but progressive improvement. Recovery takes place either rapidly or not at all in the large majority of cases.

The further course of the disease can be distinguished in no respect from that of cerebral hemorrhage. As we have stated in our discussion of the latter subject, even a post-mortem examination may fail to distinguish in old cases between the remains of a clot and an embolic process, inasmuch as the embolus itself may gradually have been absorbed and the original brain lesion replaced by a cyst or cicatrix.

For the changes in the symptomatology due to the varying location of the embolus, we must again refer the reader to the article by Dr. Starr, on *Brain Diseases: Diagnosis of Local Lesions.*

But we will here describe a very peculiar group of symptoms, apparently of bulbar origin, which has been observed in a number of instances in which the lesion was situated in another part of the brain. The clinical history of this form of disease is well shown by the following case reported by Berger:

"A man, aged sixty-one, suffering from small, contracted kidneys. In 1883 dysarthria and dysphagia developed suddenly without any violent apoplectiform symptoms. At the end of two days right hemiparesis and salivation were observed. Striking improvement after local faradization. About a year later an attack of tonic rigidity of the body, followed by an exacerbation of the disturbances of speech and deglutition, and also of the right hemiparesis. Paralysis of the orbicularis oris, particularly on the right side, and of the muscles of the tongue and deglutition. Inconstant condition of the glosso-labio-pharyngeal paralysis; no progressive course. No atrophy; normal electrical irritability of the paralyzed muscles."

Quite a number of autopsies have shown that symptoms of this character may be due to a bilateral or even unilateral lesion of the cerebral hemispheres in any position which interferes with conduction from the cortex to the centres of articulation and deglutition in the medulla oblongata, though the latter may be entirely intact. A case of this description, in which I was fortunate enough to obtain an autopsy, was seen by me only a few days ago. In this instance a spot of softening was situated in the anterior third of the posterior half of the right internal capsule, and also involved slightly the anterior part of the optic thalamus.

Diagnosis.—The diagnosis of cerebral embolism has been considered in part in the discussion of cerebral hemorrhage, so that very little need now be said on the subject.

One combination of symptoms, viz., the sudden occurrence of right hemiplegia and aphasia in a patient who has previously presented no cerebral symptoms, is extremely characteristic of embolism of the left middle cerebral artery. This group of symptoms is observed with comparative rarity as the result of any other lesion, though, of course, a hemorrhage occurring in the internal capsule may give rise to the same symptoms. In the latter event, however, the disturbance of consciousness is usually more severe than in the former, and, in addition, the onset of the disease is generally not so sudden.

The development, during an apoplectiform attack, of an embolism of the central artery of the retina is very significant of a similar affection of one of the cerebral vessels. Symptoms indicative of the formation of infarctions in the spleen, kidneys, and lungs may also aid us in coming to a conclusion.

Youthful age and the presence of valvular disease of the heart also point to embolism rather than hemorrhage. In very young children and infants, however, cerebral embolism is much rarer than hemorrhage.

If aphasia occurs as the sole symptom the diagnosis must be made from the attendant circumstances, such as the existence of cardiac disease, the occurrence of previous attacks of a clearer nature, the age of the patient, and the subsequent history of the disease.

Berger states that the pseudo-bulbar symptoms mentioned in the preceding section are distinguished from glosso-labio-pharyngeal paralysis by the following differential features:

1. Sudden apoplectiform development of the symptoms, which present no tendency to progression.
2. The presence of other cerebral disturbances.
3. The absence of atrophy of the paralyzed muscles, even after the disease has lasted a considerable time.
4. The absence of the reaction of degeneration.
5. The intact reflex irritability of the paralyzed muscles.
6. The absence of signs of progressive muscular atrophy.

Prognosis.—This depends mainly upon the situation and character of the artery—whether terminal or not—in which the embolus has lodged, and upon its complete or incomplete occlusion. The latter factor is of comparatively slight importance, since incompletely occluding emboli usually are converted into completely occluding ones from the secondary deposit of a thrombus. As a matter of course, the occlusion of one of the vessels supplying the pons or medulla may prove rapidly fatal.

