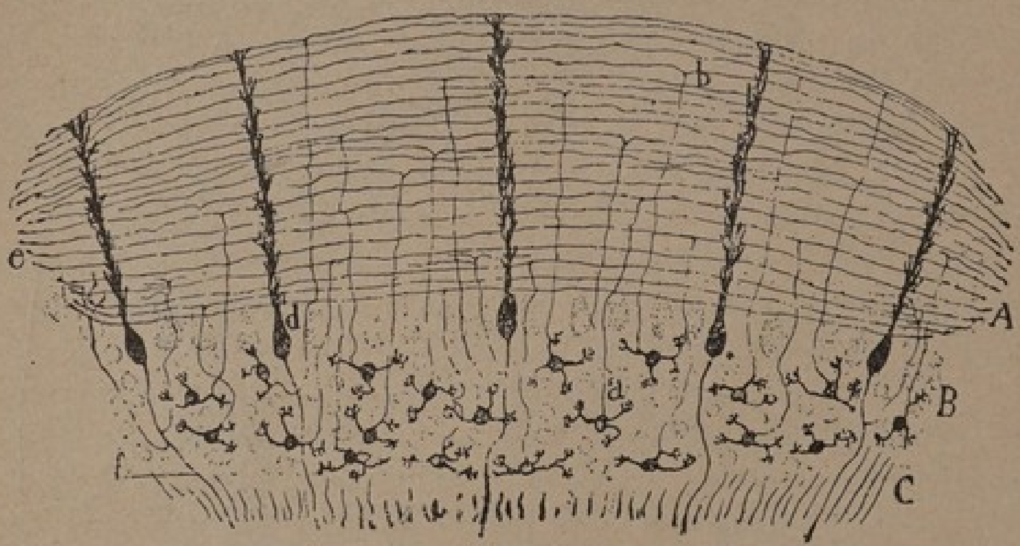

FIG. 5. Semi-schematic longitudinal section of a cerebellar convolution. (After Ramon y Cajal.)

A, molecular layer; *B,* granular layer; *C,* layer of the white substance; *a,* ascending axis-cylinders from the granules; *c,* bifurcation of this axis-cylinder and the formation of a parallel fiber; *d,* Purkinje cell seen in profile; *e,* granular terminal extremity of the parallel fibers; *f,* axis-cylinders of the Purkinje cells.

and terminates freely, but they enter into contact along the whole of their course with the terminations and protuberances of the ramifications of the Purkinje cells. In the granular layer also there are found some large star-shaped multipolar cells or cells of type II of Golgi, the axis-cylinders of which arborize very freely around the body of the cell and thus enclose in a sort of network a very large number of the "granules" or small cells of the granular layer. The protoplasmic prolongations terminate either in the granular layer or in the molecular layer.

The white substance is formed by a mass of myelinated nerve fibers which go in opposite directions; the fibers of one kind are centrifugal and originate in the cerebellar cortex, and the others are centripetal and terminate in the cortex. The centrifugal fibers are derived entirely from the Purkinje cells which have been described.

The centripetal fibers are of two kinds: the mossy fibers of Cajal, and the climbing fibers. The mossy fibers of Cajal are so called because they present nodular thickenings bristling with short divergent expansions, which resemble the moss covering trees. They arborize in the granular layer and consequently they enter into relations with the granules.

The climbing or creeping fibers ramify principally in the molecular layer and attach themselves to the ascending arborizations of the Purkinje cells; they terminate in varicose and plexiform arborizations.

The centripetal or terminal fibers are fibers of association, peduncular fibers, and fibers of projection. The peduncular fibers originate in the middle and inferior cerebellar peduncles. It is probable, if they exist at all, that fibers which originate in the central gray nuclei are very few in number. Association fibers unite the neighboring lobules and lamellæ to one another.

The structure and the division of the neuroglia and the other interstitial elements does not offer any interest in a purely physiological study. On the other hand the light thrown by histological examinations upon the morphology of the nervous elements and their reciprocal relations is of some help in following the path of excitations from the periphery to the cerebellum, and vice versa.

The stimulus carried by a centripetal fiber is transmitted simultaneously to several Purkinje cells either directly (climbing fibers) or indirectly by the intermediation of the granules or the star-shaped cells of the molecular layer. Each Purkinje cell is in relation with neighboring Purkinje cells by means of the recurrent collaterals of the axis cylinders.

The association fibers establish functional relations between the cellular elements of neighboring lobules and lamellæ. It is finally upon the Purkinje cells that all centripetal excitations are concentrated; these elements in their turn are the only ones whose axis cylinders project themselves to the central gray nuclei (fibers of projection). Justly, therefore, the Purkinje cell is considered the truly active element of the cerebellar cortex.

Thus organized the cerebellar cortex appears fitted to propagate and reinforce impressions which come to it from the periphery.

Structure of the Central Gray Nuclei.—The cerebellar olive and its accessory nuclei, *i. e.*, nucleus globosus and nucleus emboliformis, have the same structure. Three kinds of elements are found in them: numerous myelinated fibers, a large number of cells and terminal arborizations. The cells are of medium size, multipolar and elongated. From their bodies dendrites are given off which arborize in dividing dichotomously and direct themselves externally. The axis cylinders, on the contrary, turn towards the center or hilum of the cerebellar olive, *i. e.*, towards the superior cerebellar peduncle. Between the cells there are numbers of terminal arborizations dividing dichotomously several times.

The cells of the nucleus fastigii, or nucleus of the tegmentum, are, on the contrary, large multipolar vesiculated cells, analogous to the cells of Bechterew's and Deiters' nuclei. The bodies are large, the protoplasmic expansions few and slightly ramified, thick and very long.

III. The Connections of the Cerebellum

The nerve fibers which run through the white substance of the cerebellum belong to various systems. Some of them terminate in the cerebellum: these are the afferent fibers; others originate in the cerebellum and terminate either within or without it: these are the efferent fibers; or in another territory of the cerebellum at a point more or less remote from that of their origin, on the same side or on the opposite side; these are the fibers of projection or the fibers of association.

The connections of the cerebellum with the other centers are made by means of three large bundles, or peduncles: the inferior cerebellar peduncle, the middle cerebellar peduncle, and the superior cerebellar peduncle. What is the distribution of the efferent and afferent fibers in these three systems of bundles; what are the origins of the afferent fibers, and what is the destination of the efferent fibers? These are the problems which have been solved in a great measure by the study of secondary degenerations following focal lesions in man, and by sections or experimental destructions in animals. The experimental method offers the valuable advantage of being able to change the location and extent of the lesions, and it is by this means that the most precise information concerning the origin and termination of the cerebellar bundles has been acquired.

The results obtained by a study of degenerations agree with those obtained by histological methods, such as the method of Cajal, by impregnation with silver chromate. Employing this method in small mammals this author was able to follow the cerebellar fibers to their origins and their terminations. But the method is insufficient for systems of long fibers. These cannot be traced save by studying secondary degenerations.

I. *Afferent Fibers*

The afferent fibers follow two paths in entering the cerebellum, the inferior and median cerebellar peduncles. The inferior cerebellar peduncle contains fibers of bulbar, medullary and spinal origin; the middle cerebellar peduncle contains fibers of pontine origin. In fact, the spinal cord is but a relay station between the periphery of the sensory paths and the cerebellum, the medulla oblongata, an intermediary between the mid-brain and the cerebellum, and the pons is but a station between the cerebral cortex and the cerebellum. This is what anatomy and a study of secondary degenerations teaches.

The Inferior Cerebellar Peduncle or Restiform Body

This is formed of two parts: the spinal and the medullary. The spinal part is represented by: (*a*) the direct cerebellar tract and some fibers of the posterior cord; (*b*) the tract of Goll and the tract of Burdach. The cerebellum receives besides these a bundle of fibers which does not traverse the inferior cerebellar peduncle; these are the fibers from the tract of Gowers.

Spinal Part.—(*a*) The direct cerebellar tract, first described by Foville, and later by Flechsig, originates in man between the first lumbar segment and the twelfth dorsal. This limit is disputed and it is carried higher by Schultze who indicates the tenth dorsal segment, and by Kahler and Pick, who indicate the ninth dorsal segment, whereas, Flechsig lowers it to between the second and third lumbar segment. Long, Rothmann, as well as Barbacci, Pellizzi and Flatau, admit that in the dog the lowest fibers appear in the lumbo-sacral region. In the rabbit the exist-

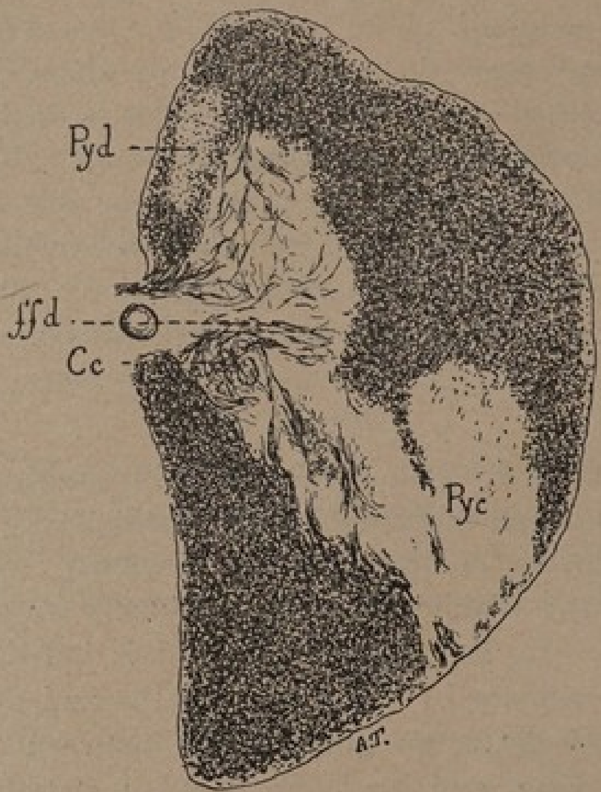

FIG. 6. Section of the spinal cord of a fetus aged 8½ months. Lower dorsal regions. (Stained by the method of Pal.)

The pyramidal tract, crossed and direct, which is not yet myelinated shows in white. The fibers which take their origin in the column of Clarke are directed outwards towards the periphery and constitute the direct cerebellar tract. *Cc*, column of Clarke; *ffd*, fibers coming from the column of Clarke and directed towards the periphery to form the direct cerebellar tract; *Pyc*, crossed pyramidal tract; *Pyd*, direct pyramidal tract.

ence of any such fibers was not found by Singer and Münzer, Sarbo, Münzer and Wiener, and Bochenek. Bing suggests the hypothesis that the direct cerebellar tract commences at a more or less high level in animals according to the greater or less development or absence of the tail. Whatever the explanation may be it is possible that variations exist according to the species of animals. The direct cerebellar tract occupies the most posterior and external part of the lateral cord, limited within by the crossed-pyramidal tract, and without by the sub-meningeal tissue, the more posterior fibers adjoin the extremity of the posterior horn; the most anterior fibers enter almost into contact with the posterior fibers of Gowers' tract. It increases in volume progressively as one examines it at the higher levels of the dorsal cord; it does not increase perceptibly above the first dorsal segment and keeps the same volume until it reaches the medulla. It originates in the column of Clarke of the same side; this in its turn extends from the first lumbar root to the first dorsal root.

The origin of the direct cerebellar tract in the column of Clarke is demonstrated: (1) by histological methods, especially by the method of Cajal, where one can see the nerve fibers coming from the column of Clarke traverse the lateral tract and

FIGS. 7 to 11. Degenerations of the direct cerebellar tract and the tract of Gowers after experimental section of the spinal cord in the superior cervical region of the cat.

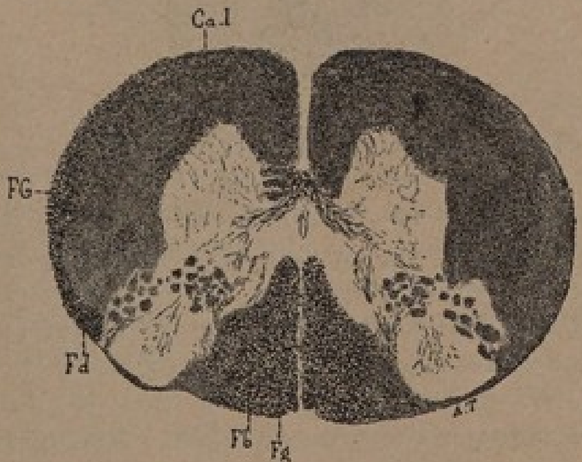

FIG. 7. Section of the spinal cord at the level of the first cervical root. *Cal,* anterior-lateral segment; *Fb,* tract of Burdach; *Fd,* direct cerebellar tract; *FG,* tract of Gowers; *Fg,* tract of Goll.

engage in the direct cerebellar tract; (2) by pathological anatomy. When this tract is severed by a transverse section, or is primarily degenerated in consequence of an hereditary disease, the cells of the column of Clarke atrophy in the planes adjacent to the lesion. In the case of unilateral lesions this atrophy occurs only on the same side, which proves that the fibers of the direct cerebellar tract do not cross in the cord, and so come homolaterally from Clarke's column. At the level of the medulla, the direct cerebellar tract bends backwards and penetrates the restiform body or inferior cerebellar peduncle, in which it occupies the central part, and then ascends into the cerebellum and terminates in the anterior portion of the cortex of the superior vermis (Auerbach, Bechterew, Patrick, Thomas, Pellizzi, Bruce, Lewandowsky, Bing).

The fibers terminate some on the same side and others on the opposite side after decussation (Figs. 7 to 10). The proportion of the direct fibers to the crossed fibers is disputed. Pellizzi

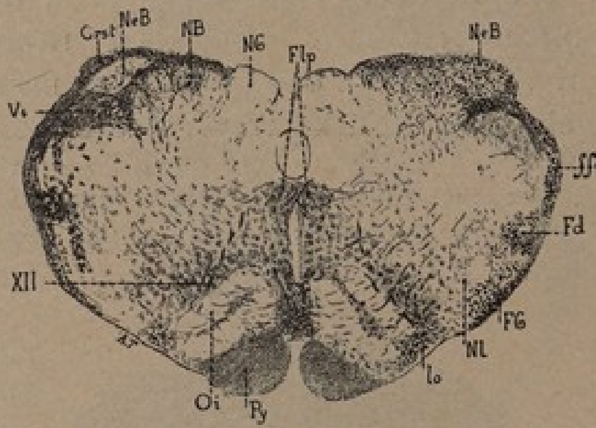

FIG. 8. Section of the medulla at the level of the olives and the external segment of the nucleus of Burdach.

Crst, restiform body; *Fd,* direct cerebellar tract; *ffd,* fibers of the direct cerebellar tract, turning around the descending root of the fifth pair to enter the restiform body; *FG,* tract of Gowers; *Flp,* posterior longitudinal fasciculus; *lo,* latero-olivary ascending tract; *NB,* nucleus of Burdach; *NeB,* external nucleus of the tract of Burdach; *NG,* nucleus of the tract of Goll; *Nl,* nucleus of the lateral tract; *Oi,* inferior olive; *Py,* pyramid; *Vs,* descending root of the fifth pair; *XII,* hypoglossal nerve.

considers the decussation total, Mott says there is a partial decussation. André-Thomas and Edinger consider that there is a decussation of the majority of the fibers, whereas, v. Monakow states that all of the fibers are direct. It seems established, however, that the majority of the fibers decussate and this opinion is also maintained by Bing.

It is known on the other hand that the cells of Clarke's column are plunged in a network of nerve fibers, nourished by the fibers of medium length from the posterior roots. The inferior extremity of Clarke's column, according to the experiments of Mott and Marguliès on the monkey receives fibers from the lumbar and sacral roots, whereas, according to Nageotte, the posterior roots below the third lumbar do not furnish any fibers to Clarke's columns. If this last fact were definitely shown it would have a certain physiological importance since the first lumbar roots innervate only the proximal portion of the lower limb, and certain authors hold that the cerebellum exercises a much more active influence over the proximal than over the distal extremity of the leg.

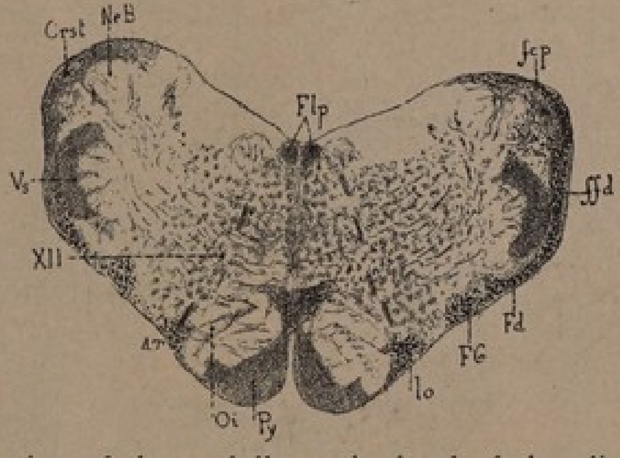

FIG. 9. Section of the medulla at the level of the olives and the restiform body.

Crst, restiform body; *fcp*, fibers of the posterior column going to the restiform body (external posterior arcuate fibers); *Fd*, *ffd*, direct cerebellar tract; *Fg*, tract of Gowers; *Flp*, posterior longitudinal fasciculus; *lo*, latero-olivary ascending tract; *NeB*, external nucleus of the tract of Burdach; *Oi*, inferior olives; *Py*, pyramid; *Vs*, descending root of the fifth nerve; *XII*, hypoglossal nerve.

The cells of Clarke's columns are in relation principally with the posterior roots of the dorsal region. The posterior cervical roots do not send any fibers to the column of Clarke. Consequently, the direct cerebellar tract does not transmit any peripheral excitation from the arms. The excitations from this origin without doubt follow another path. From what has preceded we may conclude that if the physiological conduction follows the same route as the Wallerian degeneration the direct cerebellar tract transmits to the cerebellum excitations or impressions which come from the periphery, and especially from that territory innervated by the twelve posterior dorsal roots and the first lumbar. That is to say, excitations which come from the trunk and the proximal portion of the legs. The direct cerebellar tract is not considered as a path of transmission of conscious or sensory impressions, whether superficial or deep. It is generally considered as transmitting stimuli coming from the deep tissues, bones, muscles, articulations, and not from the cutaneous surfaces.

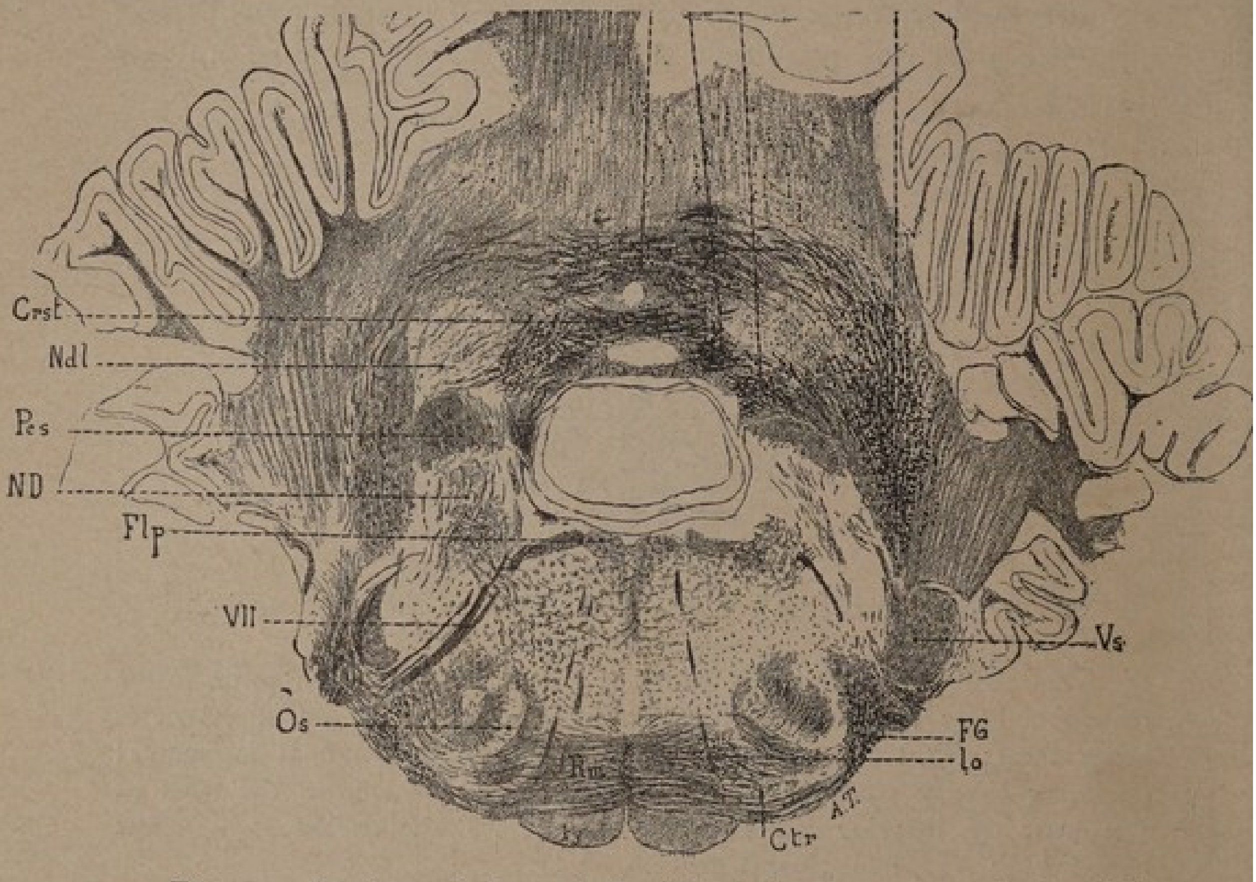

FIG. 10. Section of the medulla below the emergence of the fifth nerve and of the cerebellum at the level of the spreading out of the degenerated fibers of the restiform body. For the indications see the two previous cuts.

Ctr, trapezoid body; *ND,* nucleus of Deiters; *Ndl,* dentate nucleus; *Osoa,* superior olive and accessory olivary nucleus; *Pcs,* superior cerebellar peduncle; *Rm,* median fillet of Reil; *Ve,* vermis; *Vs,* descending root of the fifth; *VII,* facial nerve.

(*b*) *Gowers' Tract* (Figs. 7 to 12).—Gowers' tract is situated in the lateral cord immediately in front of the direct cerebellar tract, and on the border of the circumference; it is a marginal tract; it has the form of a triangle, the summit of which is directed towards the lateral horn of the gray substance and the base towards the periphery of the cord.

Some fibers originate in the lumbar regions, but most of them come from the dorsal regions (Mott). The existence of fibers originating in the cervical region has not been shown. The origins of this tract are both direct and crossed. This, according to Edinger, proves that the cells occupy the posterior horn, for Mott the lateral horn, for Gombault and Philippe the cells of the anterior horn, and for Bechterew the cells which surround the central region of the gray matter. According to André-Thomas and J. Ch. Roux, the cells of origin would be situated at the base of the anterior horn.

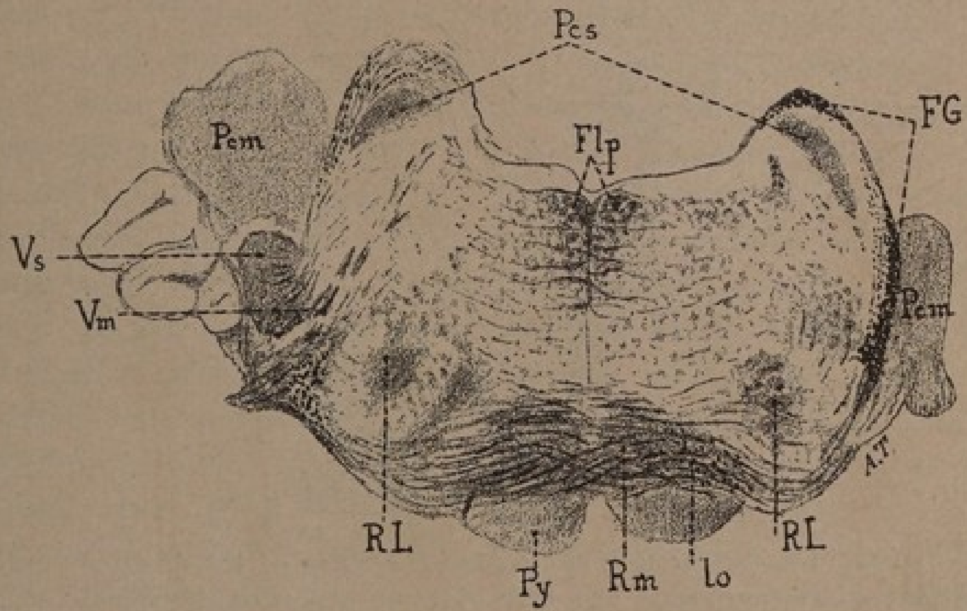

FIG. 11. Section of the medulla above the emergence of the fifth nerve prepared to show the course of Gowers' tract.

FG, tract of Gowers; *Pcm*, middle cerebellar peduncle; *Pcs*, superior cerebellar peduncle; *Rl*, lateral fillet of Reil; *Rm*, median fillet of Reil; *Ds*, descending root of the fifth; *Vm*, small motor root of the fifth.

At the level of the medulla the fibers of Gowers' tract pass immediately outside the nucleus of the lateral tract of the cord, within which they partly lose themselves (André-Thomas), the rest of the fibers follow an ascending path in the pons, winding about the superior cerebellar peduncle at its emergence from the cerebellum, and terminate in the ventral portion of the vermis, or the anterior vermis (Mott, Tooth, Pellizzi, Hoche, and André-Thomas). After a decussation almost total, a very small portion terminates in the nucleus fastigii (Auerbach, André-Thomas).

The cells of origin of Gowers' tract enter into relation without doubt with the terminal arborizations of a certain number of the fibers of the posterior roots, and this tract, doubtless, does nothing but transmit stimuli from the periphery.

To sum up, the two tracts which establish relations between the spinal cord and the cerebellum, both end in the vermis and do not furnish any fibers to the hemispheres.

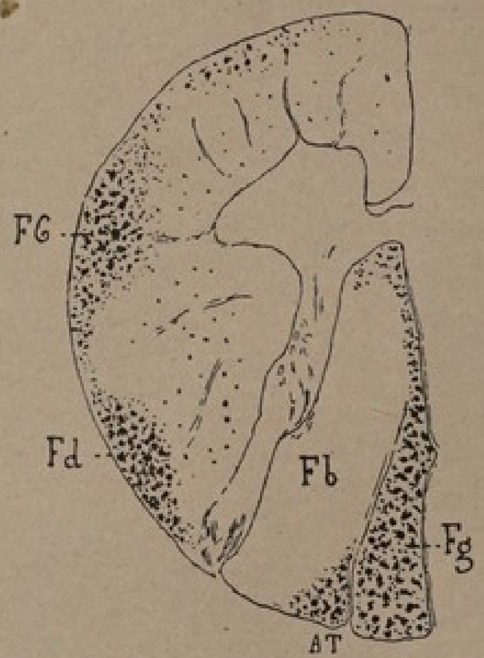

FIG. 12. Degeneration of the posterior column of the direct cerebellar tract and of Gowers' tract in a case of compression of the spinal cord at the third dorsal root (method of Marchi). Level of the eighth cervical root.

Fb, tract of Burdach; *Fd*, direct cerebellar tract; *FG*, tract of Gowers; *Fg*, tract of Goll.

(*c*) *Fibers of the Posterior Cord.*—Their existence is doubted by Flechsig; they are admitted, on the other hand, by Edinger, Darkschewitsch, Freud, Obersteiner, Pellizzi and André-Thomas (Fig. 9). These fibers are direct and perhaps crossed (Edinger, Obersteiner, Mott and Sherrington, and Tooth). They are far less numerous than the fibers of the direct cerebellar tract. They leave the tracts of Goll and Burdach at the level of the medulla, and direct themselves toward the restiform body in which they occupy the central part, intimately intermingled with the fibers of the direct cerebellar tract.

Medullary Part. (*a*) *Fibers of the Nuclei of the Posterior Columns.*—Their existence is disputed, denied by Flechsig, Edinger, Obersteiner and Van Gehuchten, and admitted by Bechterew, Darkschewitsch and Freud, Ferrier and Turner, and Vegas. They would take their origin in the nuclei of Goll and Burdach, that is to say, in the nuclei which receive the long fibers of the posterior root.

If the participation of the nucleus of Goll, and the nucleus of Burdach, in the formation of the restiform body appears debatable this is not the case with the superior, external part of the nucleus of Burdach, also called the nucleus of v. Monakow, or the nucleus of the restiform body. This nucleus is distinguished by its large cells richly provided with protoplasmic prolongations, from the cells of the nuclei of Goll and Burdach, which are far smaller. Darkschewitsch and Freud, Vegas and Blumenau were the first to insist upon the relations of this nucleus to the restiform body. Unilateral destructions of the cerebellum are followed by the atrophy and disappearance of the cells of the nucleus of v. Monakow, on the same side. This fact is shown in animals by experimental physiology, and in man by pathological anatomy (André-Thomas). These fibers are, consequently, direct fibers, going from the medulla to the cerebellum on the same side, but it is impossible to say whether they are distributed, either exclusively or preferentially to the vermis, or to the lateral lobe.

The nucleus of v. Monakow also receives fibers from the tract of Burdach; fibers which are nothing but a continuation of the posterior cervical and superior dorsal roots. One is led, therefore, to consider this nucleus as an important relay station between the peripheral excitations which come from the arm, from the neck, and from the superior part of the trunk, on the one side, and the cerebellar cortex on the other. It is probable that the nucleus of v. Monakow plays the same part in relation to the posterior cervical roots that the column of Clarke does in relation to the dorsal and superior lumbar roots.

(*b*) *Fibers of the Nucleus of the Lateral Columns of the Medulla.*—These fibers have been described by Bechterew, v. Monakow and André-Thomas. The nucleus of the lateral column atrophies after a unilateral destruction of the cerebellum and on the same side as the lesion. These fibers are therefore direct. The place of their termination, vermis or hemisphere, is still undecided. The nucleus of the lateral column receives besides some fibers of the tract of Gowers, and may be looked upon as a new relay station between the spinal cord and the cerebellum.

(*c*) *Olivary Part.*—This is the most important of the medullary cerebellar parts, particularly in man, where the olives attain their maximum development. The destruction of a cerebellar hemisphere is accompanied by a retrograde atrophy, direct, of the restiform body, and crossed, of the inferior olive. These cells atrophy and disappear (Meynert). This is a constant fact (Fig. 13).

The fibers which take their origin in the medullary olive and in the accessory olivary nuclei antero-internal, and postero-external, decussate in the median raphé with those of the opposite side and follow, before penetrating the restiform body, either the periphery of the medulla, after having turned around the pyramid (zonal cerebellar olivary fibers of Mingazzini), or the superior external segment of the internal arcuate fibers (retro- and intertrigeminal fibers of Mingazzini). These fibers are so called because they traverse, or limit behind, the descending root of the fifth nerve.

The olivary fibers occupy the periphery of the restiform body, whereas the center is formed by the direct cerebellar tract, and the fibers of the posterior columns. After section of the restiform body in the dog, degeneration of the fibers can be followed to the cortex of the superior vermis, principally of the same side, as well as to the hemispheric cortex in continuation with the lamellæ of the vermis (André-Thomas, Klimoff, Keller and Probst). Similar observations have been made by Mott, but it has been impossible in these experiments to trace the olivary fibers.

In the higher monkeys and above all in man, the medullary olive takes on a considerable development; it doubles on itself several times, and it is the same thing in the case of the cerebellar olive. There exists a certain parallelism in the development of these two formations. In man the degenerations of the olivary fibers have been followed to the nucleus dentatus, and the nucleus emboliformis by Babinski, Nageotte, and André-Thomas. Babinski and Nageotte give the names olivo-ciliary to these fibers.

FIGS. 13 to 16. Transverse sections of the medulla, the pons and the thalamic region in a case of softening of the left hemisphere of the cerebellum. Weigert-Pal staining.

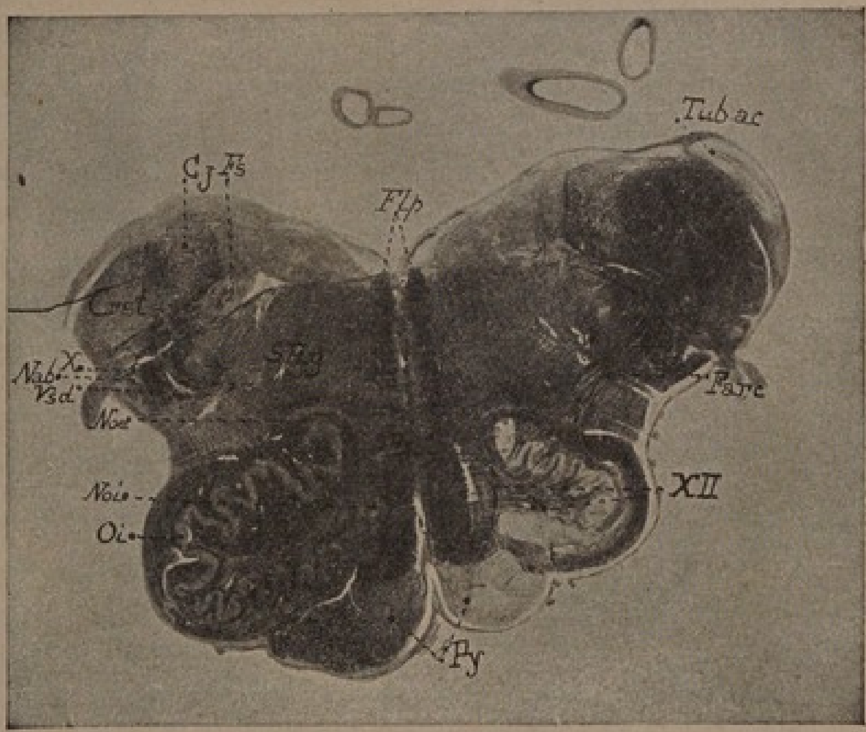

FIG. 13. Section of the medulla. Crossed atrophy of the olive. Direct atrophy of the restiform body. In this case the pyramid is equally atrophied in consequence of a lesion situated in the peduncular path.

Cj, juxta-restiform body; *Crst,* restiform body; *Farc,* arcuate fibers; *Flp,* posterior longitudinal fasciculus; *Fs,* solitary bundle; *Nab,* nucleus ambiguus; *Noe,* postero-external accessory olivary nucleus; *Noi,* antero-internal accessory-olivary nucleus; *O,* inferior olive; *Py,* pyramid; *SRg,* reticulated gray substance; *SRa,* reticulated white substance; *Tub, ac,* acoustic tubercle; *X,* pneumogastric nerve; *XII,* hypoglossal nerve; *Vsd,* descending root of fifth nerve.

The olivary fibers, consequently, have a double destination, viz., the cerebellar cortex, and the central gray nuclei (nucleus dentatus and emboliformis).

Holmes and Stewart have attempted utilizing the method of secondary degenerations in man, to define the relations of the olive to the cerebellar cortex. They have obtained the following results: (1) each olive is in connection with the contra-lateral half of the cerebellum; (2) the olivo-cerebellar fibers terminate in the lateral lobes, and probably also in the vermis. The fibers going to the central gray nuclei are certainly very few; there exists according to the same authors a definite relation between the different parts of the inferior olives and the accessory olivary nuclei on the one side, and the different zones of the cerebellar cortex on the other.

(*a*) The lateral portion of the olives are in connection with the lateral portion of the cerebellar cortex on the opposite side. (*b*) The median extremities of the inferior olives and the antero-internal accessory olivary nuclei sends fibers probably to the vermis and the median portion of the lateral lobes. (*c*) The dorsal fold of the olive is particularly in relation with the superior face of the cerebellum. (*d*) The ventral fold is rather in relation with the inferior face.

The medullary olives receive the terminal arborizations of the central bundle of the tegmentum; they do not receive any other fibers from the cortex. The central bundle of the tegmentum is formed by fibers which take their origin in the reticulated substance of the tegmentum at the level of the medulla, from the pons and from the sub-optic region. The medullary olive unites thus the mesencephalon and the rhombencephalon of the same side to the cortex, and to the cerebellar olive of the opposite side.

The Middle Cerebellar Peduncle

(Fig. 14)

The middle cerebellar peduncle is a large bundle of transverse fibers interposed between the anterior surface of the pons and the cerebellum. The middle cerebellar peduncle attains its maximum development in the higher apes and in man, and the degree of its development is proportional to that of the pons and the pyramidal tract on the one hand, and the lateral lobe of the cerebellum, including the dentate nucleus on the other.

The study of secondary degenerations and of retrograde atrophies has shown that the fibers of the middle cerebellar peduncle are nothing but the prolongations of the axis cylinders of the cells of the pontine nuclei of the opposite side. Nevertheless, some fibers come from the most external part of the homolateral pontine nuclei (André-Thomas). Besides, some fibers take their origin from the gray substance of the pontine tegmentum. Is

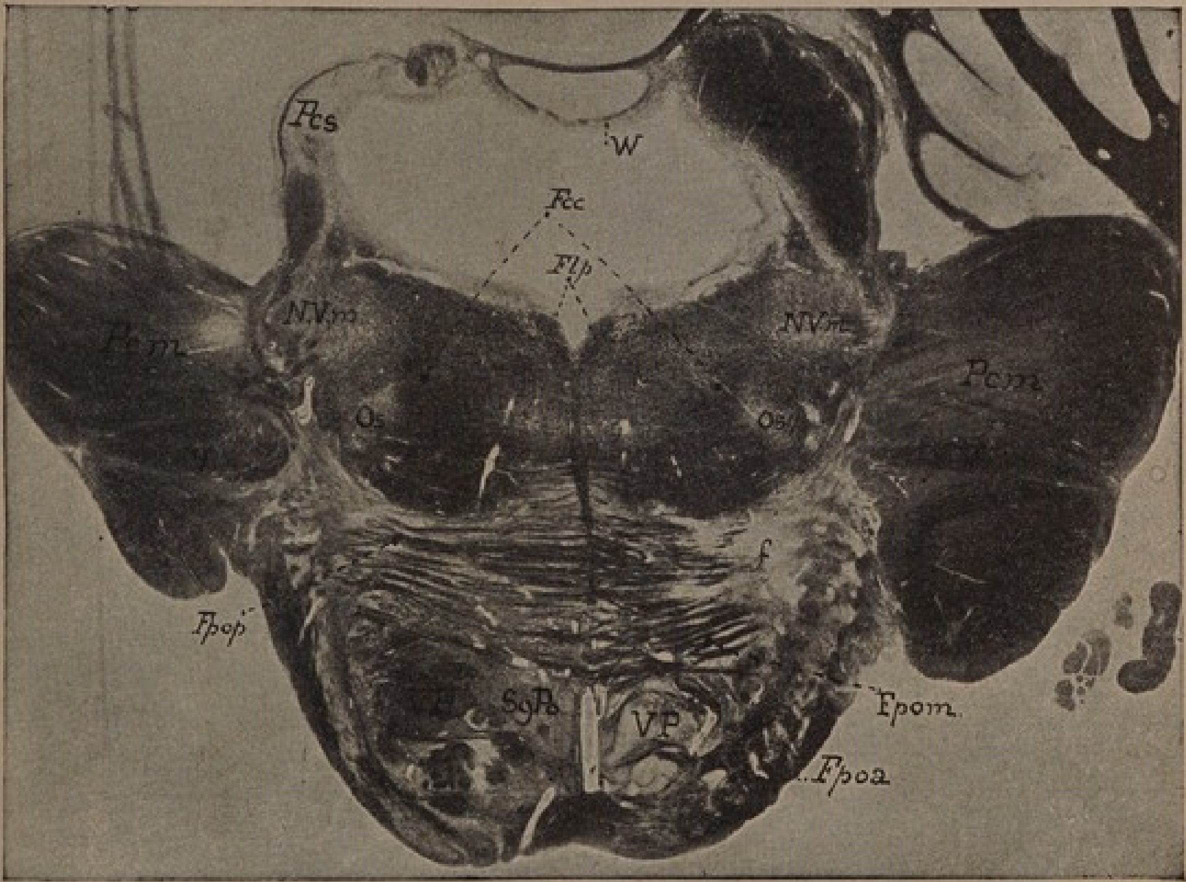

FIG. 14. Transverse section of the pons. To the right, degeneration of the superior cerebellar peduncle (*Psc*), atrophy of the middle cerebellar peduncle (*Pcm*); to the left, atrophy of the central bundle of the tegmentum (*Fcc*).

Fpoa, Fpom, Fpop, anterior, middle and posterior transverse bundles of the middle cerebellar peduncle; *NVm,* motor nucleus of the fifth; *Os,* superior olive; *SgPo,* gray substance of the pons; *VP,* peduncular tract; *W,* valve of Vieussens; *f,* small focus of softening.

it possible that some fibers have an inverse direction? That is to say, do they go from the cerebellar cortex to the gray substance of the pons? The middle cerebellar peduncle does not contain any commissural fibers between the two hemispheres.

It is also established that the fibers of this peduncle terminate exclusively in the cerebellar cortex; none of them go to the central ganglia. All these fibers are destined for the lateral lobe; it has not been shown that the vermis receives any.

The arciform or pre-pyramidal nucleus which is attached to the anterior border of the medullary pyramid also atrophies

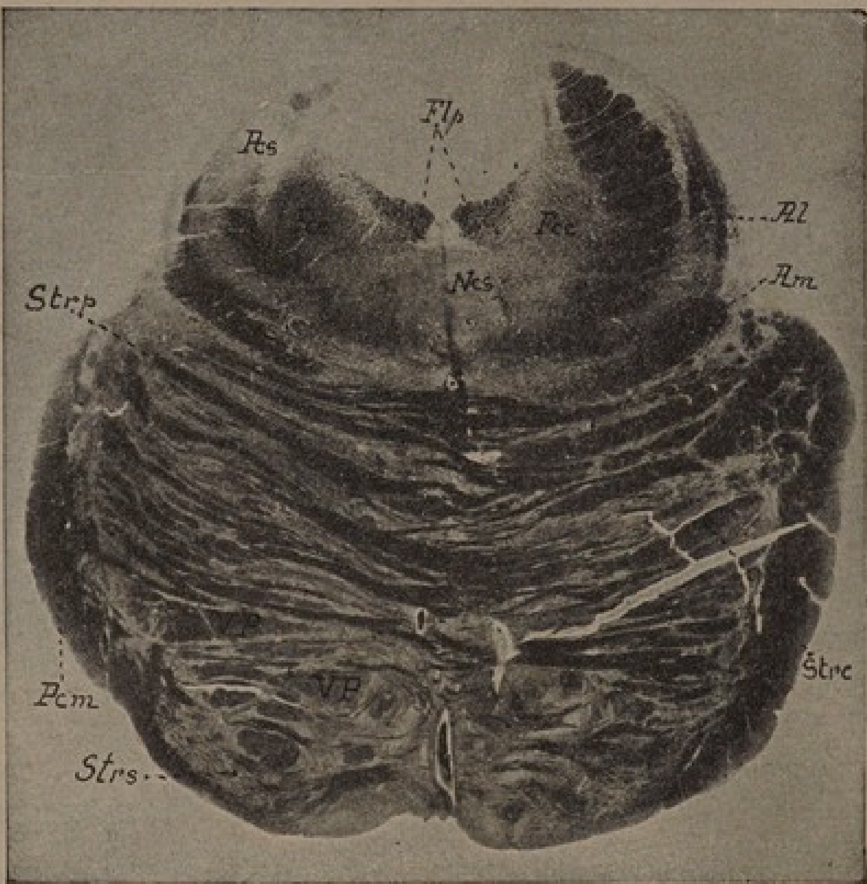

FIG. 15. Transverse section of the pons (superior extremity). Degeneration of the right superior cerebellar peduncle (*Pcs*). Atrophy of the central bundle of the tegmentum (*Fcc*) to the left.

Ncs, central superior nucleus; *Rl*, lateral fillet of Reil; *Rm*, median fillet of Reil; *Strp, Stns, Stnc,* stratum profundum superficiale and centrale of the middle cerebellar peduncle (*Pcm*). For other indications see the preceding cuts.

after unilateral destruction of the cerebellum, and this atrophy is crossed. The fibers which leave it accompany the olivary fibers to reach the cerebellum, passing through the restiform body, or they may follow the middle cerebellar peduncle. The arciform nucleus is perhaps nothing but the inferior extremity of the pontine nucleus, of which the lowest groups of cells are lodged in front of the pyramids.

The relations of the cerebral cortex with the gray substance of the pons have been established by secondary degenerations,

Fig. 16. Vertico-transverse section of the encephalic isthmus at the level of the posterior part of the optic thalamus and the red nucleus. The cut should be reversed and represents the left side. Atrophy of the red nucleus (*NR*) and radiations from the tegmentum (*RC*).

CL, body of Luys; *Fm,* bundle of Meynert; *Thnm,* median nucleus of the thalamus; *Ihne,* external nucleus of the thalamus; *II,* optic tract.

consecutive to focal lesions in the cerebral cortex, or, of its fibers of projection in the internal capsule and the cerebral peduncle.

A large number of the fibers of the cerebral peduncle, or crus-cerebri, of which the origin is exclusively cortical, lose themselves in the anterior surface of the pons. This fact is already sufficiently proven by the difference in volume which exists in the normal state between the number of fibers contained in the crus, and the number contained in the pyramid, and still more by the large number of granular bodies which occupy the pontine nucleus in the case of secondary degeneration of the crus. These cortico-pontine fibers all stay on the same side of the pons.

The relations of the gray substance of the pons and that of the cerebellum are, on the contrary, crossed; the result is that each pontine nucleus is an intercalated post between the cerebral cortex of the same side and the cerebellar cortex of the opposite side.

What are the territories of the cerebral cortex which are in connection with the cerebellar cortex through the intermediation of the pontine nuclei? They are those which furnish fibers to the crus-cerebri, and, consequently, primarily the sensori-motor zone—the frontal ascending, parietal lobes, and the paracentral lobules. The external tract of the crus, or the bundle of Türck, terminates exclusively in the superior third of the anterior surface of the pons. It takes its origin from the middle segment of the second and third temporal convolutions (M. and Mme. Déjerine). Finally, some fibers follow the internal bundle of the crus, and come from the orbital lobe (Déjerine and André-Thomas).

There should result from these anatomical relations a functional association of considerable importance between the cerebellar cortex and the cerebral cortex, an association capable of throwing light, in a certain measure, upon the physiological mechanisms of the cerebellum; especially if one reflects upon the fact that the cortical zones of the cerebrum, which are projected anatomically and physiologically upon the cerebellar cortex, are sensory-motor zones, and a zone (second and third temporal convolutions) which many authors consider as the center of impressions of labyrinthine origin.

To sum up, and to close the chapter of the afferent paths, whereas, the inferior cerebellar peduncle or restiform body brings into relation the cortex of the vermis, and the adjacent parts of the cerebellar hemispheres, with the spinal cord, the medulla and the mid-brain, the middle cerebellar peduncle serves as a tie between the cerebral cortex and the cortex of the cerebellar hemispheres. The comparative examination of the neuro-axis in the animal series shows that there is a constant parallelism between the development of the pons and the median cerebellar peduncles and the cerebral cortex.

II. *Efferent Fibers*

In the same way that the afferent fibers follow the path of the inferior cerebellar peduncle and the median cerebellar peduncle to penetrate the cerebellum, the efferent fibers for the most part pass through the superior cerebellar peduncle; some come out of the cerebellum through the internal segment of the restiform body or the juxta-restiform body, A very small number follow the inferior cerebellar peduncle.

The Superior Cerebellar Peduncle

The superior cerebellar peduncle is a large bundle which goes from one cerebellar hemisphere to the red nucleus and to the optic thalamus of the opposite side (Figs. 15 to 20). It has been by a study of secondary degenerations in animals that the origins of this bundle have been defined. It was admitted in the first place that it came from the red nucleus (Mahaim and M. and Mme. Déjerine). The experiments of Marchi, Ferrier and Turner, Russell and André-Thomas, have shown definitely that it comes from the cerebellum, not from the cerebellar cortex but from the rhomboid body or the dentate nucleus.

The fibers of the superior cerebellar peduncle decussate in the pontine tegmentum, decussation of Wernekink, with those of the contra-lateral peduncle; the decussation is complete.

After its decussation the superior cerebellar peduncle divides into two branches, ascending and descending (Ramon y Cajal, André-Thomas).

The ascending branch, by far the most important, follows an ascending path and traverses the red nucleus, to which it gives a certain number of fibers, before terminating in the optic thalamus (principally the ventral portion of the external nucleus, Figs. 19 and 20). It is possible that the red nucleus furnishes some descending fibers to the superior cerebellar peduncle, in any case these fibers would be few.

The descending branch, much more slender, terminates in the nucleus reticularis tegmenti pontis (André-Thomas, Fig. 17).

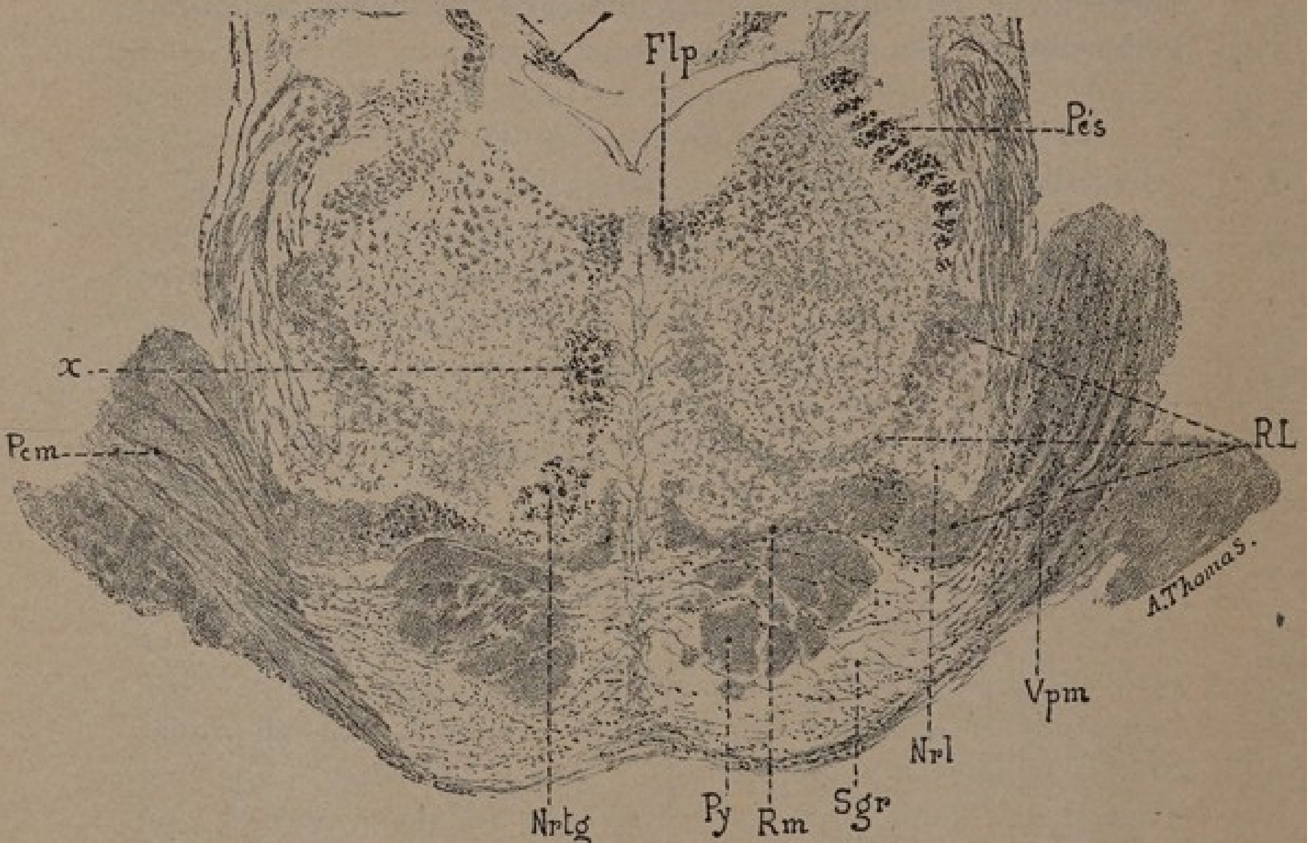

Fig. 17. Section at the level of the superior third of the pons. Degeneration of the superior and middle cerebellar peduncles after the destruction of the left half of the cerebellum in the dog. Termination of the superior branch of the superior cerebellar peduncle in the nucleus reticularis tegmenti pontis.

Flp, posterior longitudinal fasciculus; *Nrl*, nucleus of the lateral fillet of Reil; *Nrtg*, nucleus reticularis tegmenti pontis; *Pcm*, middle cerebellar peduncle; *Pcs*, superior cerebellar peduncle; *Py*, pyramid; *RL*, lateral fillet of Reil; *Rm*, median fillet of Reil; *Sgr*, gray substance of the pons; *X*, zone of degeneration in the median reticulated substance independent of the cerebellar lesion; *IV*, nervous patheticus; *Vpm*, small motor root of fifth nerve.

The nerve current transmitted to the optic thalamus by the superior cerebellar peduncle ends finally in the cerebral cortex through the intermediary of the thalamo-cortical fibers. On the other hand the fibers which go to the red nucleus form an arborization around cells the axis cylinders of which go to the spinal cord after a decussation in the pontine tegmentum (v. Monakow, Rothmann, Probst and Pawlow), and form v. Monakow's bundle, or the rubro-spinal tract of Van Gehuchten. This tract has not been followed up to now except in animals, particularly in the macaque, it is situated in the lateral column immediately in front of the pyramidal bundle (pre-pyramidal bundle of André-Thomas). Its existence has not been demonstrated in man.

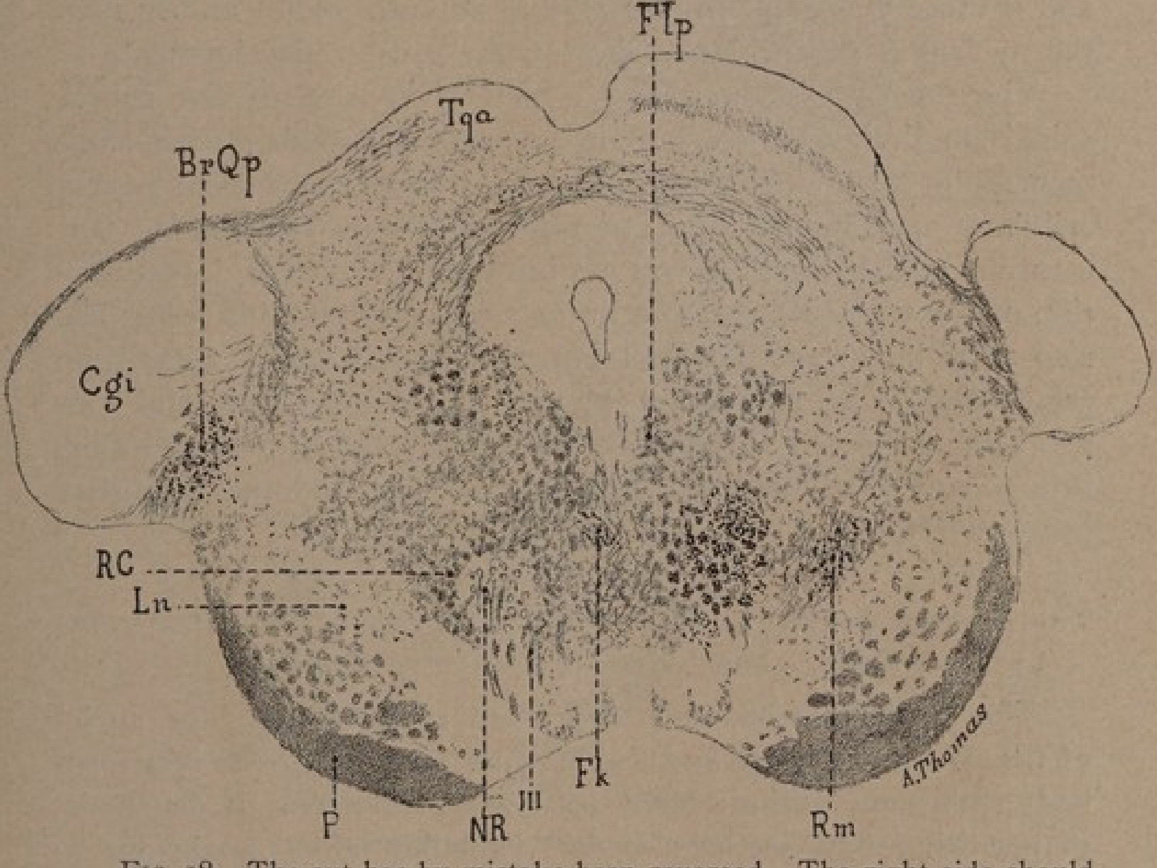

FIG. 18. The cut has by mistake been reversed. The right side should be the left and vice-versa. The same mistake has been made in the following cuts. Degeneration of the red nucleus.

BrQp, brachium of the posterior quadrigeminate body; *Cgi*, internal geniculate body; *Flp*, posterior longitudinal fasciculus; *Fk*, fontainartige Hauben Kreuzung; *Ln*, locus niger; *NR*, red nucleus; *P*, peduncle; *RC*, capsule of the red nucleus and radiations of the tegmentum; *Rm*, median fillet of Reil; *Tga*, anterior quadrigeminal tubercle; *III*, nervus motor ocularis communis.

The superior cerebellar peduncle thus establishes fairly direct relations between the cerebellum on one hand and the cerebrum and spinal cord on the other.

In a recent work v. Monakow has made a study of the red nucleus in mammals and in man, and from his researches he concludes that this nucleus is made up of two secondary nuclei.

The one with large disseminated cells in the dorso-lateral part of the pontine tegmentum forms a reticulated nucleus (*nucleus magnocellularis* of Hatschek). The other accompanies the bundles which traverse the red nucleus but occupies mostly the frontal extremity and is formed of small cells (*nucleus parvocellularis* of Hatschek). The first is phylogenetically the oldest and is more important in quadrupeds, in anthropoids and in man the nucleus parvocellularis takes on the greater development.

The nucleus magnocelluris which gives rise to the rubrospinal bundle is very voluminous in lower mammals, and is rudimentary in man. The fibers which arise from the nucleus parvocellularis rise immediately after decussation in the pontine tegmentum in the neighborhood of the fillet, and in the dorsal portion of the tegmentum. The nucleus parvocellularis it seems has also some important relations with the frontal lobe (as has been established by M. and Mme. Déjerine). The structure and connections of the red nucleus become complicated in direct proportion to the development of the frontal lobes and the cerebellar hemispheres.

The Internal Segment of the Restiform Body or Juxta-restiform Body. The Cerebello-vestibular Bundle.

The cerebellum has such important relations with the nuclei of the vestibular nerve and the internal segment of the restiform body that many authors have described phenomena of degeneration which follow sections of the vestibular nerves analogous to those which follow the destruction of the cerebellum.

The root of the eighth nerve is divided into two branches, the cochlear and the vestibular.

The fibers of the vestibular branch terminate in three medullary nuclei. The nucleus of Deiters, the nucleus of Bechterew, and the triangular nucleus. Some fibers are distributed in the nucleus of the tegmentum (André-Thomas).

The nucleus of Deiters occupies the angle in the pontine tegmentum formed by the descending root of the fifth nerve and the restiform body, or the inferior cerebellar peduncle. It is a nucleus composed of large cells; it is continuous above and behind on the side of the cerebellum with the nucleus of Bechterew, situated on the border of the fourth ventricle; below with a column

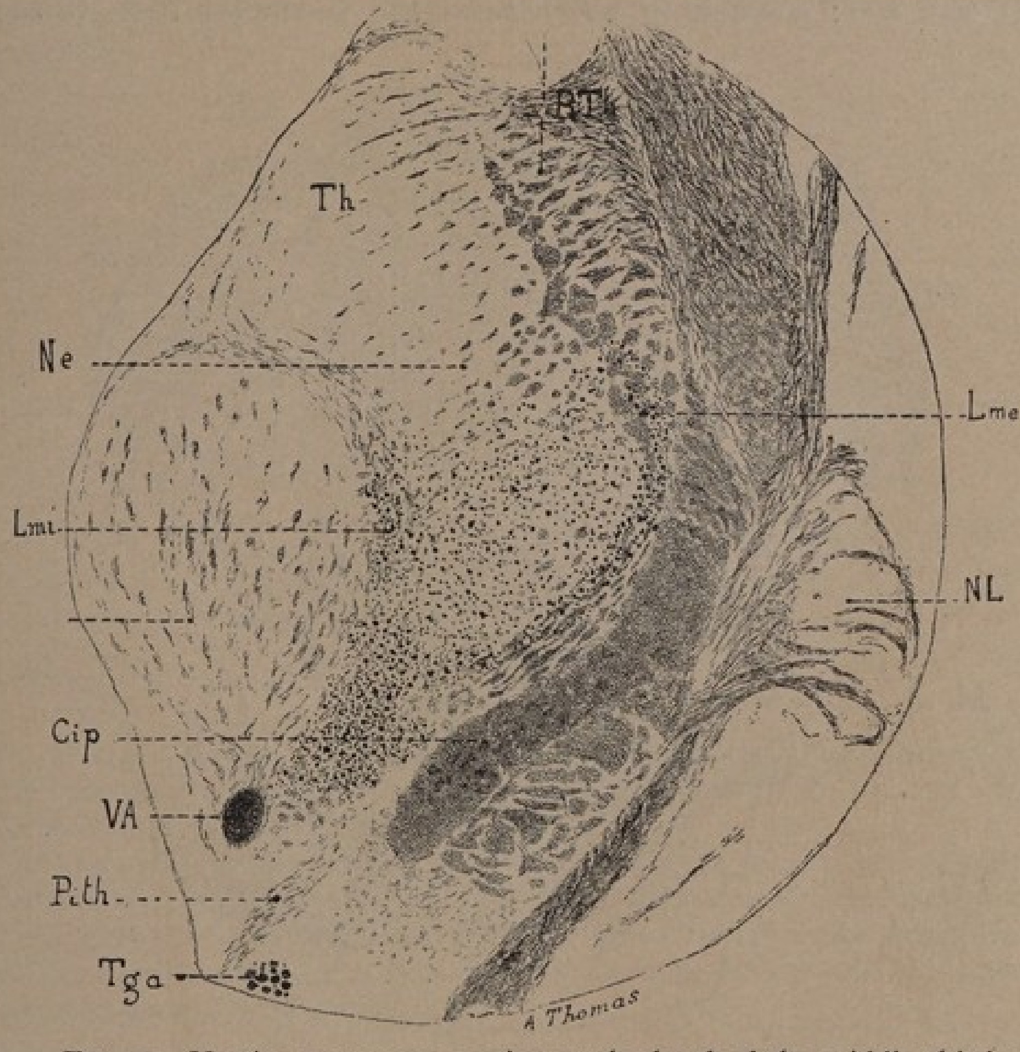

FIG. 19. Vertico-transverse section at the level of the middle third of the optic thalamus. Radiations of the superior cerebellar peduncle in the thalamus. (Same case as in Figs. 17 to 27.)

Cip, posterior internal capsule; *Lme,* external medullary fold; *Lmi,* internal medullary fold; *Ne,* external thalamic nucleus; *Ni,* internal thalamic nucleus; *NL,* lenticular nucleus; *Pith,* inferior peduncle of thalamus; *RTh,* thalamic radiations; *Tga,* anterior pillar of the trigone; *VA,* band of Vicq d'Azyr; *Tr,* reticular zone.

of gray substance lying alongside the internal border of the restiform body and which contains a certain number of little bundles which have a vertical direction. These little bundles form the internal segment of the restiform body, or better, the juxta-restiform body (old ascending auditory root, or root of Roller).

We have given these bundles the name of cerebello-vestibular bundles because they are composed of two kinds of fibers (Figs. 21 and 22): descending fibers from the vestibular root of the

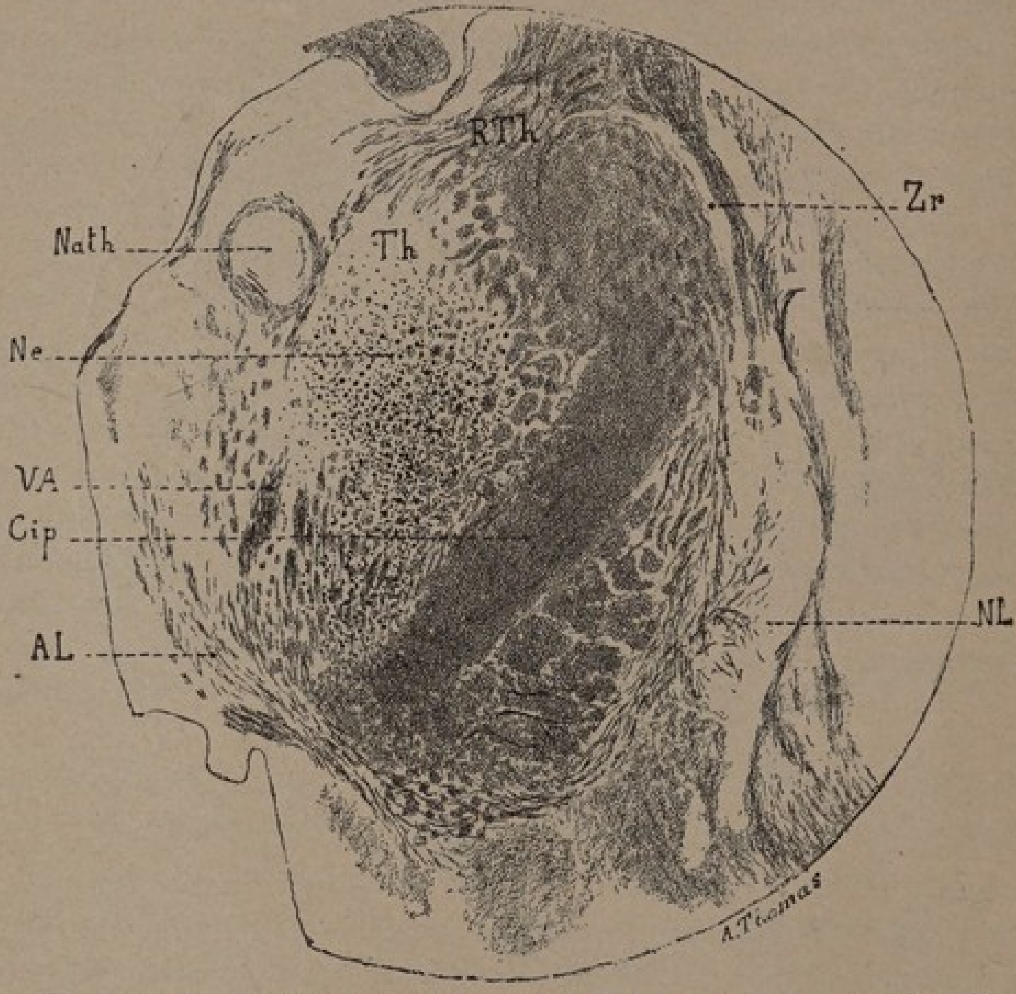

FIG. 20. Vertico-transverse section at the level of the anterior third of the optic thalamus. Ultimate termination of the degenerated fibers of the superior cerebellar peduncle in the thalamus.

AL, loop of the lenticular nucleus; *Nc,* external nucleus of the thalamus; *Cip,* posterior internal capsule; *Nath,* anterior thalamic nucleus; *NL,* lenticular nucleus; *RTh,* thalamic radiations; *VA,* band of Vicq d'Azyr; *Tr,* reticular zone.

eighth pair and fibers coming from the central gray nuclei of the cerebellum. Both of them lose themselves in the column of gray substance which accompanies them and which is a prolongation of the nucleus of Deiters. The existence of these fibers has been shown by the method of experimental degeneration after a section of the eighth pair, and after destruction of the lateral half of the cerebellum.

The triangular nucleus is a nucleus composed of small cells applied by its base to the antero-lateral angle of the fourth ventricle.

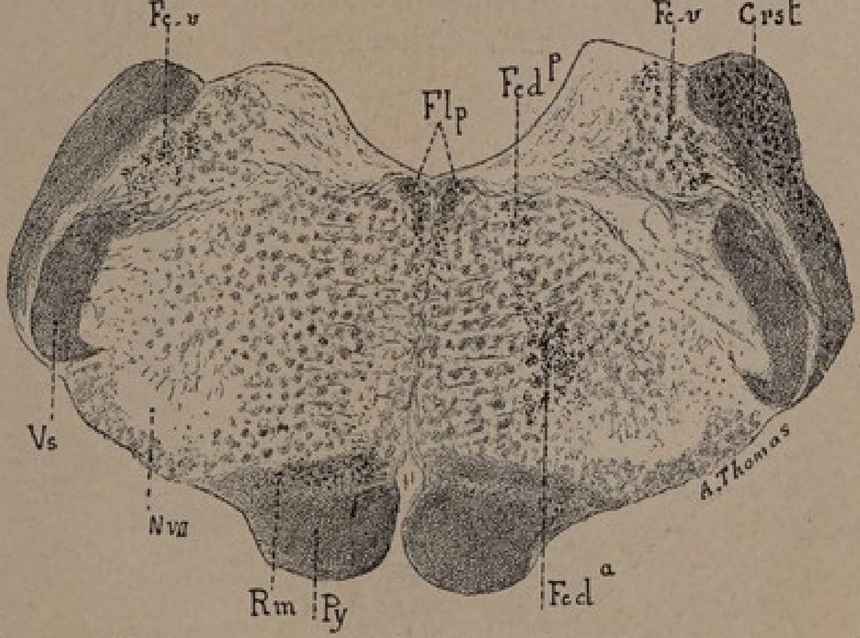

FIG. 21. Section of the medulla below the olives. Degenerations of the descending cerebellar tract, of the restiform body and of the cerebello-vestibular bundles.

Crst, restiform body; *Fcda,* anterior portion of the descending cerebellar tract; *Fcdp,* posterior portion of the descending cerebellar tract; *Fcv,* cerebellar-vestibular tracts; *Flp,* posterior longitudinal fasciculus; *NVII,* facial nucleus; *Py,* pyramid; *Rm,* median fillet of Reil; *Vs,* descending root of fifth nerve.

The cerebellum furnishes also some fibers to the vestibular root, and to the juxta-restiform body. The nucleus of the tegmentum is the principal origin, but it is probable that the globosus and the emboliformis (Koesel), and perhaps even the dentate nucleus, furnish a certain number of fibers; none of them seem to come from the cerebellar cortex.

The whole of the central gray nuclei of each half of the cerebellum thus enters into relation with the two vestibular nerves, with a certain preference for those of the same side. The direct fibers are no other than the internal arcuate fibers which run along the lateral border of the fourth ventricle before reaching the nuclei of Deiters and Bechterew, and the external arcuate fibers which traverse the white substance passing outside the dentate nucleus. The crossed fibers pass through the anterior commissure of the cerebellum and the bundle of the uncus (Russell and André-Thomas), which turns around the superior cerebellar peduncle below its emergence from the cerebellum (cerebello-bulbar bundle of Van Gehuchten) (Figs. 23 and 27).

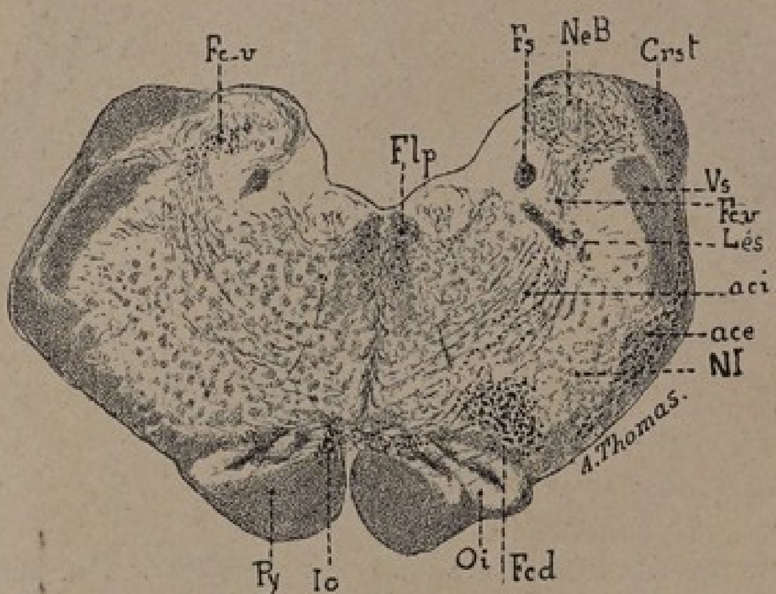

FIG. 22. Section of the medulla passing through the olives and the external nucleus of the column of Burdach. Termination of the degenerated fibers of the restiform body in the nucleus of the lateral column and the external nucleus of the column of Burdach.

Ace, external arcuate fibers; *aci,* internal arcuate fibers; *Crst,* restiform body; *Fcg,* descending cerebellar tract; *Fcv,* cerebellar-vestibular bundles; *Fs,* solitary bundle; *Flp,* posterior longitudinal fasciculus; *Io,* interolivary layer; *Lis,* an accessory lesion, several internal arcuate fibers having been cut; *NeB,* external nucleus of the column of Burdach; *Nl,* nucleus of the lateral column; *Oi,* inferior olive; *Py,* pyramid; *Vs,* descending root of the fifth nerve.

Among the fibers which go to the nucleus of Deiters, or which follow the uncus, there are a certain number which join from above, below and contribute to form the cerebello-vestibular bundles.

To sum up, there are intimate relations between the nuclei of the vestibular nerve and the central gray nuclei of the cerebellum, more particularly the nucleus of the tegmentum. Since the nucleus of the tegmentum belongs particularly to the vermis and the dentate nucleus depends more upon the cortex of the lateral lobe, it results that there should exist between the vermis and the vestibular apparatus physiological relations of the greatest importance.

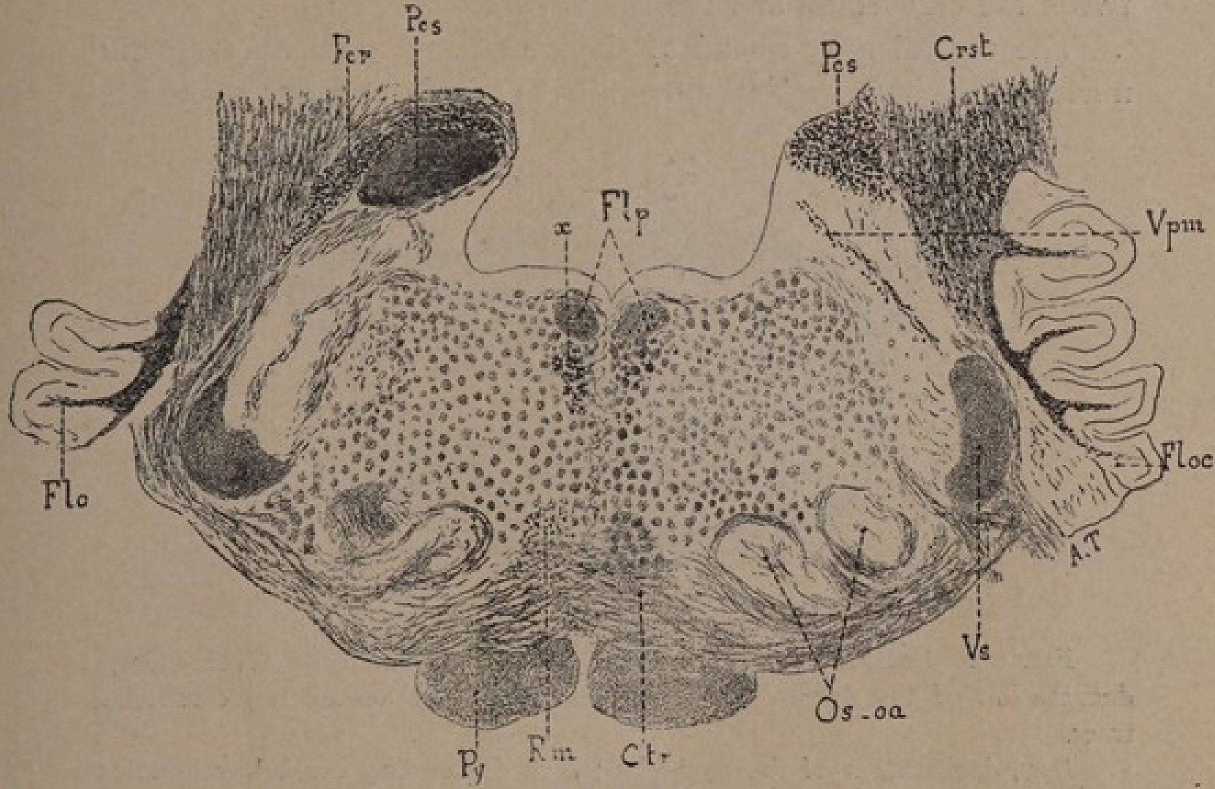

FIG. 23. Section designed to show the degeneration of the superior cerebellar peduncle on the side of the lesion and of the arciform bundle on the opposite side. (The section is not absolutely horizontal, but oblique from above downward and from right to left.)

Crst, restiform body; *Ctr,* trapezoid body; *Fcr,* unciform bundle; *Floc,* flocculus; *Flp,* posterior longitudinal fasciculus; *Oo–oa,* superior olive and accessory olivary nucleus; *Psc,* superior cerebellar peduncle; *Py,* pyramid; *Rm,* median fillet of Reil; *X,* zone of degeneration in the median reticulate substance; *Vpm,* small motor root of the fifth nerve degenerated in consequence of a lesion of its nucleus of origin; *Vs,* descending root of the fifth nerve.

The Inferior Cerebellar Peduncle or Restiform Body.—The few fibers which degenerate in the restiform body of the same side after the destruction of a cerebellar hemisphere, stop for the most part in the reticular substance of the medulla, particularly in the nucleus of the lateral segment and in the nucleus of v. Monakow (external nucleus of the column of Burdach). The inferior cerebellar peduncle, therefore, is composed almost exclusively of afferent fibers.

The Relations of the Cerebellum and the Spinal Cord.—Opinions are very much divided as to the nature of the relations between the cerebellum and the spinal cord.

The central gray nuclei of the cerebellum send fibers to the nuclei of Deiters and Bechterew. The axis cylinder prolonga-

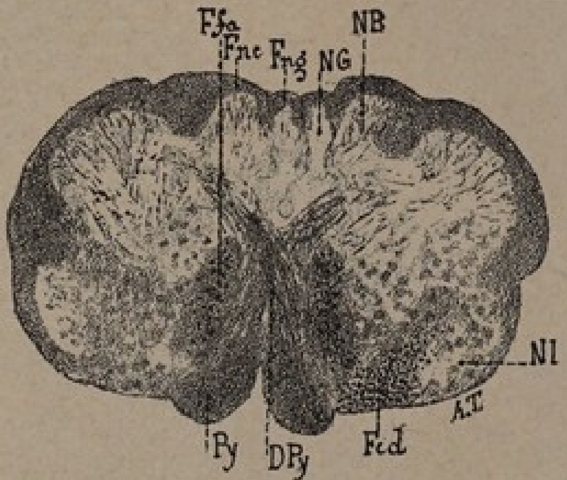

FIG. 24. Section of the medulla passing through the level of the decussation of the pyramids. Degeneration of the descending cerebellar tract.

Dpy, decussation of the pyramids; *Fcd,* descending cerebellar bundle; *Ffa,* anterior fundamental bundle; *Fmc,* funiculus cuneatus; *Fnc,* funiculus gracilis; *NB,* nucleus of the tract of Burdach; *NG,* nucleus of the column of Goll; *Nl,* nucleus of the lateral column; *Py,* pyramid.

tions of the cells of Deiters' nucleus terminate partly in the anterior horns, after having followed the antero-lateral segment of the cord. At the level of the medulla they pass through the reticular substance and the posterior longitudinal fasciculus. These fibers appear to enter more in relation with the antero-internal groups of cells than with the external and posterior nuclei of the anterior horns. They can be followed the whole length of the cord. In addition to these some fibers leave the nuclei of Deiters and of Bechterew and go to the oculo-motor nuclei, more particularly to the nucleus of the sixth pair of the same side and to the nucleus of the third pair of the opposite side. These latter follow the contra-lateral posterior longitudinal fasciculus (André-Thomas).

The tonic and coördinating influence of the nuclei of the eighth pair (vestibular), not only over the muscles of the trunk

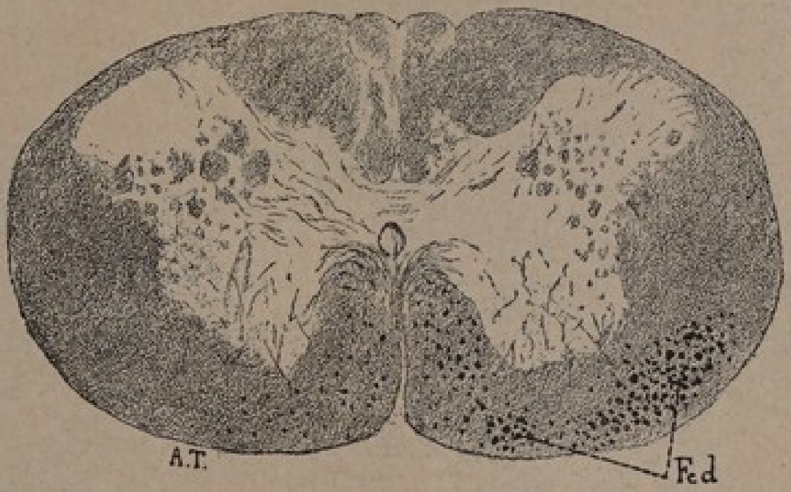

FIG. 25. Section passing through the level of the first cervical root. *Fcd,* descending cerebellar bundle (side of the lesion).

and limbs but also over those of the eyes, is deducible from these simple anatomical observations; since these nuclei receive at the same time vestibular and cerebellar fibers. One may conclude from this that coördinations of the same order may be presided

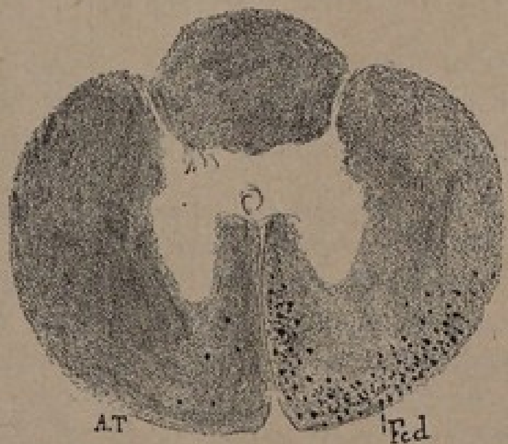

FIG. 26. The descending cerebellar bundle in the mid-dorsal region.

over both by the cerebellum and by the vestibular nerves. Physiological experiments have in fact shown that lesions of one or the other produce analogous but not identical phenomena.

The existence of indirect relations of the cerebellum with the spinal cord through the intermediation of the nucleus of Deiters is definitely admitted. This is not the case with the direct rela-

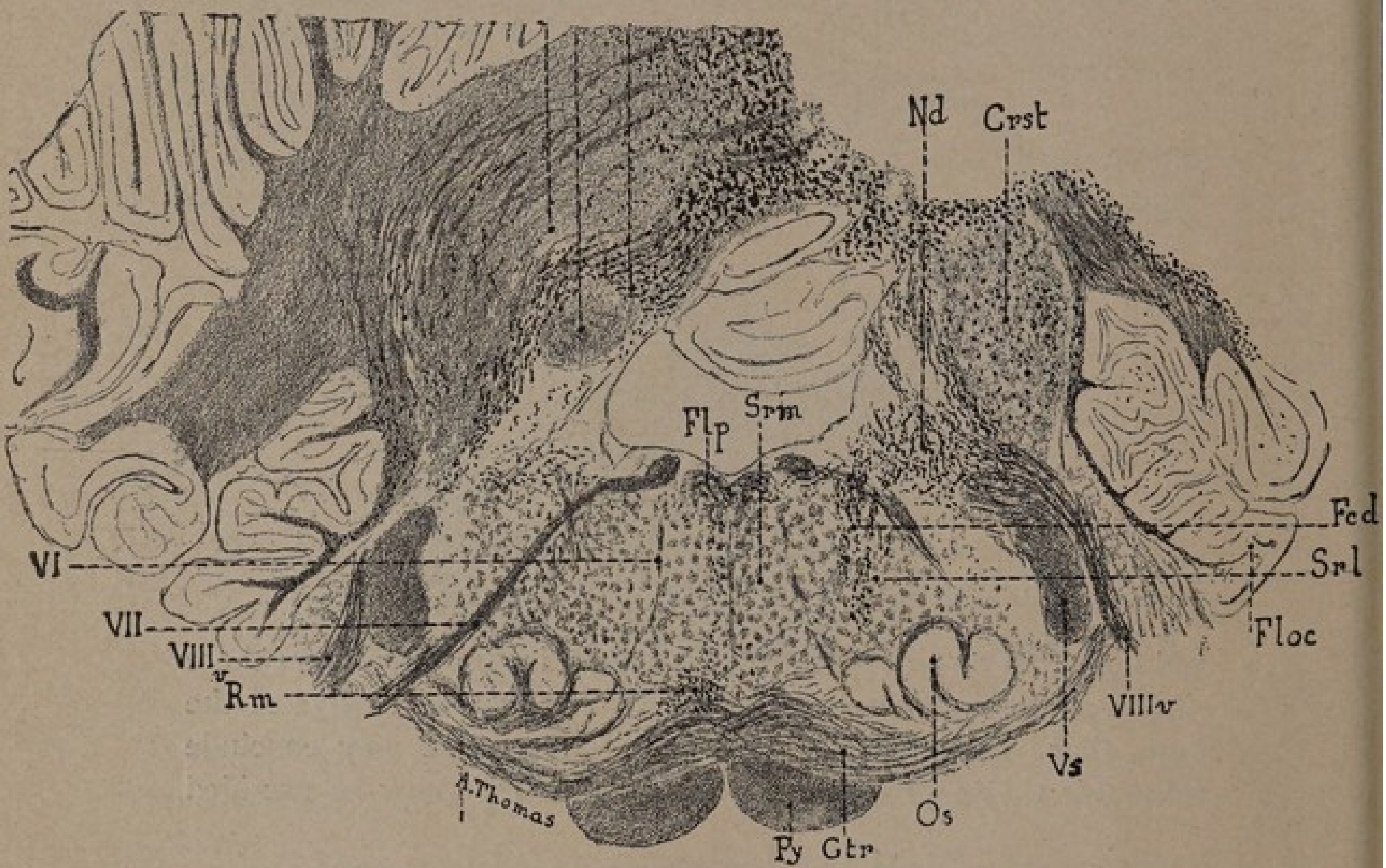

Fig. 27. Section of the medulla passing through the trapezoid body and the superior olives. The descending cerebellar bundle (*Fcd*), after having crossed the nucleus of Dieters, is directed forward in the lateral reticular substance (*Slr*).

Crst, restiform body; *Ctr,* trapezoid body; *Fcd,* descending cerebellar bundle; *Fcr,* unciform bundle; *Floc,* flocculus; *Flp,* posterior longitudinal fasciculus; *Nd,* nucleus of Dieters; *Ndl,* dentate nucleus; *Os,* superior olive; *Pcs,* superior cerebellar peduncle; *Py,* pyramid; *Rm,* median fillet of Reil; *Srl,* lateral reticular substance; *Srm,* Median reticular substance; *Vs,* descending root of the fifth nerve; *VI,* sixth nerve; *VII,* facial nerve; *VIII, v,* vestibular nerve. The nucleus of Bechterew is behind the nucleus of Dieters between the restiform body and the fourth ventricle.

tions. Descending cerebellar fibers are admitted by Marchi, André-Thomas, Orestano and Luna. They originate in the dentate nucleus. The path of this bundle which I have indicated in a former work is as follows (Figs. 27 and 28): Coming out of the dentate nucleus the descending cerebellar bundle crosses the nucleus of Bechterew throughout its whole width. Its fibers then are directed towards the reticular substance of the pons, and pass, some below, some above and some between the fibers of the facial nerve. They then take two directions, the larger

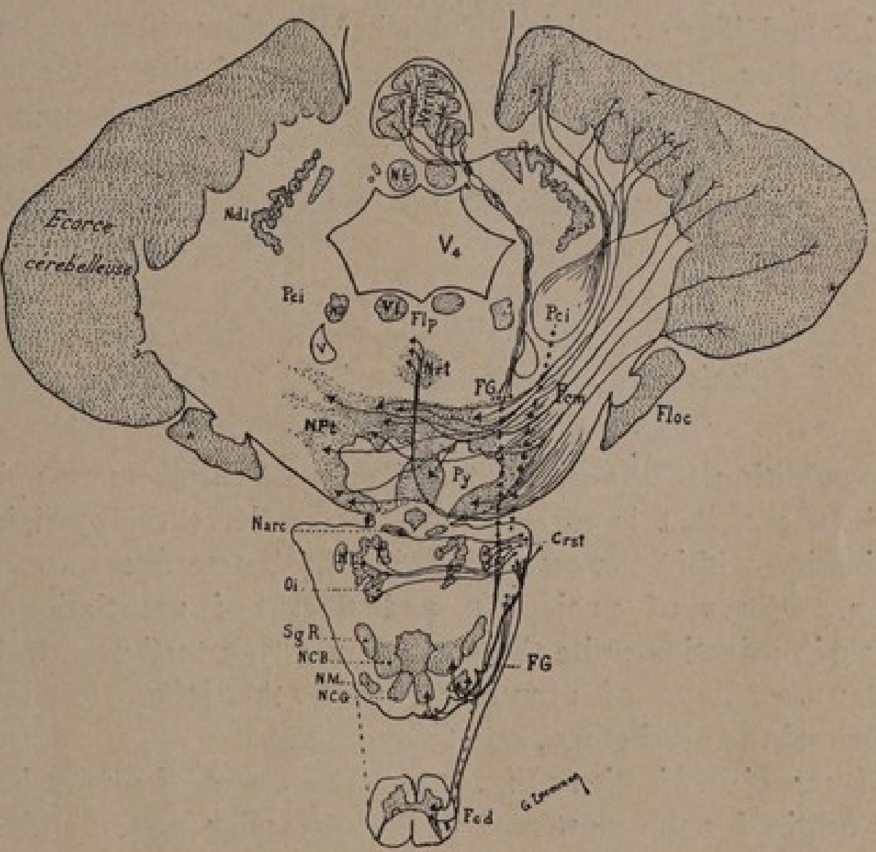

FIG. 28. Afferent fibers of the cerebellum.

number going anteriorly in the lateral part of the reticular substance and mingle with that part of the fibers of the nucleus of Deiters destined for the spinal cord; the others pass posteriorly.

The anterior group, situated at first behind the olive, then behind the nucleus of the facial nerve, occupies the antero-external border of the inferior olive lower down. The posterior group is placed in front of the genu of the facial nerve, and then in front of the triangular nucleus of the vestibular nerve. At the lower level of the medulla, the two groups tend to confound themselves one with another and after decussating form a bundle in the antero-lateral segment of the spinal cord. This bundle can be followed as far as the lumbar cord. Besides these, some fibers pass through the bundle of the uncus and internal segment of the restiform body to descend in the anterior ground bundle of the spinal cord of the opposite side. These last fibers do not go below the mid-dorsal region.

The existence of descending cerebellar fibers is denied by Ferrier and Turner, Risien Russell, Van Gehuchten and Kohnstamm. For these authors degeneration of the antero-lateral tract of the cord following a destruction of the cerebellum is not observed unless the nucleus of Deiters has been affected by the lesion. Descending cerebellar fibers have not as yet been observed in man.

III. *Intrinsic Fibers of the Cerebellum. Fibers of Projection and Association. Connections of the Cerebellar Cortex with the Central Gray Nuclei*

In addition to the afferent and efferent fibers there exist intrinsic fibers, that is to say, fibers which have their origin and termination within the cerebellum itself. These fibers are of two orders. Fibers of projection and fibers of association. The fibers of projection unite the cerebellar cortex to the central gray nuclei; the fibers of association unite the lobes, lobules and lamellæ of the cerebellum, one to another.

Fibers of Projection (Fig. 29).—The fibers of projection take their origin for the most part in the cerebellar cortex and terminate in the central gray nuclei; the dentate, globosis, emboliformis and nucleus of the tegmentum. It is also probable that a number of fibers originate in these nuclei and go to the cerebellar cortex. Their existence, however, has not been so definitely shown as that of the first kind.

There is a systematization in the cortico-nuclear relations.

The dentate nucleus receives fibers from the cortex of the lateral lobe (André-Thomas, Clarke and Horsley), and also fibers from the median lobe of the vermis (Clarke and Horsley). The nucleus of the tegmentum receives fibers from the vermis and from the flocculus. According to Clarke and Horsley the nucleus of the tegmentum would receive fibers from the whole of the cerebellar cortex. If this be true it would have an important

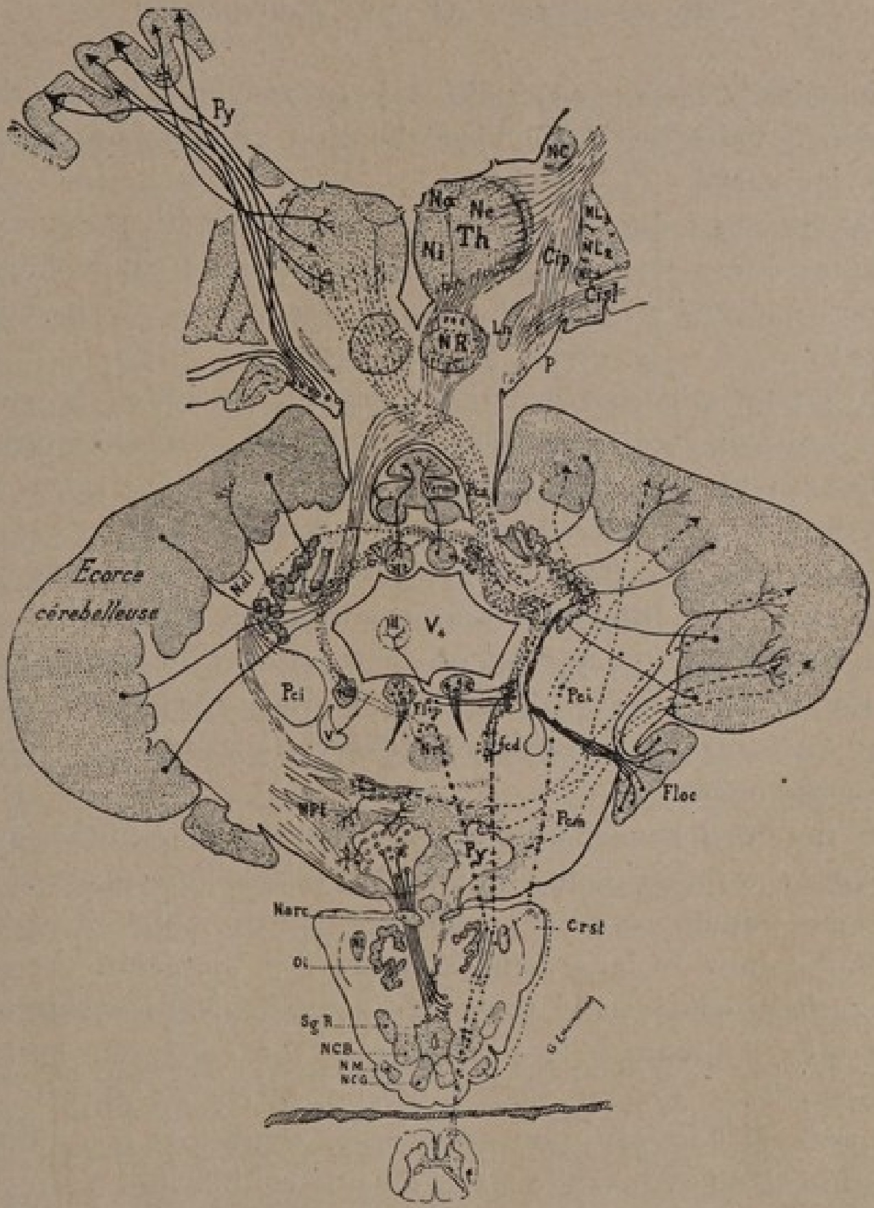

FIG. 29. Efferent fibers and fibers of projection of the cerebellum.
(Same legend for both cuts.)

Cip, posterior segment of the internal capsule; *Cisl,* retro-lenticular segment of the internal capsule; *Crst,* restiform body; *fcd,* descending cerebellar bundle; *FG,* tract of Gowers; *Floc,* flocculus; *Flp,* posterior longitudinal bundle; *Ln,* locus niger; *Na, Ne, Ni,* anterior, external and internal nuclei of the thalamus; *Nanc,* arciform nucleus; *NC,* caudate nucleus; *NCB,* nucleus of the column of Burdach; *NCG,* nucleus of the column of Goll; *ND,* Dieters' nucleus; *Ndl,* dentate nucleus; *Nl,* nucleus of the lateral column; *NL–1, Nl–2, Nl–3,* first, second and third segments of the lenticular nucleus; *NM,* nucleus of Monakow; *Npt,* pontine nucleus; *NR,* red nucleus; *Nrt,* nucleus reticularis tegmenti pontis; *Nt,* nucleus of the roof (fastigii); *Oi,* inferior olive; *P,* cerebral peduncle or crus; *Py,* pyramidal bundle and pyramid; *Pci, Pcm, Pcs,* inferior median and superior cerebellar peduncles; *Sgr,* gelatinous substance of Rolando; *Th,* thalamus; *V4,* fourth ventricle; *III,* nucleus of motor ocularis communis nerves; *V,* descending branch of fifth nerve; *VI,* nucleus of sixth nerve.

physiological bearing, especially taking account of the intimate ties which unite the nucleus of the roof and the nuclei of the vestibular nerve.

The globosus does not have any relations with the cortex of the lateral lobe. It is a part of the vermis and enters into connection principally with the paramedian lobe (Horsley and Clarke).

No matter which nucleus is concerned, the relations with the cortex are always direct; each region of the cerebellar cortex is in relation with a nucleus or with nuclei of the same side. These fibers do not cross the median plane (Clarke and Horsley).

To sum up, the fibers of projection of the cerebellar cortex are destined for different nuclei according to the region. It is to the nucleus of the tegmentum and accessorily to the nucleus globosus that the fibers of the vermis are projected. The fibers of the cortex of the lateral hemispheres project themselves to the dentate nuclei.

On the other hand the vermis receives fibers from the medulla and from the spinal cord. The lateral hemisphere receives fibers from the middle cerebellar peduncle which unites it with the cerebral cortex. Clarke and Horsley are therefore correct in basing their conclusions upon these anatomical considerations, when they distinguish two systems in the cerebellar cortex: a spino-cerebellar system, and a cerebro-cerebellar system. The same authors note also that as auditory sensations are located in the temporal lobe, that the sensations of equilibrium and orientation which are dependent upon the vestibular nerve, should have their seat in the same neighborhood. These last are localized by Mills in the posterior third of the temporal lobe (second and third convolutions). As I have already remarked it is precisely in this region, or adjacent regions, that the bundle of Türck (external bundle of the central peduncle) takes its origin. This bundle goes to the nuclei of the pons, which are the origin of the middle cerebellar peduncle.

Thus crossed relations are established between the temporal lobe, the center of labyrinthine representations, and the lateral lobe of the cerebellum. Clarke and Horsley insist upon the physiological importance of this fact.

Fibers of Association.—The paths and extent of these fibers have been particularly well studied by Clarke and Horsley by the method of secondary degeneration. Their conclusions are as follows: Some fibers pass from the vermis to the lateral lobes, but never beyond the plane of the paramedian lobe (cat, dog and monkey), some arciform association fibers take a lateral path as far as the second lamella from the edge of the lesion, rarely as far as the third. Extensive lesions of the vermis, and particularly those of the median lobe, are followed by extensive degenerations of arciform fibers which follow an antero-posterior path and are contained therefore in the vermis. The fibers which go to the nodule are very few.

These experiments have shown the almost complete independence of the vermis and the lateral hemispheres. There are no commissural fibers between the two lateral parts of the cerebellum. The same authors furnish some information as to the caliber of the different systems of fibers. The fibers of projection, or cortico-nuclear, are fine, or medium-sized fibers. The arciform fibers, or fibers of association, are fine fibers. As to the nucleo-peduncular fibers, the superior ones are large; the intermediate fine; and the inferior ones of medium caliber.

IV. *Embryological Significance of the Cerebellum*

At the commencement of the second month of the life of the embryo two grooves are seen upon the lateral walls of the human spinal cord, two lateral grooves which divide each lateral side into two halves; the anterior or fundamental fold of His and the posterior or alar fold. The fundamental fold and the alar fold are united by a lozenge-shaped intermediary portion. It is at the expense of the fundamental fold that the anterior gray commissure, the anterior white commissure, the anterior cornu, the anterior tracts, the anterior part of the lateral tracts, and the anterior half of the arcuate formation are formed; they enclose all the nuclei of origin of the motor nerves.

The intermediate part forms the neck of the posterior cornu; the column of Clarke, the reticular process and the posterior part of the lateral tract (crossed pyramidal tract and the direct cerebellar tract of Flechsig). The posterior part or alar fold forms the posterior cornu, and the posterior cord, and receives the roots of the sensory nerves. At the level of the medulla, as in the spinal column, the fundamental fold gives rise to the motor nerves. The alar fold receives the termination of the medullary sensory nerves.

The alar fold then divides into two segments: the one internal or jugal, and the other external or rhomboidal lip of His. The jugal segment becomes later on, first, in the medullary regions, the nucleus of the tract of Goll, the gray wing, the acoustic tubercle; and second, in the pontine region, the locus cœruleus.

The rhomboidal lip forms in its turn first, in the medullary region, the medullary or inferior olive, the accessory olivary nuclei, the nucleus of the tract of Burdach, the nuclei of the lateral tracts, the arcuate nuclei of the pyramids, and the gelatinous substance of Rolando. The fibers which arise from them will form the internal arcuate fibers of the medulla, the system of olivary fibers, the trapezoid body, the interolivary layer and the restiform body. Second, in the pontine region the pontine olive, the gelatinous substance of Rolando, the internal arcuate fibers, the trapezoid body and the fold of the cerebellum (J. and A. Déjerine).

The cerebellum, therefore, is developed along the path of the sensory tracts, and as an accessory of the sensory tract. At first it is a double organ, the two parts of which unite afterwards in the median line. The cerebellar fold first develops the vermis in its median portion; it is there that the first grooves to the number of three or four appear towards the third month of intra-uterine life. The grooves of the cerebellar hemispheres appear during the fourth month. The cerebellum does not acquire its final form until about the fifth month. The fibers of the vermis myelinate much earlier than those in the hemispheres.

V. *Comparative Anatomy*

The cerebellum follows a course in its development in the animal series parallel to that of the nervous system in general. Rudimentary in fishes it acquires its maximum of development in mammals.

The cerebellum of fishes is situated behind the optic lobes and consists of an elongated appendix, adherent by its base in front, and free behind, implanted upon the sides of the spinal cord. The superior face is traversed by an antero-posterior groove.

The surface is smooth in the bony fishes; in the cartilaginous fishes it is divided by grooves into lamellæ analogous to those in the superior vertebrates. The division into lamellæ is found in sharks and fish of the same order. In the sturgeon family the cerebellum is represented only by a little ball of fat.