If improvement occurs it usually takes place within one or two weeks. Otherwise the symptoms remain stationary or are complicated at a later period with secondary contractures, etc., as in cerebral hemorrhage. According to our experience, there is less danger of mental impairment than in cerebral hemorrhage. Relapses may occur at any time from the continuance of the primary cause. Death occurs much less frequently than in hemorrhage of the brain, unless the embolus lodges in the basilar artery.

CEREBRAL THROMBOSIS.—*Etiology.*—Thrombosis of the cerebral arteries is generally the result of atheromatous degeneration of the vessels. In such cases the current of blood is also usually slowed on account of weakness of the heart's action, and coagulation, therefore, takes place upon the roughened parts of the inner coat of the vessel. The deposit of coagulated blood gradually increases in extent until, as a rule, the lumen is entirely occluded. In rare instances, however, a parietal thrombus forms, leaving part of the lumen free for the passage of blood.

As we have stated previously, it is quite common to find, also, that a secondary thrombus is deposited upon a cerebral embolus, whatever the origin of the latter may have been.

A syphilitic affection of the walls of the vessels may lead to thrombosis in the same way that atheroma does, but the syphilitic vascular lesions have been discussed under a separate heading (see *Brain: Syphilis*).

As atheroma of the vessels is usually one of the accidents of advancing age, so thrombosis is also most frequent after middle life.

Another variety of cerebral thrombus is that known as the marasmic thrombus. This develops in intact vessels as the result of simple retardation of the current of blood (perhaps associated with a change in its chemical constitution), and is observed usually after protracted, exhausting diseases or severe attacks of an acute infectious disease. This variety is also observed in childhood, from similar causes.

Another form of thrombosis is the result of direct compression of the vessel, either from a mass of surrounding exudation, particularly in tuberculous meningitis, from the growth of a tuberculous new formation through the wall of the vessel, or from the pressure of a tumor of the brain. In such cases, however, the clinical history of the thrombus is usually lost in that of the primary disease.

Clinical History.—Cerebral thrombosis is frequently preceded by prodromal symptoms, which vary greatly in character and duration, lasting at times for many months. These symptoms are due probably to the impaired nutrition of the brain, on account of the slowly increasing diminution of the elasticity and calibre of the affected vessel.

Dizziness is one of the most common prodromal mani-

festations; it may be constant or intermittent, and is often aggravated by any sudden change in position. Violent headache is more infrequent, and is usually diffused over the entire head. The patient grows moody and morose, the memory is weakened, and impairment of speech may also be noticed. Sometimes intercurrent attacks occur, in which the individual partly loses consciousness, experiences numbness in an arm or leg, and, perhaps, has a slight loss of power in these parts.

In addition to the cases of mental weakness, Monakow describes a form of more decided psychical disturbance. This may assume the shape of senile mania or melancholia or the delusions of persecution. In the latter event, the patient believes himself ill-treated by his family and friends, threatens lawsuits in order to defend his rights, etc.

Others exhibit increased excitement, with vivid hallucinations and occasionally, as in ordinary acute mania, sing aloud, gesticulate violently, and exhibit complete confusion of ideas; destructiveness may also be manifested. This condition rapidly gives place, however, to a quiet dementia.

Melancholic conditions are rarer. They are characterized by mental confusion and depressive excitement; delusions of a religious tinge are sometimes noticed, and there may be a tendency to suicide. This condition also terminates quickly in dementia.

After a longer or shorter duration of the prodromal stage, the symptoms proper of the thrombosis usually develop with great rapidity. Sometimes, indeed, the attack is as sudden as one caused by embolism or hemorrhage, and if no previous symptoms have been observed, it may be impossible to make a differential diagnosis. The symptoms of the attack itself can usually be distinguished in no respect from those of cerebral hemorrhage, but there is some difference to be noted in the subsequent history. Recovery from the paralysis which has been produced is extremely exceptional. On the contrary, the impairment of motion grows more marked with time. This feature is explained in part by another peculiarity of the affection, viz., that very commonly the mental power becomes steadily impaired after the attack of paralysis. If several seizures occur (as is not infrequently the case), the patient gradually sinks into a condition in which he forgets almost everything, and even fails to attend to the wants of nature; his speech is thick and indistinct, etc.

The symptoms due to thrombosis of the basilar artery are so peculiar that they merit separate consideration.

The symptoms develop suddenly or gradually, according to the mode of development of the thrombus.