Edinger remarks that the *Myxine,* a worm-like fish which lives within the bodies of other fish as a sort of parasite, or on rocks where it fixes itself, has no cerebellum. The flat fish which lives in the sand has a cerebellum much less developed than other fish of the same family.

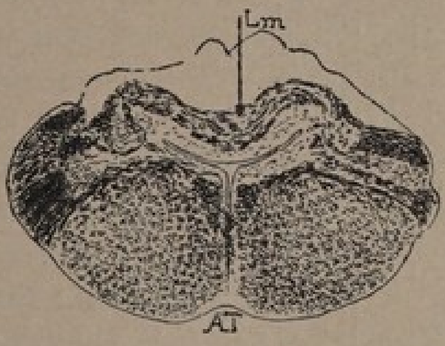

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FIG. 30. Section of the medulla and the cerebellum of a snake (morelia argus). It is reduced to a simple transverse fold. (Stained by the method of Pal.)

FIG. 31. The encephalon of a crane. The cerebellum, seen in profile, is represented by a voluminous vermis and a very small lateral appendix.

The cerebellum of reptiles is reduced to a simple transverse fold placed across the fourth ventricle, viz., toads, frogs, lizards, vipers, etc. (Fig. 30). The cerebellum is wanting in the salamander which lives under the ground. In the tortoise it has a globular form and its volume is greater than that of the optic lobe. In the turtle the cerebellum is twice as large as it is in the tortoise (Edinger); according to this author, this is due apparently to the great activity which the animal displays in swimming. The cerebellum of the crocodile is folded upon itself several times and possesses two lateral appendices.

In birds the cerebellum takes on a much greater development; even when compared with the whole encephalic mass (Fig. 31). In spite of this it is formed almost entirely by the median lobe composed of transverse lamellæ varying in number from ten to twenty, according to Leurat. In some birds the cerebellum is provided with two small lateral appendices, the first appearance of the lateral lobes of the mammals. The lateral appendices are scarcely visible in the chicken, the goose, the thrush and the sparrow. They are observable in the partridge, the pigeon, the ostrich, the duck, and the crane. The birds which rise and sustain themselves in the air like the cranes, and those whose wings and legs have considerable power, as the loon (of Bassan), and the parrots, have their lateral appendices more developed (Serres). The grooves and the folds are developed proportionately to the size of the birds. Comparing the weight of the cerebellum in different species of birds, Lapicque and Girard conclude that it seems related to certain functional attitudes. The development of the cerebellum would seem remarkable in birds of prey and in sea birds. A comparison with the pigeon and the snipe would seem to indicate an especial relation with soaring; this is practically the same opinion formerly expressed by Serres. The cerebellum of birds contains equally two organs; the cortex and the central gray nuclei. The central gray nuclei are four in number: two median and two lateral (Brandis). Besides these the bridge of nerve substance which joins each side of the vermis to the continuation of the spinal cord contains a nucleus which is in immediate juxtaposition to the lateral nucleus of the cerebellum, and which belongs to the nuclear apparatus of the eighth pair (Fig. 32).

The experimental researches of Frenkel on the pigeon permit us to establish the existence of a certain number of systems of fibers which present some analogy with those in mammals. The afferent fibers come from the base of the posterior cornu of the spinal cord, from the nuclei of the posterior columns, and from those of the corpora bigemini. The majority of them terminate in the cortex. The nuclear contingent is very scant. The fibers which come from the cerebellar cortex form the commissural fibers and the fibers of association, in addition to the fibers of projection which go to the central nuclei. Some fibers attain the nuclei of the vestibular nerve. The greater number of the efferent fibers take their origin in the median and lateral nuclei, and are destined for the nuclei of the vestibular nerve (in birds, as well as in mammals the relations of the cerebellum and the nuclei of the vestibular nerve are very intimate), to the motor nuclei of the fifth nerve, and of the facial nerve, as well as to the motor nuclei of the spinal cord. These fibers occupy the lateral tract,

FIG. 32. Transverse section of the cerebellum and medulla of a pigeon (Weigert-Pal staining), intended to show the central gray nuclei.

Na, anterior nucleus; *Np*, posterior nucleus and its relations with the eighth nerve (*VIIIv*); *Scv*, cerebello-vestibular bundles; *NB*, nucleus of Bechterew.

and are partly direct and partly crossed, to the olivary nuclei of the prolongation of the spinal cord, to the posterior longitudinal fasciculus which they follow to terminate in the oculo-motor nuclei, and in the spinal cord (anterior bundle), to the red nucleus of the opposite side and to the optic thalamus.

FIG. 33. Transverse section of the cerebellum of the macaque monkey. (Stained by the method of Pal, enlarged 3.7.) *Nal*, antero-lateral nucleus; *Npl*, posterior lateral nucleus; *NL*, lateral nucleus; *Nm*, median nucleus.

The lateral appendices of the cerebellum of birds takes on a much greater development in mammals and become the lateral lobes. The number of lobules and lamellæ increases with the height and weight. The relation of the median lobe to the hemispheres varies according to the different species. The median lobe is very large in the rodents, it is much smaller in the ruminants, the solipedes and carnivoræ. The progressive growth of the hemispheres is still more marked in the monkeys and apes (Figs. 33 and 34), and attains its maximum in man. It seems

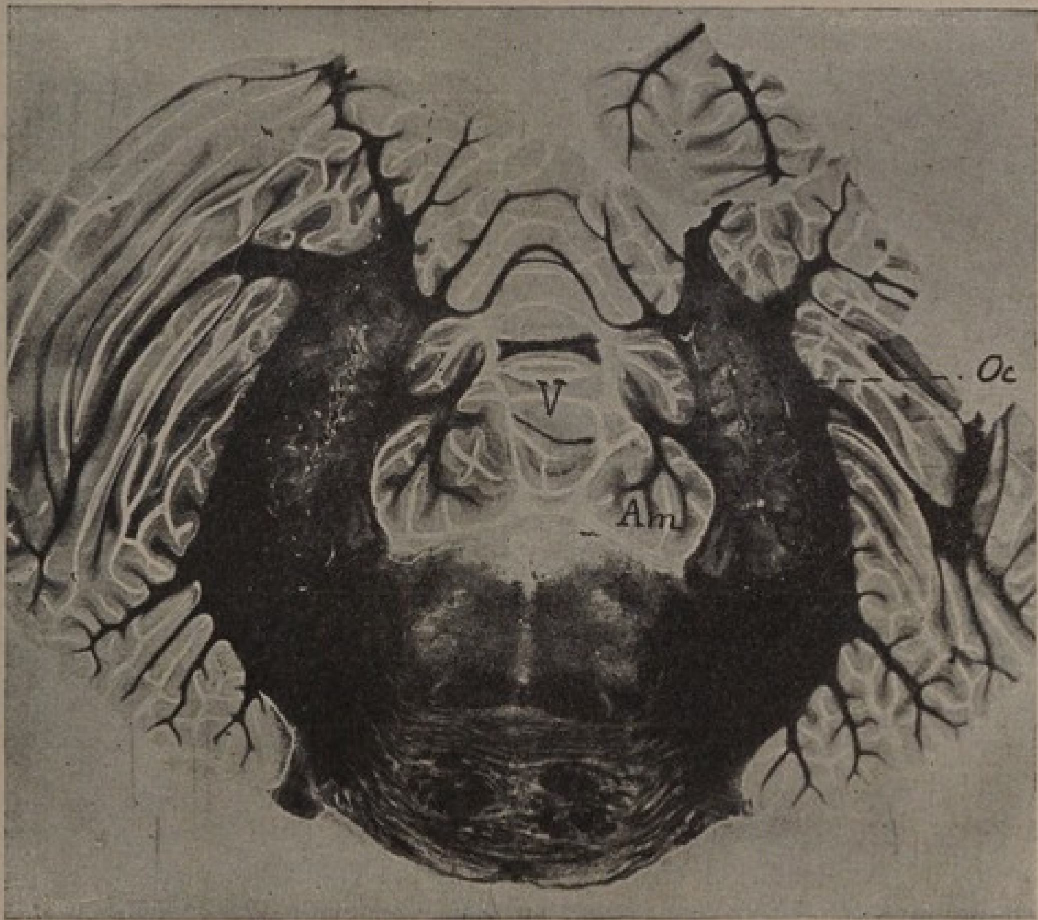


FIG. 34. Vertico-transverse section of the pons and the cerebellum of a chimpanzee (Weigert-Pal) to show the considerable development of the anterior stage of the pons, the cerebellar hemispheres and the cerebellar olives (*Oc*).

V, vermis; *Am*, amygdalæ. Enlargement 2.

subordinated to that of the cerebrum. The importance of the pons and the middle cerebellar peduncle is accentuated in the same way. In the anthropoid apes the anterior surface of the pons increases considerably in size, at the same time with the middle cerebellar peduncle and the lateral lobe (Fig. 34).

In mammals, as a study of secondary degeneration proves, there are intimate relations between the central gray nuclei of the cerebellum and the nuclei of the vestibular nerve. In all mammals except man the nucleus of Bechterew is continued as far as the nucleus of the tegmentum, under the form of little bridges

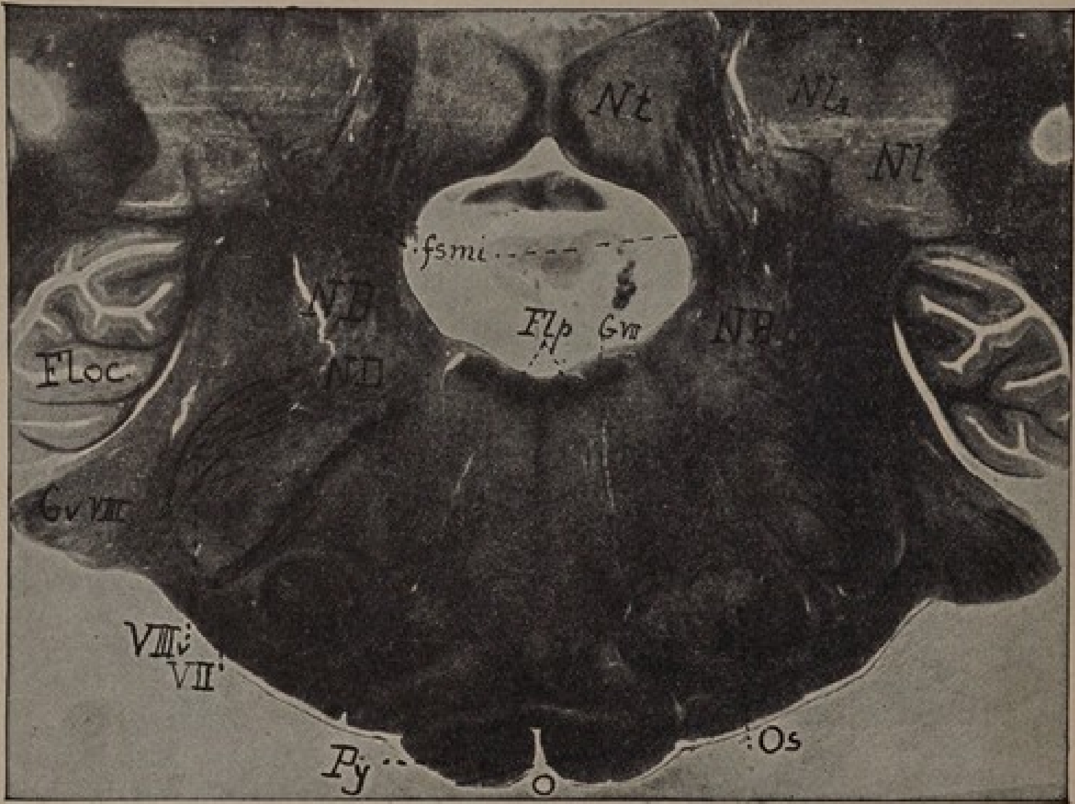


FIG. 35. Photograph of a transverse section of the medulla and the nuclei of the cerebellum of a dog (stain Weigert-Pal). Relations of the nuclei of the cerebellum with the nuclei of the vestibular nerve by means of the internal semicircular fibers (*Fsmi*).

Floc, flocculus; *Flp*, posterior longitudinal fasciculus; *CvVIII*, ventral nucleus of the auditory nerve; *GVII*, genu of the facial; *NB*, nucleus of Bechterew; *MD*, nucleus of Deiters; *Nt*, nucleus of the roof; *Nl*, lateral nucleus; *Nla*, antero-lateral nucleus; *Os*, superior olive; *Py*, pyramid; *VII*, facial; *VIIIv*, vestibular nerve.

of gray substance intercalated between the tracts which go from the vermis to the prolongation of the spinal cord (Weidenreich). This is the same anatomical disposition that has been described by Brandis in birds. In consequence of this disposition of anatomical connections, which unites the nucleus of Bechterew with the cerebellum, this nucleus can just as well be considered a cerebellar nucleus as a vestibular nucleus.

It is only in the highest mammals such as the superior apes and man, by reason of the considerable development of the cortex of the lateral lobes, that the rhomboid body or cerebellar olive takes on the folded appearance which has given it the name of the dentate nucleus. In all mammals four central gray nuclei can be distinguished: the median nucleus, the antero-lateral nucleus, the postero-lateral nucleus and the lateral nucleus (Fig. 35). The median nucleus corresponds to the nucleus fastigii, or nucleus of the tegmentum, in man. The antero-lateral nucleus to the emboliformis, the postero-lateral nucleus to the globulus, and the lateral nucleus to the dentate nucleus.

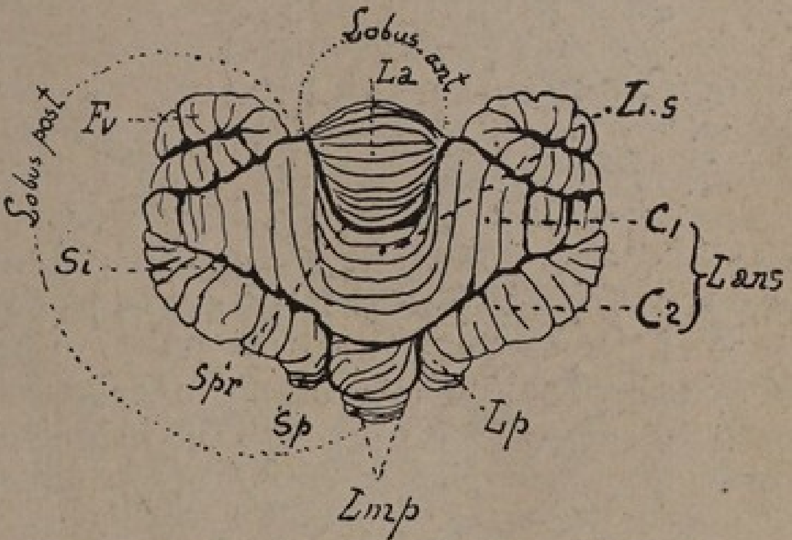


FIG. 36. Cerebellum of a dog. Superior surface. (Nomenclature of Bolk.) *Fv*, vermicular formation of petrous lobe; *La*, anterior lobe; *Lam*, auriform lobe; *C–1*, crus primum; *C–2*, crus secundum; *Lmp*, posterior median lobe; *Lp*, paramedian lobe; *Ls*, lobus simplex; *Si*, primary groove; *Sp*, paramedian groove.

Of late Bolk has contributed some important work on the comparative anatomy of the cerebellum, in an effort to establish a parallel between the degree of development of this or that part of the cerebellum, and the synergy, or greater or less individualization of the movements of the anterior and posterior limbs. He has thus defined cerebellar cortical localizations for the anterior limbs, the posterior limbs, the head and the trunk. Bolk combats the classic opinion according to which the cerebellum is divided into a median lobe or vermis, and into cerebellar hemispheres. He considers the cerebellum of all mammals to have two lobes: the anterior lobe and the posterior lobe, separated by the primary groove (Fig. 36).

The anterior lobe is formed of transverse juxtaposed lamellæ.

The posterior lobe is divided into two parts, anterior and posterior. The anterior or lobule simplex is slightly developed and

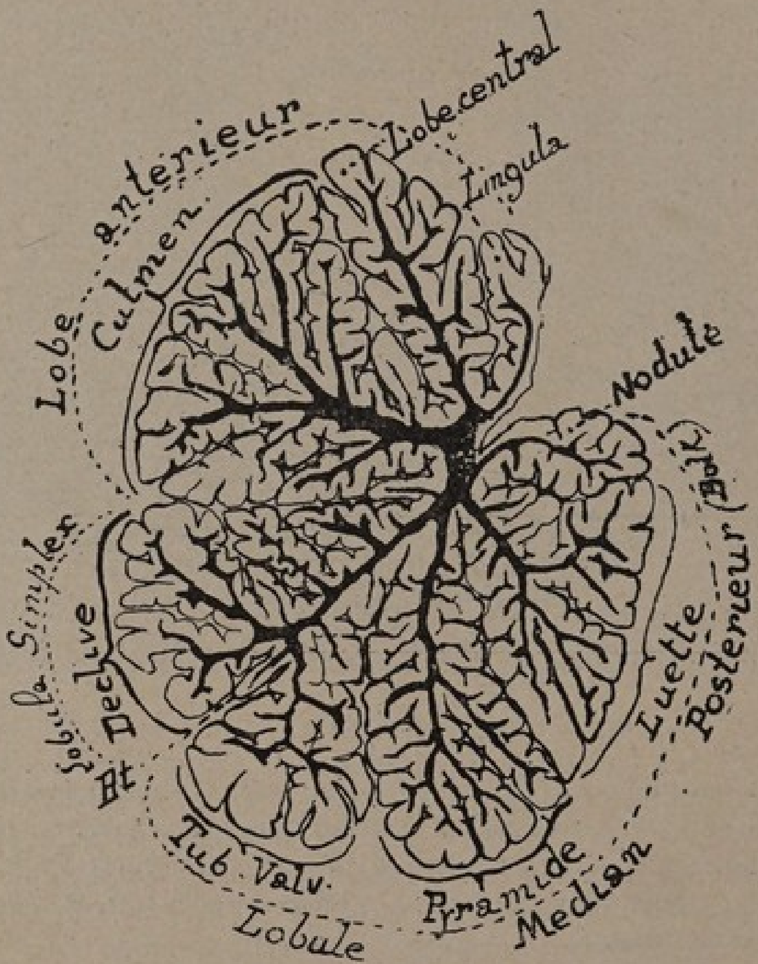


FIG. 37. Sigittal section of the vermis (man). (Application of the nomenclature of Bolk.)

formed, like the anterior lobe, of transverse lamellæ. The posterior part is composed of a median lobule and two lateral lobules. The median lobule, small and limited on each side by the paramedian groove, is subdivided into three parts, anterior, median and posterior. In each lateral lobule Bolk distinguishes three parts, the ansiform lobe, divided into two arms, the anterior and posterior by the intercrural groove, the para-median lobule and the vermicular formation of the petrous lobe. This disposition is especially well shown in the cerebellum of the dog. The anterior lobe corresponds in man to the central lobe, the culmen, and anterior quadrilateral lobe. The lobule simplex to the declive and to the posterior quadrilateral lobe (Fig. 37). In these formations there is no necessity to distinguish a vermian and a hemispheric portion; each lobe is considered as a whole.

In the posterior part of the posterior lobe, the ansiform lobe, which in man takes on a very great development, is the equivalent of the superior semilunar lobe, of the inferior semilunar lobe, of the lobus gracilis, and of the digastric lobes all together. The paramedian lobe becomes the amygdalus, and the vermicular lobe, the flocculus. In each kind of mammal, each of these parts takes on more or less importance in relation to the others, according to greater or lesser development of this or that group of muscles. The muscular groups of median organs with synergic functions have their seat in the median part of the cerebellum, in the same way that the centers of coördination of the lateral groups of muscles have their seat in the lateral parts of the cerebellum, where this function is independent of homologous groups of the same side.

The anterior lobe is the center for all the muscles of the head. The lobule simplex is the center for the muscles of the neck. The posterior part of the median lobe contains the centers of the synergic movements of the upper and lower limbs. The ansiform lobule, the independent centers of the upper and lower limbs. This is why the median lobe is developed in animals where the muscular work necessitates the synergy of movements of the upper and lower limbs. In man where the movements of the limbs have attained their maximum of individualization, the anciform lobe attains also its maximum of development.

The tonsil or amygdalus and the pyramid appear to be the centers of the movements of the trunk; the flocculus that of the movements of the tail.

CHAPTER II

EXPERIMENTATION.—DESTRUCTION OF THE CEREBELLUM

Partial or Total Destruction of the Cerebellum in the Dog

The phenomena observed in the dog will be taken as examples and described first. I will pay particular attention to the results of my own experiments without, however, neglecting the observations made by other physiologists who have occupied themselves with this question. The variations observed according to the different kinds of animals will then be taken up with a special note for the effects of the destruction of the cerebellum in the monkey.

I. *Destruction of a Lateral Lobe and the Corresponding Half of the Vermis*

(Fig. 38)

Immediate Phenomena.—Most of the animals having been operated upon in narcosis (ether, chloroform, chloral, or morphine), the phenomena described under this heading should not be confounded with the phenomena which would be produced at the moment of destruction if the animal were not anesthetized. The immediate phenomena which are about to be described are those which manifest themselves when the animal comes out of the phase of narcosis and begins to awake.

The animal moves little by little and emits plaintive whines. The body is shaken by a general trembling, more apparent in the muscles of the back. It tends to place itself in opisthotonos, the head is bent backwards, the anterior extremities are in tonic extension. When from time to time the animal attempts to make some movements, the tonic contraction of the members in extension increases.

When the animal has completely awakened, to these phenomena are added others, which follow one another, particularly when the body is not supported on the operated side. These are movements of rotation or rolling around the longitudinal axis. To observe these phenomena the animal must be taken from his cage and placed on the ground with his belly to the earth; the body then describes a curve with the concavity towards the operated side, and rests upon this side. This scoliosis is still more manifest if one hold the animal up by taking hold of the loose skin at the back. The head is turned in the same direction but it describes at the same time a movement of torsion, so that the back of the neck is directed very much downwards and behind

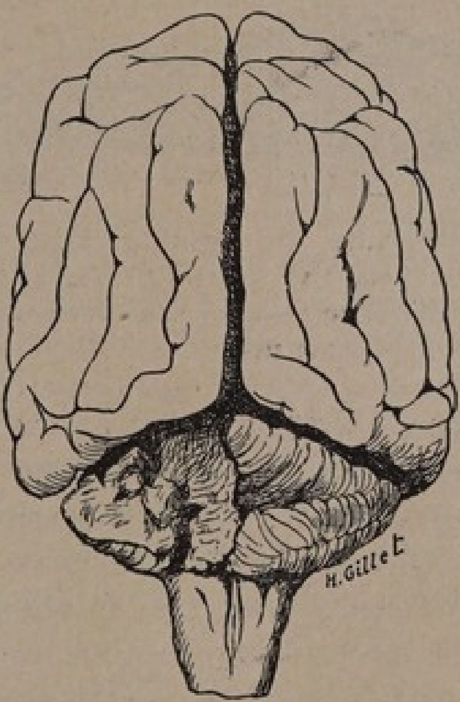


FIG. 38. Destruction of half of the cerebellum.

on the operated side, whereas the muzzle is turned in the opposite direction. The eye of the side operated upon looks inward and downward, whereas the other looks upwards and outwards. Both eyes are affected by nystagmic movements, which disappear, however, in a few days. This exaggerated movement of torsion of the head and of the neck is the beginning of the gyratory movement; the anterior half of the trunk then follows the movement of the head and the posterior half of the trunk is the last to turn (Fig. 39).

The animal thus turns over one or more times. These movements reappear spontaneously but there is no doubt that they are renewed with greater frequency under the influence of peripheral or sensory excitations, among which auditory sensations appear to be the most effective. These movements of rotation are of short duration, and hardly recur at all after the lapse of two or three days. The direction of the rotation is determined by the side upon which the animal falls, when he is placed on his four feet; as he always falls towards the operated side, one may say that the rotation takes place from the healthy side towards the operated side.

FIG. 39. Semi-schematic. Movement of rotation around the longitudinal axis from left to right which is observed after the destruction of the right cerebellar hemisphere along or associated with the destruction of the labyrinthine root of the same side.

In repose during the first days that follow the operation, the animal is contracted, he rests lying on the operated side with the head in extension and turned backwards towards the side of the lesion. The limbs are in extension, particularly the anterior ones. As regards the anterior limbs, as well as the posterior, those of

FIG. 40. Attitude of a dog after the left half of the cerebellum has been destroyed.

the operated side are the more contracted. The head is sometimes twisted so that the back of the neck looks downwards and backwards towards the operated side; the muzzle is then directed towards the healthy side. There is a conjugate deviation of the eyes toward the same side. The animal cannot lie down except on the operated side, or in a semicircle (Fig. 40). The curvature looking towards the operated side, the head lying upon the ground. When the animal is held up by the skin of his back the lateral curvature of the trunk increases (pleurothotonos), and half of the body, the operated half, rests always on an inferior plane to that of the healthy side. The anterior and posterior limbs are contracted in extension with a marked predominance on the operated side, and approach one another in consequence of this incurvation.

Phase of Reëducation or Restoration. Later Phenomena.—The pleurothotonos persists during several days, as does the extension of the limbs; up until the fifth day according to Lewandowsky. The animal attempts to lie upon his stomach, but in vain; he falls back almost immediately upon the operated side; it also attempts to make some movements, but always without success. Painful excitations provoke incoördinated movements, more marked in the limbs of the healthy side.

In the abdominal decubitus, when the animal succeeds in taking and maintaining this attitude, which he is not, as a rule, able to do for several days, the front legs are in marked abduction and the one on the operated side always more than the one on the healthy side. When it is able to lift its head from the ground, it describes lateral oscillations of increasing amplitude which cause the animal to fall again upon the operated side.

When the abdominal decubitus can be maintained for a few instants the animal tries to rise upon its four legs. At first it raises the anterior half of the body, resting upon the two front legs. Tremor and oscillations of the head and of the trunk immediately appear and result in a fall, always on the operated side.

Three or four days after the first attempts, when the equilibrium can be maintained for a certain time seated with the fore paws stretched wide apart, the dog makes some attempts to walk. One fore paw, nearly always the one of the operated side, is suddenly lifted from the ground as in walking, but the body immediately collapses on the operated side, a fall is inevitable; or this movement is repeated several times without effect, since the posterior portion of the body is immobile and fixed to the ground, and prevents progression. Nevertheless, the animal sometimes succeeds in advancing a few inches, dragging the rest of the body, which slides along on the rump of the opposite side.

At the end of a few steps, however, the fore paw of the operated side doubles up under the body and the animal falls on this side. In all these movements the fore paw of the injured side appears feebler and less mobile than that of the healthy side. At rest during abdominal decubitus it is nearly always in supination. Many more days are necessary before the animal can pass from this imperfect position to a position on its four paws; before it succeeds there are numerous attempts. The front legs always being in abduction, the posterior portion of the body is at first only half sustained, and more on the healthy side than on the operated side, where the rump is nearer the ground. As soon as a fore paw is lifted, the body falls down. Little by little, the

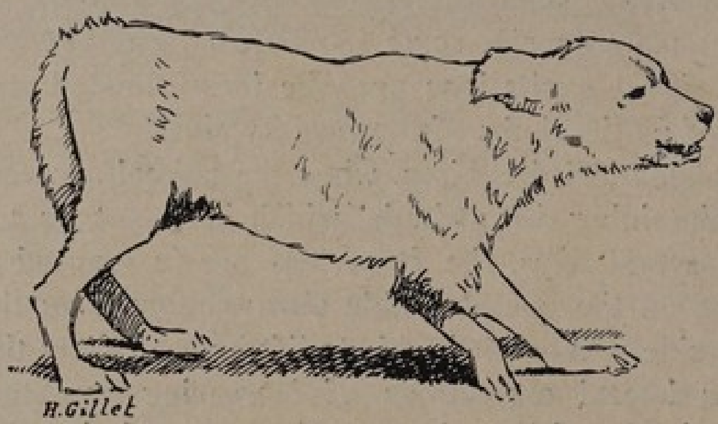


FIG. 41. The same dog at the moment of a fall, the left fore paw being put suddenly in adduction. (After a photograph.)

posterior half of the body is lifted higher above the ground, but for a long time, for several weeks even, it is upon an inferior plane to the anterior half of the body.

Fifteen days after the operation, equilibrium can be maintained on the four paws for a short time, after which the tremor and oscillations of the trunk, either antero-posterior or transverse, reappear and entail a fall. The fall is still inevitable if one paw leaves the ground. Fatigue rapidly supervenes. During the position on the four paws it is not uncommon that the front legs separate as if the paws slipped on the ground.

It is from this moment that the animal makes serious efforts to walk. The anterior paws are wider apart than in normal standing. The one of the operated side is the more in abduction, and is usually the first to be lifted. Before leaving the ground it is the seat of contractions without effect, as if the animal hesitated. Then, suddenly, it leaves the ground. At the same time the whole body follows the movement and is laterally displaced towards the same side, as if animated by an irresistible movement of translation. The animal attempts to oppose this by some movements of the vertebral column in the inverse direction, but in vain; the posterior half of the body bends towards the operated side, and the fore paw at first in abduction comes suddenly back to adduction, and the animal tumbles in a heap to this side (Fig. 41). This is why, in these first attempts, the dog seeks a wall or some other obstacle to lean the operated side against.

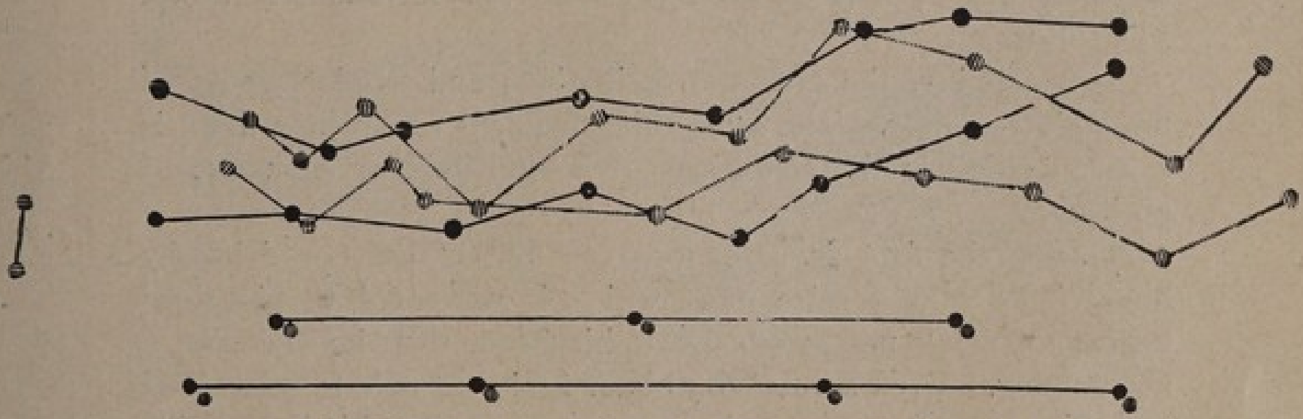


FIG. 42. Diagram of the walk of a dog deprived of the left half of the cerebellum. Fore paws in gray, hind paws in black. To the left fore paws placed in normal position. Below diagram of normal walk.

Gradually the displacements of the body become of lesser amplitude and the resistance to the movements of translation towards the operated side is prompter and more effective. The posterior half of the body raises itself higher from the ground. During the progress of walking the trunk is displaced, first to one side and then to the other (Fig. 42), each limb is lifted only after some hesitation. In the interval between the steps, wavering is constant, the gait resembles that of a drunken person, whence the name, "drunken gait."

From now on there is a marked improvement daily; wavering progressively diminishes, and the oscillations of the body and the head become slighter. On the other hand, the body no longer has the suppleness it had before the operation. It is as if it were ankylosed; the head is held stiffly, always inclined towards the side of the lesion; the paws are not lifted with the same regularity nor at the right time, and the limbs of the operated side are lifted suddenly and replaced with equal brusqueness.

After re-learning to walk, the dog learns to run again. During this reëducation, phenomena of the same type are reproduced, but of a lesser intensity. The body does not follow a straight line, but sways excessively, either to one side or to the other. The limbs of the operated side are still lifted too suddenly and too high. The total of the movements is lacking in harmony, whereas, in a normal dog running one fore paw is lifted almost at the same time as the hind paw of the other side, in the dog deprived of half of his cerebellum this simultaneity is not so perfect.

On stopping, the tremors, oscillations and displacements of the body reappear. The same thing happens every time there is a modification in the conditions of equilibrium, or a change of position.

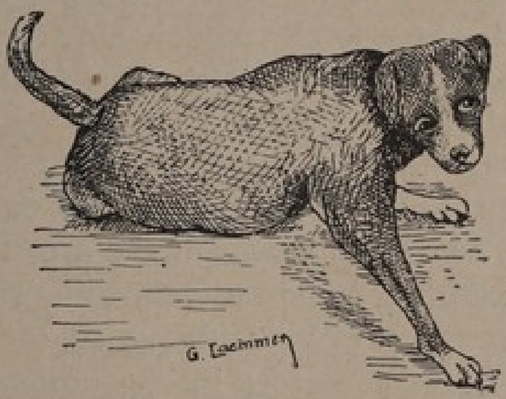
During the first days the dog can neither eat nor drink by himself, he cannot seize meat which is presented to him, and he cannot drink unless one holds his head, then he laps like a normal dog. Even several days later he is not able to seize food with his mouth; as soon as he advances or lowers his head, wide oscillations, at first localized in the head, pull it from one side to the other; they then affect the body, which is subjected to considerable displacement. The oscillations of the head increase in frequency and amplitude as the dog approaches the object, so at the moment of reaching it he is thrown far from it.

In drinking the same thing happens; the head goes further than the objective point and the muzzle instead of touching the surface of the liquid is plunged suddenly and deeply into it. The head is then suddenly thrown backwards, and this movement is followed by a movement of retreat of the whole body, which oscillates for some time in an antero-posterior direction.

These disorders of motion are augmented in progression on an inclined plane. If the dog attempts to mount a stairway, the head and the trunk are carried backwards to an exaggerated extent, and the animal falls backward. Similar defects occur in an attempt to descend; the moment the fore paw touches the step the body and the head are thrust forward and the animal falls, or the posterior half of the body is raised above the anterior half, and the dog turns a somersault. These disturbances are less pronounced if he is able to lean the operated side against a wall.

These phenomena tend to disappear with time, but slowly, more slowly even than the disturbances of progression and station.

Micturition is not accomplished in the normal way. It takes place always in the squatting position. The hind paws spread



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FIGS. 43 to 45. Attitude at different periods of reëducation of a dog which has had the right labyrinthine root and the right cerebellar hemisphere sectioned. They are the same as in a dog which has simply been deprived of the right cerebellar hemisphere but in the latter case the reëducation is more rapid.

further apart, but they always keep in contact with the ground. Attempts at micturition and defecation are accompanied by severe antero-posterior oscillations. At first a fall is inevitable.

Coitus is impossible, not because the genital instinct is abolished or diminished, but because the unstable equilibrium prevents it. Luciani even questions whether there is not an exaltation of the sexual sense. There is neither impotence nor sterility.

Swimming alone is still possible, on condition that it be not too prolonged, since fatigue rapidly supervenes. The healthy side is always immersed deeper than the operated side, the head is slightly inclined towards the healthy side, and progression is not made in a straight line but inclined a little towards the healthy side, so that the animal tends to move in a circle. When the dog comes out of the water and shakes himself, severe oscillations and displacements of the body are produced in a transverse sense; the same thing happens when the dog tries to scratch himself. Young dogs, which have never swum before having been operated on, are able to swim after the operation.

Several weeks after the operation nothing remains except a certain stiffness of the trunk, the brusque and exaggerated lifting of the limbs of the operated side, some oscillations at the arrest of movements, or in the change of attitudes, and the more prompt appearance of fatigue. In general, the movements do not appear to be so automatic and so spontaneous as before the operation. There is in them something intended, something willed. The tendon reflexes are exaggerated on the injured side.

There still exist, however, disturbances of equilibrium which can be easily demonstrated. It suffices to fix the attention of the animal and to present to him, for example, a piece of meat a little above the level of his head; as soon as he lifts his fore paws to raise himself on his hind quarters, the trunk oscillates markedly and titubation reappears in a very intense form. On the other hand, the suppression of sight control does not increase the disturbances of motility. Walking on an inclined plane still remains difficult.

During the first days which follow the operation, the dog does not bark; he recommences to bark only after he can stand up. Fatigue supervenes more rapidly than in a normal dog. His first attempts to walk exhaust him very soon; respiration becomes more rapid almost immediately, and before making a new attempt he rests for some time.

Russell has noted anesthesia and analgesia of the side of the operation during the first days which follow the operation.

II. *Destruction of the Two Lateral Lobes*

When the two lateral lobes are removed (Russell), the initial phenomena are the following: The two eyes look downward and outward, nystagmic shocks direct the eyes outward and upward; they last only three days. The dog is incapable of standing. According to Russell, a motor paralysis affects all four limbs, the posterior more than the anterior. Instability is manifested and exaggerated under the influence of excitations or attempts at voluntary movement, but the rotatory movements are lacking. The anterior extremities are rigid, stretched at a right angle to the trunk, the posterior extremities are less so; the tendon reflexes are exaggerated. There is neither deviation of the head nor deviation of the eyes. Anesthesia and analgesia of the limbs are transitory.

III. *Total Destruction of the Cerebellum*

(Fig. 46)

The initial phenomena are less striking in intensity than those seen after destruction of one hemisphere. Reëducation, however, is slower and less complete.

Total destruction of the cerebellum is not easy to effect; either one takes away too much, or one does not take away enough; in other words, it is difficult to remove the whole cerebellum and to remove nothing but the cerebellum. This is why after autopsy it is necessary to make a microscopical examination of a series of sections of the medulla and the rhombencephalon to be certain that contiguous structures have been respected.

Immediate Phenomena.—Decubitus occurs indifferently upon one side or the other. The head is in forced extension, bent backwards without lateral inclination, the trunk describes a similar incurvation (opisthotonos), the limbs are contracted in extension, particularly the anterior ones. Movements of rotation around the longitudinal axis are less frequent and less rapid than after destruction of one hemisphere, and persist for a shorter time. They are more manifest when the destruction has not been complete or perfectly symmetrical. Rotation then occurs towards the side most injured. The menagery movements are spontaneous, and are more often produced by peripheral or sensory stimuli, more particularly by auditory sensations. According to Munk such movements would be absent were the destruction total and symmetrical. When the destruction is complete and symmetrical, the rotatory movements are replaced by a hypertension of the head and of the trunk, with a tendency to draw back, and accompanied by retropulsion. The limbs are in a state of hyperextension.

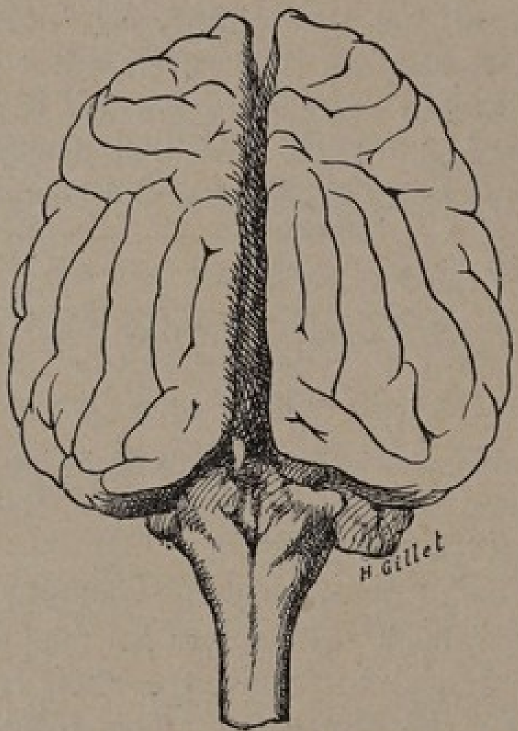


Fig. 46. Total destruction of the cerebellum in a dog. Only a small fragment of the right hemisphere remains.

The eyeballs generally show horizontal nystagmus. Strabismus is the consequence of an incomplete and asymmetrical destruction, the eyes being deviated to the side of the cerebellar hemisphere the most affected. During the first two or three days which follow the operation, there are troubles of deglutition and vomiting, which are the consequence of compression of the organs in the neighborhood. The same phenomena may be observed after a unilateral destruction of the cerebellum. Glycosuria has also been noted (Luciani).

Phase of Restoration. Later Phenomena.—After some days the dog makes efforts to lie upon the abdomen (Fig. 47). He hardly succeeds at all until after there has been considerable lessening of the contractions of the limbs, of the head, and of the trunk. Then he is able to pass from the side to the abdominal position. The first attempts generally cause an increase in or a reappearance of the contractions. The animal then falls imme-

Fig. 47. Attitude of a dog subjected to a total destruction of the cerebellum. Extreme abduction of front legs.

diately to the right or left side. Little by little, he is able to lie upon the abdomen for some seconds. The fore limbs are in a state of extreme symmetrical abduction (Fig. 48), the head and the trunk are the seat of antero-posterior or lateral oscillations;

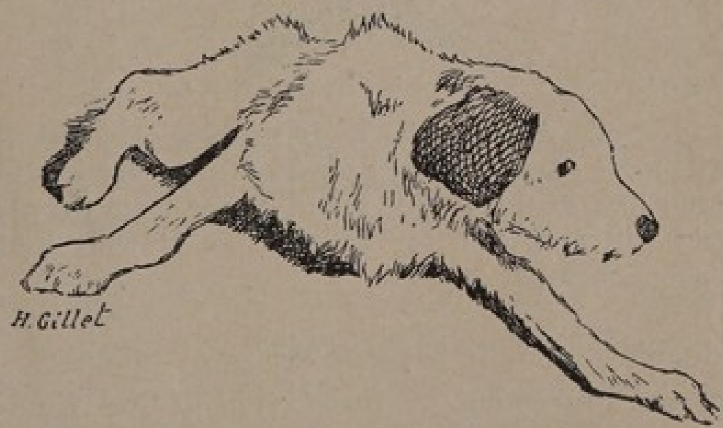


Fig. 48. Attitude of the dog during the first attempt to walk after total destruction of the cerebellum. Abduction of front legs. (After an instantaneous photograph.)

later the abduction of the fore limbs diminishes and the trunk is slightly elevated from the ground, but the instability persists and brings about a fall to one or the other side. The instability is proportionately greater as the animal makes efforts to move himself. When he is offered food a certain distance away from him, he tumbles over himself in his efforts to reach it.

After some days the hind part of the body is lifted from the ground, and the animal makes strenuous efforts to stand upon his four paws (Fig. 49). At first, as soon as the hind legs are in position, the oscillations reappear or increase in amplitude, and numerous falls occur. Nevertheless, after a certain time the dog is able to maintain a standing position for some moments, and he begins to learn to walk again (Fig. 50). From the very first the limbs, the anterior more than the posterior, are in marked abduction, each paw is lifted only after much hesitation, and leaves the

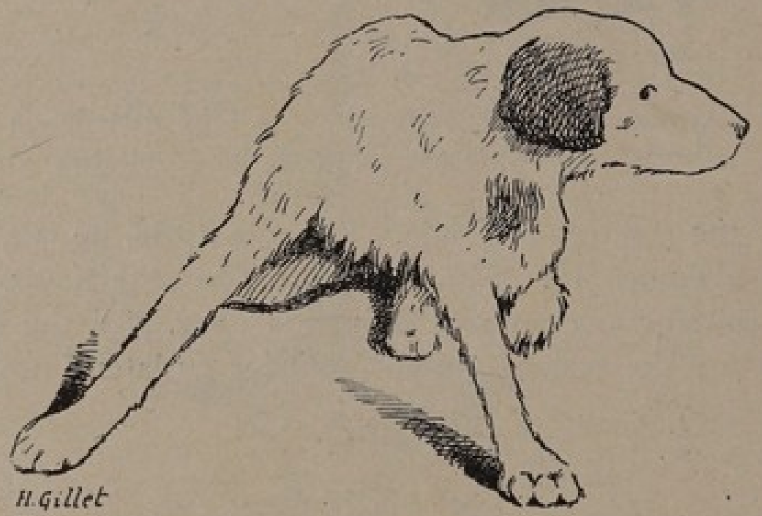


FIG. 49. Attitude during walking of the dog at a period when the amelioration is more advanced. The anterior limbs are less in abduction and the anterior half of the body is raised higher from the ground. The posterior limbs still remain in contact with the ground. (After an instantaneous photograph.)

ground suddenly and falls back in the same manner. One does not observe the movement of translation of the whole body to one side as seen after a unilateral destruction. On the other hand, an antero-lateral or antero-posterior balancing of the body is seen, when the oscillations increase in amplitude and eventuate in a fall when the paws are lifted from the ground.

Lifting of the limbs follows, but very slowly and with great irregularity. Each movement considered by itself is abnormal; The paws are raised either too suddenly or too high.

When the fore limbs are lifted and projected forward, the head is raised and carried backward, and if the movement has been forcible the animal falls backwards. In the same way when the fore paws again touch the ground and the hind paws are raised in their turn, the body is likely to be thrown forward and the muzzle bumps the ground. H. Munk (1907) described this gait as the "jumping gait." The hind half of the body being lowered, the front half with the head and the front extremities is raised suddenly, and then lowered, then the posterior half is raised with the posterior limbs in extension, immediately the two

FIG. 50. Walking and standing at a period still more advanced. The animal can sustain itself on its four paws in abduction. (After an instantaneous photograph.)

extremities make a bound forward in such a manner that they all touch the ground at the same time or nearly so. According to the same author these movements lack proportion. That is why the animal tumbles forward or falls backwards. At a more advanced period of the reëducation the muzzle, or the rump, touches the ground more or less suddenly. However, these movements do not immediately succeed one another. Between the lowering of the fore paws and the elevation of the hind quarters there is always a slight pause. In this mode of progression the head is immobile as if the neck were ankylosed and the forehead lowered to the level of the back. According to Munk, the movements of the extremities are normal during walking. From the second week, he says, the dog lifted by the skin of its back executes movements of walking with its extremities; in the same way a dog lying down, which changes its position, makes a normal movement of walking. According to Lewandowsky the gait of dogs deprived of the cerebellum would be comparable to that of a cock or a cat. Either the animal lifts his paws in the exaggerated manner of a cock, or he drags them like a cat.

With time, however, the gait becomes less irregular; the abduction of the members diminishes; the movements are produced with more rapidity and the balancing of the body is less violent. In spite of this, however, for weeks and even for months wavering, tremors, and oscillations of the body can be observed. The animal does not regain his suppleness, he walks as though ankylosed. Progression is not made in a straight line. The trunk is displaced first on one side and then on the other; the limbs are lifted either too suddenly or too high. The rhythm of walking or of running is altogether upset. Fatigue supervenes rapidly, the animal is obliged to rest frequently. According to Munk, there is no further progress after eight or ten weeks.

The disturbances observed during feeding are comparable to those which have been noted in the case of unilateral destruction of the cerebellum. There is a tremor of the head which increases in amplitude as it nears the object. The tremor is sufficiently violent to occasion lateral displacements of the body. Similar phenomena are produced when the animal drinks; when the head is lowered towards the trough it is projected suddenly downward and forward, the muzzle bumps the bottom; the animal tries to lift it out and then this movement is also too sudden; the head is thrown backwards and carries the body with it, and the animal draws back.

The troubles of equilibrium and motility are at their maximum during progress on an inclined plane, such as the ascent or descent of a flight of stairs. This is accompanied by falls and somersaults. During the ascent of the stairway, as soon as the fore paw is lifted to be put upon a step, the head is placed in hyperextension as well as the body and the animal falls backward; inversely, during a descent as soon as a fore paw is put down a step, the body frequently slides forward and the animal rolls over, or it may fall to one side. These disturbances are almost exactly the same as those noted in the case of destruction of the lateral lobe, but they are more intense and more persistent. With practice these disturbances are progressively attenuated, so that after a certain time the mounting of a stairway only causes some hesitation and some oscillations. It is however, never so rapid, and never so automatic as it is in the case of a normal dog. During micturition, defecation and coitus, the disturbances are analogous to those produced by the destruction of one hemisphere, but they are more intense and last longer.

Swimming is much less disturbed than walking. The maintenance of equilibrium in water is preserved even when uncer-ible with the preservation of equilibrium. Wersiloff observed a Fatigue supervenes, however, more rapidly than in a healthy

FIG. 51. Attitude of a dog, deprived of the cerebellum, which became blind. The animal retains any position in which he is placed. Somniform state. Left to himself he preserves without change the attitude shown in the figure.

animal. When the ability to walk and to stand have been restored, the suppression of sight control does not sensibly increase the disturbances of equilibrium. On the other hand, it cannot be denied that sight has a certain importance during the phase of restoration. For several weeks I observed a dog that had become blind a fortnight after operation, in consequence of an ophthalmia. This dog never learned to walk again; nor even to raise himself; he remained immovable lying upon the side (Fig. 51).

The character does not appear to have suffered any notable modification. The dog operated upon recognizes the person who takes care of him and who brings his food. For several weeks he does not bark, in consequence, perhaps, of the fact that barking would entail modifications of the attitude of the head incompatible with the disturbances of equilibrium. Wersiloff observed a dog who never barked after the operation. He considered it a psychic disturbance (?).

Superficial sensibilty does not appear to be affected and the same seems to be the case with deep sensibility. Luciani, however, has observed a slight retardation in the response to tactile impressions. Ducceschi and Sergi observed a certain retardation in the correction of movements. Lewandowsky insists upon the fact that animals deprived of their cerebellum place their extremities in altogether abnormal positions, and that they do not rectify the abnormal positions in which they may be placed. For instance, a dog that has been laid on a table with one paw hanging over the edge of the table, does not draw it back. The whole hind quarters may be suspended outside the limits of the table without any reaction on the part of the animal. On the other hand, when the animal tries to seize a bone, very often the paw passes over it. This phenomenon, as will be seen further on, may be explained quite otherwise than by attributing it to a disturbance of sensibility. Moreover, the delay in the correction of vicious attitudes occurs not only in the limbs of the side operated on, but also in those of the side not operated on. The correction is only a little more slow on the operated side. When the animal commences to walk it is more difficult to make the limbs take abnormal positions. (For the interpretation of these phenomena see Chapter IX.)

The sense of pain seems to me to be intact. Russell, however, noted the absence of a reaction to pain in the fore paw of the side operated on, and in the two hind paws. Lewandowsky also contends that the sensibility of the skin to pain is diminished for an appreciably long time after the destruction of the cerebellum.

IV. *Total Destruction of the Vermis*

(Fig. 52)

Immediate Phenomena.—As soon as the animal tries to raise himself upon his paws, the head is forcibly drawn back, the trunk is bent in the same direction and the front limbs are in forced extension: This produces a fall backwards. In repose the front limbs are no longer in tonic extension. The head is in slight extension. The eyes look downward and vertical nystagmic oscillations take place.

Phase of Restoration. Later Phenomena.—The following days, at rest, the animal lies upon the abdomen, the fore paws are folded backwards along the body, the hind ones directed forward and very much separated, the head is stretched out in front and rests upon the ground. From the third day station on the four paws is possible, but the body and the head are the seat of rather severe antero-posterior and transverse oscillations. The anterior and posterior limbs are widely separated, the posterior

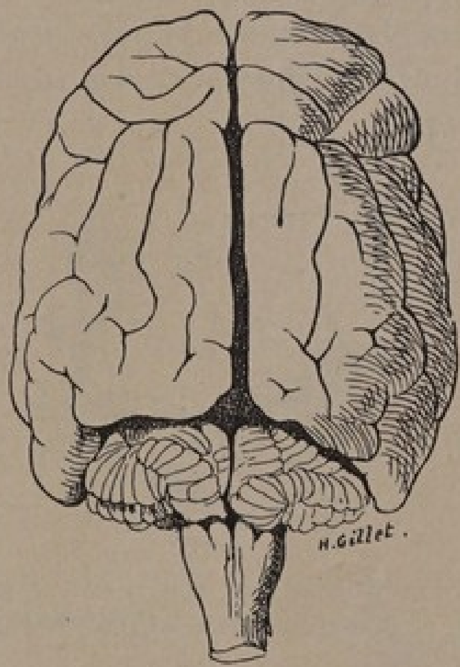


FIG. 52. Total destruction of the vermis.

always directed forward in an exaggerated fashion. During the six or seven first days progression is impossible. When one offers the animal a piece of meat and he lifts a paw to approach it he immediately draws back several steps and finally falls either backward or on the side (Fig. 52).

Five or six days after the operation the animal is able to take hold of food, but this action augments the disturbances of station, and provokes very intense antero-posterior oscillations. It is more difficult for it to drink, and at every attempt the head is drawn back brusquely entailing a backward fall.

A week after the operation the ability to progress forward commences. The fore paws are spread widely apart and the hind limbs are also in marked abduction, and held in an exaggerated manner in front of the natural position (Fig. 53). They are detached from the ground with difficulty, then suddenly lifted and replaced in as sudden a fashion. The hind quarters describe a series of zig-zag movements, being carried alternately to the right and to the left. Walking is at first slow and accompanied by antero-posterior oscillations of the trunk. The oscillations increase during the taking of food, defecation and micturition. They persist almost indefinitely but become slighter during the performance of these various acts. They disappear at the end of three or four weeks, during standing on four paws and during walking.

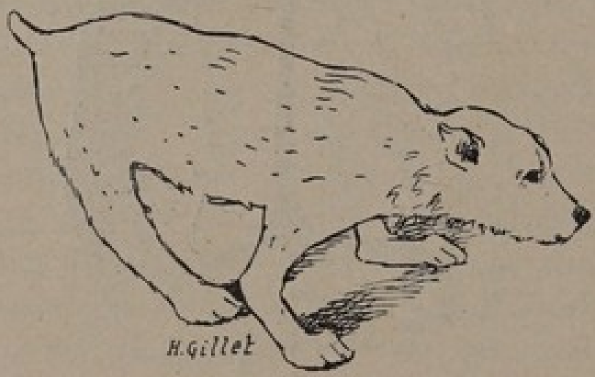


FIG. 53. Gait of a dog deprived of the vermis. Medium abduction of anterior limbs. Abduction and projection of posterior limbs.

After five or six weeks there is considerable amelioration in the act of walking. Nevertheless, abduction and forward projection of the hind paws persists. At about the same time the deviation of the eyeballs and the nystagmus have generally disappeared. Swimming is normal even in the case of puppies that have never swum before the operation. I have observed tonic hyperextension of the head and the front limbs, and drawing back in other animals; particularly in the case of a rabbit, which was not able to go forward for several weeks—it always went backwards.

V. *Partial Destruction of the Vermis*

In the cat I have been able by means of a galvano-cautery to destroy the nucleus of the tegmentum on the left side. The lesion (after a histological examination on a series of sections) had slightly affected the lateral nucleus at its internal border.

After the fourth day the animal was able to walk, but it was always drawn backwards and to the left. The head was often bent backward vigorously in opisthotonos; it raised itself on its

Fig. 54. Attitude of a dog deprived of the left cerebellar hemisphere and the vermis. Falls backwards and to the right. (After an instantaneous photograph.)

hind quarters and fell backwards. At the beginning the front limbs were in hypertension and spread wide apart. The following days it displaced itself with bounds as if animated by a veritable movement of translation at first to the left and then to the right. This movement was also combined with a motion of drawing back. The limbs were in a condition of tonic extension. The head was rigid and slightly inclined to the left. The hind paws were lifted either too high or too suddenly, and were replaced in the same manner, striking the ground. Walking on an inclined plane increased all these disturbances and provoked backward falls. Eight days after the operation the movement of translation was still present and more marked towards the right than towards the left. These phenomena persisted until the death of the animal on the twenty-sixth day after the operation. The rigidity of the limbs and of the trunk was never so marked upon any of the other animals upon which I have operated. Perhaps the method of operation had something to do with it; that is, the destruction by the galvano-cautery.

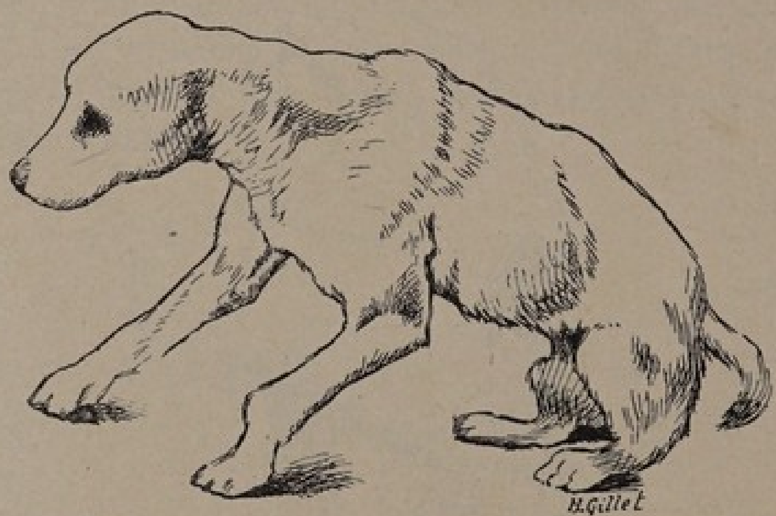


FIG. 55. Attitude of the station of the same dog. Abduction of the anterior limbs. (After an instantaneous photograph.)

When the destruction of the vermis encroaches upon one of the hemispheres, or even on both of them, the symptomatology approaches that following destruction of the hemisphere or the total destruction of the cerebellum (Figs. 54 and 55).

The destruction of the posterior half of the vermis, pyramid and declive, gives rise to the following phenomena (Russell): The immediate or transitory phenomena are downward and slightly outward deviation of the eyeballs, and vertical, rotatory or variable nystagmus. The animal walks upon a very much enlarged base. Instead of holding itself upon its hind paws it rests upon that part of the limb which extends from the ankle joint to the toes. Instability of the head increases on all movement, whether accidental or voluntary. During walking each fore paw is raised before the other one has touched the ground. The posterior limbs stay in the positions which have just been indicated. The dog thus gives an impression of a circus horse standing on his hind legs. Backward falls are very frequent. The rotation movements are lacking; the tendon reflexes are exaggerated. Rigidity of the members is slight. Sensibility is only dulled, and is completely restored after a week. When the destruction trenches upon the anterior half of the median lobe, the tendency to fall backwards is less marked. These phenomena become less marked little by little, and after several weeks it is difficult to find a clearly defined difference from the normal condition. The animal is able to stand up on his hind legs and take hold of meat.

The destruction of the lateral half of the posterior part of the median lobe (Russell) is followed by a slight incoördination and a slight rigidity in the limbs of the same side, with an exaggeration of the tendon reflexes. The eye on the side of the lesion is deviated downwards and outwards. There is nystagmus on looking towards the opposite side, and on looking upwards.

Similar results had been obtained by Ferrier. He had noted that after lesions of the posterior part of the median lobe the head was drawn backward and the animal tended to fall backwards when he attempted to walk. Inversely when the anterior portion was injured, the animal stumbled and had a tendency to fall forward.

VI. *Longitudinal Section of the Vermis*

Magendie had already practiced section of the cerebellum into two equal lateral halves. Then the animal appeared to be alternately pushed to the right and to the left without being able to preserve any fixed position. If he rolled once or twice towards one side, he turned back and rolled the same number of turns towards the opposite side.

On the other hand Ferrier had observed that the disturbances of equilibrium are of slight importance, and that there is no trace of a tendency to vacillation or to rotation. When the lesions are symmetrical, the disturbances of equilibrium are always slight.

These are the results of the latest experiments of Trendelenburg.

During the first days the spastic phenomena are lacking, as well in the limbs as in the vertebral column. When the animal attempts to raise itself the limbs are abducted and the trunk is close to the ground. The oscillations of the body which appear when the animal stands are exaggerated when it eats and drinks. At the end of fifteen days all these symptoms are considerably diminished, and they disappear at the end of three weeks. The author concludes from this that the crossed paths of the cerebellum, which were interrupted, have been compensated for in this very short time.

VII. *Localized Lesions of the Cortex of the Lateral Lobes*

My personal experiments show that the disturbances are less marked in proportion as the gray nuclei have been respected. Exclusively cortical lesions give rise to phenomena of the same order as lesions involving both the cortex and the central gray nuclei, but they are generally transitory and do not last more than ten or fifteen days. These phenomena may be lacking if the lesion is very limited. However, I make certain reservations in view of more recent experiments made by various physiologists. In my animals equilibration did not appear to be disturbed. But perhaps a more minute analysis of the motility of the members might have revealed some slight signs which escaped me (see page 294).

Destruction of the Cerebellum in the Monkey

These experiments have been made by a number of physiologists, particularly by Luciani, Ferrier and Turner, Russell, Lewandowsky and Munk. They were performed almost exclusively on the *Macacus* monkey.

The phenomena produced by total or partial destruction of the cerebellum are altogether comparable with those which have been observed in dogs and other mammals, but the more perfect skill and education of the fore limbs of the monkey, particularly the faculty of prehension possessed by the hand, permits a better study of the motor disturbances engendered by a total or partial suppression of the cerebellum, and gives a more general point of view of the functions of that organ.

In general, the immediate phenomena are less striking and the rotation momements less marked.

I. *Destruction of one Cerebellar Hemisphere*

Great instability with frequent falls follows the unilateral destruction of a lateral lobe. The vertebral column is curved presenting a concavity towards the side of the lesion. According to Russell, the cervical column is turned in such a fashion that the side of the face corresponding to that of the lesion is directed upward (?). According to Luciani, the rotation of the cervical column towards the uninjured side is associated with strabismus and nystagmus. The eye of the side operated upon is deviated downward and inward, that of the opposite side upward and outward. The animal falls very frequently and has a tendency to turn around the longitudinal axis. The movement follows the direction of torsion of the head and neck, or the strabismus, that is to say, from the side operated upon towards the healthy side (Luciani). But if one determines the direction of the movement according to the side upon which the animal falls, the movement is made towards the operated side. In seeking to fix the direction of rotation according to certain rules and to interpret from these the results obtained by the various authors, one cannot be absolutely sure that all agree that the rotation takes place in the same direction. Not having made any personal observations upon the monkey, as I have done upon the dog, I am unable to give a definite answer to this question.

During the first days the monkey lies upon his stomach, the members in abduction, with the side operated upon at a lower level (Luciani). When he wishes to displace himself he climbs in a sort of a manner, the limbs being very widely spread apart. During these various efforts the head and the trunk oscillate; the movements of the hand, especially those of the side operated upon, are very irregular and any support within reach is grasped. Instead of being in extension as in the dog, the anterior limbs are flexed.

From the first few days which follow the operation the animal is able to climb. The following days there is an amelioration of this condition; the animal walks better; the limbs of the injured side are stiffer and held further from the body than those of the other side; they are raised and replaced without coördination. Later, they are moved in a peculiar manner which Ferrier and Turner compare to a movement of creeping. The animal often describes circular movements towards the operated side; the tremors and oscillations diminish during repose, and reappear to a sufficiently marked degree during voluntary effort. Ferrier and Turner compare this tremor with the intention tremor of multiple sclerosis.

When the monkey is seated upon the ischiatic callosities, he fixes himself on the ground with two hands or with one hand only, or he may hold a piece of furniture. To avoid the oscillations of the head or of the body he will lean his head against a wall.

These phenomena become less marked by degrees. The corrections are produced more rapidly in the monkey than in the dog (Luciani). One or two months after the operation the monkey hardly differs from a normal monkey except for the slight incurvation of the vertebral column, and the incoördination of the movements of the limbs of the operated side.

The hand is less dextrous on the operated side than on the other side. The animal uses it less voluntarily (Luciani). The movements of prehension are abnormal. When he uses this hand he seizes the object either too much on one side or too near to him or too far from him (Lewandowsky). The movement is not properly measured, but there is no deviation in a determinate sense. In the same way he does not hold an object readily in his hand. Lewandowsky notes besides some disturbances in the appropriateness of the movements. For instance, when the monkey wishes to climb he seizes the bar between the third and the fourth finger. These last facts are contested by Munk. According to him the monkey only exceptionally seizes the bars of his cage in an awkward manner. The tendon reflexes are exaggerated on the side of the lesion.

Luciani contends that there is paresis of the limbs of the operated side. Russell holds that the posterior limb of the opposite side is thus affected. Ferrier and Turner and Munk do not admit that there is any diminution of muscular force.

Disturbances of sensibility, denied by Ferrier and Turner, are noted by Russell, for whom there is an anesthesia and analgesia having the some distribution as the motor paresis. According to Lewandowsky deep sensibility is also disturbed. A monkey deprived of half a cerebellum takes abnormal and vicious attitudes with the limbs of the corresponding side and does not correct positions impressed upon them.

II. *Total Destruction of the Cerebellum*

The results of the total destruction of the cerebellum in the monkey recall very closely those which have been observed in the dog.

As soon as he comes out of anesthesia, he attempts to seat himself, but does not succeed, and falls on the side. In repose he rests upon the stomach, with the posterior limbs doubled under him. When he attempts to sit up he falls always on the stomach. He is obliged to be satisfied then with moving the head and the extremities. In order to feed he attempts to crawl; if he tries to go to the right, he rolls to the right; if he tries to go to the left, he rolls to the left. If he succeeds in raising himself to a sitting position or a standing position he falls almost immeditely, either forward, backward or to the side. He can hold himself seated when he seizes a bar of the cage; he falls as soon as he lets go.

During the first few days it stays lying on its stomach, with the posterior and anterior limbs in abduction, the knees and the shoulders flexed; the abduction persists during attempts to walk. In repose the tremors disappear fairly rapidly, but reappear upon the occasion of the least effort or voluntary movement. They present the same characters as the so-called intention tremor of multiple sclerosis. For this reason the animal is not able to feed itself; from the first days it attempts to climb but in an oscillating manner. The gait is vacillating and awkward. The animal is carried either too far to the right or to the left, and the trunk is drawn to one side or the other. Hence there are frequent falls, fatigue supervenes quickly, and the necessity for repose ensues. The gait gradually amends, but it never becomes completely normal. It resembles at first the walk of a drunken man, and later it becomes slow and dragging. According to Munk, progress ceases at the end of five weeks. The animals operated upon do not execute movements as well as healthy ones, they stay wavering and awkward; they have occasional falls and move their limbs less frequently. They do not rise without some object to hold on to. They can climb.

The tremor of the arms becomes slighter but always persists.

In spite of this these monkeys are able to execute a great number of movements, eat from their hands, catch flies, etc. (Munk).

The tendon reflexes remain exaggerated. The disturbances of muscular force, admitted by Luciani, are denied by Ferrier and Turner, and Munk.

III. *Destruction of the Vermis*

The destruction of the median lobe entails disorders of a character less grave than does the total destruction of the cerebellum. After the awakening the head has a certain tendency to extension, and when the animal attempts to rise, he often falls backwards or upon one side or the other. In the first attempts to walk the limbs are in marked abduction, the stomach close to the ground and the body has a balancing movement. When they are not supported the head and the neck have an almost constant tremor. These disturbances gradually diminish. The balancing movement is less extensive, the limbs less widely stretched apart, but during walking they are lifted too high. On the other hand, they do not tremble, only the tremor of the head persists for a long time. During the first days, the backward falls are very frequent and occur spontaneously. The same phenomena are produced when the destruction involves only the posterior portion of the vermis (Ferrier and Turner), or when the vermis has been divided in the median line.

A monkey in which Ferrier had destroyed the posterior portion of the median lobe with the actual cautery was able to stay seated easily by holding to a support; if it let go it tended to fall upon the back. In the same way during walking and running it fell or tumbled backward.

Destruction of the Cerebellum in Fishes and in Reptiles

A destruction limited exactly to the cerebellum is difficult to accomplish. The cerebellum in fishes is reduced to a fold which is very thin and very narrow, and one always runs the risk of removing too much. Vulpian and Philippeaux made many experiments on fish, particularly on the carp and tench, and were not able to observe any recognizable modification of movement as long as they removed the free portion of the cerebellum only. The fish swam as well after as before the operation. On the contrary as soon as the instruments touched the cerebellar peduncles the movements became very disordered, "the fish becomes very much agitated, it swims in turning round upon itself, and moves its fins in a very incoördinate manner." According to Vulpian these symptoms are not to be imputed to the suppression, but are due to the irritation of the cerebellar peduncles.

Luys observed after operation that the movements of swimming were slow and uncertain. The body swayed from one side to the other, like a floating body without direction and reduced to a state of uncertain equilibrium.

On the other hand Steiner affirms that the ablation of the cerebellum in fish is not followed by any disturbance whatever.

To sum up, the effects of the destruction of the cerebellum in fishes, according to Vulpian, Luys and Steiner, are less noteworthy than they are in birds or in mammals. The most of these experimental researches, however, were not completed by an anatomical examination which would permit us to maintain that the lesion had not affected some of the neighboring organs.

The same remarks apply to the researches which have been made upon the cerebellum of reptiles and batrachians. We cannot accept the results except with certain reservations, since they have not been controlled by a minute anatomical examination.

After the destruction of the cerebellum, the frog moves its legs in various ways without coördination so that according to Flourens, "there is no longer any real gait." On the other hand, according to Steiner, the movements are only less precise. Vulpian and Philippeaux were not able to observe any great disturbances of locomotion.

In the adder, the undulations which constitute the mode of progression of this animal, and which are so regular and so nicely coördinated, become irregular and incoördinated. "The animal does not advance at all, and the vain efforts which exhaust it do not enable it to change its position. The lizard is not able to walk, nor to hold itself up upon its paws" (Flourens).

Destruction of the Cerebellum in Birds

The larger number of the experiments of Flourens were made upon the cerebellum of birds, and more particularly upon the cerebellum of the pigeon. He repeated them on the turkey, the magpie, the swallow, the duck, etc. The cerebellar mutilations were followed by a loss of harmony of the movements of coördination and equilibration. The symptoms are the more marked as the destruction is the more profound. Flourens suppressed the cerebellum in the pigeon in successive layers. Following the ablation of the first layers there was nothing further produced than weakness and disharmony of movement. During the destruction of the median layers the animal executed sudden objectless movements, it was only upon the destruction of the deeper layers that the animal lost the faculty of jumping, flying, walking and standing up, which had been more and more disturbed by the superficial and median mutilations. "Placed on the back the pigeon was unable to raise itself, it moved wildly and continually but never in a firm and determined manner." It was unable to hold itself in a standing position except by the aid of its tail and wings. When it walked it progressed like a drunken man going too far to one side or the other. It wavered and fell frequently.

According to Flourens these diverse coördinations are not lost simultaneously. In proportion as the animal loses its cerebellum it loses gradually the faculties of flying, then of walking, and, finally, of being able to stand upright. One can at will suppress only flight, or suppress flight and walking, or suppress all at the same time, flight, walking, and the ability to stand up. When the cerebellum is thus destroyed by successive sections, each of these faculties is progressively altered before being completely lost.

"The animal commences by not being able to stay for a long time upright upon its legs, it staggers almost every instant. Then its feet are not sufficient to preserve station and it is obliged to have recourse to its wings and its tail; finally, any fixed or stable condition becomes impossible."

It is the same in the case of the gait, which is from the very beginning staggering as in drunkenness. When the mutilations are deeper the animal is unable to walk except with the help of its wings, and finally it is unable to walk at all. Partial resections of the organs do not determine any except temporary disturbances. In a young cock from which Flourens had taken the whole superior half of the cerebellum, wavering diminished from the fourth day after the operation, fifteen days later equilibrium was totally reëstablished. It was the same thing in the case of a pigeon which had only been deprived of half of the cerebellum. On the other hand, a chicken from which the whole cerebellum had been removed, had not recovered its equilibrium four months after the operation.

Longitudinal or transverse sections of the organ do not disturb the functions of coördination and equilibrium except for a few days.

Superficial punctures on one side of the cerebellum were followed by a rather marked weakness of the opposite side, and the destruction of a lateral half, was followed by a very marked weakness of the opposite side of the body.

The destruction of the cerebellum of other birds gave analogous results. The coördinations related to swimming were equally disturbed, a duck placed in the water made movements of swimming with its feet but in an incoherent and ineffectual manner.

These results have been controlled by various authors. The symptoms differ a little according to whether the destruction is total or partial. In the last case the birds describe circular movements towards the same side or towards the side opposed to the lesion (Wagner). At the end of several days these phenomena become considerably less marked, and one is hardly able to observe anything more than the tendency of the limbs to be put in extension and the torsion of the head and neck and the peculiar tremor which Wagner compares with the tremor of paralysis agitans. This tremor becomes exaggerated if one takes hold of the animal or if one feeds it. Besides, all of the movements appear to be feebler than in a normal bird (Dalton).

I intentionally insist very little upon the disturbances determined by the destruction of the cerebellum in the inferior vertebrates. Most of the researches in this direction were made at a time when the essential elements of the experiment were lacking. That is to say, the anatomical control, and the analysis of the symptoms was rather rudimentary. Besides, in animals where the movements of the limbs are only slightly differentiated, it is more difficult to study the nature and the mechanism of the anomalies of motility. It would, however, be interesting to take up these experiments again taking into account all of these considerations.

CHAPTER III

EXPERIMENTATION (*continued*)

Stimulation of the Cerebellum

Stimulation of the cerebellum is far from giving such constant results as experimental destructions in animals, or lesions of the cerebellum in man.

Whereas, certain physiologists indicate precise reactions in relation to the stimulation of this or that cerebellar part others doubt even the excitability of the cerebellum. Some deny this property to the cortex, but accord it to the central nuclei.

Since it is impossible to give a definite solution to this problem it seems best simply to recount the results obtained up to now by the different forms of stimuli (mechanical, chemical, and electrical). This last is about the only one employed by contemporary physiologists. Renzi tried to stimulate the cerebellum of birds by means of a pin, but without results. The first serious attempts of this description were made by Weir Mitchell. He excited the cerebellum by applying or injecting caustics (injections of mercury, applications of perchloride of iron, or tincture of cantharides, and refrigeration by an ether spray). The immediate phenomena, incoördination, drawing back and backward falls are of short duration. The more enduring phenomena are characterized by a rather marked weakness of all movement, whether voluntary or involuntary.

Nothnagel, stimulating the cortex by a red hot needle, provoked muscular contractions at first localized on the same side as the excitation, and then generalized. The disturbances are always more grave and persistent when the stimulation affects the median third of the vermis. Similar results have been obtained by Baginsky.

In all these experiments the interpretation of the results is a very delicate matter. A part of them are attributable to irritation of the organ and another part to destruction. In the phenomena observed by Bouillaud, in 1827, in the course of his attempts to destroy the cerebellum by actual cautery, the author himself distinguishes disturbances due to the destruction of the organ and those which are the results of irritation. The first consist in faults of coördination, of gait and of station. The irritation determines leaps, tumbles, pirouettes, and an agitation analogous to epilepsy. For these methods (cauterization, and physical or chemical stimulation), Ferrier in 1878 substituted electricity and employed it in a systematic fashion on many types of animals.

Electric stimulation is applied in the same way as in the experiments made upon the cerebral cortex, but the cerebellum is less easy to reach than the cerebrum. The excitability of the cerebellum is subject to great variation, and it is necessary sometimes to wait for a certain time before the phenomena manifest themselves, and only upon a relatively small number of animals was Ferrier able to obtain any satisfactory results. They deserve, however, to be recorded.

Electrical Stimulation of the Cerebellum of Monkeys

I. *Pyramid of the Median Lobe.*—Both eyes turn to the left or the right in a horizontal plane, according to whether the electrodes are applied to the left or to the right. At the same time forward or backward movements of the head are produced.

II. *Superior Vermiform Process (Posterior Extremity).*—Both eyes look directly downwards when the electrodes are applied exactly in the middle of the prominence. This looking down of the eyes is generally associated with a forward or downward movement of the head. On the left side both eyes look down and to the left, on the right side both eyes look down and to the left, on the right side both eyes look down and to the right.

III. *Superior Vermiform Process (Anterior Extremity).*—In the median line, both eyes look directly upwards. At the same time the head is drawn backwards. One notes also a tendency to separation of the legs and some spasmodic movements of the arms. These movements of the head and limbs, according to Ferrier, are not due to the transmission of the current to the corpora quadrigemina. In all his experiments, barking and whining, which are indices of an irritation of the posterior corpora quadrigemina, are lacking. When the stimulation is carried to the left, the eyes look diagonally upwards and to the left.

There is a movement of the head upward, backward and to the left. With the stimulation to the right, the eyes look diagonally upwards and to the right, and there is a movement of the head, upward, backward and to the right.

IV. *Lateral Lobe* (*Semilunar Lobule*).—On the left side the eyes look upward and turn to the left, on the right side, the eyes look upward and turn to the right.

V. *Flocculus*.—The eyes turn around their antero-posterior axes.

Whatever the region stimulated, the movements of the limbs are always produced on the side stimulated. They are sudden, spasmodic, and difficult to describe. The pupils contract—more so on the excited side. Nystagmus is often produced at the beginning of the stimulation.

Electric Stimulation of the Cerebellum in Dogs and Cats

Electric stimulation of the cerebellum of the cat and dog is difficult and the field of experiment is limited. The proximity of large venous sinuses only allows a very incomplete view of the organ.

Pyramid.—To the left, the eyes look to the left. To the right, the eyes look to the right.

Posterior Extremity of the Superior Vermiform Process or Declive.—In the middle, the eyes look downward; to the left, the eyes look downward and to the left; on the right, the eyes look downward and to the right.

Lateral Lobe (*Right Postero-Superior Lobule*).—Both eyes look upward and to the right. Both eyes look upward and to the left. In the dog there is at the same time a rotation around their axes.

Right Flocculus.—Rotation of the ocular globes around their antero-posterior axes, first to the right and then to the left. Contraction of the pupils has been observed. Nothing can be affirmed as to the movements of the head or of the limbs.

Electrical Stimulation of the Cerebellum of Rabbits

Median Lobe.—In the superior part the two eyes look to the right, on a horizontal plane. Median and inferior part, the two eyes look to the left on a horizontal plane.

Lateral Lobe, Left Side.—Superior lobule, rotation upward and inward of the left eye; rotation downward and outward of the right eye. Median lobule, rotation upward and outward of the left eye; rotation downward and inward of the right eye. Inferior lobule. The two eyes turn to the right on their antero-posterior axes.

In general, there is produced simultaneously a bulging outward of the eyeballs, movement of the limbs of the same side, dilatation of the nostrils, and movements of the ears.

Electrical Stimulation of the Cerebellum of Pigeons

There is produced no movement of the eyes. The head is drawn backwards and to the stimulated side. The homolateral wing flaps and the corresponding leg is retracted.

Electrical Stimulation of the Cerebellum of Fishes

Irritation in the median line produces a bulging of the eyeballs and upward incurvation of the tail, and a stretching out of the fins. Irritation on the right makes the right eye bulge, the tail is bent to the right, and the fins stretched out. The same phenomena are produced when the stimulation is reversed, but the orientation of the movements is made to the left, and the left eye bulges.

Ferrier has compared the effects of electrical stimulation of the cerebellum in animals to the phenomena observed in man, when a galvanic current is passed through the cranium at the level of the cerebellar region. These phenomena consist of vertigo—called galvanic vertigo. When the current is passed from the right to the left, the positive electrode or anode, being applied in the right mastoid fossa, and the negative electrode or cathode in the left mastoid fossa, the subject experiences an illusion that the objects which it sees are animated by a movement comparable to that of a wheel parallel to the face, which turns from right to left (Purkinje). If the eyes are closed, the subject feels that he himself is turning, he feels himself drawn from right to left. At the same time, the head and the body lean towards the anode, and the eyeballs move in the same direction, and are the seat of nystagmic shocks.

The objective phenomena of galvanic vertigo recall the movements of the eyes, the head, and the limbs of animals whose cerebella were stimulated by Ferrier. Galvanic vertigo, however, is not a consequence of the stimulation of the cerebellum. It is absent in animals deprived of the labyrinth, or simply of the semicircular canals, and in individuals affected with lesions of the internal ear, or of the vestibular nerve. Many deaf mutes do not experience any sensation of vertigo, and do not execute any movements of the head, body, or eyes, during the passage of the current. Galvanic vertigo is due to an irritation of the vestibular apparatus.

The results obtained by physiologists who have followed Ferrier in this direction are less convincing. Employing currents of minimum intensity, Mendelssohn was not able to reproduce the reactions observed by Ferrier. He was only able to produce by an irritation of the cerebellum, limited to the lateral lobe, a deviation of the eyes towards the irritated side, contrary to that which is seen following an irritation of the cerebral cortex; the eyeballs often presented oscillatory movements. Dupuy also obtained reactions localized in the eyes, and most of the muscular groups by exciting different points of the cerebellum.

Wersiloff compares the effects of electrical, mechanical and chemical excitation of the cerebellum with those obtained by excitation of the cerebrum. Each half of the cerebellum is related to the corresponding half of the trunk; the vermis acts in the same way towards the two halves of the body. The superior vermis reacts upon the inferior limbs; the inferior and posterior vermis upon the superior limbs. Its action is not limited to this. The skin muscles and the conjugate movements of the eyes are also dependent upon it. Excitation of the cerebellum produces nystagmic movements, horizontal, vertical and rotary, as well as the protrusion or the retraction of the eyeball, and winking of the eyelids.

Pruss, whose experiments were made upon the dog, admits the existence of motor centers in the cerebellar cortex. Each hemisphere contains centers for muscles of the same side. Excitation of the vermis in the median line produces bilateral shocks.

The results of his experiments are as follows: *Pyramid:* Deviation of the eye and the head to the same side and downward, homolateral dilatation of the pupil, elevation of the shoulder, flexion of the elbow, and an extension of the fingers. *Tuber of the vermis:* Homolateral rotation of the head to the side and downward, exophthalmis, mydriasis, contraction of the muscles of the back of the neck, of the back, and of the extensors of the homolateral anterior extremity. *Declive:* Contractions of the muscles of the back, particularly of the lumbar region, and of the extensors of the posterior extremity. *Culmen:* Contraction of the extensors of the posterior extremity. *Anterior segment of the monticulus:* Movement of the tail. *Uvula:* A motor influence on the anterior extremity, the ear, and the extensor muscles of the back. *Inferior semilunar lobe:* The eyes look downward, and there is an occlusion of the eye and movements of the shoulders. *Superior semilunar lobe:* Contractions in the extensors of the fore paw. *Quadrilateral lobe:* Contractions of the muscles of the hind paw.

The cortex is not excitable except by currents passing perpendicular or longitudinal to it. The longitudinal currents produce tonic contractions. The perpendicular currents produce clonic contractions. Negro and Roasenda employed bipolar and unipolar faradic currents. In the rabbit bipolar excitation of the crus primum produced muscular contractions of the face, and of the fore paw of the same side, when the intensity of the current did not exceed the limit of excitability of the region being explored. With stronger stimulation the muscles of the opposite side contracted at the same time.

With unipolar currents they were able to localize more precisely. The centers of the face and the fore paw are situated in the antero-lateral lobe, within and towards the anterior lobe and the lobule simplex. The center for the face is situated in front of that of the fore paw. It was sometimes necessary to prolong the current or to repeat the excitations in order to obtain a contraction. The same authors have made experiments which would tend to show that in order to arrive at the spinal cord and the muscles, the faradic excitations of the cerebellar motor centers are not obliged to traverse the cortical motor zone, either of one side or the other, nor the subcortical cerebral motor zone. These centers have an individuality of their own independent of the Rolandic area. The centrifugal motor influx would appear to go through the middle cerebellar peduncles.

According to the results of the experiments of Lourié, made upon the dog and the cat, one is not able to show the existence of limited or special centers. When the excitation is limited to a very small area of the cerebellum, contractions are produced in almost all of the muscles of the same side of the body. Excitation of the semilunar gyrus produced adduction and elevation of the shoulder, concavity of the vertebral column towards the opposite side, an inclination of the anterior limb towards the right side if the excitation is on the left, and inversely. The posterior limb is thrust forward, and there are also movements of the tail, which is displaced towards the opposite side. With a more prolonged current and the excitation on the left, the right anterior limb is placed in extension, and turned to the right, the left anterior limb is placed in adduction and raised. Excitation of the vermis is followed by an extension of the anterior limb and an inclination towards the excited side. The vertebral column is curved and the concavity is turned in the same direction. Lourié was not able to verify the conclusions of Ferrier as to the movements of the eyes.

These contradictory results are probably explicable by the enormous intensity of the currents employed by these various physiologists. Under these conditions the phenomena observed are not in reality due to the excitation of the cerebellar cortex, but to the irritation of the subjacent nuclei, and diffusion through neighboring tracts.

This is the opinion held by Horsley. For him the cerebellar cortex is not excitable, and, consequently, cannot be considered as a motor center. When in the course of experiments with electric currents, the electrode is made to penetrate more and more deeply into the white substance, that is, when it approaches the central gray nuclei, and the para-cerebellar nuclei, Deiters' and Bechterew's, for example, the excitation becomes greater and greater with a current less and less strong. These nuclei are the true efferent, or motor, centers of the cerebellum. The cortex being considered by Horsley as a receptive center, analogous to the visual center of the cerebral cortex. Movements of the eyes, of the head, the trunk and the limbs are represented in these nuclei. The contraction produced by their excitation is tonic or hypertonic. Oscillations of the eyeballs are also produced, the contractile force augmenting with the excitation, but without clonicity when the excitation ceases. The application of the excitation unilaterally is followed by a homolateral effect, contrary to that which takes place in the case of the cerebrum.

The excitation of the superior part of the dentate nucleus deviates the eyes and the head to the same side. That of the dorsal regions of the dentate nucleus produces a bicipital flexion of the homolateral elbow. Whereas, the excitation of the basal region of the dentate nucleus, with a maximum stimulus, produces (in addition to the lateral deviation of the head and the eyes), a homolateral flexion of the elbow, a deeper excitation of the para-cerebellar nuclear region produces a contra-lateral extension of the elbow, a hyperextension of the neck and trunk and a forcible extension of the inferior limbs. So that, while the anterior limb is flexed at the elbow, the posterior is extended along the body.

The study of the excitation of the cerebellum by chemical irritants has been resumed by Pagano. This author injects curare into the various regions (one to three tenths of a cubic centimeter of a one per cent. solution). There seem to be distinct regions where the excitation produces isolated movements, either of the anterior limb or of the posterior. The stimulation of a certain point in the lateral lobe in the neighborhood of the vermis provokes a movement of retraction and adduction of the anterior limb of the same side, sometimes a flexion and adduction, more rarely of extension. This movement is maintained. The attitude which is determined by it may last for several minutes, and be reproduced during several hours. The extirpation of the respective cerebral center does not prevent its being produced. The excitation of another point very near the first produces tonic flexion, sometimes extension, of the posterior limb. The results are less constant for the anterior limb. In all these experiments the excitation is transmitted, sometimes, to the opposite side.

The excitation of a third point in the anterior and superior region of the vermis, provokes a tendency to fall backwards, which resembles a motor impulse. The excitation of the posterior part of the vermis provokes, on the contrary, a tendency to fall forwards, with the head striking the ground.

The excitation of the anterior extremity of the vermis, monticulus, central lobe, and lingula, gives rise to a psychic agitation. Howlings, barkings, anxiety, terror and relaxation of the sphincters, all of which are accented under the influence of peripheral excitation, particularly auditory ones; the whole of which constitutes for Pagano a sort of psychic strychninism. At its maximum intensity it ends in generalized epileptiform convulsions. This is not due to a diffusion of the stimulation to the neighboring organs. The stimulation of the quadrigeminal bodies engenders phenomena which we must interpret as an expression of sentiments, or of emotions (Ferrier).

In order to be followed by results the injection must be made below the surface. A sub-dural injection is either without effect or gives different results. It is unfortunate that Pagano did not complete his experiments by a series of sections which would have permitted a topography of the lesions; lacking this we cannot accept these results except with a certain reserve.

By polar faradic excitation of the quadrilateral lobe (lateral part of the lobule simplex of Bolk), in the dog, Rothmann, 1910, obtained movements of the toes of the anterior extremity of the same side, movements of flexion by exciting the inferior part, and movements of extension by exciting the superior part. With stronger currents, the limbs were elevated. The excitation of the anterior lobe provoked movements of spreading apart and drawing back of the two anterior limbs.

Excitations of the cerebellum do not seem to always have the effect of augmenting the tonus of certain muscular groups. They may have the reverse effect. According to Sherrington, faradization of the anterior surface of the cerebellum produces a relaxation of the muscles of the neck, head and inferior limbs, principally on the side excited, in animals previously in a state of contraction due to decerebration.

CHAPTER IV

EXPERIMENTATION (*continued*)

Effects of Section of the Cerebellar Tracts

Section of the Spino-cerebellar Tracts (Direct Cerebellar Tract of Flechsig and Tract of Gowers).—The effects of the section of the spino-cerebellar tracts (direct cerebellar tract of Flechsig and tract of Gowers) have been minutely studied by Russell, by Marburg, and lastly, by Bing, in a work devoted specially to this subject. The results obtained by Bing are as follows:

Unilateral Section.—In the upright station the limbs of the operated side are in abduction. The posterior limb more than the anterior. If the limbs are placed in their normal position the animal is unable to hold himself upright, and he immediately replaces them in the former position. The two extremities are in extension. The animal places very little weight upon the limbs of the operated side, resting almost entirely on those of the other side.

Neither oscillation nor wavering is observed, the trunk is slightly turned towards the operated side, but without scoliosis. If the paws of the operated side are placed on their dorsal surface the animal nearly always corrects this vicious attitude, but more slowly than a healthy animal does. There is nothing abnormal in the positions of sitting or lying down.

During walking the abduction of the limbs is still more marked. From time to time a stronger movement of adduction is produced which has for consequence a crossing of the paw over the limb of the healthy side. Before lifting the posterior limb from the ground there is a period of hesitation, and then it is carried further forward than that of the healthy side. Replacing it upon the ground, the action is brusque and sudden.

The gait is slow and cautious, like a normal animal which is forced to walk upon a narrow plank, but the general direction is well preserved and there is no lateral deviation. When the animal directs himself forward he has a tendency to describe a circular movement towards the healthy side. If he is compelled to go back, he turns to that side. He is more awkward when he is obliged to displace himself towards the injured side as when a piece of meat is offered to him on this side.

These disorders of locomotion described under the name of hemiataxia by Bing are exaggerated in various circumstances, such as the occlusion of the eyes, the acceleration of the gait, and the descent or ascent of a stairway.

The muscles of the pelvis and of the thighs are in no way paralyzed. There is a hypotonus of the operated side, particularly of the posterior limbs. When the body of the animal is suspended vertically, the limbs of the injured side give the impression of being weaker, and hanging down further. Their resistance to passive movements is feebler. The difference between the two sides is more striking in the muscles of the pelvis and the scapular girdle; it is hardly appreciable in the carpal and tarsal muscles. The reflexes are normal.

Improvement is rapid. At the end of four days the abduction of the limbs is very much less, as well in walking as in standing. Hypotonus is less marked. Four weeks after the operation the difficulty of turning toward the operated side is the only phenomenon that persists.

The ventral bundle (Gowers) and the dorsal bundle (direct cerebellar) seem to have the same functions. When the ventral bundle is spared, the disturbances are only less intense, and of shorter duration.

Bilateral Section.—The posterior limbs are in very marked abduction. The pelvis is lowered and the paws are directed forwards. The attitude of the anterior limbs is variable. Either they are spread apart, although to a lesser degree than the posterior ones, or, they are held very close together so that the paws touch one another. The head is lowered. The animal has an anxious, uneasy expression. There are neither transverse nor longitudinal oscillations. They do not occur unless the paw is lifted; as soon as it is replaced upon the ground, the animal resumes his steadiness. In lying down the attitude is normal; in the seated position the hind paws are directed outward.

During walking the posterior limbs are in abduction. If the gait is accelerated, the posterior paws cross one another. The same thing happens to the fore paws, but to a lesser degree. The body is projected alternately to the right and to the left, as well for the anterior half as for the posterior half. The posterior limbs are carried very far forward, and the anterior limbs are thrown forward, as it were, the paws striking the ground instead of being replaced in a natural manner.

This awkwardness is increased during the occlusion of the eyes, and the ascension of a stairway, and when the animal goes backwards. The ability to jump is preserved. Tonus is diminished. Improvement occurs rather rapidly. Four weeks after the operation, it is only during running, and in gyratory movements that the animal experiences any difficulty. In the standing position a slight abduction of the posterior limbs and adduction of the anterior persists.

Bing concludes from his experiments that the phenomena in dogs after section of the spino-cerebellar bundles, or after the destruction of their terminations in the cerebellum, are the index of a double primordial alteration which has effect upon the musculature of the extremities. It is a special disturbance of muscular regulation and a diminution of tonus.

All these anomalies of station and locomotion are the expression of disturbance in the attitudes and movements which are seated at the roots of the limbs; that is to say, in the muscles of the pelvis and the scapular girdle.

To sum up, it is a question of a disturbance of the main movements of the extremities, principally the combined and associated movements. It would not be proper, however, to speak of any disturbances of equilibrium, as neither oscillations nor waverings are produced.

Section of the Inferior Cerebellar Peduncle.—This experiment, when the section is made very high, is difficult to accomplish. It is, however, absolutely necessary that the nuclei of the root of the eighth pair be respected.

Magendie noted movements of rotation after section of one of the peduncles, and he remarked that the rotation was always made from the side where the peduncle was cut; sometimes with such rapidity that the animal made more than sixty revolutions in a minute. He obtained also similar results by vertical sections of the cerebellum, but, "with this remarkable circumstance, that the movement was all the more rapid as the section approached nearer the origin of the peduncles." In the same way, after the section of the medulla oblongata, he observed a circular movement to the left or the right, like that of a circus horse according as the section was directed to the right or the left.

The symptoms described by Ferrier and Turner, and later by Russell, in the monkey are as follows:

After the operation the animal takes the following attitude: The neck and the trunk present a scoliosis, with the concavity turned towards the side of the lesion, the head is scarcely or not at all twisted on the longitudinal axis; when it is twisted the occiput is turned towards the side of the lesion and the chin towards the shoulder of the healthy side (Ferrier and Turner). The curvature of the vertebral column is increased when the animal is excited, or when an attempt is made to make him stand upright. When he lies it is upon the side of the injury and he returns always to this position if an attempt is made to place him in another. He executes rolling movements from the healthy side, towards the side operated upon, during the first twenty-four hours.

The motor disturbances consist in an impossibility to stand upright and in abnormal attitudes of the limbs. When the left peduncle has been divided the members of the right side are in extension, and those of the left side more or less flexed. These attitudes are dependent partly upon the rigidity and partly upon an alteration of the muscular sense, or of the notion of position. Perhaps also to a certain degree of motor paresis. Placed flat upon the ground, the limbs are in abduction; in this position the animal is capable of displacing himself by crawling. Later, about a week, when the first phenomena are somewhat amended, the animal walks and runs like an ataxic. The movements are incoordinate, especially in the limbs of the left side (the posterior paw of the side operated upon is the last to recover). It falls often on the left side, particularly when it is excited, and it cannot remain seated except by spreading the legs wide apart and holding on to some neighboring object. The eyes are directed downward and to the side opposite the one operated upon. The displacement outward of the eye of the healthy side is more marked than the displacement inward of the eye of the side operated upon (Russell).

This eye regains its normal position before the other one. After the disappearance of the ocular deviation, the animals are still incapable of directing their vision towards the injured side. Spontaneous nystagmus is rare. It appears only when the animal does not feel itself secure. The reflexes are exaggerated on both sides, more on the injured side (Russell).

During the first week sensibility to pain (superficial and deep) seems to be abolished in all four limbs. Deep sensation seems to return first. From this point of view, the anterior paw of the healthy side is the first to be cured and the posterior paw of the side operated upon the last (Russell). According to Ferrier and Turner, however, there are no disturbances of sensation.

The cerebral hemisphere of the side opposite the lesion is less excitable than the other. After an intravenous injection of absinth there are no convulsions in the anterior limb of the side of the lesion. The other three limbs contract. Three weeks after the section of the inferior cerebellar peduncle the convulsions in the two anterior limbs have different characters; on the side of the lesion the convulsions are more of the tonic type, on the opposite side they are clonic (Russell).

After hemisection of the cerebellar bundles at the superior termination of the spinal cord, intravenous injections of absinth give the same results as they do after section of the restiform body.

The animal reëducates itself gradually. At the end of three weeks it is able to maintain a more stable equilibrium; it only falls occasionally when it is excited, or when it is bumped into. In a *Macacus* monkey, which lived only two months, the equilibrium was unstable to the end and the movements of the limbs of the side operated upon were always more irregular than on the other side. The results consecutive to section of the inferior cerebellar peduncle may thus be summed up. Disturbances of equilibrium in standing and walking, falls and movements of rotation around the longitudinal axis towards the side of the lesion, incoördinate movements of the limbs on the same side, incurvation of the vertebral column with the concavity turned towards the injured side. In one word, there is an orientation and predominance of the symptoms towards the side of the lesion.

Section of the Middle Cerebellar Peduncle.—This experiment gave very contradictory results to the first physiologists who undertook it. Following Pourfour du Petit, who was the first to describe it, all are unanimous in observing the movements of rotation around the longitudinal axis, but the controversy begins with the direction of the rolling, whereas, for Magendie the rotation is made from the injured side; Longet describes it in the inverse sense. Schiff states that the rotation can be made in both directions; everything depends on the level of the section. The reason for these divergencies will be more fully discussed in the chapter "Interpretation." Ferrier and Turner have made experiments which were followed by anatomical verifications, the results of which are more convincing.

These authors performed transverse section of the median cerebellar peduncle of the monkey, directly outside the plane of penetration of the fifth pair. After the operation (the left peduncle was cut), the vertebral column was curved to the left, and the monkey rolled around the longitudinal axis to the left. The occiput was turned backwards and to the left, and the chin turned towards the right shoulder. The limbs of the right side were abducted and in extension. The left limbs were flexed and in adduction. Decubitus was on the left side.

The following days the animal lay on its stomach, the body inclined to the left; to move the body was slowly drawn forward. The movements of rotation diminished progressively, only the falling and the inclination of the body to the left side persisted. Ferrier and Turner, however, note falls and movements of rotation to the right side. (This last phenomenon appears to be the exception.) Whereas, standing up and walking were impossible, or very defective, the animal was still able to climb.

For several days equilibrium was very unstable. The trunk oscillated in standing and during walking. In order to maintain the sitting position the monkey was obliged to hold on to some neighboring object.

The limbs of the left side were animated by irregular movements and oscillations, but there was no fine tremor. (In this case the superior cerebellar peduncle of the left side had been slightly injured.)

Equilibrium was progressively and slowly reëstablished. In spite of that a slight instability and a tendency to fall upon the left side always persisted. The tendon reflexes of both sides were equal; there was a very slight nystagmus.

To summarize: The rotation around the axis was made from the healthy towards the injured side, as Magendie had already noted, provided that one determines the direction of the rotation by the side upon which the animal falls, after having been placed in a standing position upon the four paws.

Magendie not only observed that all lateral sections of the pons produced a movement of rotation, but that this movement was arrested by a section of the opposite side. "Cut a peduncle," said Magendie, "and immediately the animal commences to roll, then cut the one of the opposite side, and at once the movements cease, and the animal loses the power to stand up and to walk."

Section of the Superior Cerebellar Peduncle.—This section has also been performed on the *Macacus* monkey under good conditions and with anatomical control by Ferrier and Turner. Immediately after the operation the animal cannot maintain its equilibrium, it remains lying upon its stomach, the limbs of the operated side flexed and in adduction, and those of the opposite side extended and in abduction. This attitude, however, may not be constant, all four limbs may be in abduction; all attempts to stand up and to move are followed by falls on the operated side and a tendency to roll in that direction. In its cage the monkey grips the bars with the limbs of the healthy side, in order to avoid a fall on the side of the injury. It is, however, still capable of climbing vigorously by using its four limbs. Nystagmus is inconstant; when it is present it is more marked in the eye of the injured side, and when looking in that direction. Gradually the animal becomes more stable, preserving, however, the same tendency to fall towards the side of the lesion; it wavers and balances its body. During the first days it is not able to maintain the position of sitting up, at any rate, not unless it is assisted.

From the beginning the limbs of the operated side tremble as a result of effort and of volitional movement. The tremor is comparable to that of multiple sclerosis. The animal takes food more readily with the hand of the side which is uninjured.

Fifteen days later the disturbances of equilibrium have almost entirely disappeared. The animal does not fall unless it turns around or executes movements too suddenly; it can sit up without holding on to anything.

A *Macacus* which Ferrier kept for forty days after the operation did not fall towards the end, unless it were jostled; the tremor of the superior and inferior limbs persisted to the end, as did the nystagmus.

Summarizing, the troubles following section of the superior cerebellar peduncle are as follows: Uncertainty of equilibrium, falls, and a tendency to roll on the side operated, intention tremor of the same side and a permanent nystagmus. The tendon reflexes are equal on both sides.

CHAPTER V

SYMPTOMATOLOGY OF THE AFFECTIONS OF THE CEREBELLUM

In man the symptomatology of the affections of the cerebellum corresponds to the phenomena noted after experimental destructions in animals. However, all the clinical observations cannot be used in this way for a physiological demonstration. Only those should be retained which by the precise determination of the nature and of the localization of the lesion, have the value of a true experiment. Consequently, we must eliminate all those complex cases wherein the lesion, although not exceeding the limits of the cerebellum, is nevertheless susceptible by its nature of compromising the functions of neighboring centers. This is the case in a large number of abscesses and tumors of the cerebellum, without taking account of the fact that in these cases the cerebellar symptoms may raise some difficulty of interpretation, and may be looked upon as phenomena of excitation or as phenomena of defect.

It is preferable to consider separately the observations in which the cerebellar lesions have commenced suddenly (hemorrhages, softening) and those in which the lesions have had a slow and progressive evolution. Only the first class can be rigorously compared to destructions performed upon animals. In both cases there is a sudden suppression of the organ and of its functions.

Finally, one must establish clinical differences as to whether the lesion is cortical or central, or both.

I. Hemorrhage or Softening

The symptomatology of hemorrhagic foci, or foci of softening of the cerebellum, is very slightly known for two reasons. The anatomical examinations are generally incomplete, and it is impossible to affirm that the symptoms are exclusively localized in the cerebellum. Many observations have been published simply as findings at the autopsy, that is to say, as having given rise to no symptoms during life. One may note, a propos of this subject, that it is more often than not impossible to fix the date of the commencement of the softening, and that, perhaps, several months or even several years have elapsed since the commencement of the lesion and the observation of the person who makes the examination, and that the symptoms may have had time to have completely disappeared, or nearly so.

Only those observations, followed by an histological examination made upon a series of sections, have any real documentary value, as well from the physiological as from the anatomical point of view. How is it possible to give a physiological signification to any observation if one is unable to affirm that the lesions are strictly localized in the cerebellum and do not trench upon the neighboring centers? The case published by V. Negel and A. Theohari is an example in point. The patient who was the subject of this observation presented disturbances of upright station, of gait, and of speech, dating back some six weeks before the time of his first examination. The body oscillated in an antero-posterior direction; when the patient passed from the dorsal decubitus to a seated position, he had a very manifest tendency to fall backwards; during walking the base of support was very much enlarged. The upper and lower limbs were affected by tremors during the execution of movements. The voice was nasal and words were emitted with suddenness. During the last days the patient fell into a comatose condition and all of the muscles were in a state of marked stiffness. The autopsy revealed a focus of softening in the left cerebellar hemisphere, which involved the white substance and the dentate nucleus. An histological examination upon a series of sections showed, besides some other small foci situated in the left superior cerebellar peduncle, the median fillet of Reil, the posterior longitudinal fasciculus, and the central bundle of the tegmentum; another involved the pyramidal bundle of the same side, and still another one the path of the right fillet of Reil.