Sometimes merely a severe apoplectic attack is produced, accompanied often by contraction of the pupils and irregular breathing, the attack proving fatal in a period varying from a few hours to several days.

But usually very characteristic phenomena are developed. If hemiplegia is present (and this is usually the case), it is generally of the so-called "alternate" type (Gubler). In this form of hemiplegia the body is paralyzed on one side and the face on the opposite side (the paralysis of the facial nerve involves the occipito-frontalis and orbicularis palpebrarum, and is therefore similar to peripheral facial paralysis). In addition, there is another very rare form of alternate hemiplegia, in which the face and body are paralyzed on the same side, the motor oculi communis on the opposite side. Leyden proposes to call the former variety inferior alternate hemiplegia, the latter variety superior alternate hemiplegia.

In addition, disturbances of speech and deglutition are frequently produced, the former more commonly than the latter. The difficulty of speech is shown by the thick, muffled articulation, and is due to paresis of the muscles of articulation; in other words, it does not present the characteristics of any of the forms of aphasia. The tongue is usually moved with difficulty. The bodily temperature is apt to rise very high in these cases shortly before death, and Eichhorst has reported a case in which the temperature reached 108° F.

Despite the gravity of the lesion, some patients make a tolerably complete recovery, and again become able to walk about, until a further extension of the disease produces a second and fatal attack.

Diagnosis.—As we have on several occasions remarked, the symptoms of an apoplectic seizure due to cerebral hemorrhage, embolism, and thrombosis may be identical. But the attendant circumstances are often of such a nature that we shall be enabled to distinguish cerebral thrombosis from the two other affections mentioned.

When the prodromal stage is very long and the attack itself develops slowly, the recognition of thrombosis is usually quite easy. But when these conditions do not hold, the diagnosis depends chiefly upon the age of the patient, the condition of the blood-vessels (particularly the radial and temporal arteries), and the subsequent history of the case.

Furthermore, it is characteristic of this disease that it is very often attended by a gradual, pronounced failure of the mental powers, so that the patients finally sink into a demented condition.

In a considerable proportion of cases, however, it is impossible to make a positive diagnosis between cerebral hemorrhage and thrombosis.

Prognosis.—The prognosis, as regards complete recovery, is extremely unfavorable, not so much on account of the severity of the lesion itself, but from the fact that the vital powers are usually at such a low ebb that restoration of function in the affected parts is impossible.

Sometimes a considerable interval elapses between the individual attacks, but the disease is always progressive, and unless carried off by an intercurrent disease, the patient gradually sinks into a condition of imbecility, finally gets up bed-sores, etc.

Treatment.—During attacks of cerebral embolism or thrombosis very little can be done beyond keeping the patient perfectly quiet. When indicated by the pulse, stimulants should be administered to rouse the failing action of the heart.

After the primary attack has passed over, the treatment of the residua of embolism will be essentially the same as that advised concerning cerebral hemorrhage.

After thrombosis, the paralysis and other symptoms do not yield to treatment, and little can be done beyond keeping up the general nutrition of the patient.

Leopold Putzel.

BRAIN: FUNCTIONS OF CEREBRAL CORTEX.—It is now conceded that the physiological processes underlying sensation and perception, emotional expression, language, voluntary movement, memory, the association of ideas and intellection are to be sought within the encephalon. It is admitted, also, that the structures which are thus prerequisite to every manifestation of mental life are the neurones of the cortex of the cerebral hemispheres. Exner's statement that a "physiology of the cerebral cortex in the sense in which there is a physiology of the muscle, etc., scarcely exists at the present time" is doubtless as true now as it was two decades ago. And yet the functions of the cerebral cortex, both of its entirety and also of differentiated portions, are at the present day in large measure ascertained and comprehended.

A bare recital of the facts of cerebral localization conduces only to confusion. It would be difficult to point to another department of science in which facts as facts have so little significance. Before a fact or reputed fact can be comprehended and made to serve as the basis for conclusions concerning the nature and localization of the cerebral functions, it must not only be critically examined on its own merits; it must also be connected with a great multitude of other complicated phenomena and interpreted in relation to general theories of mental and neural activity. The comprehension of the functions of the cerebral cortex is mainly the result of psychological interpretation and analysis.

Six different methods of investigation or lines of inquiry have contributed all the facts upon which the conclusions that constitute the science of cortical neurology are based. Each has certain advantages not possessed by others, and each has its limitations. The first of these methods is the *method of biological comparison*. Although this is the oldest method, it is certainly the least important. Even the ancients had noted the greater size of the human brain in comparison with that of the lower animals, as well as the more complicated structure of its convolutions; in consequence, some taught that the superior intelligence of man was to be accounted for by the greater size of his brain, and that the brain was peculiarly the seat of intelligence. It has been customary, also, to compare the size of the frontal lobes in the more intelligent races with that of the same structures in the less intelligent races and in the lower animals. But this method alone would lead to the conclusion that the occipital and perhaps the temporal lobes were also the seat of higher psychical processes. Attempts have been made to draw positive conclusions from examination of the relative size, weight, thickness, and surface area of the cerebral convolutions in normal and degenerate individuals or classes of men. This method furnishes only presumptive evidence that relative excess of cortical substance is associated with higher grades of intelligence.

The second method is that of *experimental extirpation*. This method was the first to give convincing evidence of diversity in the localization of functions within the cerebro-spinal nervous system. Observations on the brainless frog revealed the significant difference between those functions which could be carried on by the spinal cord alone and those which required the spinal cord and brain. The distinction between a reflex and a conscious reaction was thus no longer a matter of definition, for the brainless frog was shown to be a simpler, more mechanical, and less intelligent frog than the intact frog. The differentiation between sensory and motor paths of conduction, first demonstrated by Bell through sectioning of the ventral and dorsal nerve roots, next revealed the possibilities of artificial interference or extirpation. Increased refinement of procedure has made possible the destruction of small or large portions of the cerebrum for the purpose of observing the resultant effect upon the behavior of the animal after recovery. The interpretation of the results of small or large ablations is beset with many difficulties. It is therefore not surprising that different observers have obtained widely divergent results. If the effect of experimental extirpation be restricted to paralysis of a group of muscles or to some disorder of motility, and if these disturbances persist long after the operation, the inference is relatively direct. But after ablations that affect sensation only, the exact amount and character of the sensory disturbance is sometimes difficult to ascertain, because these experiments are necessarily restricted to the lower animals, and the loss of sensation must be inferred from disorders of movement functionally related to the sense in question. Moreover, it is not easy even with the most approved method to limit the area destroyed. Inflammations ensue, degenerations take place, cicatrices and abscesses may form. Post-mortem examination will not always serve convincingly to distinguish areas that have been rendered functionless from those that were still active at the time of death. Many of the phenomena of motor and sensory disturbance are evanescent, while others are so minute as to escape all but the most careful observation. Paralyses which slowly recover may be explained either by assuming an identity of function for different portions of the cortex or by a substitution of function on the part of cells that have learned to perform an unwonted task. To distinguish between a simple loss of sensation and those losses which have been variously described as soul-blindness, soul-deafness, etc., is a matter of extreme difficulty. The exact nature of the details of the psychical life of the lower animals is wholly conjectural; anatomical homologies between the human brain and the brains of lower animals are of doubtful significance, and it may be questioned whether anatomically identical parts of the brains of man and the lower animals perform similar functions. It is, therefore, not surprising that the functions of the frontal lobes were first unassailably established by this method only within the last decade through the painstaking experiments of Bianchi.

The *pathological method*, which may also be called the method of natural extirpation, has peculiar advantages. The subjects of such experiments of nature are human beings, who may be carefully studied and questioned. The post-mortem location of cerebral lesions has been of the greatest service in furnishing early and convincing evidence of cortical areas of specific function in the human brain. The existence and location of a speech centre was demonstrated by Broca from pathological findings as early as 1861 and was suggested by Bouillaud even in 1825. The evidence furnished by the pathological method is, however, often equivocal and even contradictory. The morbid anatomy of the brain is vague and indecisive compared with the definiteness of many established forms of mental disease. Conflicting evidence is to be expected. Cerebral lesions are seldom circumscribed; tumors or hemorrhages at any one point often produce associated and secondary functional disturbances which may obscure the exact relations of cause and effect. It is also very seldom that bilaterally symmetrical lesions occur; and yet these are in some cases the only cause of the complete and persistent loss of function. Moreover, observers have not until recently determined and reported the ante-mortem condition of the patient with sufficient regard for essential details. To this lack of careful observation chiefly is ascribable the tenacity of the belief in the existence of so-called "silent areas."