To summarize: These symptoms were incontestably those of a cerebellar lesion and the principal lesion was situated in the cerebellum. However, some of the lesions were in the paths of the cerebellar tracts. If, however, one wishes to proceed to an interpretation in a rigorously scientific manner, one cannot but take into account the interruption of the other bundles, of which there would have been no question had not the authors made a conscientious anatomical examination of the case.

The principal symptoms of foci, of softening or hemorrhage of the cerebellum are: Titubation, with a widening of the base of support, disturbances of equilibrium, falls to the side or backward, according as the focus is situated in a hemisphere or in the vermis, an intention tremor or clonic movements of the upper limbs, sudden but non-ataxic movements of the lower limbs and rapid fatigue. As less constant phenomena, vertigo, ocular disturbances and nystagmus.

The symptoms of onset are less well known; apoplexy is usual, and vomiting has been frequently noted. On the other hand, movements of rotation or rolling, analogous to those which are produced in animals after the destruction of the cerebellar hemisphere, are exceptional. They are mentioned in an observation of Meschède. The patient had movements of locomotion, repeated in a determinate direction, affecting an impulsive form. Sudden goings and comings, movements in a circle, movements around the longitudinal axis, always from the left to right; the gait was also oscillating, the movements of the limbs awkward, and speech halting. The right cerebellar hemisphere was atrophied.[1] It is more common to see patients drawn laterally in the direction of the lesion, and consequently, to describe a sort of circular movement.

The symptoms predominate or only exist on the injured side. Some cases are noted of a unilateral paralysis or paresis, in direct relation to the cerebellar lesion. But is the paralysis really due to the destruction of a part of the cerebellum? Is it not rather the consequence of a concomitant lesion in another region of the encephalon? In several cases of hemiplegia I have found at the autopsy a focus of softening in the cerebellum, but on making an histological examination of the lesions and degenerations in a series of sections, I have found similar foci in the pons, and on

[1] Serres observed a patient who turned around himself from right to left, and the lesion was found in the right peduncle of the cerebellum. Belhomme also observed movements of rotation to the right in a patient in whom the left cerebellar peduncle was compressed by an exostosis.

the path of the cortical motor tract. This condition is far from being exceptional.

To summarize: The symptomatology of hemorrhages or softenings of the cerebellum is still quite doubtful. It comprises disturbances of locomotion, of equilibrium, of motility of the limbs, and sometimes disturbances of speech. What relations exist between the seat of the focus and the clinical picture? What is the duration of the symptoms? Are there quantitative or qualitative differences, according as to whether the lesion affects the cortex, the white substance, or the central gray nuclei? So many questions await a precise rigorously scientific solution. Certainly limited foci in the cortex are more silent than those which cover a large surface of the cortex, or than central foci affecting the gray nuclei and the peduncles. But many of the notions which we have of this subject are still vague and undecided.

The majority of authors do not admit that lesions of the cerebellum can produce homolateral or direct hemiplegia (v. Monakow, Bruns, and Oppenheim). Contrary to this opinion, Mann described a cerebellar hemiplegia which is distinguished from a cerebral hemiplegia: First, by the fact that it affects all of the muscles, whereas, in a cerebral hemiplegia, certain groups only are affected more than others (dorsal flexors of the foot, flexors of the leg, extensors of the hand, external rotators of the arm, etc.); second, the absence of contraction; third, a simple exaggeration of the reflexes without spasticity, the absence of epileptoid trepidation, and of the Babinski sign.

This opinion is based upon observation and arguments, the value of which will be discussed further on.

II. Ageneses of the Cerebellum

The congenital atrophies of the cerebellum, or, better, ageneses, are rarely total. Either there is a lack of a cerebellar hemisphere or the cerebellum exists with a configuration resembling the normal, but reduced in all its dimensions.

Generally speaking, the clinical expression of these ageneses is very slightly marked, compared to atrophies developed in the adult or with tumors; sometimes there are no clinical symptoms at all.

In a case of almost total agenesis of the right hemisphere of the cerebellum, Neuburger and Edinger observed no disturbance which allowed them to suppose the existence of a cerebellar lesion. "There was no incertitude in the gait or the station; no weakness of the extremities, no nystagmus, no disturbances of speech, no vertigo, etc.; it was only noted that during infancy and adolescence, the head was often turned to the left, and oscillated." The right hemisphere was almost entirely lacking; it was about the size of a walnut, but of an entirely normal consistence and possessed well-formed convolutions. The vermis was altogether normal.

In a case of total agenesis of a cerebellar hemisphere, Nonne also observed no disturbance whatever.

A patient examined by Andral was incapable of doing the slightest thing that required application or dexterity. If, for example, she undertook any delicate work, she was immediately seized with a convulsive tremor of the hand. She was always afraid of falling when she walked. Her step was not certain. She was strong, robust, capable of lifting heavy burdens, but a feeble-minded imbecile. The left hemisphere of the cerebellum was altogether wanting, and in its place a sort of stump or tubercle was found. There was nothing abnormal in the cerebrum or the meninges. In this case a complete anatomical examination was not made.

A patient observed by Lallemant presented only a slowness of gait. The left cerebellar hemisphere was reduced to a small mass about the size of a hazel nut, attached to the lateral portions of the pons.

A patient examined by Hitzig had no motor disturbances up to the age of thirty-two. She had learned to walk at the regular time and could jump and dance. It was only after attaining the age of thirty-two that symptoms supervened which must be attributed to tabes and general paralysis. The right cerebellar hemisphere was reduced to two small lobules about the size of a bean.

Among the observations of total absence of the cerebellum, that of Combettes is the most celebrated. The cerebellum was represented by two small masses of white substance, having the volume of a pea. The cerebrum and the spinal cord appeared to be normal. The little patient had only lived for thirteen years. She developed very slowly and was backward from every point of view. She spoke with difficulty and with hesitation. Her legs, although very weak, were sufficiently strong for her to walk, but she fell frequently. She could use her hands with ease.

Anton observed a patient very comparable to the one of Combettes. It was the case of a little girl six years old, all of whose movements were slow and incomplete. She did not commence to sit up, to stand up and to walk until after she was four years old. She was unable to walk or to hold herself upright except by holding on to something. The movements of her legs were incoördinate. She staggered and fell frequently. The movements of the arms were slow and somewhat incoördinated. Fatigue supervened rapidly. Speech was not very clear, but there was no sign of tremor in the writing. The patellar reflexes were exaggerated. At the autopsy there was a total absence of the cerebellum.

In the case of a patient of Verdelli, nineteen years of age, the cerebellum was almost as much atrophied as in the patient of Combettes. Unfortunately, rachitic deformities of the skeleton and lower limbs prevented a study of the gait. The patient stammered. He was able to use his arms with facility and they were strong enough to support the weight of his body upon crutches.

There was also a total absence of the cerebellum in a patient of Shuttleworth's, fifteen years of age. A great general muscular weakness had been observed, combined with a tremor of the hands and arms. Besides, there was a very pronounced arrest of intellectual development.

An observation of Otto must be ranked in the group of partial ageneses. Clinically there was nothing particular to be noted except that the movements, forcible and dextrous, were febrile and impulsive. The cerebellum was very small. It was five centimeters wide and three centimeters at its greatest depth. (This was the case of a man thirty-nine years old.) The microscopic examination showed that this little organ was composed of absolutely normal elements.

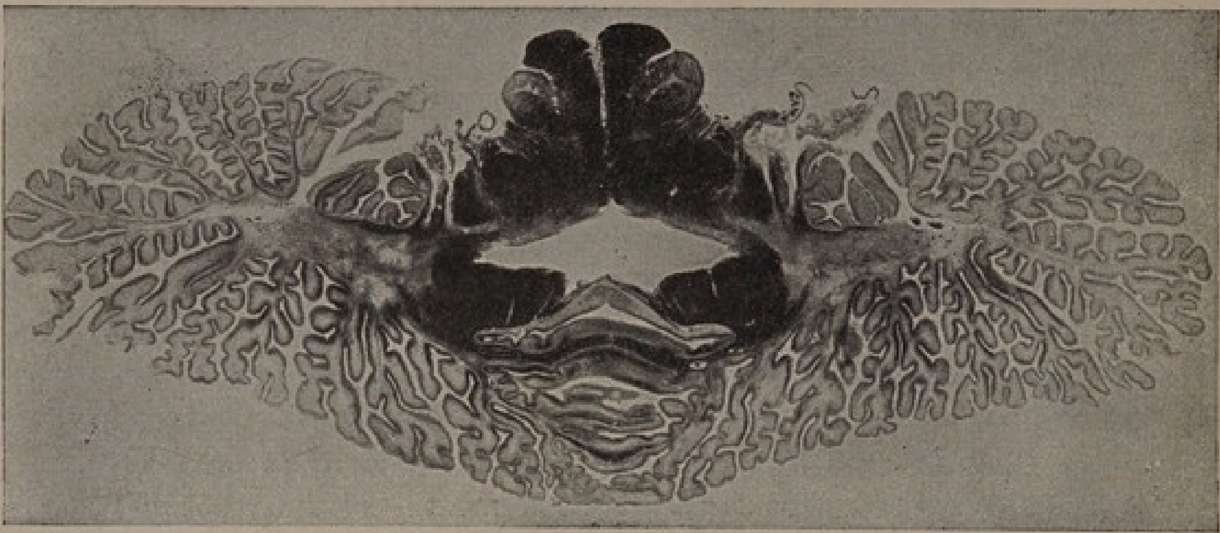
The results of an examination of a boy with an epileptic psychosis reported by Borell, and in whom speech and walking became difficult from the age of ten years, is as follows: Movements were difficult and awkward, particularly of the legs. There was a bending of all parts of the body during walking, as if they were attached together only by loose ligaments. The feet interfered with one another. When he ran he manifested a certain degree of fear and turned his right side forward. He oscillated when he stood up in order to preserve his equilibrium. Speech was slow and scanning. The cerebellum was very small. The left hemisphere was completely lacking. The largest diameter of the right hemisphere was twenty-eight millimeters, and the vermis was very much reduced in size.

These observations of ageneses of the cerebellum are far from giving concordant results. To consider them only from a physiological point of view, one cannot but be surprised to learn that a unilateral agenesis so complete as that related by Neuburger and Edinger had a clinical evolution of so silent a character. The total ageneses of the cerebellum have a more marked symptomatology than the unilateral ageneses. In the majority of the observations motor disturbances have been mentioned, but they have been insufficiently described.

III. Atrophies of the Cerebellum

The cases of primitive atrophy of the cerebellum of a slow and progressive evolution form a very important group. Among the observations of these cases, however, there are very few that are physiologically utilizable, because along with the systemic lesions of the cerebellum there are also systemic lesions of other organs, particularly of the spinal cord. An exception should be made in the case of olivo-ponto-cerebellar atrophy, of which we have published either alone or with M. Déjerine several observations followed by autopsies. The one which we examined with M. Déjerine is the only one in which the atrophies and degenerations were strictly localized in the cerebellum: The pons and particularly the anterior layer and the olives were equally atrophied, but these are organs which enter into direct relation with the cerebellum.

The following is a list of the anatomical lesions: (1) A symmetrical atrophy of the cerebellar cortex more pronounced in the hemisphere than in the vermis, and contrasting with a relative integrity of the central gray nuclei, *i. e.*, the dentate nucleus, the nucleus of the roof, the globulus and the embolus (Figs. 56 and 57); (2) total atrophy of the gray substance of the pons and total degeneration of the middle cerebellar peduncle (Fig. 58). The superior cerebellar peduncle, which takes its origin in the dentate nucleus, was, on the other hand, relatively well preserved.



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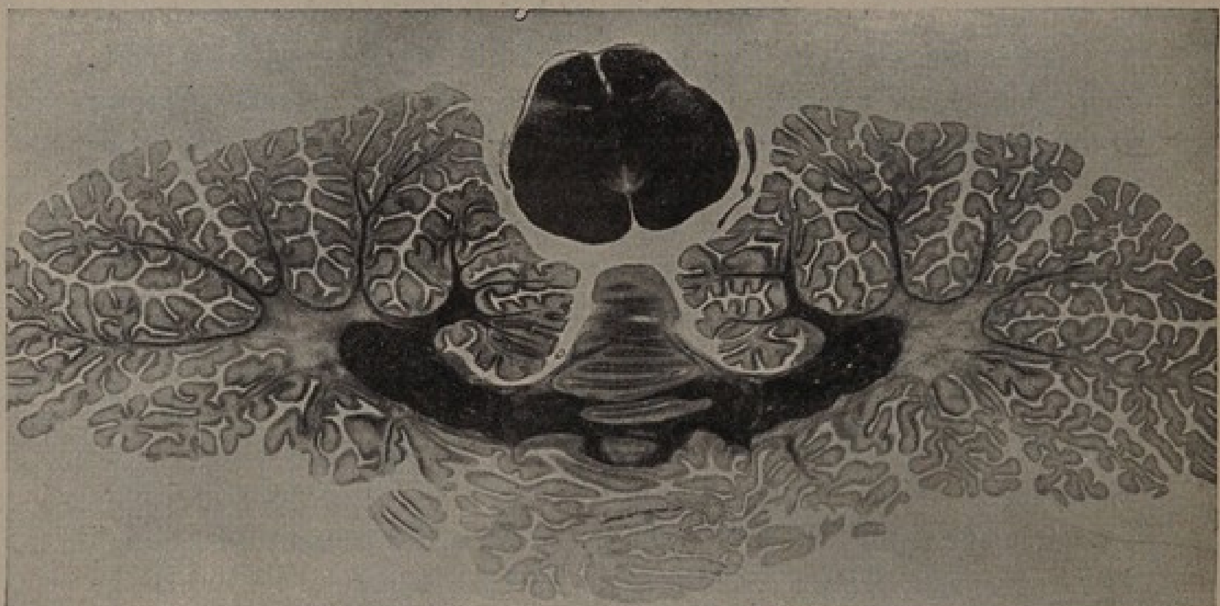

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FIGS. 56 and 57. Lesions of the cerebellum in a case of olive-ponto-cerebellar atrophy. Atrophy of the cortex and degeneration of the white substance. Integrity of the central gray nuclei and of the superior cerebellar peduncle. Atrophy of the medullary olives and the restiform body. (J. Déjèrine and André-Thomas, *Iconographie de la Salpetriere,* 1900.)

(3) A very pronounced atrophy of the inferior olives, of the accessory olivary nuclei, and of the arciform nuclei, and a degeneration of the external arciform fibers and of the restiform body. The pyramids and the cerebral peduncles appeared smaller than normal, but without any trace of degeneration.

The lesions of the cerebellar cortex were essentially characterized by the disappearance of most of the Purkinje cells.

Clinically the movements of the body as a whole were profoundly altered, whether they took place in the seated or in the upright position, whether the patient walked or passed from the seated position to a position lying down, or from a position lying

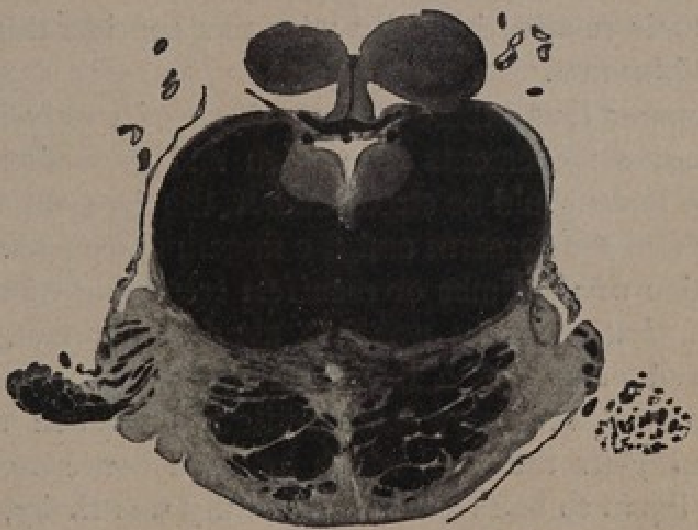


FIG. 58. Same case as Figs. 56 and 57. Atrophy of the anterior surface of the pons and the middle cerebellar peduncles.

down to a position standing. All these changes of attitude were executed with slowness, hesitation, uncertainty and awkwardness. A fall was sometimes the consequence of this disequilibration.

Upon rising the body was agitated by oscillations and the patient could not pass from the seated to the standing position without holding on to some neighboring object.

In the upright position the feet were spread wide apart, the base of support enlarged; the elbows were held in abduction and the body was the seat of either antero-posterior or transverse oscillations. The patient had the sensation that he was about to fall forward. Upright station with the feet close together was difficult, if not impossible.

In walking the lower and upper limbs preserved the same position. The patient walked with caution as if seeking his equilibrium. Each foot was only lifted after hesitation, but then suddenly and replaced in the same manner. The steps were short and irregular and described a wavy line, because the body was carried either too far forward or backward, or to the side, and oscillated.

Summary.—There are no traces of the rhythm or of the cadence of the normal gait. Fatigue supervenes rapidly. The disturbances of station and of locomotion are hardly augmented by covering the eyes, consequently there was no Romberg sign.

The isolated movements of the upper and lower limbs, contrasted in their relative integrity with this considerable perturbation of equilibration.

In the upper limbs there was no trace of paralysis. Resistance to passive movements of flexion and extension was very great. The limbs could be stretched out, the forearm on the arm, the hands from the forearm and the fingers spread apart without any oscillation of the limbs or manifest trembling of the fingers. In spite of that, motility was not absolutely intact, when the patient seized or moved a heavy object she became awkward. The movements were slow and hesitating. When the patient tried to fill a glass the hand which held the bottle oscillated and poured the liquid to one side. The writing was shaky, the letters irregular and unequally spaced, and some of them unrecognizable, notwithstanding the characters were written slowly, the patient taking great pains to trace them.

Motility was not disturbed in the lower limbs; all the movements executed in bed were correct.

The limbs and segments of limbs could be placed in abnormal attitudes. Consequently there was no hypertonus. Sensibility in all its modes, superficial and deep, was intact. There was neither paralysis nor muscular atrophy.

The movements of the head were slow. The same slowness was found in the movements of the face (elevation of the lips, opening of the mouth, and the action of making a grimace). The physiognomy was almost without expression. The ability to mimic very slight. Neither the tongue or the palate were paralyzed. In spite of that speech was slow, drawling and slightly scanning. All isolated and synergic movements of the eyes were normally executed except elevation, which was done in several stages. This was rather a series of nystagmiform shocks than true nystagmus.

The tendon reflexes were exaggerated, but there was no sign which indicated a disturbance of the pyramidal tract (signs of Babinski, or of Oppenheim, epileptoid trepidation, etc.).

Similar phenomena were observed by the same authors in another patient, but without anatomical verification. I only cite them in comparison and not as evidence of equal value. The disturbances of equilibrium were of the same nature. They were exaggerated upon a change of attitude. In walking the patient gave the impression rather of having lost his balance than of walking like a drunken man. The upper limbs were awkward. "When the patient wished to seize an object, a glass, for example, he grasped too suddenly. When he tried to lift it to his mouth he hesitated a little, he was not sure of holding it well, and there were some small lateral movements which prevented the hand from accomplishing the desired object. The patient said himself that he was more awkward with his hands, and it very often happened that he upset objects at the moment of taking hold of them or carrying them." The same disturbances of speech, nystagmus and exaggeration of reflexes, etc., were found in him.

These observations, of which one was followed by a rigorous anatomical control, clearly show the influence of the cerebellum upon the equilibration of the body in general, and also upon the motility of the limbs. We will see further what physiological interpretation we may give to these various symptoms.

There exists in the literature a number of observations of atrophy of the cerebellum. It is to be regretted that one cannot give a collective description of them, but the observations are not sufficiently superposable to enable one to do so without reserve. One must be contented with an exposition of the facts; the facts are few, and in reading a résumé of some of those which are ordinarily cited as the most convincing, one will perceive that this chapter is far from being conclusive, at least, unless one sacrifice rigorously scientific methods, and is more content with impressions than with exactness.

In two other observations of olivo-ponto-cerebellar atrophy, followed by autopsies and reported in my thesis, I observed symptoms of the same type as in the preceding observations, but in one of these cases the columns of the spinal cord were only slightly degenerated, and in the other the degenerations were more extended, occupying the posterior columns, the direct cerebellar tract, and the tract of Gowers.

Pierret, Menzel, Royet and Collet, and Arndt, in their observations mention not only disturbances of equilibrium and gait, but also incoördination, or intention tremor. However these lesions were not exclusively distributed in the cerebellum and the parts dependent upon them: the bundles of the spinal cord, and more particularly the pyramidal tract and the posterior columns were partly degenerated (observations of Menzel and Arndt). The patient of Pierret had tremors of the arms, although the spinal cord was intact. In the patient of Royet and Collet the arms were affected by a slight tremor when in extension with the fingers spread apart, or when it was attempted to raise an object to the mouth; the objects were carried to their destination practically in a direct manner, but with some oscillation; but the anatomical examination does not appear to have been complete. In all of these patients disturbances of speech were noted, diversely described, according to the authors (embarrassment of speech, slow speech, hesitating, uncertain, etc.).

The observation of Fraser concerns a case of cerebellar atrophy, but unfortunately from the anatomical point of view it is very incomplete. Equilibrium and motility of the limbs were both compromised: "When one asked the patient to seize an object he acted like a choreaic, although to a less marked degree. After having seized the object he could hold it at arm's length without tremor or hesitation; asked to touch the end of his nose with his finger, he could do it almost as well as a normal individual, although he hesitated slightly."

The observation of Nonne has a more difficult interpretation. The atrophy of the cerebellum appeared to be due to an arrest of development. The encephalon was smaller than a normal encephalon. "The patient was able to dress himself alone but with such pains and so slowly that he was usually assisted. He was able to eat by himself also but not without spilling his food. It was particularly during attempts at writing that the disturbances of motility appeared. During walking the foot was lifted from the ground in an incoördinate manner, but he did not replace the heel first nor did he throw the legs forward like an ataxic."

The observation of Miura may be compared to that of Nonne. From the triple point of view—anatomical, clinical, etiological (in both cases heredity and family characteristics were found). The first symptoms appeared at the age of twenty-five. The gait became gradually uncertain; the body vacillated and described oscillations during walking; the hands were equally clumsy. When the patient was examined by Miura disturbances of gait and equilibrium, incertitude of the extremities in all actions, and visual disturbances were noticeable. Progression was not made in a straight line, the body was carried first too much to the right, then too much to the left, and sometimes even backward, so that he was threatened with a fall. The hands did not tremble, nevertheless, writing revealed great uncertainty and a manifest ataxia of the hands. With the arms widely separated the patient could touch his two index fingers together, as well with the eyes shut as with them open. Speech was explosive, badly articulated and scanning, sometimes hardly comprehensible. There was a slight horizontal nystagmus. In the upright position the legs were spread wide apart and the big toes in hyperextension; the body was animated with oscillations which were not much augmented by the closure of the eyes. The tendon reflexes were normal; the same was the case for deep and superficial sensation. On the other hand, there were serious disturbances of vision (diminution of visual acuity, the disks were injected and not well limited, and the pupillary reflexes to light and accommodation were sluggish).

At the autopsy the cerebellum was found to be small, only weighing 80 grams, the white and gray substances were less developed than in a normal individual, but they were well proportioned to one another. Compared to a normal cerebellum, the fibers of the white substance and their ramifications in the lobules and lamellæ were spaced further apart. But this was not all; the cerebro-spinal axis was smaller than normal. This reduction in size was particularly remarkable in the spinal cord. The cerebral convolutions, however, were also atrophied. The peripheral nerves were also degenerated. (The patient was at the same time affected with kakké, or beri-beri.) The two retinæ showed some lesions. One cannot, therefore, without reserve put down all these symptoms observed in this patient of Miura to the account of cerebellar atrophy.

In the patient examined by Schultze, there were besides the disturbances of equilibrium during walking and standing, disturbances of speech and traces of intention tremor in the arms, as well as nystagmus. The lesions consisted of an atrophy of the cerebellum affecting not only the cortex but also the dentate nucleus, which was very much compromised; besides, the medullary pyramids were slightly colored (method of Pal), and in the spinal cord the crossed pyramidal tracts were degenerated.

In some cases atrophy of the cerebellum presents itself in a more striking form. The atrophy does not affect equally all of the lobes, lobules and lamellæ; it affects irregularly certain lamellæ and other neighboring lamellæ may be absolutely untouched. In the affected lamellæ the cells of Purkinje completely disappear and are replaced by a thick felt-work of neuroglia.

In one of these cases which I have studied under the name of lamellar atrophy, the disturbances of equilibrium during the upright position were of a distinct character. The description is as follows: During walking the legs are spread wide apart, the base of support is very much widened, the toes are manifestly directed outwards, the arms are in marked abduction. The patient walks distinctly upon her heels, but she does not throw her legs forward like an ataxic. She does not follow a straight line, but describes, in walking, a broken one, the body being carried alternately too much to the right or too much to the left. In spite of that the general direction towards the goal is preserved. At the same time the body is constantly the seat of antero-posterior and lateral oscillations, and the patient constantly looks at the ground seemingly preoccupied in reëstablishing her equilibrium, or at least in avoiding the loss of it. The closing of the eyes does not sensibly augment the disturbances of equilibrium during the upright position or in walking, on condition that the feet remain spread apart; as soon as they are approached to one another she cannot stand upright, and as soon as the control of sight is suppressed she is threatened with a fall. She is also unable to support herself on one foot.

59 60 61

Figs. 59 to 61. Troubles of gait and equilibrium in a woman affected with lamellar atrophy of the cerebellum. Enlargement of the base of support. Abduction of arms. From an enlargement of an instantaneous photograph. (André-Thomas, *Revue Neurologique,* September, 1905.)

The arms are not at all affected. Their muscular force and sensibility are intact. There is neither ataxia nor intention tremor. The olecranon and radial reflexes are normal. In contrast, the movements of the legs are irregular. They are accompanied by an intention tremor analogous to that of multiple sclerosis. This irregularity cannot be put entirely to the account of the cerebellar lesion. There is also a double club foot, the remains of an infantile paralysis, the lesion of which was easily found at the autopsy.

Two similar observations have been found by Rossi and Murri.

In the case of Rossi (followed by an autopsy), the cerebellar symptoms are mentioned. There was intention tremor of the arms, adiadochokinesis and asynergy of the legs (see page —). There was a manifest Romberg. But besides the cerebellar lesion Rossi noted lesions of the posterior column and of the posterior roots.

This very brief bird's-eye view of the pathology of the cerebellum suggests to us the following reflections: (1) Observations of primitive atrophy of the cerebellum are very rare; (2) they become exceptional if one only takes account of the observations in which the other parts of the neuraxis are absolutely healthy.

In the more clear-cut and typical observations, such as the one I published with J. Déjerine under the name of olivo-ponto-cerebellar atrophy, the symptomatology is confined to disturbances of motility. They are not due to paralysis or sensory disturbances; this is a fact upon which I have already insisted. It is above all equilibration which appears to be the most affected; during walking, during the upright position, and in all changes of attitude. The gait does not at all resemble the gait of a normal person, where the movements of the arms and legs and trunk are harmoniously related to one another; the compensatory movements necessary for the maintenance of equilibrium during the variations of attitude, are lacking or are imperfect. Thus, when a cerebellar patient descends a stairway, his body is thrown too far backward and he risks a backward fall. When he attempts to stand upon one leg, the body is carried either too much towards the side of the leg that is lifted or too much to the other side.

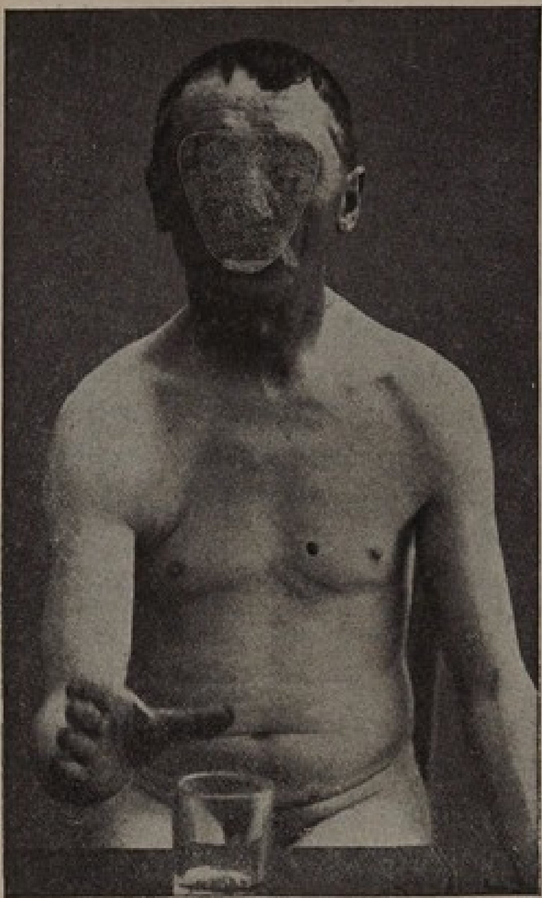
A patient of M. Babinski afflicted with a pontine affection in which, apparently, the cerebellar tracts participated, presented still more marked disturbances: During walking the trunk did not follow the legs. When a foot was carried forward, the trunk did not advance with it. M. Babinski classes this phenomenon in the group of asynergic phenomena. I have not yet observed this fact in the patients affected by cerebellar atrophy whom I have had occasion to examine.

There are, in cerebellar cases, other things than disturbances of equilibration. There is a general disorder of motility which appears in the execution of every act and movement; as well in writing as in speech (scanning), and movements of the eyes (nystagmus). In their observations Royet and Collet mention oscillations of the vocal cords. The patient has difficulty in holding a note. The reflexes are exaggerated.

Of what nature are these disturbances of motility? They have been differently interpreted according to various authors. They have been qualified as awkwardness, tremors, incoördination, etc. In the most typical observation which we published with J. Déjerine, the patient became awkward; when she seized a heavy object, or when she moved it, her movements were slow and hesitating; when she tried to fill a glass the hand which held the bottle oscillated and poured the fluid on one side. Another patient, the observation of which is very comparable to the preceding, had a certain awkwardness of the hands; thus, when she tried to take hold of an object, a glass, for example, she seized it too suddenly.

M. Babinski has insisted equally upon the excessive movements of those affected with cerebellar lesions. "If, for example, the patient carries the point of his index finger towards the end of the nose, which should be the terminal point of the finger after having followed its course in the desired direction, it does not stop when it has reached the object, but passes over it and violently strikes the jaw." As another example, he cites also the fact: "When the patient tries to trace a line on a sheet of paper, which should be stopped at a determinate point it is carried beyond this limit." Up to now M. Babinski has only observed this phenomenon, as have others also, as one related to disturbances of the cerebellar apparatus, where there is also an affection of the medulla and the pons and where the lesions are not localized exclusively in the cerebellum. In all of the autopsies which have been made, the lesions have been too wide spread and numerous to be attributed entirely to the cerebellum.

Recently, with Jumentié, I have had occasion to study more in detail these disturbances of motility in an individual very comparable by the ensemble of his symptoms with patients afflicted with olivo-ponto-cerebellar atrophy. In him the lack of the pro-



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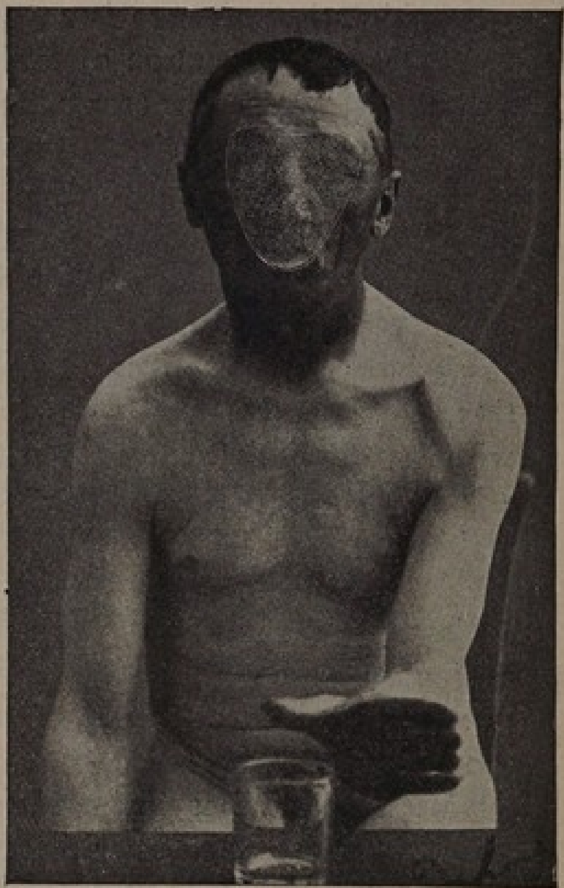

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FIGS. 62 and 63. Dysmetria in an individual probably affected with cerebellar atrophy. Exaggeraed opening of the hand to let go of a glass. The phenomenon is more marked on the left where the other symptoms predominate. (André-Thomas and Jumentié, *Revue Neurologique,* November, 1909.)

portion, the *dysmetria* noted by Luciani and other physiologists in animals deprived of the cerebellum, was very easily observable. When he was asked to place his finger upon his nose, the movement was executed differently according to whether it was spontaneous, rapid or slow.

When the movement was executed spontaneously and naturally, it was done in several stages—it was not continuous. There was, so to speak, a certain degree of intention tremor. Also when the finger reached the nose, the hand was unstable and executed alternative movements of supination and pronation before reaching a state of repose; the tremor, therefore, was both kinetic and static. It will be studied further on. If the movement was made slowly and carefully, it was practically executed correctly, continuously, and did not extend further than it should have.

If the movement were rapid, the finger passed over the object and touched the cheek at the side of the nose; this time it was very clearly out of proportion, and there was dysmetria.

Dysmetria existed in all movements; if he tried to take hold of a glass the hand was opened too far (Figs. 62 and 63).

If the patient was lying down on the back, and he was asked to place the heel of one side upon the knee of the other side, the heel was lifted too high and passed by the knee, but was then replaced upon the knee. The patient, if he was standing and asked to raise his foot and then to put it down again, the foot was so replaced that the heel struck the ground, although the patient was held during this test in a manner to avoid any disturbance of equilibrium.

Dysmetria differs from peripheral ataxia by two fundamental characteristics: the complete or almost complete orientation towards the object, and the almost entire absence of the influence of sight upon the regulation of movement.

Babinski has already drawn attention to the disturbances of *diadochokinesis*. Diadochokinesis is the ability to execute rapidly successive volitional movements. Adiadochokinesis (Bruns) is the loss of this faculty. A cerebellar patient is not able to execute rapidly and regularly alternative movements of supination and pronation, or alternative movements of extension and flexion of the forearm upon the arm, etc., although the muscular force is preserved and sensibility is intact.

Adiadochokinesis has been noted by various authors in individuals afflicted with cerebellar affections (in the majority of cases they were tumors). It is mentioned by Italo Rossi in a case of parenchymatous atrophy of the cerebellum, and for the various reasons which we have enumerated above, observations of this order appear to us to have a great physiological importance.

According to Babinski adiadochokinesis would be the result

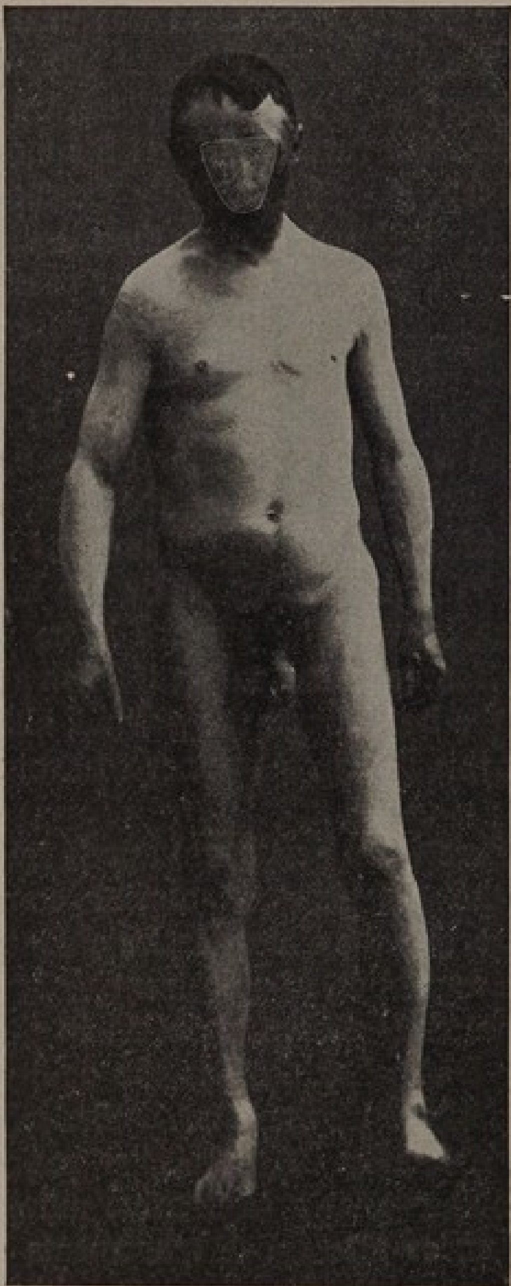

Fig. 64. Same patient as in Figs. 62 and 63. Gait of patient affected probably with cerebellar atrophy. Enlargement of the base of support. The gait is slow and uncertain. The right arm follows the left leg, but the inverse does not take place.

of the fact that each of these successive movements is not proportional (démesuré), and that the time lost between the two successive movements is not reduced to a minimum. There would seem to be some sort of delay in the excito-motor action. According to my opinion, dysmetria plays a considerable and even a preponderant rôle in the production of this phenomenon. Upon the patient to whom I have previously alluded I have been able to demonstrate the influence of dysmetria upon the difficulty of executing alternative movements of pronation and supination by the following test: When, after having directed the two arms forward, they having been put previously in extension with the palmar surface looking upwards, the patient turns them over, the movements of pronation are exaggerated on the left, and the left thumb is lowered further than the right one. A similar phenomenon is produced when the arm is put back into supination again, therefore, diadochokinesis is only present on the left side. On the other hand, when the patient has placed the arms in flexion or extension by a powerful contraction and he is asked to let them go, the decontraction is instantaneous and attains its maximum at once. In the same way with movements executed at command there is no delay in the volitional incitation. This is why adiadochokinesis seems to me to be only the consequence of dysmetria.

At the moment when the patient attempts to reverse the movement the initial movement is prolonged, and that is the reason of the delay.

The tremor of cerebellar patients is absent during repose. It occurs in two conditions: during the execution of voluntary movements and during the maintenance of an attitude, or rather, at the beginning of either of these conditions.

When the tremor is analyzed, as I have done in the case of the preceding patient, it is remarked that it is more apparent at the beginning of the movement. Instead of contracting in a continuous or tonic fashion, as in the normal state, the muscles contract in several stages. Interrupted and exaggerated shocks can be seen under the skin which recall to a certain extent those which are seen in the crises of epilepsy. The normal tonicity has given place in a way to clonicity.

The tremor is manifested also during the maintenance of an attitude. The patient takes, for example, a glass in the left hand, several brusque movements of pronation and supination are produced before immobility is attained. This fact is still more marked if the glass is filled with water. In the same way, when the index finger and the thumb are approached one to another, one can see very clearly in the beginning clonic shocks in the first interossei muscles. The experiment may be varied by having the patient put the thumb and little finger in apposition. The results are identical. After a certain time the shocks disappear and equilibrium is obtained.

In this patient, therefore, the tremor is both static and kinetic. The static tremor hardly exists except at the beginning of an attitude.

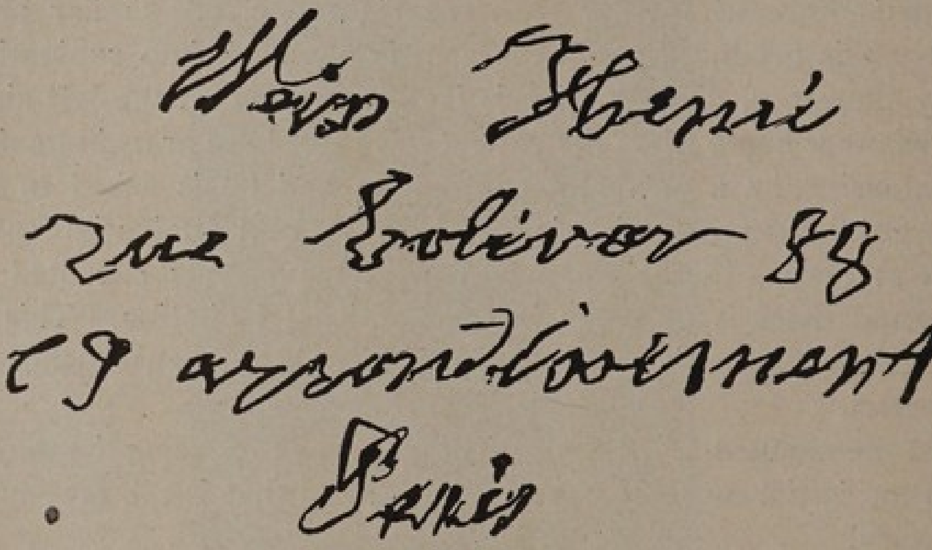

FIG. 65. Writing of same patient.

The tremor may be explained in various ways: (1) Either the movement is too brusque and disproportioned and the patient corrects it spontaneously by the intervention of the antagonist muscles; or (2) there are pauses and recontractions in the muscles.

According to my opinion, the antagonist muscles only play a small part in the production of this phenomenon. Their contraction can neither be perceived by the eye or by palpation; and they should be perceivable by one means or the other if they are sufficient to arrest the movement. It appears more probable that there are stoppages and recontractions of the muscles. In the normal condition every voluntary movement presents itself as the effect of a continuous contraction, a tonic contraction. The difference which exists between a healthy subject and one suffering from a cerebellar affection appears to be due, in great measure, to the fact that the volitional incitation which starts the movement is not prolonged in the last case into a tonic contraction.

The movement, therefore, is not only dysmetric but discontinuous (clonic or epileptoid), and these characters are found again in various physiological actions. In the speech, which is often explosive and scanning; in the writing, where the characters are irregular, the lines of unequal length and unevenly spaced and trembling. The intensity of the alterations in writing is attributable to the fact that the tremor is more accentuated at the beginning of movements or attitudes. That is why actions consisting of a succession of short and rapid movements are more compromised than others.

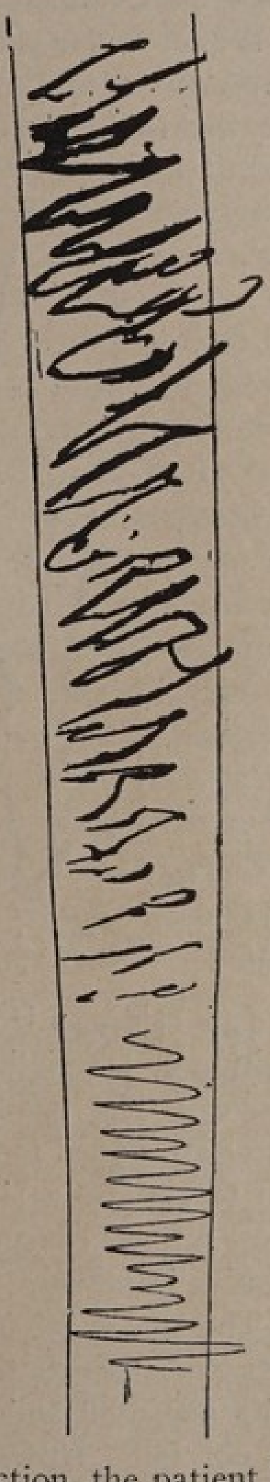

Fig. 66. Same patient. Model to the left, copy to the right.

Dysmetria and discontinuity of movement appear to us to be, after the disturbances of equilibrium, the fundamental characters of cerebellar affections.

Under the name of asynergia Babinski has described the loss of the faculty of association of movements.

(1) A normal subject placing his foot upon a chair bends the thigh upon the pelvis at the same time that he flexes the leg upon the thigh, a cerebellar patient first flexes the thigh upon the pelvis and then the leg upon the thigh. The two movements are not simultaneous; there is a decomposition of the movement. This first experiment does not prove asynergia unless the patient is seated or in a stable position, otherwise the decomposition of the movement could very well be nothing but a voluntary, calculated action, the patient behaving in this way because he is afraid of falling, and many ataxics do not act differently.

(2) If one asks a normal subject who is standing upright to bend his body and his head backward, at the same time that he executes this movement he flexes slightly the leg upon the foot and the thigh upon the leg in a manner to avoid a fall backwards. In the cerebellar patients examined by Babinski this compensating movement of equilibrium was lacking, and if they were not held they fell backwards.

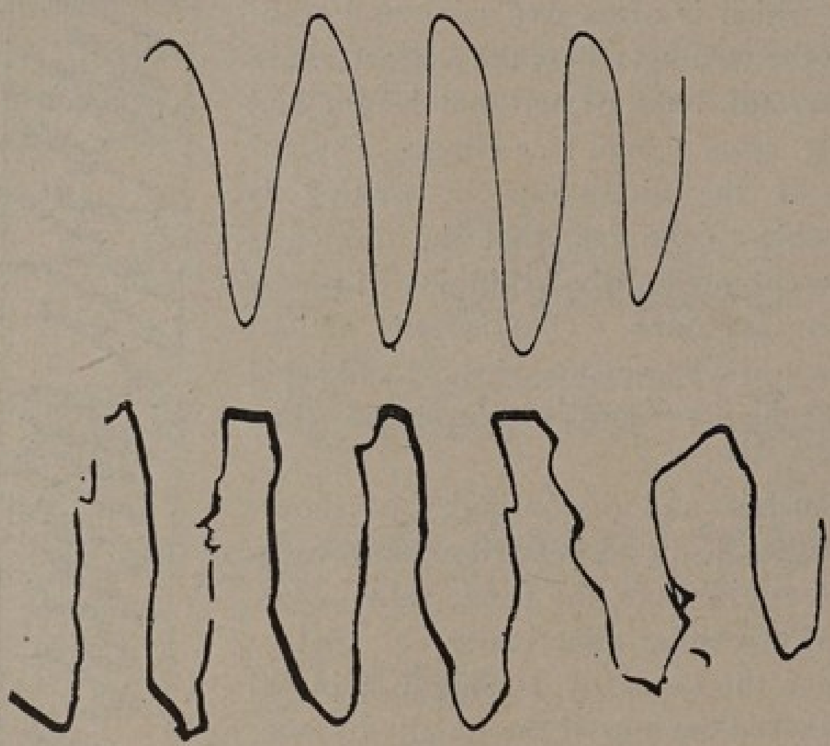

FIG. 67. Same patient. Model above, copy below.

(3) If the patient is asked when he is lying down in the dorsal position on a resisting plane to sit up, he cannot do it in a normal manner. The trunk is flexed a little upon the pelvis, but the thighs are flexed more upon the pelvis, and it is these that enable him to assume a sitting position. The results of these experiments are not constant. They are positive in certain patients and negative in others.

The backward fall (in the second experiment) did not occur in several patients that I examined. In some the movement was badly executed and accompanied by oscillations, but the patient did not fall. However, the patient in whom Babinski observed this fact in all its clearness was not a pure cerebellar case, as various associated symptoms enable us to affirm.

Finally, the third experiment requires a more delicate interpretation. There are normal subjects who cannot sit up, or sit up with difficulty in these conditions, and in their repeated attempts they sometimes flex the thighs from the pelvis. It is necessary, therefore, that this movement of flexion of the thighs should be very accentuated to have real significance. I have formerly attributed these disorders of equilibration in cerebellar patients to asynergia without so calling it. I have remarked that during walking the movements of the arms do not associate themselves with those of the legs in cerebellar patients as they do in normal subjects. When a cerebellar patient descends a stairway the movements of projection of the trunk do not associate with the movements of the legs. The first have a retardation compared to the second. In the attempts to stand upon one leg, the body is inclined too much to the side, either to the right or to the left. As I have previously noted in my thesis, those movements which tend to displace the center of gravity do not provoke the tonic muscular reactions which assure the perfect maintenance of equilibrium. The loss of these reactions of equilibration in cerebellar patients is only in a certain way a manifestation of asynergia. Besides, in the experiments invented by M. Babinski, does not asynergia manifest itself by preference in those movements of the whole in which there is a question of equilibrium?

Babinski has also noted catalepsy in one patient (this patient was not a pure cerebellar type); that is to say, a tendency to maintain fixed attitudes for a longer time than a normal subject. Without catalepsy cerebellar patients would have the power to maintain fixed attitudes just as long as a normal subject. With a patient lying upon the back, the thighs flexed upon his pelvis, the legs slightly flexed upon the thighs, and the feet separated from one another when the patient raises his limbs both they and the trunk are affected at first by oscillations of large amplitude, and then at the end of some moments the body and the legs become fixed.

I have also noticed this phenomenon in a patient apparently afflicted with a cerebellar affection. When the patient is placed upon the back (this is the attitude of choice indicated by Babinski) with the thighs flexed upon the pelvis and the legs slightly flexed upon the thighs, the body is at first unstable, or oscillates around the longitudinal axis. The same thing happens in the case of the legs, which do not at first rest immobile, then the oscillations disappear and the patient can preserve, for a very long time, the same attitude. Occasionally one may note some very fine oscillations. In fact there does not exist at this moment any appreciable difference between that and what one sees in the case of a normal subject. The stability is in contrast with the oscillations which were produced at the beginning of the attitude. This is exactly what takes place in static tremor. What is true for the stability of partial movements is also so for the movements of equilibration. Cerebellar patients have a special difficulty in establishing stability or equilibrium promptly.

The movements of cerebellar patients are usually slow, but this slowness is not the immediate consequence of the functional insufficiency of the cerebellum, because they are able to execute rapid movements. The slowness is (apparently) willed, intentional, and has for its object the purpose of overseeing the movements and of combating more efficiently the tremor and the dysmetria.

Patients afflicted with cerebellar atrophy resist, generally sufficiently well, pushings and pullings which may be exercised upon them for the object of making them lose their equilibrium. I have never observed in them, or at any rate, to the same degree, a provoked latero-, antero- or retro-pulsion, so often seen in patients afflicted with Parkinson's disease.

In those patients whom I have examined on a turn-table in order to study their reactions to centrifuging, I have not been able to notice any appreciable difference between them and normal subjects.

IV. Lesions of the Cerebellar Peduncles in Man

The experiments made upon animals and the observations collected concerning the systemic or non-systemic lesions of the cerebellar paths, whether medullary or spinal, in man are comparable. Among these observations are some cases described under the name of heredito-cerebellar ataxia and of which the principal lesions are represented by the systemic degeneration of the direct cerebellar tracts and the tract of Gowers (André-Thomas and J.-Ch. Roux). The posterior columns are degenerated to a lesser degree, so that the disease assumes the clinical form very comparable to cerebellar affections (slowness of movements, tremors, oscillating gait, wavering, dynamic nystagmus). It borrows also some of its symptoms from Duchenne's disease (sign of Romberg, pains and disturbances of sensibility, etc.).

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FIGS. 68 and 69. The various attitudes of the cerebellar gait, after enlargements from instantaneous photographs, in a woman affected with a focus of softening at the level of the left restiform body, and with two small foci of multiple sclerosis situated the one to the left in the central bundle of the tegmentum, the other to the right at the superior extremity of the facial nucleus behind the superior olive. These lesions are represented in Figs. 72 and 73. Disturbances of equilibrium, enlargement of the base of support, uncertainty of gait, abduction of the arms, particularly of the left one. (André-Thomas, *Revue Neurologique,* January, 1905.)

Certain medullary lesions give rise to symptoms which recall the unilateral and bilateral destructions of the cerebellum. Babinski and Nageotte observed a patient who presented hemiasynergia of the left leg, latero-pulsion towards the left and a slight tremor of the arms. (There existed also a slight hemiplegia with right hemi-anæsthesia, difficulty of swallowing, and a slight contraction of the left pupil.) A histological examination

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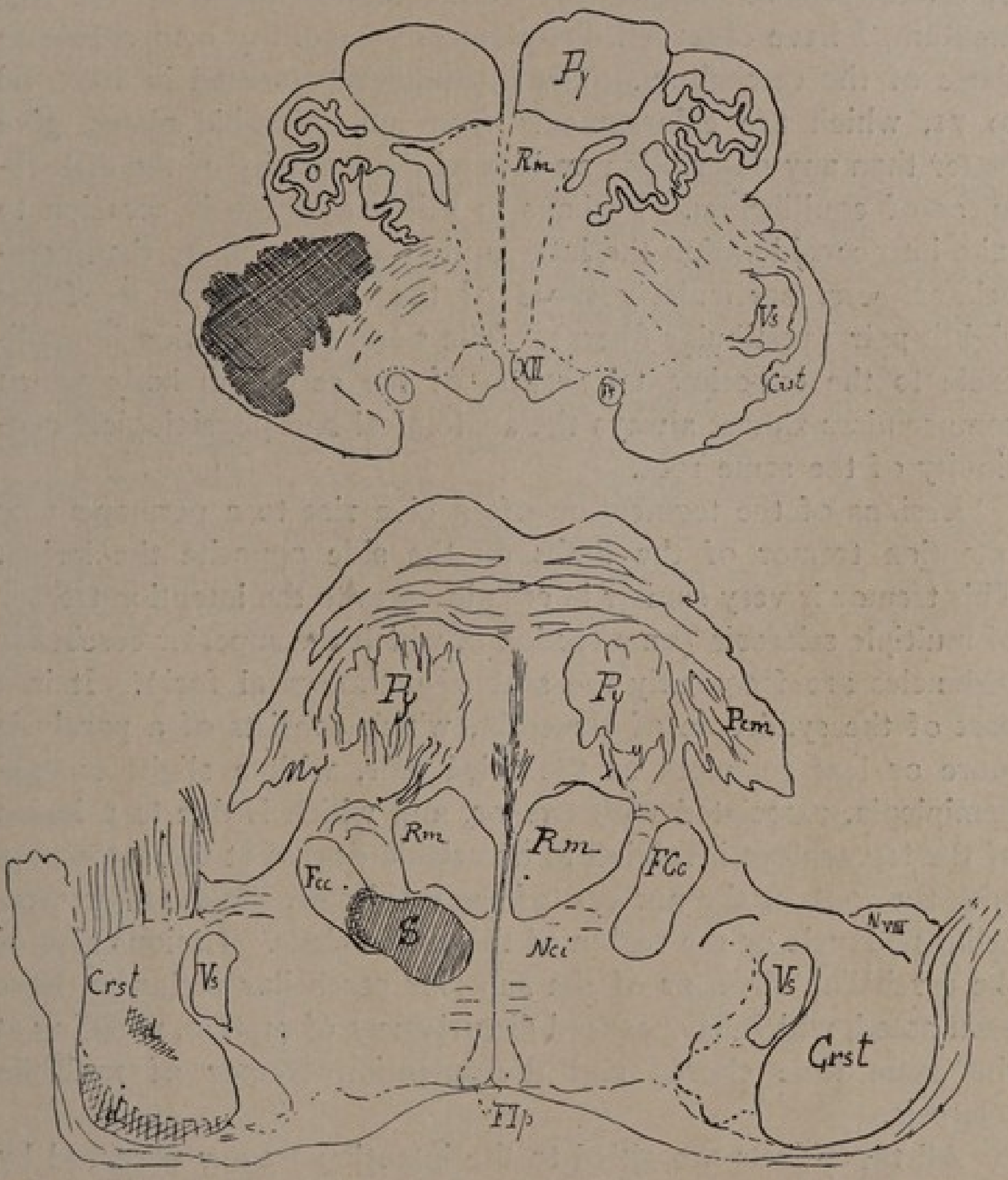
FIGS. 70 and 71. The various attitudes of the cerebellar gait, after enlargements from instantaneous photographs, in a woman affected with a focus of softening at the level of the left restiform body, and with two small foci of multiple sclerosis situated the one to the left in the central bundle of the tegmentum, the other to the right at the superior extremity of the facial nucleus behind the superior olive. These lesions are represented in Figs. 72 and 73. Disturbances of equilibrium, enlargement of the base of support, uncertainty of gait, abduction of the arms, particularly of the left one. (André-Thomas, *Revue Neurologique,* January, 1905.)

of a series of sections showed the presence of multiple softenings in the left half of the medulla and the fibers of the restiform body had been partially divided. An analogous symptomatology is encountered in cases of tumor of the cerebello-pontine angle, that is to say, those which are developed in the angle formed by the pons and the cerebellum. These are very complex cases: firstly, because it is a question of tumors which compress at the same time the cerebellum, the middle cerebellar peduncle and the pons,



FIGS. 72 and 73. Lesions of the medulla giving occasion to the disturbances of gait represented in Figs. 68 to 71.

and also because the vestibular nerve is usually likewise affected. Consequently the coëxistence of functional disturbances of the vestibular nerve or its central paths contributes towards augmenting considerably the disturbances of equilibrium present. In a case of softening of the medulla oblongata, located at the union of the inferior third with the superior two thirds of the left half in the lateral reticulated substance (encroaching upon the inferior extremity of the restiform body), and associated with a patch of sclerosis upon the pathway of the central bundle of the tegmentum, I have observed disturbances of motility comparable to those of the cerebellum. The attitudes represented in Figs. 68 to 71, which are enlargements from photographic plates, give better than any description an idea of the intensity of the disturbances of equilibrium. Perhaps in this case there is occasion to take into consideration the interruption of other fibers than cerebellar fibers, particularly those of the descending root of the eighth pair (vestibular fibers). The same consideration is applicable to the experimental section of the restiform body which compromises almost always the anatomical and physiological continuity of the same root.

Lesions of the tegmentum often give rise to a permanent or intention tremor of the limbs on the side opposite the lesion. This tremor is very similar in certain cases to the intention tremor of multiple sclerosis (an affection in which the superior cerebellar peduncles are frequently the seat of pathological foci). It is a part of the syndrome of Benedikt, which consists of a paralysis more or less complete of the third pair, with a slight crossed hemiplegia, associated with tremor, and which is due to a lesion of the tegmentum involving to a variable degree at the same time with the root, or the nucleus, of the third pair, the superior cerebellar peduncle or the region of the red nucleus. Lesions also of the cerebellar olive, or of the superior cerebellar peduncle, have been noted, which have caused disturbances of motion, recalling at the same time chorea and the intention tremor of multiple sclerosis.

All these facts are allied to the intention tremor observed by Ferrier and Turner in the monkeys in which they divided the superior cerebellar peduncle.

PART SECOND

INTERPRETATION

After having set forth the results of experimental physiology and clinical observation, it is well to pass in review the various interpretations of the several authors to explain the mechanisms, that is to say, the divers theories propounded as to the functions of the cerebellum. The theories of a purely hypothetical nature will only be mentioned. Only those should be retained and discussed which are based upon the findings of clinical and experimental physiological observation. I will afterwards endeavor to make an impatrial criticism, appealing only to positive facts, and reducing to a minimum the rôle of hypothesis, which, in spite of everything, is inevitable in a question of a purely doctrinal order.

CHAPTER VI

THE CEREBELLUM AND THE ORGANIC FUNCTIONS

One might expect that the discussion would be limited to a very restricted series of facts and would not have reference to anything except the mechanisms of the recorded phenomena. However, there is far from being an unanimous accord as to the facts themselves, and if one takes into consideration all of the theories that have been propounded, one can say that there is no function of animal life, or of the life of relation, into which the cerebellum does not intrude.

Willis has maintained that the cerebellum is not foreign to the organic functions and to the involuntary movements, meaning by these last expressions not only automatic or reflex movements, but those of animal life, the beatings of the heart, respiration, digestion, etc., etc. The intervention of the cerebellum in the glandular and visceral functions has been accepted by some great physiologists, who bring to bear the results of various experiments. Claude Bernard stated that he stopped the secretion of the crop in pigeons by wounding the cerebellum, that the excitation of the cerebellum would produce movements in the bladder, in the stomach, and in the intestinal canal. According to Dugès, its intimate relations with the pneumogastric nerve cause it to intervene in respiration and digestion, in the complex instinctive phenomena, in acts relative to the sustaining of life, in the appetites, and in the necessity of breathing.

Likewise, according to different authors, the sexual instinct and the genital functions are located in the cerebellum. Goll was the principal protagonist of this theory. He made the cerebellum the organ of the instinct of propagation or of the inclination to physical love. To the support of this hypothesis he invoked the following arguments: Persons of a very ardent temperament feel a tension and a sensation of heat in the back of the neck, particularly after excessive and profuse emissions or after prolonged continence. In rabbits deprived of a testicle the lobe of the cerebellum on the opposite side from the removed testicle is smaller and the corresponding occipital boss is more flattened than the other. Females have a cerebellum smaller than males because the sentiment of physical love is less pronounced in them, and finally, the complete development of the cerebellum coincides with that of physical love. All of these propositions are in disaccord with reality; there is no appreciable difference in the cerebellum of males and of females. The development of the cerebellum is completed a long time before the appearance of the genital instinct. Castration does not in any way involve the atrophy of the cerebellum (Leuret and Lelut).

It is known what the physiological works of Goll were worth. He had, however, his partisans, and his ideas seem to be confirmed by some physiologists of talent. Budge and Valentin are said to have provoked, by the direct stimulation of the cerebellum, movements in the vesiculæ seminales, the testicles, the Fallopian tubes and in the uterus. Spiegelberg obtained uterine contractions by mechanical or chemical irritation of some one or other region of the cerebellum; the vesicular turgescence, the cause of erection, could be produced according to Ekhard by an irritation of the pons. Thion reports the autopsy of a cow which had a calf without lactic secretions having been produced, and which later would not allow the approaches of the male, and in which he found a number of tubercles in the cerebellum. Serres has reported seven observations of apoplexy of the median lobe, in which there was priapism and exaltation of the feeling of physical love, and he concludes from this that the vermis is the excitor of the organs of generation.

All of these facts have only the value of simple coincidences and have not been established with the control and scientific rigor necessary; besides, they may be opposed by contradictory facts of which the conclusions are more significant. Flourens maintains that the cerebellum does not intervene in any way in the instinct of propagation or of physical love, and he bases this upon the following fact: A cock from which he had removed the greater part of the cerebellum attempted to mount the hens, but he was not able to do so on account of his disequilibration, and this great physiologist adds "his testicles were enormous." Since then the majority of physiologists have observed that the destruction of the cerebellum does not interfere in any way with the manifestations of the sexual instinct except by the difficulties that are introduced towards the maintenance of equilibrium or of attitudes.

The animals operated upon by Luciani had polyuria, glycosuria and acetonuria. This Florentine physiologist attributed these phenomena to action upon the neighboring fourth ventricle. In the same way emaciation, alopecia and the various dystrophic disturbances are not attributable directly to the lack of cerebellar innervation; they are indirect and inconstant effects.

Influence of the Cerebellum on Development and Growth

The cerebellum does not appear to have any influence upon the development of the body and upon growth. In the cases of destruction of one half of the cerebellum in young dogs aged from fifteen days to three weeks, I was not able to observe any difference between the two sides of the body. Certainly when these animals are compared to other dogs of the same litter it is observed that their growth is less rapid (Borgherindi and Gallerini, and André-Thomas). The operative shock and traumatism are seemingly the principal cause of this. However, Russell observed a cat in which the right lobe was only about half the size of the left lobe. This atrophy was manifested during life by an accentuated paresis of the two extremities of the right side, and the right paw was a little shorter than the left. But was this partial agenesis of the cerebellum really the cause of the retardation of the growth of the corresponding limb? One can well doubt it, since, in the various observations of agenesis of the lateral lobe in man, no similar asymmetry has been mentioned.

CHAPTER VII

THE CEREBELLUM AND SENSIBILITY

The relations of the cerebellum to sensibility have been variously estimated. Admitting such relations some authors base their conclusions upon anatomical facts, some upon the results of physiological experiments, and others upon clinical observation.

In the domain of sensibility there are generally distinguished general sensibility and the special sensibilities (hearing, sight, smell and taste). The relations of the cerebellum to sensibility should be studied from this double point of view.

The Cerebellum and General Sensibility

Lapeyronie and Pourfour du Petit base their conclusions upon clinical observations; Saucerotte, Foville and Pinel-Grandchamp on the results of their physiological experiments, and conclude that the cerebellum is an organ eminently fitted to the sensory function.

Foville and Pinel-Grandchamp even recognize a sensibility peculiar to the cerebellum. Dugès, considering that the cerebellum receives in its hemispheres the sub-spinal bundles of the spinal cord, looks at the cerebellum as an organ belonging to general sensibility; it would preside also over taste and hearing, owing to its relations with the glosso-pharyngeal, trifacial and auditory nerves.

The deep sensibilities and the muscular sense will be considered later on. Only the sensibilities to contact and pain will be considered here. According to Luciani, sensibility to contact is respected. He has noted that if one touches the animal while he eats, or while he has his eyes bandaged, he reacts by a movement which indicates that he has felt. Russell maintains, on the contrary, that the destruction of one half of the cerebellum is followed by an anesthesia and an analgesia of the same distribution as the motor paresis, that is, localized in the two limbs on the side of the lesion and the posterior limb of the other side; the total destruction of the cerebellum entails an anesthesia and an analgesia of all four limbs.

Regarding sensibility, however, clinical observations appear to me to have more value than physiological experiments. In an animal, sensibility is always difficult of exploration and one cannot judge as to its conservation or alteration except by reflex acts. Atrophies of the cerebellum exclusively cortical or generalized do not give rise in man to any disturbance of sensibility, either superficial or profound.

Besides, the proximity of the nuclei of the posterior columns and of the cerebellum allow one to suspect that they have been compressed by blood clots following the experimental destructions. It is perhaps through this mechanism that one must explain the sensory disturbances noted by various authors; besides, they are transitory and only last a few days (Russell).

The Cerebellum and the Special Sensibilities

Among the special sensibilities hearing is the one which one most willingly localizes in the cerebellum. Treviranus has already established a relation between the degree of development of the organ of hearing and that of the cerebellar hemispheres on one side and between the vermis and the trifacial on the other side. The macroscopic relations between the eighth pair and the bulbopontine angle are of a nature to justify this hypothesis. Today it is known how little faith we must put in the findings of topographical anatomy. One can only obtain a knowledge of the relations between the different parts of the neuraxis based upon secondary degenerations in man and animals.

The eighth pair is formed from two roots. One takes its origin in the cochlea, that is, the cochlear or auditory root. The other, which originates in the semicircular canals of the vestibule and saccule, is the vestibular root, or the vestibular nerve. The cochlear root serves exclusively for the transmission of sound waves and terminates in the ponto-medullary nuclei, the ventral auditory ganglion and the acoustic tubercle, and does not contract any relation, direct or indirect, with the cerebellum. The vestibular root is of more interest to us: First, because some of its fibers, at least in animals, terminate in the nucleus of the tegmentum, second, because almost all of its fibers arborize around the cells of three nuclei (nucleus of Deiters, nucleus of Bechterew, and the triangular auditory nucleus), which are themselves in intimate relations with the cerebellum. The study of a microscopic series of sections of the medulla, the pons, and the cerebellum, show, in effect, that there exists between these nuclei and the central nuclei of the cerebellum, an important anatomical connection, represented by the internal and external semicircular fibers. Secondary degenerations show besides, that after destructions of the vermis, lesions of the vermis and of a hemisphere, the degenerated fibers can be followed to the nuclei of the vestibular nerve; on the other hand one cannot affirm that any fibers which go to the cerebellum come from these nuclei.

One cannot, therefore, affirm that the cerebellum is a center for the storage of peripheral excitations gathered by the vestibular nerve, and, consequently, a center of perception for this class of impressions.

The most that one can say, based upon the existence of some vestibular fibers which go directly to the nucleus of the roof, is to admit with Stefani that the cerebellum utilizes impressions which are furnished by the terminations of the nerves of the eighth pair to regulate the attitude of the head in space.

The fact that in cerebellar patients there is no disturbance of the compensatory reactions of the head and eyes, nor of the perceptions of movements of rotation on the centrifugal apparatus, may be cited still further against the opinion of those authors who make of the cerebellum a center of perception of vestibular impressions. Spontaneous vertigo does not enter either into the symptomatic picture of cerebellar atrophies, at any rate, if it is not foreign to certain phenomena produced by experimental lesions of the cerebellum (Vulpian and deCyon), it does not play any except a very minor rôle in the pathological physiology of the disorders of equilibration.

But one must admit that the cerebellum exercises some action upon the medullary nuclei of the vestibular nerve. Since these nuclei, the nucleus of Deiters and the nucleus of Bechterew, contain cells the axis cylinders of which, after a more or less complicated course, terminate in the nuclei of the third and the sixth pairs, and in the gray substance of the anterior horn, they represent important reflex centers.

The posterior longitudinal fasciculus is the principal path followed by these fibers. The relations of each nucleus of Deiters-Bechterew are principally crossed for the third pair and direct for the spinal column.

It is established, on the other hand, that the cerebellar fibers which terminate in the nuclei of the vestibular nerve are derived from the central nuclei (principally the nucleus of the tegmentum), and as these last named nuclei receive in their turn fibers of projection from the cortex (and more particularly from the region of the vermis), it results that the vermis is the territory of the cerebellar cortex, of which the functional activity is the most intimately connected with that of the nuclei of the vestibular nerve.

I will discuss later the importance of these anatomical relations in connection with the various hypotheses which have been given out on the physiology of the cerebellum.

The cerebellum does not play any rôle in the perception of visual, gustatory, or auditory sensations.

CHAPTER VIII

THE CEREBELLUM AND INTELLIGENCE

It is apparent that in order to study the rôle of the cerebellum in the elaboration of psychic processes, it is necessary for one to address oneself to the highest individual from the intellectual point of view in the animal series, that is, to man. The anatomo-clinical method shows itself here superior to the method of experimental physiology.

While it is true that in a sufficiently large number of observations the coincidence of intellectual disturbances with cerebellar lesions has been noted, how many times has a relation of cause and effect been established in a rigorously scientific manner between the two? Those who have thought that they have found this relation have not taken into consideration the possibility of the coëxistence of cerebral lesions, or the insufficiency of the examination of the cerebrum. Courmont, who has consecrated a large volume to the study of the functions of the cerebellum, has not been able to avoid this objection. He has utilized for the support of his doctrine—for him the cerebellum is the organ of psychic sensibility—observations in which there existed at the same time cerebellar and cerebral lesions.

With this preconceived idea as a point of departure, he chose the rat as the subject of his experiments, because, said he, "it is very impressionable." In the rat deprived of the cerebellum he examined the modifications of the five modes of expression of the emotions of the animal: "The attitude, the gesture, the jump, the flight, and the cry." After the operation, the animal assumed an indifferent attitude; he did not spring away; at each noise which startled him the jump was not the same. "There was no more any modality, there was a simple reflex movement; there was no tendency to flight, or if there was, it was slow and apathetic; the psychic cry did not exist." Among these disturbances some may be explained by disorders of motility, others by the traumatism, or the shock of the operation, and there is nothing to prove that they were the consequence of any psychic disorder.

According to Luciani monkeys appear to have their natural timidity exaggerated; in dogs, during the first few days that follow the operation, there seems to be an increase of their affectionateness. Later they are lazier and more apathetic. In this there is nothing that indicates a serious perturbation or suppression of psychic sensibility.

Patients afflicted with cerebellar atrophy are usually slow in their acts and in their reactions, and that is easily explained by the disturbances of motility and of locomotion. The apparent asthenia is caused seemingly simply by the suppression of an organ, which permits, in a sort of reflex manner, the play of all the mechanisms adapted to the perfect execution of movement, and which permits the cerebral activity to dispose itself almost entirely in the elaboration of psychic processes. As one will see further on the cerebrum supplies, in a large measure, the insufficiency or the absence of the cerebellum. If a man is obliged to exercise his will and to constantly oversee his equilibrium, his attention would be distracted from phenomena purely psychic, and this would be at the expense of the development and the upkeep of his intelligence.

CHAPTER IX

THE CEREBELLUM AND MOTILITY

The most striking phenomena observed in animals where the cerebellum has been totally or partially destroyed, and in man affected with cerebellar lesions, are above all disturbances of motility. This is the almost unanimous opinion both of physiologists and clinicians. The same unanimity is lacking when it is a question of interpreting them. For some the cerebellum is a center of energy, or reinforcement of muscular tonus; for others a center of coördination, and for still others its rôle is much more limited, it is a center of equilibration. As a center of coördination its rôle has been variously interpreted. For some authors it is intimately connected with the perception of deep sensation and therefore the center of muscular sense; the majority, however, consider that it does not contribute in any way towards the perception of sensations. This hypothesis will be discussed first, as it is of fundamental importance to know whether or not the cerebellum is a center of perception and of sensory impressions.

The Cerebellum and the Muscular Sense

Magendie had already considered the cerebellum as the center of muscular sense. Lussana and Lewandowsky are the principal protagonists of this theory.

According to Lussana the cerebellum is the central organ of the muscular sense, and he considers the posterior columns as the organs of transmission (this is an error, since the contingent of fibers of the posterior columns which terminate in the cerebellum is extremely small; several anatomists even deny their existence). According to this author the coördinating innervations from the two sides of the body unify and lose themselves in the cerebellum, and it is from this resultant that is deduced the appreciation of the center of gravity of the body and its various parts in their movements so complex and their functions so varied. The fibers of the spinal cord which terminate in the cerebellum bring to it the notions of space, of touch, and of pressure. It coördinates in this manner voluntary movements adapted to translation of the body, in the same way that a coördination of language and the movements of the face are made in the olives, and the movements of mastication and of the mouth are made in the medulla oblongata. The cerebellum contains also the centers for the coördinating movements of the eyes. The ataxia strikes in animals the thoracic limb because in animals the center of gravity is nearer the thorax; for the same reason it predominates in the lower limbs in man.

The works of Lussana have contributed to throw light upon the functions of the cerebellum in their relations to equilibration and the coördination of movements, but he has shown no experiment which was of a nature to prove that the cerebellum is a center of perception of muscular sensations and of deep sensations in general. Besides, it is only in man that it is possible to study this type of perception, as it is with every form of conscious sensation.

The theory of Lussana has been taken up again recently by Lewandowsky. He invokes to the support of his thesis some phenomena which do not lack interest.

According to Lewandowsky "each motor disturbance following a cerebellar lesion is accompanied by disturbances of the muscular sense." To the support of this theory he cites certain abnormal attitudes and certain disturbances of locomotion. Among the attitudes he insists upon that of the fore paw during repose (on the same side as the lesion, if the lesion be unilateral), often it does not lie upon the plantar but upon the dorsal surface. In the same way if the animal is lying down in the abdominal decubitus upon a table, and if the paw (on the side of the lesion) hangs over the table, the animal does not draw it back, whereas a healthy animal always does. The hindquarters may be hung over the edge of the table and the animal does not make any effort to draw them upon the table.

The motility of the isolated movements of the limbs is also disturbed. For instance, a dog wishes to seize a bone with its paw, very often the paw passes over it. The majority of physiologists have noted that during walking the paws of the dog are lifted too high. Lewandowsky has noted the same fact in other animals. In some other animals, on the contrary, the paws are not lifted high enough; in the first case he compares the gait with that of a cock, in the second with that of a cat. Not only is the amplitude of the movement exaggerated, but it is also too rapid. When the dog reëducates itself and commences to walk, the members of the side operated upon are lifted and replaced too suddenly; the phenomenon is particularly marked during running.

Luciani has also mentioned that the hand of the monkey (on the operated side) is less active, it takes hold of food in a different manner. A similar fact has been noted by Lewandowsky; the movements of prehension are abnormal, the animal seizes an object to one side, or too close to him, or too far away, and he cannot easily hold it in his hand. The disturbances of the appropriateness of the movements is seen even when the monkey tries to climb; he seizes the bar between the third and fourth fingers.

Synergy does not appear to be disturbed; it is not only direction that the animal has lost, but also the chronological sense of its muscular contractions. "Cerebellar ataxia is a sensory ataxia which depends upon a grave disturbance of the muscular sense entailing a loss of the power to graduate the movements, and regulate the proportional force, the rapidity and the succession of muscular contractions either isolated or synergically united: the movements take a marked character of non-appropriateness. . . ." Lewandowsky goes further: The cerebellum is not a stranger to the perception of superficial excitations. "The loss of the reflex of contact indicates a disturbance of cutaneous sensation."

The observations of Lewandowsky have been partially contested by H. Munk. According to his own observations (and contrary to those of Lewandowsky), the monkey only exceptionally seizes the bars of his cage in an abnormal manner. He recognizes that the dog does not always correct the vicious attitudes of his body, or at least corrects them more slowly than he normally would, nevertheless when these attitudes have been artificially produced (as Ducceschi and Sergi have noted), the correction is sometimes made in a normal manner, and at other times with a notable slowness; often also, it is true, that they are only incompletely made. These same authors also insist that this phenomenon is produced not only on the side of the operation, but also on the healthy side. They note only that the correction is slower on the operated side. Besides, when the animal commences to walk one is more rarely able to impress upon the limbs these abnormal attitudes.

To sum up, these abnormal attitudes or positions exist; the interpretation of them is more delicate. Lewandowsky attributes them to a loss of the perception of the right or wrong position of the limbs and this interpretation at first sight seems quite logical. However this may be, the lack of, or the slowness in, the correction of these abnormal attitudes attenuates or disappears with time, and it is difficult to attach to this temporary sign a definite loss of the muscular sense. May not the lack of correction of these vicious attitudes be occasioned by the feeling of uncertainty and the tendency towards inertia on the part of the animal? The animal is conscious of its awkwardness and during the first days following the operation avoids moving.

A more serious criticism has been made of Lewandowsky's position—which has nevertheless contributed to throw light upon the disorders of the isolated movements of the limbs, but in which he is possibly wrong, to deny those of synergy—that is, to have too much neglected, as also has Lussana, clinical observations. For in patients affected with cerebellar atrophy, disturbances of deep sensation are altogether lacking. Up to the present no one has noted any perturbation comparable to that observed in the affections of the optic thalamus, that is to say, in the thalamic syndrome (J. Déjerine and Egger, Roussy). One can also reproach him with having envisaged the cerebellar ataxia as a grave disturbance of the muscular sense and having hesitated as to the conscious or unconscious nature of this sense. What is an unconscious sense or sensibility anyway?

One cannot deny, however, that the peripheral excitations which originate in the trunk, or in the limbs, have a part in the mechanism of the cerebellum. These excitations are transmitted to the cerebellum through the intermediation of the direct cerebellar tract and the tract of Gowers, as noted, and section of these bundles gives rise to symptoms which have some resemblance to those which follow a destruction of the cerebellum (Bing). But these excitations are not *perceived* by the cerebellum.

On the other hand, the cerebellum receives through the intermediation of the pontine nuclei, the crura cerebri, and the middle cerebellar peduncles, a large number of impressions, which for the most part, are derived from the sensory motor zone of the cerebral cortex. The cerebellum therefore stores up impressions which come to it either directly from the periphery (spinal and restiform paths), or indirectly after having been subjected to a representation or an elaboration, from the cerebral cortex. Mann, who considers the ataxia as one of the principal cerebellar symptoms, does not differentiate it in any way from the peripheral ataxia or the tabetic ataxia. In the two cases the ataxia is due to the lack of or the suppression of peripheral excitations which originate in the muscles at the moment of their contraction. These indices of muscular innervation would normally be recorded in the cerebellum and rest below the threshold of consciousness. Mann remarks that in fact the execution of movements does not give rise to conscious sensations of articular displacements, and is not accompanied by conscious sensations of muscular contractions; this is why cerebellar ataxia is not accompanied by any apparent disturbance of sensibility. The same can be the case in peripheral ataxia.

This conception will have to be slightly modified if certain phenomena, to which Lotmar has recently drawn attention, should again be noted in cases of lesions strictly cerebellar. In two patients presenting a clinical syndrome very comparable with that of cerebellar lesions (in one case it was a question of cerebellar apoplexy, and in the other a lesion of the tegmentum of the crus cerebri affecting the superior cerebellar peduncle), Lotmar observed a disturbance of deep sensibility consisting of a defect in the estimation of weight.

The weights were contained in a pasteboard box and placed in the hollow of the hand, the two elbows being symmetrically supported, and the forearm in supination; the patient was told to estimate the weight in the right hand in comparison with that in the left by slowly weighing them in the hands. On the side of the cerebellar hemi-ataxia the weights were estimated below their real value; on the other hand the notions of displacement, position and sensibility to pressure and stereognosis were intact. Making every reserve as to the location of the lesions, which was not verified by an autopsy in either of these cases, Lotmar concludes that the cerebellum should be envisaged as a central organ, and as a relay station, not for all modes of deep sensation, but for those excitations which result in variations of tension in contracted muscles.

Hitzig has expressed a very similar opinion: The cerebellum with the subcortical organs, which are annexed to it groups the peripheral impressions coming from various sources, forms of them representations of an inferior order which it then transmits as a whole to the cerebrum. This alone would be capable of utilizing the impressions as a whole, but it would not be able to penetrate into each unit of these impressions, which would rest below the threshold of consciousness. The cerebrum has a different action from the cerebellum in the sense that it delivers conscious intentional impulses, which are divided afterwards by the cerebellum for each particular motor center.

To sum up: It has not been demonstrated that the cerebellum is an organ of perception for deep sensation which is currently designated by the name of "muscular sense." It is legitimate to admit, however, that it utilizes the oscillations of nervous flux which take their source in the displacements of the deep parts, and the variations of muscular contraction or tonicity.

As to cerebellar ataxia, it is, in my opinion, in no way identical with tabetic ataxia. Not only is the disturbance of tonicity not the same in the two cases, but they differ from one another by the absence of disturbances of deep sensibility in the first, and by their extreme frequency, not to say constancy, in the second. The observations upon which Mann bases his contention are for the most part observations of a complex nature, and in which the lesion has interrupted other than purely cerebellar paths.

Are the Phenomena Observed After Total or Partial Destruction of the Cerebellum, all of the Same Order? Is there Reason to Distinguish Between the Immediate Irritative Phenomena and the Later Ones Due to the Imperfection or Lack of Cerebellar Innervation? The Cause of the Movements of Rolling or Rotation.

The partial or total experimental destructions of the cerebellum determine, according to Luciani, two types of phenomena: (1) Immediate phenomena due to irritation. (2) Subsequent phenomena due to imperfection or lack of cerebellar innervation.

The phenomena considered by Luciani as irritative phenomena are the following:

(1) *Unilateral Destruction.*—Pleurosthotonus, or the incurvation of the vertebral arc towards the side operated upon, associated with the tonic extension of the forward limb of the same side (in the dog), and with clonic movements of the three other limbs. A contortion of the vertebral axis in a spiral fashion, principally in the cervical region, towards the healthy side, associated with strabismus and unilateral (sometimes bilateral) nystagmus (deviation of the eye of the side operated upon, inwards and downwards, and of the other eye outwards and upwards). A tendency to rotation around the longitudinal axis according to the direction of the torsion and the strabismus, that is, from the operated to the healthy side. These movements are not constantly produced except during the first days, they do not become exaggerated the following days except when the animal is approached or excited, or when it attempts to walk.

(2) *Total Destruction.*—Incurvation backwards of the vertebral column in the form of opisthotonus, tonic extension of the two forward limbs with clonic movements of the hind limbs and bilateral convergence of the eyeballs. A tendency to draw back and fall backwards. These symptoms are at first continuous, afterwards they do not arise except intermittently when the animal is excited, or when it attempts a voluntary act.

In both cases (partial or total destruction), we must add to the irritative phenomena: Agitation, restlessness, and the frequent whining of the animal.

This shows, according to Luciani, that these phenomena depend upon irritation of the efferent fibers which compose the cerebellar peduncles, that is, that in an animal which has been subjected to an extirpation of the median lobe of the cerebellum some time back, and in which many of the fibers of these peduncles have undergone degeneration, and consequently lost their excitability, if then a hemisphere is removed, the phenomena are of a much lighter character and more evanescent than if the operation had been made in one stage upon another animal.

This interpretation is very debatable, and the diminution in the intensity of the so-called immediate phenomena, after the second operation, can be just as well explained by a certain habituation and by cerebral substitution upon which Luciani has so rightly insisted, to account for the reëducation of the animal deprived partially or totally of the cerebellum.

Luciani has devoted a long and critical study to the movements of rolling or rotation around the longitudinal axis described for the first time by Parfour du Petit, and observed by Magendie, Lafargue, Schiff, Longet and Vulpian.

Physiologists have been for a long time in disaccord as to the direction of the movements which follow lesions of the cerebellum, or of the cerebellar peduncles, possibly because they have not agreed sufficiently well as to the manner of describing the direction of rotation.

According to Magendie the rolling takes place from the healthy side towards the side operated upon; according to Longet, in the opposite direction. Schiff has attempted to explain these contradictory results by the difference in the technique of the authors in doing the operations. Magendie appears to have sectioned the inferior peduncle of the same side; Longet not only sectioned a cerebellar hemisphere but also the inferior cerebellar peduncle of the opposite side (which he wrongly considered formed of crossed fibers in the white substance of the cerebellum). Schiff has brought to light another fact of great value. He observed that if the rabbit (it was upon this animal that he made the demonstration) is left free at the moment of section of the peduncle, he executes at first two or three rolling movements from the operated side towards the healthy side, and afterwards a whole series of movements in the opposite direction;

the first movements would be due to irritation and the second to paralysis. Section of the middle cerebellar peduncle would place an obstacle to the passages of the voluntary influx to the muscles of the vertebral column of one side.

Contrary to the hypothesis given out by Serres and Lafargue, the limbs would not play any part, or at least any prominent part, in the production of the phenomenon because it takes place just as well when the posterior limbs are immobilized or paralyzed by section of the sciatic nerve. Nevertheless, Schiff contests the theory of Henle, Gratiollet and Leven who attributed the movement of rotation to an optic vertigo: the phenomenon takes place just the same in blind animals as in those which can see.

Luciani admits also that movements of rotation take place after section of the peduncle at first towards the healthy side, and afterwards in the opposite direction. The first movements towards the healthy side are engendered by the unilateral exaggeration of the cerebellar influx transmitted to the irritated peduncle, whereas, the others are produced in the opposite direction because the cerebellar influx suddenly ceases to exist in half of the centers, while the other half continues to receive them. The predominance of the action of half the centers is the necessary condition, and the impression of vertigo is the immediate cause. Luciani admits, however, that the phenomenon of rolling can exist without vertigo, but the vertiginous movements seem to have the character of impulsive and irresistible movements. The movements of simple functional predominance of half of the encephalon would have the character of ordinary voluntary or reflex movements. But Luciani attacks the fundamental conception of Schiff for whom the movement of rotation is due to the unilateral interruption of voluntary impulses to the rotatory and fixing muscles of the vertebral axis: The cerebellum is not an organ of the will, that is to say, an organ intercalated in the great path of cerebro-spinal conduction.

Nevertheless, in animals from which he had removed half the cerebellum, Luciani observed movements in only one direction, that is, towards the healthy side, movements which he had observed during the phase of excitation, and which he considered as irritative phenomena. The movements of rotation in the opposite direction would not have been avoided except for the intervention of the muscular sense, and the proof is that if the muscular sense and the motor impulse be suppressed by destroying a part of the sensory-motor area, the animal is seen at every effort to walk, to roll around the longitudinal axis towards the side upon which the cerebellum is lacking. Upon this point my own experience does not coincide with that of Luciani.

Besides, in the dog, according to Luciani, it is not only the muscles of the vertebral axis which contribute to the production of the rolling, those of the limbs have also their part.

The opinion of Luciani which I have just cited, almost word for word, does not appear to me to be acceptable, and for several reasons. Luciani considers the movements of rolling which he observed in dogs, as movements due to irritation of the peduncle; we must recall that the animals Luciani operated upon were anesthetised and that the movements which he calls irritative were not produced until after the awakening of the animal. I, also, operated upon animals under an anesthetic, but in some cases the anesthesia was not complete when I removed the cerebellum and sectioned the peduncles. I then observed, exactly at that time, some movements of rotation in the opposite direction to those which I observed upon the awakening of the animal. These results may be compared with those obtained by Schiff when he sectioned the peduncles. The first movements which are irritative movements, provoked by section of the peduncle, are altogether comparable to the muscular contraction which is produced when an anterior root is sectioned; those which take place after the awakening are paralytic movements, that is to say, due to the suppression of the cerebellar function. It is these that Luciani has mistaken for irritative phenomena. He did not take into account the fact that the really irritative movements were masked by the narcosis.[1]

It is enough, besides, as I have already remarked in my thesis, to follow the evolution of the disorders of locomotion to thoroughly understand the nature of the phenomena. "When

[1] Luciani says that in animals the rotation around the longitudinal axis is made from the operated side towards the healthy side, but he determined the sense of rotation according to the direction and torsion of the head, and the strabismus; the results which he obtained, therefore, accord perfectly with ours.

half the cerebellum has been destroyed, whatever be the attitude that the animal wishes to take, and whatever be the movement that he wishes to execute, he is drawn towards the side of the lesion and falls on that side. The first days after the operation he is animated with movements of rotation around the longitudinal axis from the healthy side towards the side operated. (The sense of the rotation is determined by the side upon which the animal falls when he is placed in an upright station, *i. e.*, when he is placed upon his four paws. As he always falls upon the operated side one may say that the rotation takes place from the healthy side towards the side operated.) In repose he rests upon the side of the lesion, and in the abdominal decubitus the head is deviated in the same direction. Later, when he makes his first attempts to walk he is drawn in spite of himself by a movement of translation towards the operated side, and if he falls, he falls on this side. It seems, therefore, that the rotation around the longitudinal axis from the healthy side towards the side operated upon, the decubitus upon the side of the lesion, the fall and the movement of translation in the same direction are but different degrees of the same phenomenon. If the movement of rotation is due to the irritation of the efferent fibers which have been cut, there should be a different direction of the movements consecutive to the suppression of these fibers, and they should be made from the operated side towards the healthy side."

We see how involved is this question of the movements of rotation, not only as concerns the fact itself and its nature, but also as regards the terminology and manner of indicating the direction of the movement. Perhaps these last explanations will permit us to understand this phenomenon, and the contradictions to which it has given rise, more thoroughly. The physiological mechanism of the movements of rotation of the body, as well as those of the conjugate deviation of the eyes, may be cleared up in a certain measure by the knowledge which we have acquired in the last few years concerning the architecture and the anatomical relations of the cerebellum.

The tonic action of the cerebellum is exercised in the case of the vermis by the intermediation of the descending cerebellar bundle, the cerebello-vestibular bundles, and the nucleus of the vestibular nerve, in relation to the spinal cord; for the hemispheres by the intermediation of the superior cerebellar peduncle and the red nucleus; upon the spinal column (the rubro-spinal bundle) by the intermediation of the superior cerebellar peduncle and the thalamus upon the cerebral cortex (thalamo-cortical fibers).

Each half of the vermis enters into relation with the nuclei of the two vestibular nerves, and with the two sides of the spinal column, but more with the same side by the cerebello-vestibular bundles. It is probable that each half of the vermis does not contract the same relations with the two sides of the spinal column, and consequently, presides over a certain coördination.

Each nucleus of Deiters sends fibers to the oculo-motor nuclei, particularly to the nucleus of the sixth pair of the same side, to the nucleus of the third pair of the opposite side, to the centers of the muscles of the trunk, and the limbs of the same side (posterior longitudinal fasciculus and antero-lateral bundle).

When the cerebello-vestibular bundles are interrupted on one side, a conjugate deviation of the eyes results, such that the eye of the side of the lesion looks downward and inward, and that of the opposite side looks upward and outwards. There is a deviation of the head in the same direction, and a movement of rotation from the healthy side towards the operated side. This totality of phenomena does not differ in any way from that which is obtained from exciting the nucleus of Deiters-Bechterew on the side opposite the lesion. One may admit that in the normal state the forces developed by the two nuclei of Deiters balance one another. If one of them disappears or is diminished in large measure on account of the suppression of the cerebello-vestibular bundles of one side, the other, continuing to act, produces symptoms analogous to those obtained by the excitation of the homolateral nucleus of Deiters-Bechterew. We may reason in the same way concerning the olivo-thalamo-cortical path (superior cerebellar peduncle, thalamus and cerebral cortex), and for the olivo-rubro-spinal path. The results of section of the superior cerebellar peduncle justify this point of view.

Is the Cerebellum a Center of Muscular Energy?

Based upon numerous experiments made upon animals belonging to four types of vertebrates, Rolando attempted to demonstrate that the cerebellum was an organ destined for the preparation and secretion of nervous energy, which diversely conducted and modified manifested itself principally in the production of motion and of voluntary movements. Partial alterations of it gave rise to disturbances of voluntary movements, complete destructions to total paralysis. The cerebellum would have even a greater part than the cerebrum in the phenomena of motility. In placing one of the poles of a battery in contact with the cerebellum and the other with a limb, stronger shocks were obtained than if the first pole were placed upon the cerebrum. This influence, however, did not belong properly to it—it borrowed it either from the senses or from the hemispheric excitations. Taking microscopical examination, on the other hand, into consideration, Rolando thought that the large number of lamellæ, alternately gray and white were an electric battery which developed electricity which excited movements.

This theory was criticised by Magendie. He did not deny the facts announced by Rolando, but he did not accept the explanation for he had seen animals deprived of the cerebellum "which nevertheless executed very vigorous movements. I have seen hedgehogs and guinea-pigs deprived not only of their cerebrum, but also of their cerebellum scratch their noses with their fore paws when I placed a bottle of vinegar under their noses."

The theory sustained later by Luciani presents some marked analogies with that of Rolando. Once the irritative phenomena have subsided, the Florentine physiologist distinguishes two orders of phenomena, the phenomena of suppression and the phenomena of compensation.

The suppression is essentially characterized by the imperfect energy that the animal uses in its voluntary acts, by the lack of tonicity of the muscles, and by the abnormal method of their contraction.

Luys also considered the general state of weakness, and the progressive extinction of muscular power as a disturbance characteristic of the locomotor functions in individuals affected with lesions of the cerebellum.

This weakness "may present an infinite number of degrees, from a simple lassitude to a profound prostration with the most complete apathy. The movements are sometimes not harmonic, but hardly ever completely abolished. There is asthenia and not paralysis."

After the destruction of the cerebellum by caustics Weir Mitchell observed the phenomena of incoördination, drawing back, and backward falls, but these phenomena were of short duration. That which persisted was a well marked weakness of all movements, whether voluntary or involuntary. The cerebellum would then be an organ of reënforcement, the action of which would be very analogous to that of the spinal and cerebral ganglionic masses.

Dalton insisted also upon the persistence of weakness when the phenomena of the first stage had disappeared.

Dupuy sustained a similar opinion: If a complete ablation of the cerebellum were made, the peduncles sectioned entirely and at the same level, and the whole operation done at one time, there were no locomotor symptoms in the animal experimented upon (dog, rabbit, and guinea pig). The most striking thing was the extreme weakness in the movements of the individual as a whole, and even comparing the weakness which follows the ablation of the cerebral lobes with that consecutive to the ablation of the cerebellum, one is surprised to see that the animal preserves more strength in the first case than in the latter.

The compensatory acts consist according to Luciani, in the isolated form of the voluntary movements, in the anomalies of measure and direction. The totality of these phenomena constitutes cerebellar ataxia.

After the unilateral destruction the weakness is such in the muscles on the side of the operation that the animal might be taken for a hemiplegic; he drags himself along the rump of the side operated upon making his efforts with the limbs of the healthy side. This condition may last for several weeks, according to Luciani. By leaning against a wall the animal may move in a regular manner, but his limbs bend under his own weight. The animal can, however, swim, but the flank of the side operated upon is always plunged deeper in the water than that of the healthy side. The same phenomena are observed for a month or more, during which time the animal makes various attempts to get up and walk. These attempts are the manifestations of the compensatory acts which are capable of correcting and repairing the effects of the suppression of the cerebellum. The animal broadens its base of support by spreading the front limbs apart, particularly the one on the injured side and the vertebral column is incurved towards this side.

This compensation has its limit. The animal which walks in this way on a smooth surface cannot walk upon a rough or curved surface. When food is offered to it, if it is held a certain distance above the head, the animal attempts to rise up vertically, but falls back on account of the flexion of the posterior limbs. If it is made to pull a weight tied to the tail or to the limbs, its fall is almost certain, particularly if the weight is tied to the limbs of the heathy side.

Luciani concludes from this that the lack of innervation from one half of the cerebellum determines a homonomous neuro-muscular hemiasthenia. There is a diminution of the normal tonus of the muscles, on palpation the muscles appear to be more flaccid, and less tense on the side of the operation than on the healthy side. This is *asthenia*.

During station upon the four paws the animal often flexes the limbs of the side operated upon. The falls seem to be due to the relaxing of the muscles. He raises the paws of the injured side higher from the ground, and replaces them more suddenly. To this second category of phenomena Luciani gives the name of *atonia*.

Finally, there exists tremor, oscillations and wavering which depend upon an imperfect summation of the elementary impulses which govern contraction. This third category of phenomena constitutes *astasia*.

In animals completely deprived of the cerebellum, atonia, asthenia and astasia are still more marked. After a period during which the animal falls continually, first on one side and then on the other, striking the head, he succeeds at first in raising the front paws, but the hind paws bend under him. When the animal tries to eat, his body is animated by strong antero-posterior oscillations. Little by little, he succeeds in walking without falling, and progressing without help. These phenomena are not caused by a lack of coördination says Luciani, because the animals are able to swim. The functional restitution which gradually is produced is due entirely to a substitution by the sensory-motor zone of the cerebral cortex when the extirpation has been total.

The falls are due to the atonia and the asthenia of the muscles of the vertebral column which cause a greater upward convexity of the vertebral axis, and determine thus an elevation of the center of gravity, and, consequently, a loss of stability of equilibrium. There results also a lesser fixity of the vertebral axis which renders the horizontal oscillations either active or passive, more difficult to resist. Luciani does not see in the drunken gait any perturbation of the sense of equilibrium. The efficacy of the compensatory acts by means of which the animal avoids a fall, shows on the contrary that this sense functions normally.

Luciani concludes, from his experiments, and the anatomical findings furnished by the study of secondary degenerations, that the cerebellum is an homogenous organ. An organ of which each segment has the same function as the whole, and the power of supplying the absence of the others. The loss of the vermis may thus be compensated for by the lateral lobe. The cerebellum exercises, in the normal condition, an influence upon the rest of the nervous system, which is expressed by an action, neuro-muscular, sthenic, tonic and static, that is to say, a complex action by which the cerebellum augments the potential energy which is dispensed by the neuro-muscular apparatus (sthenic action). It increases the duration of their tension during the functional pause (tonic action); it accelerates the rhythm of the elementary impulses during their functional activity and assures a normal fusion and regular continuity of action (static action). The influence of the cerebellum does not alone manifest itself upon those muscles which enter into activity in the different forms of upright station and locomotion, but also in all voluntary movements, particularly those of the superior and inferior limbs, and upon those muscles which fix the vertebral column.

The complex action of the cerebellum is a trophic action, which is exercised directly or indirectly. Directly it is shown by the secondary degenerations; indirectly it affirms itself by the slow degeneration of the muscles and the skin, by the general or local dystrophic troubles, by a greater slowness in the growing and the renewing of the tissues, by a diminution of the resistance of the animal against the harmful actions of external agents, and, finally by a general shortening of life.

The activity of the cerebellum is not an activity *sui generis* but rather an activity common, and so to say, fundamental, to the whole nervous system. The physiological value of the cerebellum in the animal life is quite comparable to the value of the peripheral nerve ganglia in the vegetative life. The cerebellum may be considered as a small auxiliary and reënforcing system of the great cerebro-spinal system.

"Finally if it were shown that dysmetria were a constant phenomenon, it would be necessary to add to the sthenic, static, and tonic effects, an action of accommodation, "umpassen de Wirkung," upon which would depend the proper measure, the precision, and the accommodation to the object in view, of the different voluntary, automatic or reflex acts."

The ideas of Luciani have not been universally accepted, and some objections may be made to them. Some in relation to the facts, and others to the interpretation of them.

The observations of Luciani agree, for the most part, with those that other physiologists have made in repeating his experiments. Nevertheless, if I may be allowed to bring in my personal experience, I would remark that reëducation has been less slow with my animals than with Luciani's. In the dog deprived of half the cerebellum, the weakness has never been such that the animal could have been taken for a hemiplegic, or that at any advanced period he sank down under his own weight when he tried to stand up on his hind legs to seize food. Animal fell on one side or backwards, but contrary to what Luciani says, the fall was not due to the flexion of the hind legs. The animals operated upon by Luciani seem, therefore, to have been weaker than those operated upon by other physiologists and by myself. Perhaps in the course of his experiments, Luciani injured centers in the neighborhood of the cerebellum, particularly those of the pons. To the support of this explanation we may mention the secondary degenerations studied by Marchi in the animals upon which Luciani had operated. The degenerations in the spinal cord pass the limits of those which are produced by lesions strictly limited to the cerebellum. They included a bundle situated in the lateral column, and which was none other than the rubro-spinal bundle, or bundle of Monakow, that is to say, a bundle which comes from the red nucleus and passes through the pons.

It is probable that the diffusion of destructive lesions upon the organs of the neighborhood is the reason why there was a greater intensity of the symptoms and a paralytic weakness in Luciani's animals.

Nevertheless, Patrizi contends that the movements of protection are less energetic upon the side corresponding to that of the cerebellar hemisphere which has been removed in the dog. To demonstrate this fact he suspended weights from the hind legs after having fixed the trunk and the fore legs; then he excited the skin of the back by means of a faradic current; on the operated side the weight was not lifted so high. The same was the case when the muscle was directly excited, which the author explains by a diminution of tonus.

Longet had already remarked, in opposition to the theory of Rolando, that after the operation on the cerebellum in birds and in young mammals Rolando himself had always seen these animals still perform energetic but incoördinate movements with their four limbs.

The cocks from which Laborde removed the cerebellum, lifted without trouble somewhat heavy weights suspended from their claws. When the paw of a decerebellated animal is pulled, even on the injured side, he retracts it with energy. Asthenia, in the sense which Luciani gives to it, is altogether lacking; the giving way of the legs is not a part of the symptomatology of cerebellar affections.

In patients affected with cerebellar atrophy without a cerebral or spinal lesion at the same time, there is no paralysis.

I have never observed muscular relaxation or hypotony in the sense which is given it by clinicians, in the patients which I have had an opportunity to examine. The sthenic or tonic action of each half of the cerebellum upon the corresponding half of the body nevertheless exists, but it appears to me adapted for a certain purpose, that is, the maintenance of equilibrium.

On the other hand, when Luciani attributed the tremor, the oscillation, and the wavering, to an imperfect summation of elementary impulses, he furnished an explanation which is more conformable to reality.

For certain authors, Adamkiewicz, among others, the cerebellum is more than a regulator. It is an organ, the action of which assures the execution of all of the movements of the body, of which the will assures the initiation. It not only elaborates the force which is transformed into movements in the muscles—it contains also a particular center for each group of muscles, and for all a sort of keyboard upon which the will plays in the same way that the musician plays upon the piano. Considerations of various kinds have given to the cerebellum a preponderant rôle in the elaboration of movements. In mammals, even those at the top of the scale (superior apes), the hemiplegia, which follows the ablation of the motor zone of the cerebral cortex, is only transitory, and the animal recovers almost completely the faculty of executing movements with his paralyzed limbs. In the same way the section of the two pyramids in the monkey does not abolish the faculty of executing movements. After the section of the crossing of the pyramids Rothmann did not observe any symptoms of spastic paralysis, only a certain awkwardness and an exaggeration of reflexes, which persisted two or three weeks, was produced. In man, the resection of the motor zone, practiced for the purpose of relieving epilepsy, is often only followed by a light hemiplegia which improves with time. Often, only disturbances of sensibility and incoördination of movements are observed.

These results appear to be in contradiction to the teachings of pathology, and in effect, foci of cortical softening situated in the motor zone entail permanent paralyses, which are accompanied by very severe contractions of the paralyzed member. This contradiction, is perhaps only apparent; the foci of softening are rarely limited to the cortex of the motor zone, and always trench more or less upon the adjacent white substance and the neighboring convolutions and are not in any way comparable to surgical resections. The zone of the cerebral cortex which projects itself upon the cerebellum through the intermediation of the cerebral peduncles, the pontine nuclei, and the middle cerebellar peduncle, is much more extended than the cortical motor zone (ascending frontal convolution). It comprises, among others, the ascending parietal and the second and third temporal convolutions. If we only take into consideration the involvement that these two types of lesions (that is, surgical resections and foci of softening) may have upon the anatomical and physiological relations of the cerebrum and the cerebellum, we cannot put them both in the same category.

We may ask in fact, what organ is it that presides over the elaboration and execution of movements since the motor zone of the cerebrum may be destroyed without abolishing motility. By reason of the importance of its development and its anatomical relation and of its indisputable rôle in the physiology of movement, one would be disposed to admit that this organ is the cerebellum. It is more probable that it is one of the vicarious organs which may supplement the excitable zone of the cerebral cortex. The disturbances of locomotion are, in fact, permanent when the cerebellum and the excitable zone are simultaneously destroyed, but we cannot range ourselves with Adamkiewicz and make the cerebellum the center of voluntary acts and movements, since, after the destruction of the cerebellum (both in animals and in man), voluntary movement is not abolished, but only modified.

Horsley has returned recently to this question in connection with a very interesting case of resection of the gyrus precentralis (ascending frontal), in an individual affected with Jacksonian epilepsy. The portion of the gyrus which was to be removed was excited by bi-polar faradic currents, and it was posisble to ascertain that the excited lesion corresponded to the center for the upper limb. After the operation the motility of the limb was, in large measure, restored, and from this point of view the result was quite comparable to those which have been obtained in monkeys. Horsley recalls, in this connection, that Rothmann was able to obtain isolated movements of the arm by electrical excitation of the corresponding center, after having interrupted, and consequently put out of consideration, the pyramidal path. He concludes from these various observations that voluntary movements have not their only source in the motor zone of the cerebral cortex. The motor function would also be put into play by the gyrus post-centralis (ascending parietal) which is a center of representation of the limbs, and the fibers of which project themselves through the thalamus by following the internal capsule. One might suppose that after the disappearance of the peduncular path, the restitution of the motor functions was made through the red nucleus and the rubro-spinal bundle of Monakow. The red nucleus does receive, in fact, fibers from the thalamus and from the cerebellum (superior cerebellar peduncle). For these reasons we cannot accord the cerebello-rubro-spinal path the principal part in substitution for the cortical motor zone in the execution of voluntary movements, and the hypothesis given out by Horsley, that of the substitution by means of the parieto-thalamo-rubro-spinal path, seems at present the more acceptable. There is occasion, however, to make some reservations as to this interpretation. It is applicable, perhaps in the case of man, whereas, it is debatable in the case of monkeys and other mammals. In fact by making a bi-lateral section of the lateral columns of the spinal cord, that is to say, by interrupting at the same time the pyramidal tract and the bundle of Monakow, Rothmann produced in the monkey only a slight and transitory paresis of the extremities. The question, therefore, is not definitely solved, and besides, the respective rôles of the various centers in the elaboration of movements is far from being definitely elucidated, and it would be imprudent, in this connection, to force analogies between man and animals. Nothing, in any case, authorizes us to look upon the cerebellum as a generating center for voluntary movements.

Hemiplegia, or rather hemiparesis, noticed by Pineles and Mann in certain individuals afflicted with lesions seated in the cerebellum or in the course of the cerebellar paths, may be invoked in support of the theory at present under discussion. Without entering into the details of these observations in which it is mentioned, we may remark that these observations concern principally tumors, or at any rate lesions which do not affect exclusively the cerebellar paths. When these lesions are located in the tegmentum pontis, and cut off, either partially or wholly, the efferent or afferent fibers of the cerebellum, it is rare that they do not trench upon other fibers of the tegmentum, and the pathological physiology therefore becomes extremely complex.

On the other hand, hemiplegia is not constant, and is lacking in observations of lesions strictly confined to the cerebellum. Mann explains it besides as cerebellar ataxia, due to the suppression of the peripheral excitations which come from the muscles. This has, as a consequence, a weakening of the force of innervation.

The Cerebellum the Center of Coördination and Regulation

Flourens (1824–1842), whose numerous experiments on the cerebellum have remained justly celebrated—these experiments were made principally upon birds but also upon reptiles and mammals—is the first author who localized the faculty of coördinating and regulating movements in the cerebellum.

I recall firstly, the fundamental results of his experiments. In removing the cerebellum of a pigeon by successive layers, he noted that the movements became at first brusque and ungoverned then, gradually, the animal lost the ability to jump, to fly, to walk, and to hold itself upright. Equilibrium was abolished, to remain in an upright position the animal was obliged to support himself with his tail and his wings. The gait was staggering and it had the air of a drunken animal.

It was the same in the case of a turkey cock, whose staggering gait resembled that of a drunken man. After complete destruction, the upright position and walking were impossible. A dog, from which he had removed the cerebellum by deeper and deeper resections, lost immediately the ability to move with order and regularity. The gait became staggering; he drew back when he wished to go forwards. His efforts to feed himself were very great but he could not moderate them. He threw himself forward with impetuosity, and did not fail to fall or roll over himself. He could not seize with his mouth with certainty any object which was presented to him.

From the ensemble of these experiments, Flourens draws the following conclusions:

"1st. In mammals as well as in birds, a slight alteration in the cerebellum produces a slight disharmony in the movements. This disharmony grows with the alteration, and finally, the total loss of the cerebellum engenders the total loss of the regulating faculty of movements.

"2nd. Nevertheless, there is in this regularity and this exact repetition of phenomena, a curious fact, and that is that the movements thus disordered by reason of the lesion of the cerebellum, correspond to all the ordered movements. In a bird which flies it is in the flight that the disorder appears; in a bird which runs, it is in the gait; and in a bird which swims, it is in the act of swimming. There is a swimming and a flight resembling drunkenness, just as there is a gait.

"Along with the loss of the cerebellum coinciding constantly with the loss of the locomotor faculties, the intellectual and perceptive faculties do not lose their integrity in any way and on the other hand, as long as the operation does not pass the limits of the cerebellum, there is no sign of convulsions.

"The faculty productive of convulsions or muscular contractions, the faculty of coördination of these contractions, and the intellectual and perceptive faculties, are three orders of faculties essentially distinct, reposing in three kinds of nervous organs, also essentially distinct."

Although all the movements of locomotion may be lost, the movements of conservation are none the less preserved.

One cannot express more positively the coördinating and regulating action of the cerebellum in all movements and in the maintenance of equilibrium.

The coördinating action of the cerebellum has been variously defined by physiologists. Schiff criticizes the theory of Flourens. It is not the irregular succession of movements that is observed after a cerebellar lesion. It is an alteration of the form and the direction of the movements; but the general direction of the movements is preserved. The head is raised when the animal wishes to raise himself upon his paws; it is lowered when he wishes to run away. Schiff recognizes nevertheless that all these movements are disturbed, that there are oscillations and waverings, but the animal reacts in an appropriate manner to these oscillations and to this wavering. To verify the conservation of coördination he placed a squirrel which had been deprived of its cerebellum upon a sounding board; it was easy to observe that the rhythm of the gallop was preserved. The succession was not altered, but the isolated sounds which made up the principal tempo had become unequal in intensity and duration, etc.

The reason for the oscillation of the head is not to be sought, according to Schiff, in an insufficient muscular contraction, which allows the weight or the elasticity of the antagonistic muscles to act, but in a too intense nervous impulse to the antagonistic muscles at the same time. This is why when the animal seeks to take a piece of meat which it sees upon the ground, one can feel by palpation of the back of the neck, slight intercurrent contractions of the elevator muscles of the head. These contractions are provoked every time that the head attempts to take or preserve an attitude. If the animal is lying down or if he wishes to sleep all these contractions disappear. The same phenomenon can be observed in the fixator muscles of the dorsal column, and of the lumbar column when the animal wishes to sit up upon his hind paws.

In conclusion, there are aberrations of the motor innervation, which act, not only upon the muscles whose contraction is necessary, but also upon the antagonists and the neighboring muscles.

The action of the cerebellum would thus not be a braking action, such as one arresting certain irradiations of the motor innervation; this action would rather be concentrated entirely in a determinate impulse. In such a hypothesis a bilateral lesion of the cerebellum would entail alterations of movements twice as intense, whereas Schiff insists upon the fact already brought to light by Vulpian that the disturbances of coördination are much less marked after absolutely symmetrical lesions of the cerebellum.

The conclusion of Schiff is that in the cerebellum the apparatus is located which puts into play groups of muscles necessary for the accomplishment of a complicated movement. Not only groups of muscles which direct the wished for movement, but also other groups of muscles which only fix the limb and the joints, and which thus prepare fulcrums for the levers and whose feeble contractions are antagonistic to the movements of the whole.

If paralysis and feebleness of movements are not the consequence of cerebellar lesions, it is, nevertheless, necessary to admit that from the beginning movements are not made with their normal force, the slowness of the movements proves this. Schiff admits that he is entirely unable to explain the mechanism of this seeming reënforcement of movements.

There are, in the views of Schiff, upon the functions of the cerebellum, some very ingenious ideas and some hypotheses which are at first sight extremely seductive. They are not, however, beyond discussion. If coördination is disturbed it is not in as far as concerns the direction of the movement which is preserved. The majority of the authors, both physiologists and clinicians are unanimous upon this point. Once more, the motor disturbances of cerebellar patients differ from peripheral ataxia by the preservation of the direction of the movement and by the practically negligible influence of the suppression of sight. On the contrary —both experiments and clinical observation have shown it—the measure of the movement is altered. Luciani admits, with some reserves, that dysmetria exists. The same with Munk. The squirrels of Schiff appear also to execute movements of unequal force, lacking measure. A dog in which the cerebellum has been destroyed raises his paws higher than normal. When the destruction has been in one hemisphere only, only the paws of the same side are raised too high and replaced too forcibly. The same thing happens with a cat (André-Thomas). Lewandowsky mentions unmeasured movements of the fore paw when the animal tries to seize a bone. The clinicians have noted a number of times movements of too sudden a nature in the course of cerebellar atrophies (Déjerine and André-Thomas). Babinski has observed unmeasured movements in patients "in whom the cerebellar apparatus" was in question. I myself with Jumentié have insisted upon the presence of dysmetria when the movements were too rapidly executed, and this is probably the reason why the movements of cerebellar patients are usually slow. They have a feeling of their awkwardness in the too prompt execution of movements.

In the execution of a movement there is nothing but dysmetria. Whether it is a question of movements or attitudes of the head, of a limb, or of the body in cerebellar patients, or in an animal upon whose cerebellum there has been an operation (above all, the monkey), these movements differ from normal movements by oscillations or tremor. The tremor does not exist in the state of complete relaxation of the muscles. It is produced in two conditions: during the execution of the movement, and during the maintenance or beginning of an attitude (see page —).

We recall that this tremor may receive two explanations: (1) The movement is too sudden and unmeasured and the patient corrects it by the antagonistic muscles; this explanation has been previously refuted by me. This is a hypothesis similar to the one proposed by Schiff, with this difference, that according to him intervention of the antagonistic muscles is not voluntary but consecutive to an aberration of the motor innervation. This does not appear to us to be any better founded. If when the dog, alluded to by Schiff, seeks to seize a piece of meat which is on the ground, one can feel by palpating the neck slight intercurrent contractions of the elevating muscles of the head; it is not proper to consider these contractions as contractions of the antagonistic muscles, for in this attitude the action of these elevating muscles is directly adapted to the object in view. Really, during the lowering of the head these muscles are relaxed, but incompletely so. The maintenance and variation of their tonicity are essential conditions for the accomplishment of these movements of prehension.

The second hypothesis seems to me to conform more to the facts, as I have already said.

(2) Arrests and recontractions are produced in the muscles. The movement instead of being continuous or tonic is in a way epileptoid or clonic (André-Thomas and Jumentié). There is, according to the expression of Luciani, a defect in the summation of the elementary impulses. The cerebrum supplies the place of the cerebellum, but to a measure in an incomplete manner, and it does not succeed at first in fusing the volitional incitations which preside over the execution of the movement, or the maintenance of the attitude, unless the movement be slow and watched over. Stability, nevertheless, can be attained, but at the expense of a certain time and it is preceded by a period of attempts.

Dysmetria shows in its turn that the elementary impulses are too strong, and consequently that the cerebellum exercises a braking influence upon the totality of the movements. J. Babinski expresses a similar opinion. But, we say again, this influence is manifested in moderating the elementary impulse, and not in causing the antagonistic muscles to intervene.

If the suppression or the diminution of the cerebellar function is followed by dysmetria and discontinuity of movement, one must admit that the cerebellum has a particular tonic influence which has for its object the regulating of the movement and the assuring of its execution with a minimum effort and a perfect adaptation to the object in view. It is thus that we must look upon the tonic action of the cerebellum, and the astasia (*i. e.*, the oscillation and intention tremor) would seem only to be a consequence of it. In reality this is practically the same idea expressed by Luciani when he says that the tonic action of the cerebellum consists in increasing the duration and the tension of the muscles during functional pause. The action of the cerebellum is, therefore, at the same time inhibitory or braking, and excitor-motor or tonic. In any case, the disturbances of tone of cerebellar origin should not be confounded with the hypotonus of tabetics, which is manifested by an articular relaxation.

The cerebellum is a regulator, but it is not only a regulator of muscular contractions; according to Schiff the cerebellum is the seat of apparatus which puts into play the muscular groups necessary for the accomplishment of complicated movements, and as such it plays a preponderant rôle in equilibrium. This is, in fact, the theory of asynergy propounded by J. Babinski, which will be taken up again a little further on in relation to equilibration. Munk and Probst have expressed a similar opinion. For them the cerebellum is a regulating apparatus for muscular action, entering into play in the maintenance of the station of the body, in locomotion and in voluntary automatic and reflex movements.

According to the observations of Horsley, the activity of the nerve centers is translated by a combination of clonus and tonus, and the motor manifestations differ according to the proportions of one or the other. Clonism is a property of excitation from the cerebral cortex and tonism of the subjacent centers. The conclusions of Horsley and Bouché are very easily demonstrable on this point. They injected essence of absinth into the jugular vein of a cat three weeks after the ablation of the left cerebral hemisphere. On the left side a tonico-clonic access of contractions was produced with the limbs in flexion, on the right side a tonic access, principally in extension. During the course of an access, the authors made an instantaneous section of the mesencephalon: immediately the clonic movements were changed into tonic ones in the whole body, the head was drawn backwards and the limbs of the left side were in extension. Excitations of the inferior centers, among which is counted the cerebellum, gave rise to exclusively tonic attacks. Some clinical facts also sustain this observation. I will cite among others the following observation of Jackson. It concerns a child afflicted with a tumor of the median lobe of the cerebellum as large as a billiard ball. The gait was staggering, the legs executed excessive movements and were stiff and in extension along the prolongation of the body.

The feet were in hyperextension, slightly inclined inward. Occasionally tetanoid convulsive attitudes were observed. This is how they were produced according to Mackenzie who observed them: The forearms were flexed upon the arms, the arms were held close to the sides, the head drawn backwards, with an incurvation of the back, the legs stretched out, also incurved. The patient passed urine sometimes during these crises. During the crisis the attitude was the caricature of a man or a child running very rapidly. Jackson concludes from this that in convulsions of cerebellar origin the spasm is tonic, whereas in cerebral convulsions it is principally clonic. The convulsions affected more the bilateral muscles of the legs and trunk, whereas in cerebral affections the muscles of one side are more affected, and those of the arm more than those of the leg. These crises resemble tetanus more than epilepsy. In conclusion, according to Jackson, the cerebellum coördinates more particularly those movements which serve the purpose of locomotion and other quasi-automatic acts, whereas the cerebrum coördinates more particularly those movements which serve for voluntary acts.

This opposition established by Jackson between the clonic character of the cerebral convulsions and the tonic character of those of cerebellar origin, is to be compared with the special form that movement takes in individuals affected with cerebellar atrophy. It becomes discontinuous and clonic, apparently on account of the disappearance of the tonic cerebellar influx.

The Cerebellum and Reflex Movements

In animals which are deprived of half of the cerebellum the tendon reflexes without being spasmodic are exaggerated on the side of the destruction (Russell and André-Thomas). In the same way an exaggeration of the reflexes is noted in man in most of the cases of primary atrophy of the cerebellum. It seems, therefore, that under the influence of the functional suppression of the cerebellum there would be in the reflex movements, as in the voluntary and automatic movements, a defect of measure. One may allow to the cerebellum a general braking influence, exercised over all movements. Patrizi has controlled this fact by the graphic method, the reflex is prompter, and the excursion of the member is greater on the side of the hemi-destruction.

The Cerebellum, Equilibration and Synergy

It is incontestable that dysmetria and discontinuity of movement contribute to disturb equilibration. The disturbances of equilibration, however, appear to consist of more complicated disorders.

The loss of equilibrium was noted by Flourens in the animals from which he removed the cerebellum in successive layers. According to Bouillaud, an animal deprived of its cerebellum is not paralyzed. What it lacks is coördination of the movements of walking and of standing. On the other hand, the simple movements of the head, of the trunk and of the limbs can be performed. Bouillaud admits that there exists in the cerebellum a force which presides over the association of the movements of which the divers acts of locomotion are composed.

The experiments of Ferrier upon the functions of the cerebellum have been previously related at length. Some reservations were made as to the value of the results from electrical excitations, because those authors who have repeated them did not obtain concordant results; the excitability of the cerebellum is still a question to be studied. Ferrier looks upon the cerebellum as a complex arrangement of centers individually differentiated, which, acting together, regulate the divers muscular adaptations necessary for the maintenance of equilibrium. Comparing the effects of excitations with the symptoms observed in the course of disease, or in experimental lesions of the cerebellum with those which have been described by Purkinje and Hitzig, as when one causes a galvanic current of moderate strength to flow through the head, with the vertiginous sensation produced by rotation around the longitudinal axis, and the secondary compensatory reactions, Ferrier deduces that the right side of the cerebellum coördinates the muscular mechanism which prevents a displacement of equilibrium to the opposite side; in the same way the movement backward of the head, the extension of the trunk, and the limb, and the elevation of the eyes, determined by an irritation of the anterior part of the median lobe, are the compensatory efforts to counterbalance rotation forward.

"The cerebellum would apear to be, therefore, a complex arrangement of centers individually differentiated, which, acting together, regulate the various muscular adaptations necessary for the maintenance of equilibrium; every tendency to a displacement of equilibrium around a vertical, horizontal or intermediary axis, acting as an excitant for the particular center which calls into play the compensatory or antagonistic action."

The cerebellum is developed proportionally to the variety and complexity of the muscular activities. Lesions of the cerebellum do not cause paralysis of voluntary movements. If fatigue supervenes rapidly in animals upon whom a cerebellar lesion has been made, it is as a result of the efforts which they are obliged to make to replace a mechanism independent of consciousness, and not because the cerebellum is a source of energy, that this takes place.

In his later researches, made in collaboration with Turner, Ferrier is less categorical, and he recognizes that the problem of the function of the cerebellum is not nearly solved.

I have insisted in my thesis upon the importance of the disturbances of equilibrium in animals deprived partially or wholly of the cerebellum. When an animal has been deprived of half its cerebellum, no matter what attitude it wishes to take, or what movement it wishes to execute, it is drawn towards the side of the lesion, and falls towards that side. The first days after the operation it executes movements of rolling about a longitudinal axis, from the uninjured towards the injured side. In repose it lies upon the injured side and in the prone position the head is deviated toward that side. Later, when it makes its first attempts to walk, it is drawn in spite of itself by a movement of lateral translation to the operated side and falls in that direction. The rotation about the longitudinal axis, the decubitus upon the side of the lesion, the fall, and the movement of translation, are but the same phenomena in different degrees. I have explained a few pages back the nature of these phenomena and I have rejected the theory proposed by Luciani, who makes them irritative phenomena. For me they show, on the contrary, the loss of the totality of those reactions which prevent the displacement of the center of gravity towards the side of the lesion, and consequently a disturbance of equilibrium.

While standing upon the four paws, one can admit that in a normal animal equilibrium is preserved because the tonicity of the muscles of the head and the vertebral column are equal on both sides. Suppose that the actions of the muscles of one side are lacking or are weaker? That of the muscles of the opposite side, continuing to act alone, will determine a movement of torsion about the longitudinal axis, that is to say, a movement of rotation.

When, during walking, a fore paw is lifted from the ground, equilibrium is compromised, and the body tends to sink down on the same side if a modification of tonus in certain muscular groups is not produced. A modification which is only a force of reaction consisting of, in this type of animal, a movement of torsion of the neck and the anterior portion of the body, about the longitudinal axis, associated with an inclination of the head in the opposite direction, or, if one prefers, in an augmentation of the tonicity of the corresponding muscles. In an animal deprived of the cerebellum this reaction is lacking, this is why the animal falls on the same side as the destroyed hemisphere. The fall is all the more brusque as the contra-lateral force of reaction continues to act. This is why according to the judicial observations of Schiff and Vulpian equilibrium seems to be more profoundly disturbed after the destruction of half of the cerebellum than after the destruction of the whole of it.

What is true for the lifting of the fore paw is equally so for the lifting of the hind paw.

Whether the destruction of the cerebellum has been unilateral or total, these phenomena amend progressively and the animal succeeds successively in standing up, in walking, and, eventually, in running. The cerebellum is supplied by other centers and more by the cerebrum than by all the others. Equilibrium, instead of being spontaneous and automatic, becomes in a manner a thing intentional or willed. The body has no longer the suppleness it had before the operation and is as if ankylosed. The head is stiff and fixed. The paws are not lifted with the same regularity and at the proper time. The limbs are lifted suddenly and replaced in the same manner. These disorders reappear or increase when the animal progresses on an inclined plane. During the ascent of a stairway the head and the trunk are placed in exaggerated hyperextension, and at the moment of projecting its paws forward the animal falls backward. It is no longer capable of associating the movements of the head and the body with those of the limbs; or either it does it too suddenly and equilibrium is broken. Recently Hulshoff Poe insisted upon the differences between the jump of a normal dog and that of a dog deprived of its cerebellum. In the first, at a certain moment, the two hind paws are drawn simultaneously to the body; the dog deprived of the cerebellum, after the period of asthenia has passed, can also jump, but his two hind paws take dissimilar attitudes, instead of being placed simultaneously in a symmetrical position as in the normal dog.

An individual affected with cerebellar atrophy conducts himself in the same manner. When he descends a stairway, the body does not follow the movement of the legs, and he often risks falling backward. In the same way as in the dog the movements of the posterior and anterior paws do not associate themselves together regularly, so in man during walking, the movements of the arms do not associate themselves with those of the legs and the body. When a cerebellar patient places his foot upon a chair, or simply lifts it from the ground, he does not any longer execute the necessary compensating movements for the maintenance of equilibrium broken by the displacement of the center of gravity. Besides, is he not conscious of this defect of equilibrium and stability, which manifests itself at the least change of attitude, or the least displacement of the center of gravity?

Schiff is right when he says that the cerebellum is the center of an apparatus which puts into play the necessary group of muscles for the accomplishment of a complicated movement. Ferrier is also right when he maintains that the cerebellum regulates the various muscular adaptations necessary for the maintenance of equilibrium.

Luciani has vigorously combated this theory; the preservation of the power of swimming in animals deprived of their cerebellum and the efficiency of the compensatory acts by means of which they seek to avoid a fall show, on the contrary, according to him, that the sense of equilibrium functions normally.

These two arguments are weak. Is it not evident that the conditions of equilibration are very different in the water than upon the ground, and that in the first situation they are much more easily realized? As to the efficiency of these compensatory acts, it merely proves that the faculty of equilibration can be regained in part, thanks to the intervention of other centers than the cerebellum, and particularly to that of the cerebrum.

The theory of asynergy, set forth by M. Babinski, after an examination of patients with diseases of the cerebellum, or of the cerebellar paths, but in whom the cerebellum does not always appear to be the only organ in question, hardly differs from the theory of Schiff, of Ferrier, and of the one which I have myself maintained. Since asynergy is nothing but a disturbance of muscular association, the impossibility, or the difficulty of associating simple movements which combine for the execution of a complicated movement, it does not differ because asynergy, such as is understood by M. Babinski, is a more general fact, and includes all muscular association, and because it does not consider anything but the association of movements. In the theory which I have formerly maintained, I had particularly in view the muscular reactions adapted to the maintenance of equilibrium. The animals deprived of the cerebellum, the patients afflicted with cerebellar atrophy, have in effect lost the rhythm and harmony of the movements as a whole, whether it is a question of walking, running, ascending a stairway, or jumping. It is to be noted likewise that in the majority of the tests that M. Babinski has invented to show asynergy, it is a question of association of movements during which the equilibrium of the body is in consideration, but in some of them, nevertheless, asynergy exists in the execution of movements or acts which do not compromise equilibrium.

One can only ask if sometimes the patient does not voluntarily intervene in the decomposition of the movement, because he is conscious of the awkwardness produced by dysmetria. In any case, the tests invented by M. Babinski should be repeated with other patients, and more particularly with patients afflicted by destructive lesions strictly localized in the cerebellum. It is only in such patients that one can appreciate their physiological value.

With Luciani, Munk recognizes that the cerebellum plays a rôle of motor reënforcement which it exercises upon the spinal muscle centers. This function is in no way peculiar to the cerebellum, it shares it with the cerebrum. (Luciani also thinks that the very complex physiological activity of the cerebellum is not a specific activity, *sui generis,* but rather a common activity, or so to say, a fundamental activity, of the whole nervous system.) The true specific function of the cerebellum would be, according to Munk, the static function, which has already been admitted by Luciani.

In an animal in which the cerebellum has been destroyed, it is above all the fine and delicate equilibrium which disappears, it can no longer take a dangerous position, or at least it takes it with great difficulty, but when taken it can preserve it, thanks to a coarser faculty of equilibration assured by other nerve centers. Munk inquires, nevertheless, if in destroying the cerebellum he really removes a center of delicate equilibrium, or if he does not only disturb motility and the sensibility necessary for the realization of this delicate equilibrium; but he adopts the first hypothesis because the animals are still able to execute normally a large number of movements: licking, to wagging the tail; the monkey can eat from its hand, lick its paw, catch flies, etc.

The differences which exist between the normal and the cerebellar gaits do not depend, according to Munk, upon a disturbance affecting the execution of movements of the extremities adapted to walking. From the second week after the operation the dog, whether he is lying upon his side or lifted by the skin of his back, executes in the air the normal movements of walking with his extremities. A monkey climbs with normal movements. Consequently, according to Munk, if these animals are not able to walk normally, it is because they have been deprived of the power of maintaining their equilibrium by the aid of the muscles of the vertebral column and the extremities. This deprivation concerns the maintenance of equilibrium which is allied in the normal movement of walking to these normal movements of the extremities. After the operation the animal tries to walk as before, but as he fails to do so, he adopts a new method, which is the jumping gait. This is a functional compensation. The thing that proves this is that the monkey walks normally when he is leaning against a wall and does not take to the jumping gait until he leaves the wall.

The isolated movements of the limbs, however, are not so intact as he at first affirmed; since Munk admits the existence of dysmetria, for him this is the necessary consequence of the diminution of the excitability of the muscular and spinal centers of the coördinated movements. When it is necessary to change the elevation of an extremity to a depression, flexion to an extension, abduction to adduction, the diminution of excitability retards the second movement or even inhibits it, and the first movement exceeds the normal; it is thus that it is necessary to explain the diminution of the strength of the operated side, and the awkwardness of prehension.

Munk does not accept the disturbances of cutaneous sensibility observed by Russell and Lewandowsky. On the other hand, he maintains that deep sensation is affected: "Sensory excitations which originate in the muscles, in the articulations and in the bones, a part of which normally go to the cerebrum in passing through the cerebellum, are lost when the cerebellum is destroyed." He concludes also that there exists a cerebellar tonus limited to the vertebral column and to the extremities, and which takes its source exclusively in deep sensation, but that this function is common both to the cerebellum and to other nerve centers. Its specific function, repeats Munk, is the delicate maintenance of equilibrium, or its regulation; in the seated or lying position, in walking and in standing up.

The theory of Munk approaches closely to the theories propounded before upon the rôle of the cerebellum in equilibration. It differs from them by its complexity. The disturbances of deep sensibility are open to dispute. This explanation of dysmetria conforms very little to the actual reality. Nevertheless, the works of Munk have served to throw light upon the rôle which the cerebellum plays in the maintenance, and particularly in the reëstablishment of equilibrium. All the same he has justly brought out the fact that the function of the cerebellum as a center of reënforcement is by no means specific.

As I have already formerly explained, in an animal in which the cerebellum has been destroyed, every complicated movement and every attitude necessitates a sum of efforts much more considerable than in a normal animal. Before he is able to reacquire or to find the mechanism which permits him to reëstablish his equilibrium, the dog which has been operated upon must, so to speak, test his muscles, and from this arises the cause of fatigue and of atony in the sense that Luciani has given it. Each cerebellar hemisphere is certainly a source of energy for the corresponding side of the body. But this energy has a special use: it is principally adapted to the reëstablishment of equilibrium or of stability in all of the attitudes and all of the movements of the body. When the cerebellar function has just disappeared equilibrium is not on that account definitely lost, because it can be in large part reacquired, but it is then an equilibrium or a stability less perfectly and less rapidly obtained. The oscillations, at times very strong at the beginning of the movement, can afterwards become much slighter and even disappear.

This is the distinction between fine equilibrium and coarse equilibrium proposed by Munk. The cerebellum looked upon thus is an organ of perfecting, and as such it spares this task from the cerebral activity and permits it to spend itself otherwise.

M. Babinski establishes a distinction between kinetic, volitional equilibrium which would be disturbed in cerebellar patients, and static equilibrium which would be preserved or even exalted. To the support of this opinion he invokes catalepsy, which he has observed in some patients affected with cerebello-pontine lesions, and which has been noted by Rossi in a case of parenchymatous atrophy of the cerebellum. Experimentation and clinical observation show in effect that static equilibrium is less disturbed than kinetic equilibrium, and that immobility is easier to obtain in those movements which do not modify the conditions of equilibrium of the body. Animals deprived of the cerebellum have, besides, a tendency to inertia. In young animals when the sight is suppressed, there is a complete inertia of volition; the limbs remain in any position that is given them, on the condition that it does not provoke a painful reaction and that they are not in opposition to the laws of gravity (Borgherini and Gallerani).

I observed a dog deprived of his cerebellum who later became blind, which found itself in the same condition; it kept any position that was given it; it seemed indifferent to everything that happened around it, and scarcely reacted even to painful excitations. It did not bark, and was in a very marked somniform state (Fig. 51).

The same tendency to keep the attitudes of the limbs which were given to them has been noted in some patients affected with abscess or tumor of the cerebellum, but these facts, strictly speaking, do not enter into the type of catalepsy described by M. Babinski and approach more the abnormal attitudes, or the persistence of given attitudes which have been noted by various authors in animals deprived of the cerebellum (Lewandowsky and Munk).

Finally, I admit that the functions of the cerebellum are not limited to the equilibration of the body, and that the inhibitory and tonic action of the cerebellum makes itself felt in all movements and all attitudes. But as regards the disturbances of equilibrium in cerebellar patients and in animals deprived of the cerebellum, they appear to me to depend not only upon the loss of the tonic and regulatory action of each muscle which enters into contraction, but also to a lack of tonic synergy in the muscular groups which act together in the maintenance of equilibrium for a given movement.

I recall, therefore, the conclusions which I formulated in my thesis in 1897. "The cerebellum should be considered as an organ developing itself in the course of the sensory paths, with which it enters into relations in the adult, by more than one bundle of fibers. It registers peripheral and central excitations and impressions and reacts upon one and the other. It is not the seat of any peculiar sense but the seat of a particular reaction put into play by various excitations. This reaction applies itself to the maintenance of equilibrium in the various forms of attitudes or actions reflex, automatic or voluntary. It is a reflex center of equilibration." I had, then, in view particularly the equilibration of the body in general; during walking and during the upright position. But on account of the tremor of the limbs and of the too sudden movements noted in a number of observations I likewise supposed that the cerebellum intervened in the maintenance of equilibrium of the different parts of the body and of the limbs in particular. Is it not logical, indeed, to consider as a perturbation of equilibrium the difficulty or impossibility in which animals or individuals deprived of their cerebellum find themselves to obtain perfect and immediate stability in the execution of various movements, or in the taking of an attitude?

It is in the vermis and perhaps also in the lateral lobe that the tonic function of the cerebellum which is adapted to the maintenance of equilibrium and the attitudes and displacements of the body is seated. It is exercised under the influence of peripheral excitations which come to the vermis traversing the restiform bodies (fibers of medullary and spinal origin), or central excitations which leave the cerebral cortex and reach the lateral lobe after having followed the crural path, the superior layer of the pons, and the middle cerebellar peduncle. Among these central excitations those which come from the cortex of the temporal lobe, passing by the bundle of Türck, deserve special mention, since their center of origin is considered by Mills as being a center of labyrinthine representation. This is why we cannot exclude the lateral lobe from the centers which preside over the functions of equilibration. According as to whether it is the vermis or the lateral lobe which enters into activity, the centrifugal excitations follow the nucleus of the roof, and the cerebello-vestibular bundles in the first case, and the dentate nucleus and the superior cerebellar peduncle, in the second. In the first case, they end in the motor spinal centers through the intermediation of the vestibular nuclei, or the descending cerebellar bundles. In the second case, they do not end there until they have traversed either the red nucleus (cerebello- rubro-spinal path) or the thalamus and the cerebral cortex (cerebello-thalamo-cortico-spinal path). It is probable that the regulatory function of movements has its principal seat in the lateral lobe and that it is exercised under the control and command of the cerebral cortex by the intermediation of the cerebro-rubro-spinal path, and the cerebro-thalamo-cortico-spinal path (see Figs. 28 and 29, pages 39 and 41).

These considerations have for a basis the notions of normal and comparative anatomy, and also clinical and experimental facts. Sections of the superior cerebellar peduncle are followed by a homolateral tremor of the limbs analogous to that of multiple sclerosis, likewise in man, lesions of the tegmentum, which destroy the red nucleus, or the superior cerebellar peduncle, give rise to the same phenomena (syndrome of Benedict).

But in their intimate mechanism, these coördinations are not identical in man and in the various types of the animal series, because the anatomical centers which enter into play have neither the same importance nor the same structure. The red nucleus in man and in the anthropoids, to give only one example, is not the same as it is in the inferior mammals (Monakow). The rubro-spinal bundle is rudimentary in the higher apes and in man.

Substitution for the Cerebellum by the Cerebrum

The observation of animals which have been deprived of their cerebellum shows that this organ is partially supplied by other centers. At first, particularly as concerns equilibrium, it seems that the two halves, or even the various parts of the cerebellum, can substitute for one another to a certain degree. The characters of movement, which become more intentional, lets one suppose that a large part is attributable to the cerebrum, and more particularly to the motor zone of the cerebral cortex. This influence seems to be again demonstrated by the fact that in a dog deprived of half of the cerebellum, and already very much improved, the disturbances of equilibrium reappear when its attention is distracted.

In man the progressive atrophies do not ever give rise to disorders so intense as in an animal immediately after an operation. The restoration of the function is contemporaneous with its progressive weakening and partially masks it. This restoration is also due to the substitution for the cerebellum by the cerebrum.

Luciani has shown that a dog deprived of its cerebellum from which the two sigmoid gyri had also been removed, became incapable of learning to walk or to stand upright again, even several months after the second operation. Similar observations have been made by O. Polimanti, who observed that the disturbances consecutive to the destruction of one half of the cerebellum were augmented after the ablation of the frontal lobe of the opposite side. This author believes that the frontal lobes contribute in a measure to the maintenance of equilibrium, particularly to the maintenance of the coarse equilibrium of Munk.

The following anatomo-clinical observation can be compared with this fact. In a woman aged fifty-four years affected with olivo-ponto-cerebellar atrophy (diagnosis verified by autopsy), the disturbances of equilibrium, of station, and of gait, nystagmus and scanning speech, were so marked that the diagnosis of multiple sclerosis had been made. Dr. Touche gave me the specimens for a histological examination by serial section (Figs. 74 to 76). This examination demonstrated that besides the cerebellar atrophy there was a bilateral lesion of the cerebral peduncles. In the sections colored by the method of Weigert-Pal the bundle of Türck and the internal three fifths were completely decolored. The large fibers were less numerous in this case and the fine fibers were abundant. The neuroglia was proportionately proliferated. Lower down in the superior half of the pons some small bundles of the crural path were also manifestly degenerated. The pyramids were absolutely intact. Histologically the lesion was quite comparable to that of multiple sclerosis. However, in no part were patches of sclerosis found. Compared to other reported observations of cerebellar atrophy, this observation is very important. It demonstrates that the disturbances

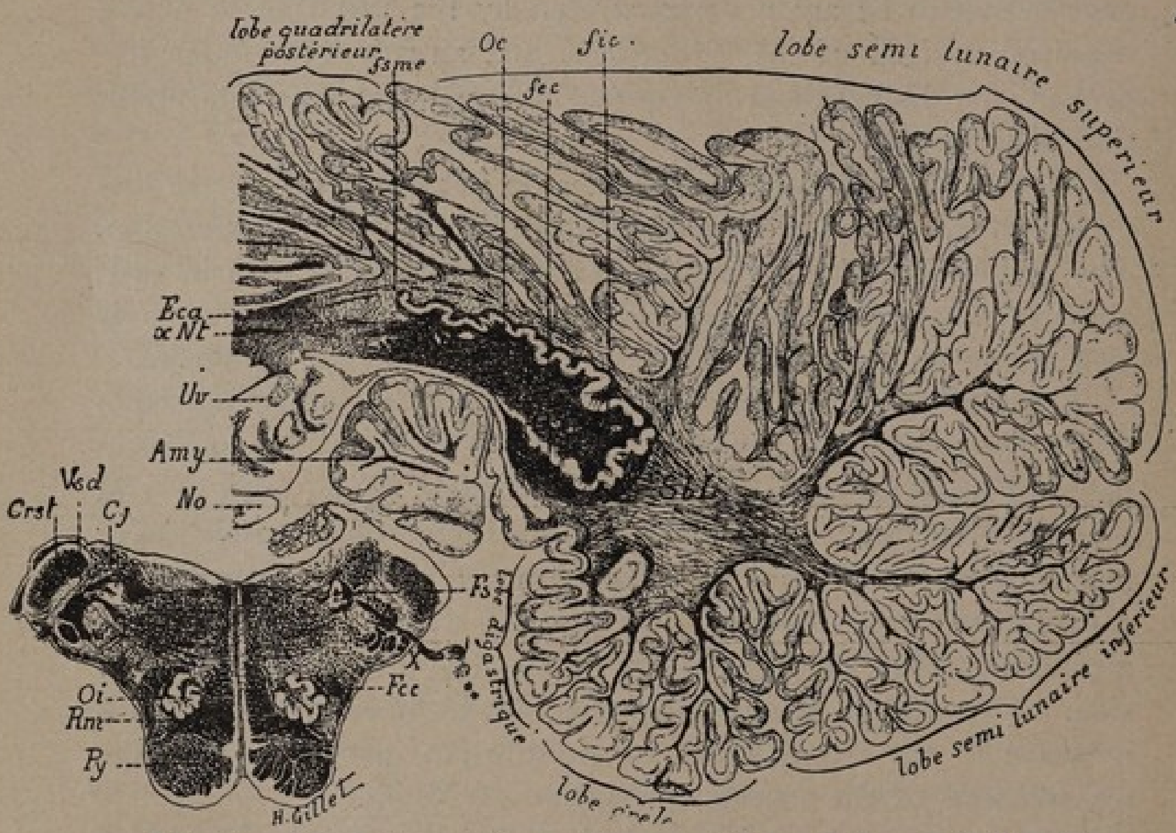


FIG. 74. Transverse section of the medulla and the cerebellum in a case of olivo-ponto-cerebellar atrophy, associated with a double peduncular lesion (Weigart-Pal stain). Atrophy of the cortex and the white substance of the cerebellum (*SbL*). Atrophy of the medullary olives (*Oi*), and the restiform body (*Crst*). Relative integrity of the cerebellar olive (*OC*). (André-Thomas, *Revue Neurologique,* 1905.)

due to atrophy of the cerebellum are accentuated by the fact of the interruption of the cortico-motor path, and consequently that the cerebral cortex substitutes in a large measure the cerebellum.

What happens to the electrical excitability of the cerebral cortex after the destruction of the cerebellum?

Russell noted that ten or fifteen minutes after unilateral destruction of the cerebellum the cerebral hemisphere of the opposite side is more excitable than the homolateral hemisphere. The difference of excitability amounts to 200 to 300 on the scale of Kronecker. The same results have been registered three months after the operation. If, in an animal, from which half the cerebellum has been removed, intravenous injections of absinth are

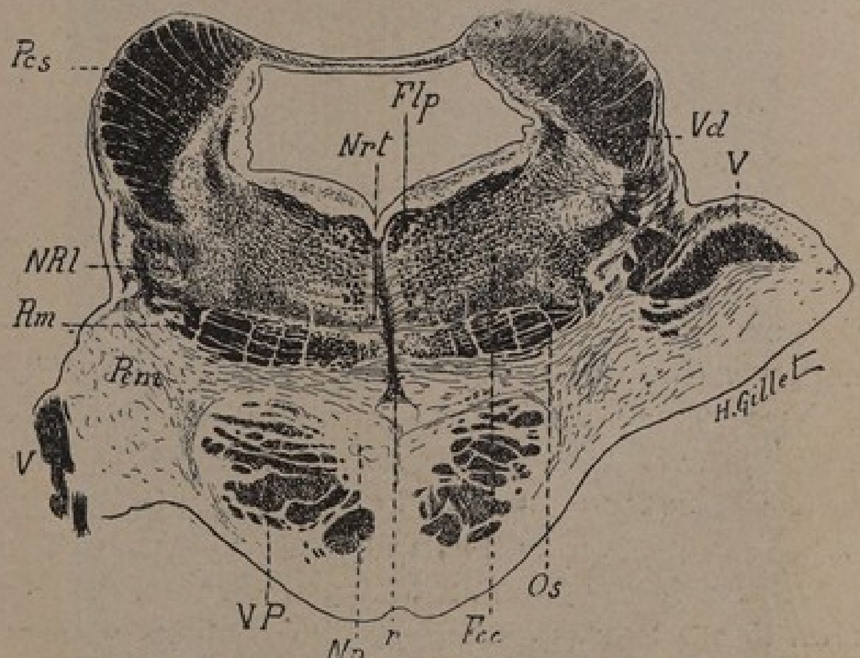


FIG. 75. Same case as the preceding figure. Transverse section of the pons. Atrophy of anterior surface and total degeneration of the median cerebellar peduncle (*Pcm*). Integrity of the superior cerebellar peduncle (*Pcs*), and of the crural path (*VP*).

made, the convulsions are much more intense on the side corresponding to the hemisphere removed (Figs. 77 and 78). Luciani has made analogous observations. Electrical excitations of the cerebral cortex on the side opposite the destruction of the cerebellum produces reactions which are stronger for the majority of the points excited. Bianchi, on the contrary, has found that the motor reactions determined by excitation of the cortex are not modified by partial total destruction of the cerebellum. If in reality the excitability is augmented, one may conclude that each cerebellar hemisphere exercises a crossed, braking action on the motor cortical zone. This exaggeration of excitability ac-cords very well with dysmetria and the epileptoid character of movement noted in man and in animals, in the case of the enfeeblement or disappearance of the cerebellar function.

The cerebrum supplants the cerebellum not only as a motor center but also as a sensory center. The elaboration of peripheral impressions appears to play a certain rôle.

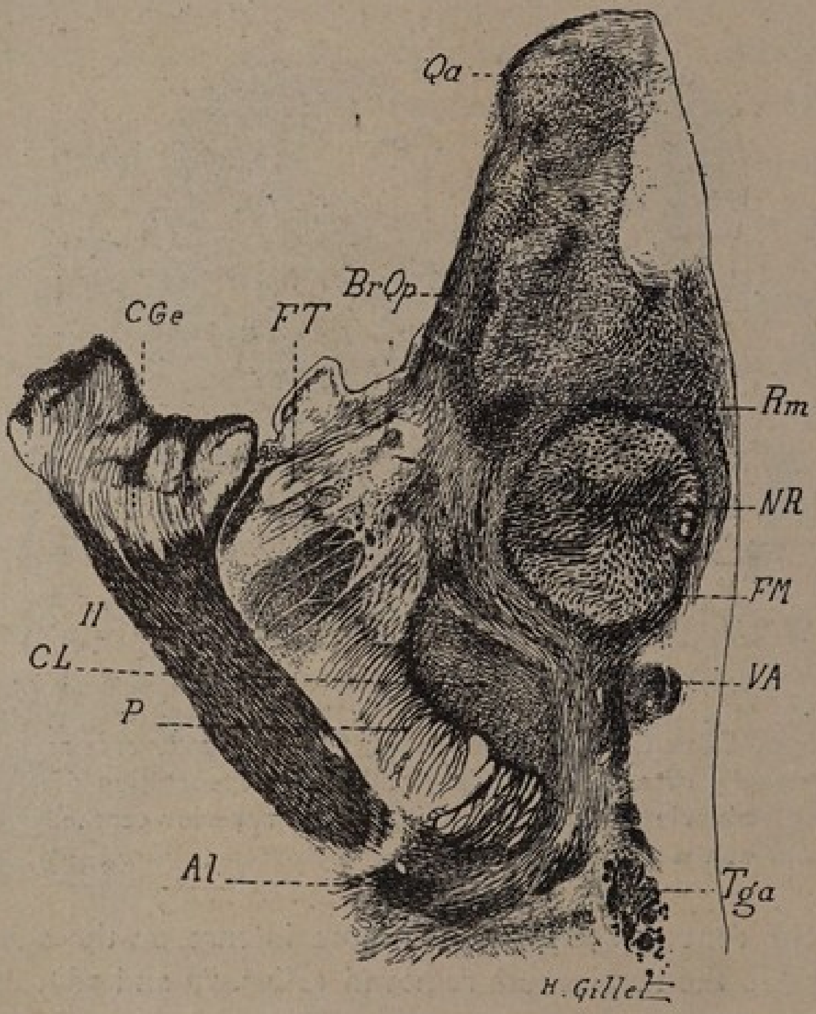


Fig. 76. Same case as the preceding figures. Degeneration of the internal three fifths of the crus cerebri and of the external fifth, or bundle of Türck (*FT*). Integrity of the red nucleus.

When a dog has partially reacquired the function of equilibrium after the total destruction of the cerebellum, he presents the graver cerebellar and ataxic disturbances in the posterior extremities if the posterior lumbar roots are sectioned (Bickel and Jacob).

The influence of the peripheral excitations which come from the labyrinth is still more remarkable. In a dog upon which I made an intracranial section of both eighth nerves, the cerebellum was totally destroyed about a month after the first operation.

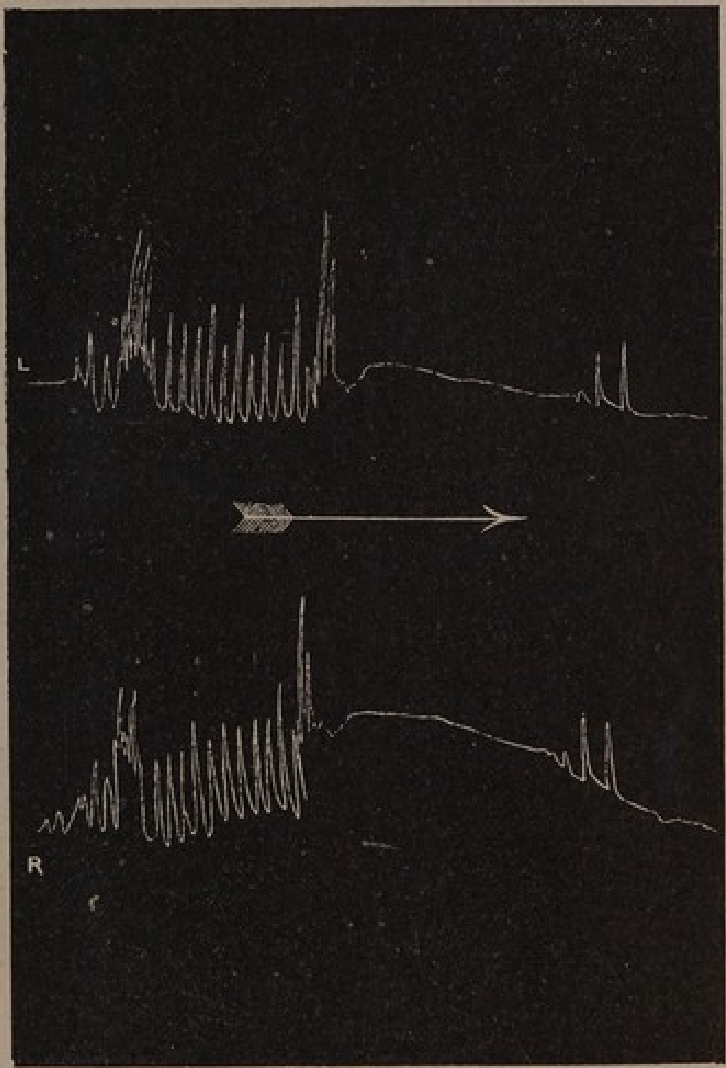


FIG. 77. This and the following figure are borrowed from Risien Russell. Experimental researches into the functions of the cerebellum. Philosophical Transactions of the Royal Society of London. Vol. 185, pp. 819–861. Convulsions produced by absinthe in a normal dog. Record of the extensor muscles of the anterior extremities.

He was unable to learn to walk again, or even to stand upright. The two front legs were folded under the body; he made some efforts to raise himself and walk, but he fell immediately on his side and nearly always on the right side.[1] During the taking of food the head oscillated violently and, although he was well fed, emaciation was very marked. Sixty days after the operation the

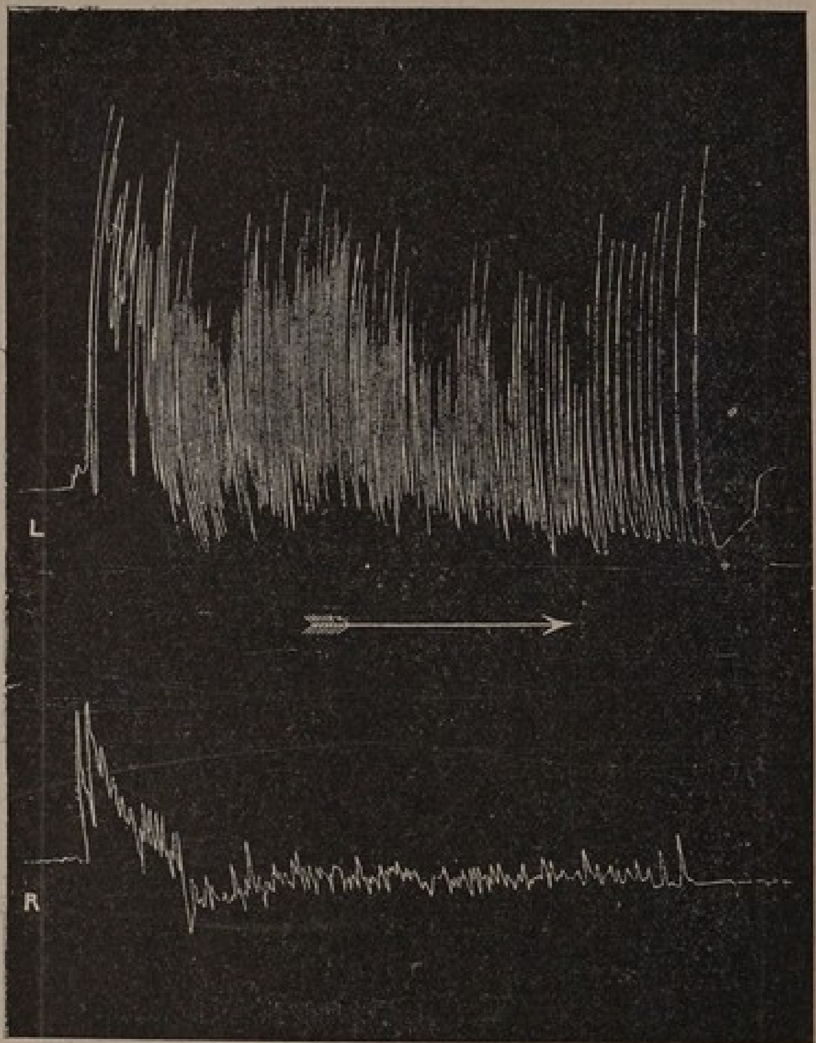


FIG. 78. Convulsions produced by absinthe in a dog deprived of the left lateral lobe of the cerebellum. Record of the extensor muscles of the anterior extremities. To the left (*L*) the shocks are greater than to the right (*R*).

animal had made no progress, either towards walking or standing upright.

[1] The examination of the neuraxis in a series of sections revealed besides the destruction of the cerebellum, and the bilateral section of the eighth pair, a lesion of the nuclei of the posterior column on the right; the triangular auditory nucleus and the nucleus of Bechterew, on the same side, were also slightly affected.

The simultaneous destruction of a cerebellar hemisphere and the eighth nerve of the same side provokes disorders of an intensity and a duration far greater than the simple section of a cerebellar hemisphere (Figs. 43 to 45). The movements of rotation persist much longer and it is the same for the other cerebellar symptoms. In an animal deprived of the cerebellar hemisphere and of the vestibular nerve of the right side in a first operation the left sigmoid gyrus was removed over seventy days later. The movements of rotation reappeared with extreme intensity and persisted for about twenty days. They were made in the same direction as after the first operation. (This is a new argument against the irritative nature of the movements of rotation.) The disorders of motility reappeared with greater intensity and three months after the second operation the animal was incapable

FIG. 79. The same dog as the one represented in Figs. 43, 44 and 45, after destruction of the left sigmoid gyrus. Repeated falls on the right side.

of standing up or of walking. At each attempt it fell almost immediately to the right, *i. e.*, to the side of the cerebellar lesion (Fig. 79).

Another dog which was operated upon on three occasions for section of the right auditory nerve, ablation of the sigmoid gyrus on the left side, and destruction of the right cerebellar hemisphere, was unable to reëducate itself after the last operation. After the second operation there was a recrudescence of the symptoms.

Experiments of the same type have been made upon pigeons by Lange. This author destroyed: First, the labyrinth in animals which had previously suffered a destruction of the cerebellum: Second, the cerebellum in animals which had previously suffered the destruction of the labyrinth.

In the first case the movements of rotation of the head appeared sooner. These movements were very disordered: there were tumbles backward and to the right, inability to stand upon the legs, emaciation was rapid and the animals showed no tendency towards an amelioration of their condition. In the second case if the operation is performed at a time when the animal only presents those symptoms discoverable by delicate means of examination, the disturbances which follow the extirpation of the cerebellum are the same as those which follow a simple cerebellar extirpation, but the tendency to draw back is more marked and the symptoms show a greater intensity.

The substitution of the cerebellum by the other nerve centers, and more particularly by the cerebrum, raises a delicate question of pathological physiology. Without counting the cases of softening limited to the cerebellar cortex which have shown no clinical expression, how can we explain the complete agenesis of a cerebellar hemisphere which has shown itself only as post-mortem finding and has not affected the functional locomotion or motility. Several hypotheses can be proposed to explain a fact apparently so paradoxical; either there may be a substitution for the absent cerebellar hemisphere by the cerebellar hemisphere which is present, or it may be substituted by the cerebral hemisphere of the opposite side or perhaps both these methods of substitution are associated. In the observations of total agenesis of the cerebellum it is rare that disturbances of motility and locomotion are not mentioned. More often it is true these disturbances have not been analyzed and it is difficult in merely reading of them to conceive an exact idea of their nature. It is nevertheless surprising, to only cite one example, that the extreme smallness of the cerebellum in the patient of Oddo had not occasioned any motor disorders. It is clearly specified in this observation that the movements were forceful and dextrous, but febrile and impulsive. This time also we must have recourse to the preceding hypotheses in order to explain the absence of symptoms and must invoke the idea of cerebral substitution. Perhaps, if in those individuals in whom the cerebellum is either only partially developed or totally lacking, the symptomatology is more abortive than in those individuals who at a more advanced age are affected by a cerebellar lesion, it is because in the last case one must take into account not only the functional suppression of the cerebellum but also the secondary modifications introduced into the functioning of other organs by the derangement of a mechanism with which they have always been associated. *A priori* it seems logical to admit that the substitution is more easily made, and more complete the earlier it takes place, and before it has been affected by previous habits. Finally, the variations of one case from another may be explained by individual differences which are the more accentuated as the subject is higher in the animal scale. The same is the case in all other cerebral involvements.

Analogies between the Phenomena Following Section of the Eighth Pair of Nerves and Those Following the Destruction of the Cerebellum. Anatomical and Physiological Relations between the Labyrinth and the Cerebellum

There exist between these two orders of phenomena some very marked analogies. For Flourens the cerebellum is a center of coördination and equilibrium and the nerves of the semicircular canals collaborate equally in the maintenance of equilibrium by means of their moderating action. Goltz also makes of the semicircular canals an organ of equilibrium. Later Ewald brought to light the influence of the labyrinth upon the precision of movements, and he invented a theory which I will have occasion to refer to later. I will content myself by citing the opinions of a number of the more celebrated physiologists who have made a study of the functions of the labyrinth, of the eighth pair of nerves, and of the semicircular canals. It is admitted that the motor disturbances which follow section or lesion of the eighth pair of nerves are caused by the perturbation or the abolition of the functions of the semicircular canals, of the utricle and of the saccule; that is to say, of those parts which are innervated by the vestibular nerve.

The symptoms following section of the eighth pair should be studied in cases of unilateral section and in cases of bilateral section. With the object of facilitating comparison with the disturbances consecutive to the destruction of half, or of the whole of the cerebellum, I will recall the result of my personal experiments upon the dog,[2] since it is also upon this animal that I have studied with greater detail the phenomena produced by destruction of the cerebellum.

Unilateral Section of the Labyrinthine Root is sometimes followed by a movement of rotation around the longitudinal axis, but this movement is isolated and not reproduced in series as after the destruction of half of the cerebellum.

In certain animals, such as the rabbit, unilateral section of the auditory nerve is followed by movements of rotation around the longitudinal axis. In the dog movements in a circle or like the spokes of a wheel are usually observed (Figs. 80 and 81).

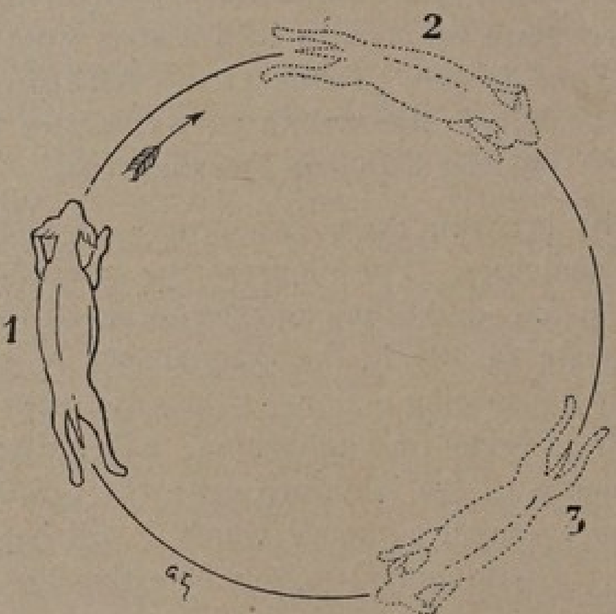


FIG. 80. Movements of rotation in a circle. Section of the right labyrinthine root in the dog.

The combination of section of the left labyrinthine root and the right cerebellar hemisphere gives rise to a peculiar movement of rotation represented in Fig. 82. The head is inclined towards the side of the section and at the same time there is a torsion, so that half of the face (on the side of the lesion) is on an inferior plane. After the hemi-destruction of the cerebellum the inclination is more marked and the torsion less so.

The deviation of the eyes is such that the eye of the injured side looks downwards and slightly inwards, the eye of the unin-

[2] These results coincide with those of other authors.

jured side looks slightly upwards and outwards (Fig. 83). During the first few days some nystagmic oscillations are seen, which

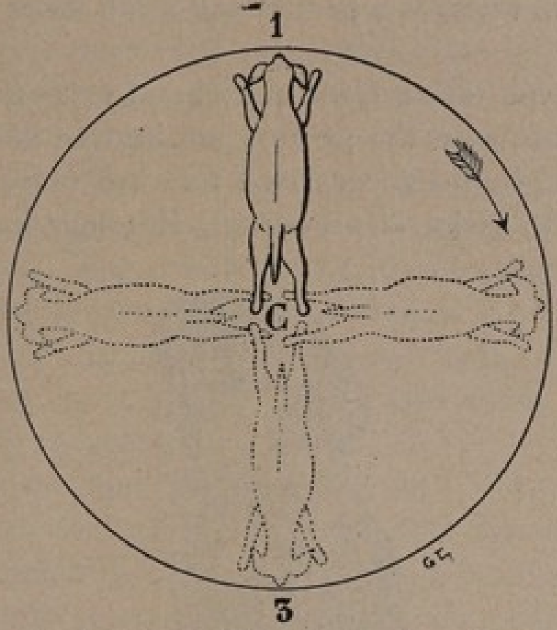


Fig. 81. Movement of rotation like the spokes of a wheel. Section of right labyrinthine root in the dog.

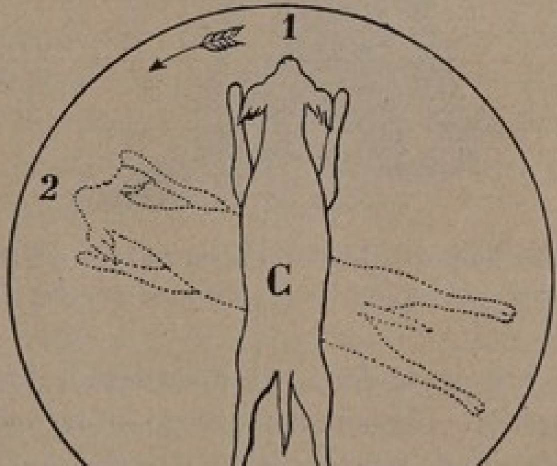


Fig. 82. Movement of rotation analogous to that of the needle of a compass. Section of the left labyrinthine root and the right cerebellar hemisphere.

have for their object the replacing of the eyeballs in their normal position.

The limbs of the side operated upon are weaker and the animal often sinks down with his paws bent under him. Those of the healthy side are in abduction. This is augmented when the animal tries to jump towards a person and a fall takes place upon the injured side.

If the fore paws are seized in the hand so as to make the dog walk on his hind paws, the paw of the injured side is lifted less easily from the ground and carried forward more suddenly.

The power to swim is preserved, although in the beginning

FIG. 83. Inclination and rotation of the head and of the eyes in a dog whose eighth nerve had been sectioned on the right side.

the movements are irregular and disordered, but they become normal very rapidly. The resistance to movements of propulsion, retropulsion and lateropulsion (particularly towards the operated side) is very much diminished. Placed on a movable surface he does not resist the inclination of the surface so well as a normal dog, particularly when the surface is inclined laterally and towards the side of the lesion.

Submitted to centrifuging the reactions of the head differ from those of a normal dog, particularly when the animal is turned towards the side of the lesion.

The movements in a circle, the ocular deviations, the attitudes of the head, and the awkwardness, attenuate progressively. The inclination of the head and the torsion are the most persistent symptoms.

After Bilateral Section of the Eighth Pair of Nerves the head oscillates in every direction: it is very mobile and does not resist movements which are imparted to it. During walking the limbs are in slight abduction, the head describes oscillations of great amplitude; this is why the animal advances in a wavy line, he walks in zigzags. The instability of the head appears to be the cause of these irregularities of gait, whereas in the cerebellar gait the whole body is displaced, at the same time, as an entity. In running the progress is interrupted by falls either to the right or to the left, or by movements in a circle.

Walking on the hind paws is difficult. The paws are raised from the ground with great pains and then thrust suddenly forward. If the animal is held so that it stands upon its hind paws in an almost vertical position and then released, it falls almost immediately backwards. During the first days it has more difficulty in seizing its food and swallows it slowly. During prehension of the food the oscillations of the head are augmented in frequency and amplitude; the same phenomenon takes place when it drinks. This muscular atony is not limited to the muscles of the head or of the neck. It may be observed in the muscles of the jaw. The mouth may be widely opened and kept open without its manifesting the slightest resistance.

It is unable to jump; placed upon a table it approaches its head near to the edge but instead of gathering itself together for a jump like a normal dog, it allows itself to fall in a lump. The hind quarters pass over the head and it turns a somersault.

The first days which follow the operation it does not seem to have an exact notion of its situation in space. Upon a young dog which had been submitted to a bilateral section of the auditory nerve I performed the following experiment: Suspended gently by the hind legs the animal sought to defend itself by raising the head, placing the front legs in extension and bending the trunk. When this experiment was repeated, after having suppressed the control of vision by blindfolding it, the animal did not attempt any movements whatever. It remained suspended in an inert mass. The same experiment repeated the first days after the operation always gave the same results (Figs. 1 and 2).

At the end of several days the animal protects itself just as well with the eyes closed as with them open.

The descent of a stairway is impossible or very difficult. The animal is very well aware of this, and when it is pushed towards a stairway it tries to escape to one side. If it is obliged to descend it loses its equilibrium and rolls down like a ball. The ascension of a stairway is less difficult; nevertheless, it frequently falls backward.

If the animal is held above the ground and allowed to fall suddenly it falls in a heap.

All these disturbances attenuate progressively and more rapidly if the animal is constantly at liberty. But certain symptoms persist much longer. These are the awkwardness during jumping, the difficulty of descending a stairway, *and principally the impossibility of swimming,* a fact to which attention has not perhaps been sufficiently attracted. When the animal is plunged in the water it commences immediately to turn around its longitudinal axis, either from right to left or from left to right, and then sinks in the water and would drown if it were not saved. Finally, we repeated the experiments of Goltz and Ewald. These authors remarked that a pigeon deprived of its semicircular canals was no longer capable of reacting by appropriate muscular adaptations. I undertook experiments of the same kind upon three dogs, which had previously been submitted to a bilateral section of the eighth pair. With this object the animal was placed upon a plank, movable around a horizontal axis, either parallel or at right angles to this axis. The eyes were blindfolded. The reactions were then studied in the movements of inclination of the board, both slow and sudden. If this experiment were made with a normal dog and under the same conditions, it reacted by appropriate movements which were very easy to observe during the slow inclinations. These movements prevented it from falling forward or on the sides, according to its situation in relation to the axis. In the more sudden inclinations it reacted also in a manner to avoid a fall, or it jumped. If now the experiment is repeated upon the dog upon which the double section of the eighth pair has been performed, some days after the section, the normal reactions are no longer produced and a very slight inclination of the board is enough to cause the animal to fall and roll on the side if it is placed parallel to the axis of rotation, or it falls backwards or forwards if it is placed at right angles to this axis, the head being to the side of the inclination in the first case and the tail in the second. These reactions take place in a more marked degree as the inclination is more sudden.

This experiment has been repeated several times upon the same animal several weeks and even more than two months after the section of the auditory nerve; with the slow inclination it reacted then a little better; but a very great inclination is not necessary for the animal to tumble or roll over, as it is the first days after the section. The amelioration which is produced during the slow inclination seems to be due to a substitution by peripheral impressions, the sensations furnished by the sliding of the paws warning the animal of the modification which has taken place in its situation.

Falls upon the side or backwards or forwards are also produced when the animal is placed upon a board to which movements of lateropulsion, propulsion or retropulsion are given.

Some weeks after the operation it walks almost as well as a normal dog and keeps its equilibrium very well, either when standing or when walking.

The disturbances of equilibrium and of motility have been mentioned by several authors in patients affected by disease of the inner ear. Incoördination and the disturbances of equilibrium are a part of the syndrome described under the name of the vertigo of Menière. Van Stein has insisted upon the disturbances of static and dynamic equilibrium in diseases of the ear, and his observations have been many times confirmed. Voltolini has also called attention to these facts.

In labyrinthine otitis, as well as in cerebellar disease, the upright position cannot be maintained except with the feet spread apart—the base of support is enlarged. The patient cannot stand upon one leg. The gait is uncertain, the body being carried alternately from one side to the other. The steps are unequal and irregularly spaced. Muscular energy is very much diminished and fatigue ensues rapidly. The labyrinthine ataxia differs however from the cerebellar ataxia. The sign of Romberg is the rule. The variations of the attitude of the head augment considerably the disturbances of equilibrium. The muscular weakness is more pronounced, and, moreover, when the patient is subjected to passive movements of rotation or translation, the orientation of these movements is no longer perceived; the nystagmus and rotatory vertigo, which appear in a normal individual after rotation around the longitudinal axis, have disappeared. The passage of a galvanic current through the skull, in the line of the two ears, no longer provokes nystagmus or ver-vertigo.

Disturbances of equilibrium have been noted in deaf mutes, although it is true they are less pronounced, only in the rough. James observed that in some of them orientation in the water was impossible, and if left to their own devices they would drown. Animals in which the two auditory nerves have been sectioned have the same inability to direct and orient themselves in water (Ewald, André-Thomas). Whereas, for animals deprived of the cerebellum swimming is still possible (Luciani, André-Thomas).

In birds the horizontal, sagittal and vertical canals may be suppressed at will, and thereby abnormal attitudes of the head produced, varying according to the canal injured, also troubles of motility, and movements in a circle. When all the canals are cut, the head oscillates in every direction, like a pendulum, and the animal is no longer able to stand upright (Flourens).

Finally, between the disturbances produced by section of the eighth pair of nerves, and those produced by destruction of the cerebellum, there exist analogies and differences. It seems that the first condition gives rise to defective attitudes of the head, and that the disturbances of equilibrium are due to disorientation of the head. The musculature of the head is, however, not alone in question. The musculature of the limbs and the trunk is also disturbed.

The vestibular apparatus, and by this general term we must understand the semicircular canals, the utricle and the saccule, advises us as to the attitude and progression of our body (otoliths of the saccule and the utricle), and as to the rotation of the head (movements of the endolymph in the semicircular canals) (Breuer, Ewald). But it seems to have other functions; Ewald was struck by the diminution of muscular force and the lack of coördination of certain movements in the animals upon which he operated; the muscles contracted either too slowly or too late. He admits the tonic influence of the labyrinth upon the musculature, the existence of a labyrinthine tonus. After suppression of the labyrinth, there would be a considerable diminution of muscular energy, and the muscles most effected are those which have need of precision in the accomplishment of their functions. Thus, in pigeons, after the destruction of the labyrinth, there was no disturbance in the functioning of the muscles of the legs during walking; whereas, in cockatoos, who use the muscles of the legs and the feet to seize their food and to climb, there was a very marked disturbance.

The labyrinth, according to Ewald, reacts upon all of the muscles, but each labyrinth is particularly in relation with the muscles of the opposite side, which move the vertebral column and the head (muscles of the back of the neck, of the neck, and muscles which go from the body of one vertebra to the transverse processes of the vertebra above). As to the muscles of the extremities, each labyrinth is in relation with the extensors and abductors of the same side. All the muscles of the eyes, with the exception of the external rectus (?) seem to depend principally upon the homonymous labyrinth.

In conclusion, the continual excitations which come from the labyrinth are transmitted to certain nervous centers, which reflect them in their turn to the muscles, in which they augment the tonicity, a tonicity which is accompanied by modifications in the terminal organs of the sensory nerves of the muscles. This labyrinthine tonus, when it begins to disappear, results at the same time in modifications of tonus and muscular sensibility. This is why the movements become less energetic, and less precise.

What are the nerve centers that govern the labyrinthine tonus? The resemblances noted above between the cerebellar symptoms and the labyrinthine symptoms allow us to suppose that the cerebellum is the principal of these centers. Goltz has already advanced the hypothesis that the cerebellum is the center of perception of attitudes of the head. The proximity of the cerebellum, and the nuclei of the vestibular nerve, support this opinion. Luciani has returned recently to this subject, and he assimilates almost completely the phenomena which are manifested after the destruction of the labyrinth, and those which follow the destruction of the cerebellum. The destruction of either one or the other has for consequence a diminution of tonus; this is one of the points upon which the Florentine physiologist has most insisted, and he compares the cerebellar tonus with the labyrinthine tonus. He pushes too far the resemblance between the cerebellar symptoms and the labyrinthine disturbances. The muscular weakness in fact is much more marked after the destruction of the labyrinths. "At Naples, Ewald saw some sharks which required four vigorous arms to hold them, and were held by a single hand after the section of the auditory nerves; nevertheless, after the removal of large portions of the cerebellum, which constituted a much graver operation, this muscular enfeeblement did not take place" (Kœnig).

The cerebellum is not a center of perception for labyrinthine excitations. Submitted to centrifugation, individuals affected with atrophy of the cerebellum perceive the movements of rotation very well, the reverse of those affected with labyrinthine otitis. The fibers of the vestibular root lose themselves almost entirely in the medulla, in the nuclei of Deiters, Bechterew, and in the triangular auditory nucleus. The fibers which go to the nucleus of the roof are very scanty. Luciani therefore commits an error in affirming that the labyrinth acts upon the centers through the intermediation of the cerebellum. There are, nevertheless, important connections between the labyrinthine apparatus and the cerebellum, but they are of another order. The central gray nuclei of the cerebellum, the nucleus of the roof, the globulus, and the embolus, and perhaps also the dentate nucleus, give rise to fibers which terminate in the three vestibular nuclei (nucleus of Deiters, nucleus of Bechterew, and the triangular auditory nucleus, see anatomy). The greater number of these fibers are apparently direct, though some are crossed (Fig. 84). The result is an anatomical disposition altogether unique, and the activity of the vestibular nuclei may be brought into play, either by labyrinthine excitations, or by cerebellar excitations. One can easily conceive, therefore, that the suppression of one or the other of these sources of excitation should have in both cases very comparable results, but not identical ones, for the excitations are not of the same nature, and the relations of each category of fibers with the cells of these three nuclei are probably not the same. It appears to be demonstrated that the vestibular apparatus contributes to assure the maintenance of equilibrium of the head and of the trunk in passive movements. Does the cerebellum govern, in its turn, equilibration in active movements (voluntary,

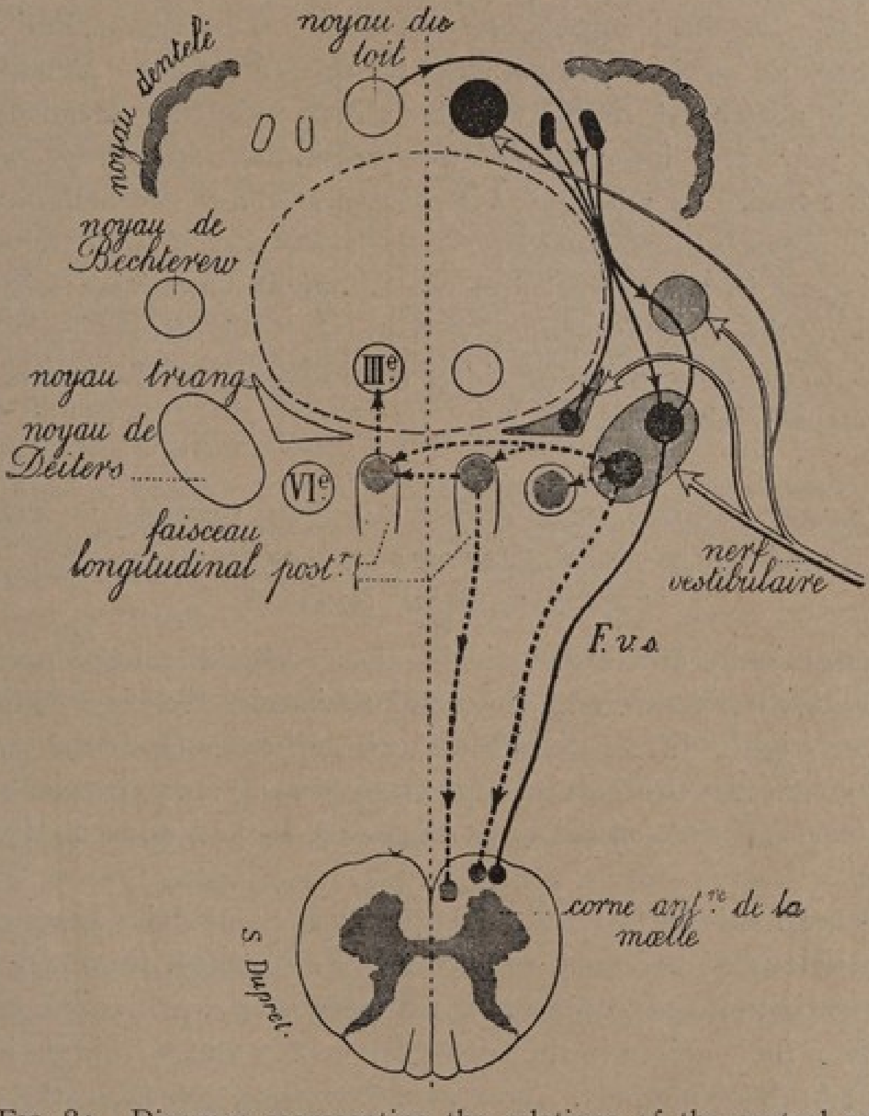


FIG. 84. Diagram representing the relations of the central nuclei of the cerebellum with the nuclei of the vestibular nerve, the oculo-motor nuclei, and the spinal cord. (This diagram redrawn according to my direction is borrowed from the work of E. J. Moure and Couzard upon the functional examination of the labyrinth, 1909.)

automatic and reflex)? This seems to be none the less solidly established. It does not seem, however, that it exercises this function entirely by itself to the exclusion of the vestibular apparatus.

One can represent in a different manner the physiological relations between the cerebellum and the labyrinth. The cerebellum has a moderating action in regard to the reflexes provoked by the vestibular apparatus (in moderating the reflex tonus through the intermediation of the nucleus of Deiters), the same as it has towards the cerebral impulsions (Adler). The cerebellum has, therefore, an action antagonistic to the cerebrum. When the vermis is destroyed, or the bundles which unite the nuclei of the eighth pair are interrupted, the vestibular apparatus works without a brake, its reactions are exaggerated and cerebellar ataxia is the immediate consequence. In the same way if the cerebellum is no longer in anatomical and physiological connection with the cerebrum, the involuntary movements become disordered. According to the conception of Adler the influence of the cerebellum is, above all, inhibitory.

Is there Reason to Distinguish Two Organs in the Cerebellum—the Cerebellar Cortex and the Central Gray Nuclei?

Anatomically and histologically the cerebellar cortex presents itself with a structure and character so special that it constitutes an organ highly differentiated, and very distinct from the central gray nuclei. In the cerebellum, as in the cerebral hemispheres, the cortex and the central gray nuclei are looked upon as distinct organs.

Between the cortex and the central gray nuclei (dentate nucleus, nucleus of the roof, globulus and embolus), there are intimate relations through the intermediation of the projection fibers. They take their origin in the cerebellar cortex and terminate in the nuclei (André-Thomas). One can, therefore, represent the cerebellar cortex as the point of departure of the excitations which will transform themselves into tonic variations by passing through the central gray nuclei and the centers with which they are in connection.

Physiologically, the cerebellar cortex comports itself differently from the central gray nuclei. The destructions of the cortex are translated by symptoms which are less grave, and less enduring, than those destructions which affect the deeper organs.

The cerebellar cortex is not excitable, whereas the central gray mass is (Horsley).

Horsley and Clarke have shown besides that the cortex and the nuclei have a very different influence upon the contractures of animals which have been decerebrated. In a first group of experiments these authors sectioned the mid-brain in a dog and produced a generalized rigidity which was due to the interruption of the cerebral influx. In removing, by successive layers, the cerebellum, these authors noted that this hyper-tonicity did not commence to recede until the moment the section intersected the intrinsic nuclei, and the para-cerebellar nuclei (probably the nuclei of the vestibular nerve). In another group of experiments, they separated by a massive horizontal section, the dorsal half of the cerebellar cortex, and three weeks later they sectioned the mid-brain. In this case, the rigidity of the decerebrated animals did not differ from that of normal dogs.

The cerebellar cortex, therefore, is not indispensable for the maintenance of contracture, and the principal source of the motor impulses of the rigidity is the central gray nuclei and the para-cerebellar nuclei. (Thièle arrived at the same conclusions.) According to Horsley and Clarke, the cerebellar cortex is a receptive center of impressions from the trunk and from the limbs of a special character, always coördinated.

According to Sherrington, the contractures consecutive to decerebration can be inhibited by the excitation of the anterior surface of the cerebellum. Faradization of this region is followed by a relaxing of the muscles of the neck, the head, and the hind legs, more particularly on the side of the excitation. This author thinks that the cerebellum has an inhibitory influence.

Do Localizations Exist in the Cerebellum?

This question should be studied separately for the cerebellar cortex, and for the central gray nuclei.

One can only accept with great reserve the results obtained by excitation of the cerebellar cortex, since the excitability of the cortex is disputed, and even denied by some physiologists, such as Horsley and Clarke. As to the destructions of the cortex, they generally only give rise to temporary disturbances unless they are widespread. Some authors maintain, however, that they have obtained very localized symptoms by the destruction of very limited regions of the cortex.

After the destruction of the most internal portion of the crus primum (terminology of Bolk), Marassini observed abnormal movements of the front leg of the same side. They were lacking if this region remained uninjured, even when the lesion of the lateral lobe was more widespread. The destruction of the most internal portion of the crus secundum and of the paramedian lobe is followed by abnormal movements of the hind leg of the same side.

Von Rynberk observed also disturbances of motility in the front legs, which were realized constantly and exclusively when the crus primum of the anciform lobule was destroyed. The concomitant lesion of the lobule simplex only caused an increase of the intensity and the duration of these effects. There exists a center for the muscles of the neck in the lobule simplex: a localized lesion of this level has, for a consequence, rotatory instability of the head.

After destruction of the ansiform lobule in the goat, Vincenzoni did not observe any anomaly, but if the lobule simplex were simultaneously destroyed he observed ambulatory dysmetria ("gait of a cock"), in the anterior homolateral limb. The resection of the lobule simplex in which he got no results from the dog, had, as a consequence, a complete but temporary suppression of locomotion. With the suppression of the paramedian lobe, movements of rotation around the longitudinal axis appeared. The doctrine of cerebellar localizations is also accepted by Hulshoff Pol, and by Rothmann. According to Hulshoff Pol the suppression of the posterior median lobe in the dog gives rise to incoördination in the hind limbs; that of the paramedian lobe, besides ataxic symptoms, pleurosthotonus and peculiar gait, which he calls the "walk of parade." After destruction of the crus secundum of the ansiform lobe he observed ataxia and the "gait of a cock."

The experiments of Rothmann were made upon the dog and the monkey. The unilateral resection of the quadrangular lobe (lateral segment of the lobule simplex and crus primum of the ansiform lobule) in the dog, was followed by a disturbance in the position of the front leg of the same side. The paw was held to one side and behind its normal position; the fore paw was turned over and the animal did not draw it back when it hung over the edge of the table. Disturbances of the same type occurred in the hind leg after destruction of the crus secundum of the ansiform lobule, which corresponds to the semilunar lobe. In the monkey, lesions limited to the cortex of the quadrangular lobe occasioned disturbances limited to the homolateral anterior limb. Movements of the hand and the fingers were awkward, and were accompanied by a fine tremor, and the arms were put into an exaggerated flexion. These phenomena diminished gradually, but still persisted at the end of a month. They were more marked in both limbs when the two quadrangular lobes were destroyed. Locomotion remained unaffected. When the destruction was carried to the semilunar lobe, similar disturbances appeared in the posterior limbs.

The authority of the physiologists who have made these experiments gives them a real value; and although the results do not absolutely agree, they favor the idea of functional localizations in the cerebellar cortex. We must await the confirmation of these results by new researches.

As to the central gray nuclei they could be decomposed into special centers, if one takes into account the experiments of Clarke and Horsley cited. One may remark, however, that the excitation of the central gray substance of the cerebellum is a very difficult experiment to perform, and that it is very difficult to say from which of the nuclei of the cerebellum, and of the neighboring nuclei, the excitation comes.

It is necessary to make some reservations as to the existence of precise localizations in the cerebellar cortex—only taking into account the results of experiments. One cannot affirm the functional unity of the cerebellar mantle. On the contrary, anatomical facts permit us to suppose that the vermis and the hemispheres have, in relation to one another, a certain independence. The vermis is phylogenetically older than the lateral lobes. It represents, in a way, the primitive cerebellum, the cerebellum of the animals whose brain, or, rather, whose cerebral cortex is still rudimentary, and in whom the movements of the limbs are still only slightly differentiated. The lateral lobes are altogether rudimentary in certain birds, and in reality do not make their appearance except in mammals, and for each species they are developed according as it occupies a higher place in the animal scale. They attain a maximum importance in those animals whose cerebrum itself is very highly developed, and the movements of whose limbs is the most differentiated.

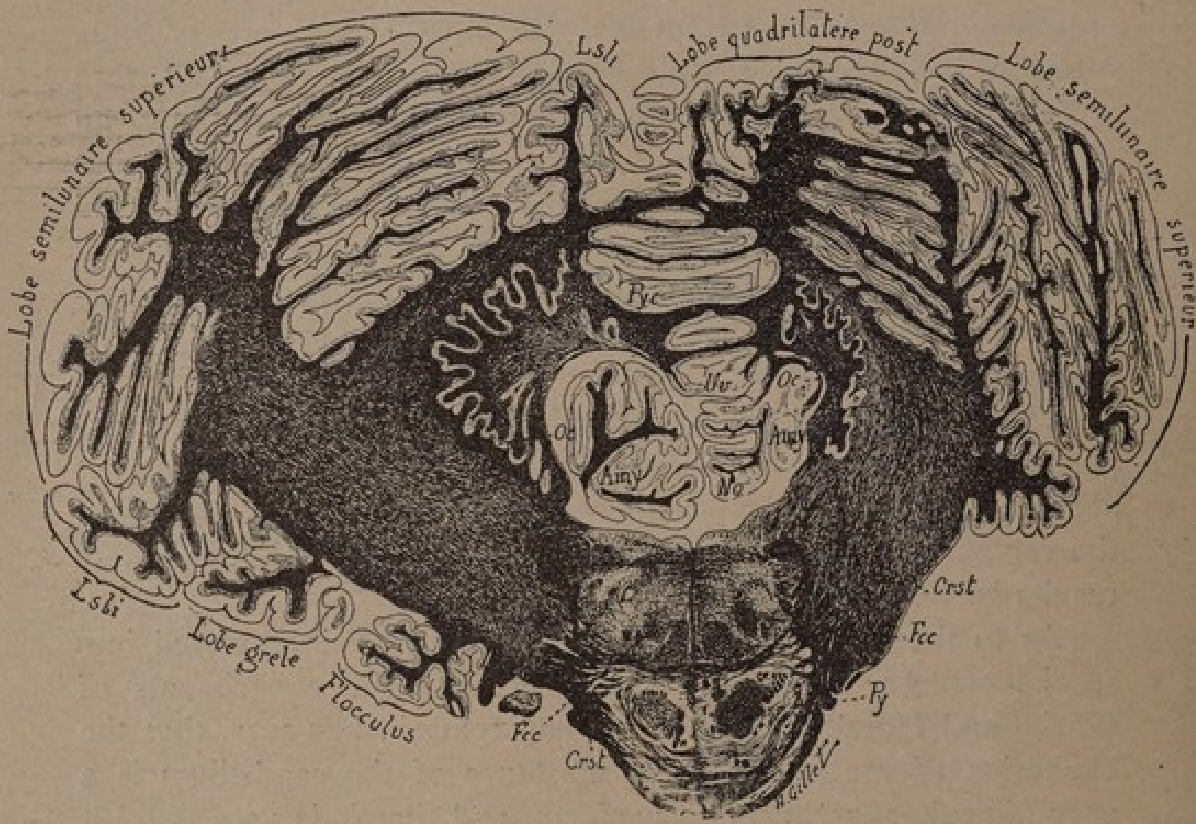


Fig. 85. Vertico-transverse section of the pons and the cerebellum, in a case of crossed atrophy of the cerebellum due to a lesion of the right cerebral hemisphere dating from infancy. To the right the path of the crus cerebri is degenerated (*PY*). On the left it is intact. The atrophy of the left cerebellar hemisphere affects the convolution of the lateral lobe, the white substance, and the cerebellar olive. The central bundle of the tegmentum (*Fcc*) is atrophied on the right. In this case there was an atrophy of the medullary olive on the right. (Consequently crossed in relation to the cerebellar atrophy.) (Thomas and Cornélius, *Revue Neurologique,* 1905.)

When the cerebral cortex is destroyed over a large area of the motor zone, and particularly when the optic thalamus is at the same time injured or atrophied, a crossed hemi-atrophy of the cerebellum results (Figs. 85, 86 and 87). This hemiatrophy is very frequent when the cerebral lesion dates from infancy (and in this case not only the cortex is atrophied, but the cells of Purkinje are lacking in the corresponding regions); this may be found also in the adults (Figs. 88 and 89), but less constantly, and in a less marked degree. It has been observed in animals which have suffered grave cerebral mutilations during the first weeks of their lives (Von Monakow). The crossed hemiatrophy of the cere-

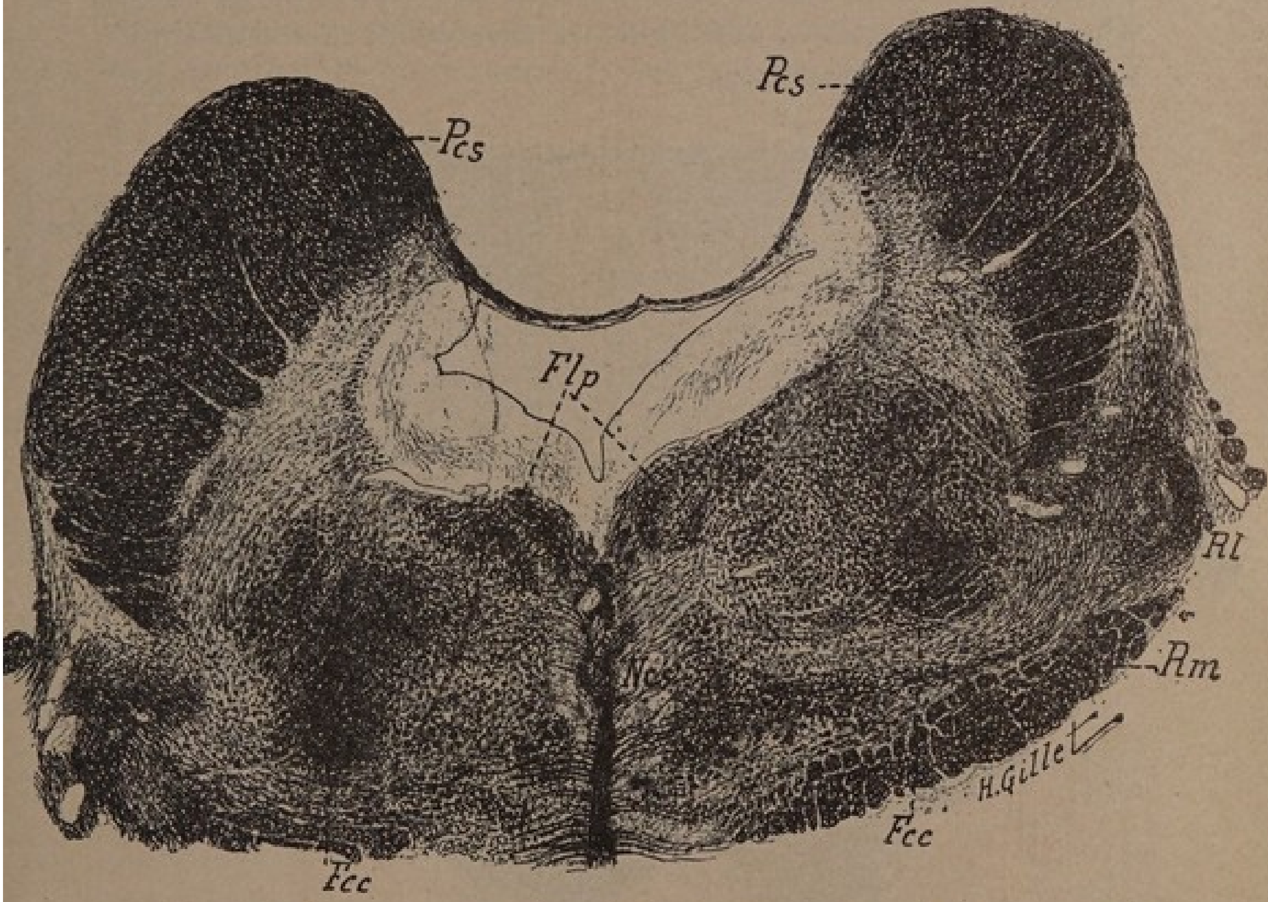


FIG. 86. Transverse section of the tegmentum pontis in a case of crossed atrophy of the cerebellum due to a lesion of the cerebral hemisphere dating from infancy. Atrophy of the left cerebellar peduncle (*Pcs*).

bellum affects the lateral lobe of the cerebellum and respects the vermis (André-Thomas and Cornélius). In the lateral lobe it has a certain predilection for the quadrilateral lobe.

The atrophy of the superior cerebellar peduncle can be followed as far as the dentate nucleus even in adults. It depends upon the atrophy of the optic thalamus. The atrophy of the cerebellar cortex, of the middle cerebellar peduncle, and the white substance, is the consequence of the degeneration of the peduncular paths, and its interrelation with the gray substance of the pons.

The pathogenesis of crossed hemiatrophy has been very much debated. Some have attributed it to a functional inactivity, others to a secondary transneural atrophy. Against the first theory the fact may be invoked that crossed atrophy of the cerebellum is rarer and less marked in the adult than in the child, whereas, the functional activity of the cerebellum should attain its maximum in the first case.

FIG. 87. Transverse section of the medulla. In a case of crossed atrophy of the cerebellum dating from infancy. Crossed atrophy of the medullary olive (*OI*) (see Figs. 85 and 86).

The explanation is of little importance. The main point is, the intimate association of each cerebral hemispere with the cerebellar lobe of the opposite side, and the subordination of the latter to the former. The cerebral cortex of the fronto-parietal and temporal regions is projected upon the cortex of the opposite lateral lobe of the cerebellum, and slightly also upon the homolateral lobe, by the intermediation of the cerebral crus and the pontine nuclei, while the spino-medullary centers are projected upon the cortex of the vermis. The efferent fibers of the vermis are exclusively directed to the terminal nuclei of the vestibular root of the auditory nerve, and by their intermediation to the medulla and the spinal column; the efferent fibers of the hemispheres go partly to the red nucleus, and partly to the thalamus, and the thalamus transmits their excitations to the cerebral cortex. This is why, basing oneself upon comparative anatomy, normal anatomy, and pathological anatomy, we must consider the vermis and

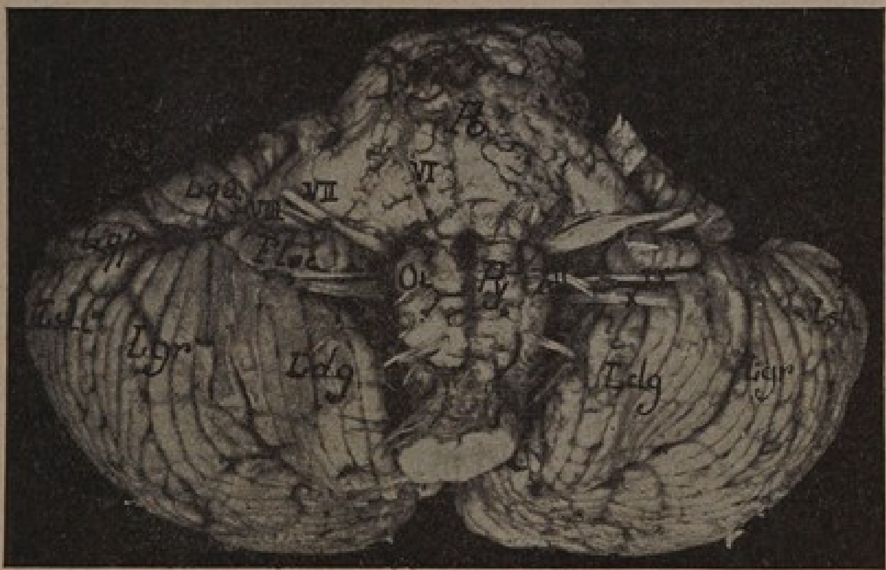


FIG. 88. Atrophy of the right crus cerebri (*P*), and of the pyramid (*Py*). Atrophy of the left cerebellar hemisphere. For the other indications see the figures in the chapter on anatomy.

the lateral lobes as functionally different regions, not having the same attributes. We are able therefore to distinguish two systems: The cerebro-cerebellar, or hemispheric system, and the medullo-spino-cerebellar or vermian system. We must consider all the lessions seated in the paths of the first system, as having manifestations of the same kind, as would all the lesions seated in the paths of the second system. In future attention should be drawn to this point.

Whatever it may be, the activity of each cerebellar hemisphere is intimately connected with that of the opposite cerebral hemisphere; whereas, that of the vermis is subordinated to that of the spinal column and the medulla. Perhaps, also, one might maintain that the vermis and the hemispheres have an identical function, varying in its intimate mechanism according to the type of animal considered. The appearance and the development of the cerebellar hemispheres are only witnesses of the subordination of the inferior centers to the cerebral influence in superior vertebrates; nevertheless, anatomy teaches that in this class of animals there is a manifest independence between the vermis and the hem-

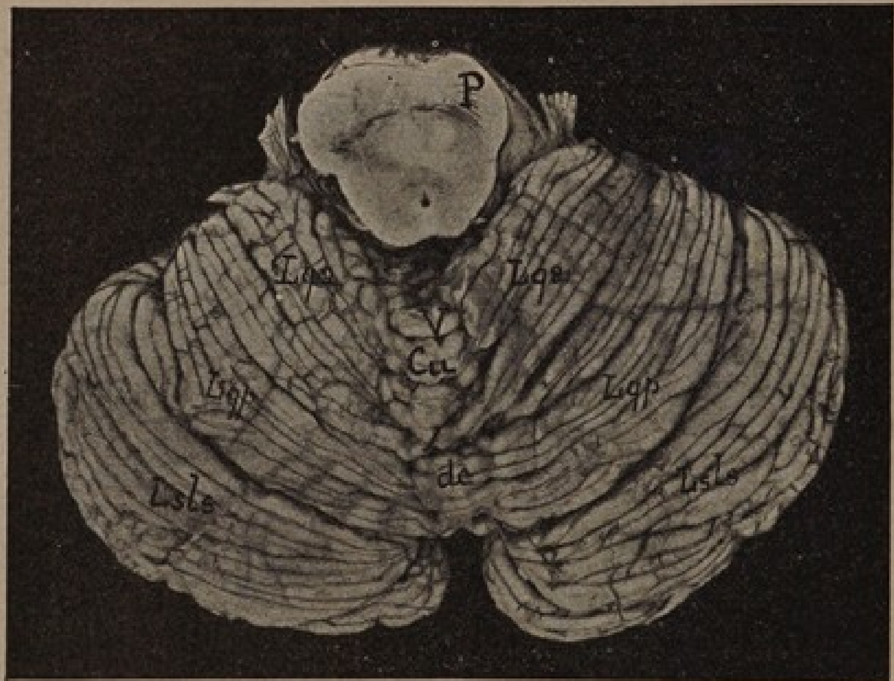


Fig. 89. Crossed atrophy of the cerebellum in a case of cerebral hemiplegia in an adult. Above the superior surface. Below the anterior surface.

ispheres (Horsley and Clarke). This is why it seems more probable that the vermis and the lateral lobes do not have absolutely identical functions. The first would be more particularly related to the functions of equilibration, and the second to the functions of regulation.

Summary

Among the results of experimental and clinical investigation, we must distinguish a group of concordant and a group of discordant facts.

The first group consists of the phenomena produced by the destruction of the organ. The second group of those produced by its excitation. This last group should be again studied before we can make any definite physiological deductions.

The symptoms following the destruction of the cerebellum are above all disturbances of motility, whether the movement is reflex, automatic or voluntary.

The motor perturbation affects not only each movement considered alone but also the association of movements, or better, the motor synergies.

Each movement, isolated by itself, is not incoördinate as in locomotor ataxia. It is characterized by dysmetria and discontinuity. When the movement relates to the maintenance of an attitude, there is instability or astasia.

The disturbances of the motor synergies are particularly manifested in tonic reactions applied to the maintenance of equilibrium. There is a perturbation of the reactions of equilibration. The cerebellum perfects and accelerates the reëstablishment of equilibrium, in the same way that it renders movement precise and regular.

The cerebellum assures the measure and the continuity of movement, stability, and the reactions of equilibration by a special tonic action. This regulatory action is governed partly by the cerebrum, and partly by peripheral excitations, but it is not a center of conscious sensibility.

We cannot but look upon the action of the cerebellum on muscular tonus, and on the centers, as braking or inhibitory, rather than excito-motor. It is probably either one or the other. Is not the cerebral cortex at the same time excito-motor and inhibitory (Hering and Sherrington)? By the excitations of the cerebral cortex have not physiologists obtained at the same time contractions of certain muscles and inhibition of the tonus of their antagonists?

Contrary to the cerebrum, the influence of the cerebellum is exercised principally upon the muscles of the same side of the body.

In the same way as after the suppression of the cerebellum, the motility of the limbs is not abolished, so the function of equilibrium is not definitely lost. It may be reacquired, in a certain measure, thanks to cerebral and labyrinthine substitutions.

The existence of individualized centers of differentiated or coördinated movements in the cerebellum, is not yet absolutely demonstrated, but researches in this line up to now are rather favorable to this hypothesis. One must distinguish two organs in the cerebellum, the cortex and the central gray nuclei. In the cortex we must admit a certain function of independence between the vermis and the hemispheres. The same is the case for the various central gray nuclei.

The vermis, or primitive cerebellum, is principally in relation with the inferior centers (spinal, medullary, pontine); the hemispheres with the superior centers (cerebral cortex, central ganglia of the cerebrum). The action of the cerebellum may be exercised either through a reflex path (nucleus of the vestibular nerve, red nucleus), or through the intermediation of the cerebrum (superior cerebellar peduncle and thalamo-cortical fibers).

The vermis, the relations of which are very intimate with the nuclei of the vestibular nerve, is more particularly adapted to the regulation of the coördinations upon which the equilibrium and the station of the body depend; the hemispheres to the regulation of voluntary movements.

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