The *method of irritation* (chiefly electrical irritation) has contributed materially to the exact localization of cortical centres for the various bodily movements. By this method very small areas are incited to functional activity either by the electric current or by mechanical or chemical irritation. An objection to the localization of centres in the cortex by direct stimulation of the gray matter of the cerebral hemispheres has been found in the fact of electrical diffusion through the substance of the brain, whereby even weak currents may act upon areas remote from the electrode. Even the separation of the mass of a particular area by section from adjacent parts will not eliminate the diffusion of the current through the blood or along the nerves of the normal pathway of projection. Although it had been established that a current will produce similar movements whether applied to the gray matter of the cortex or to the fibres immediately below, Franck and Pitres and Carville found that when applied to the cortex the current may be weaker and that the movements follow the application of the stimulus at an appreciably greater interval. These results demonstrate the participation of the gray matter of the cortex in the production of the movements. The epoch-making investigations of Fritsch and Hitzig advanced conclusive evidence that movements of greater co-ordination can be produced by the application of currents to restricted areas of the Rolandic cortex than by stimulation elsewhere. The method of irritation has been employed chiefly on the lower animals, but occasionally also upon man.

The *histogenetic method*, more familiarly known as the embryological or myelinization method, which is the outgrowth of modern improvements in histological technique, has, in the hands especially of Meynert, Edinger, and Flechsig, contributed results of great value. This method seeks to establish the anatomical relations of conduction pathways and cerebral centres at ontogenetic periods before the number and complexity of interlacing fibres defy the analysis of the microscope. The projection and other fibres of the cerebral cortex take on their myelin sheaths at different periods of fœtal and infantile life; before their myelinization they are believed to be functionless. The maturity of the cortical areas to which these fibre tracts belong may be inferred, according to Flechsig, from the successive development of the tracts themselves.

The last method to receive mention is the *histo-degenerative method*. Secondary degeneration of nerve fibres and tracts invariably follows artificial extirpation and natural lesions. This degeneration is at first always in the direction of the functional conductivity of the tract; but later degeneration is also observed in the contrary direction toward the centre of neural emission. The study of the course of such degenerations has supplied much new evidence pointing to the anatomical and physiological connection of cortical areas with lower centres. The histological methods may be expected to supply in the future the more valuable contributions toward the comprehension of the interrelations of the neuronal elements of the various parts of the cerebral cortex.

These various methods have contributed within the present century a mass of material evidence, the several details of which are often self-contradictory, but from which a consistent consensus of opinion can be gathered by critical sifting and weighing of opposing contentions. The present article attempts to present only the general tendencies of the results and to outline the more significant conclusions. The over-emphasis of conflicting details and of erroneous interpretations of results has often caused the localization of specific cerebral functions to appear more doubtful than it really is. The psychological and metaphysical theories, which have helped to form the opinions of physiologists and other investigators, have contributed not a little to this confusion. Physiologists, in revolt against the dogmatism of metaphysical speculation, have frequently sought to frame conclusions in such manner as to avoid entanglement with psychological theory. The result, unexpected by them, has often been to warp or pervert their conclusions by primitive psychological points of view, which had long before been discarded even by traditional psychology. The controversy of Pflüger with Lotze is a notable illustration of this tendency of the physiological mind to assail certain doubtless unjustifiable psychological theorizing, and yet, in the effort, reverting to a speculative attitude that the history of the development of the anatomy and physiology of the nervous system shows to have been a distinguishing characteristic of the science only at its earliest beginnings and to have long since been set aside. Speculative views on the nature of the human soul or mind and on its relation to the body and objects of nature have always determined the trend of conclusions respecting the specific functions of the cerebral cortex; for the reason, as has been before maintained, that these conclusions are necessarily psycho-physiological inferences.

Until the time of Descartes all interpretations of physiological functioning were based upon crude psycho-physiological theories which were the outgrowth of a notion variously described as *animism*, *vitalism*, and *anthropomorphism*. Briefly, animism identifies consciousness, life, and movement. The soul may be identified with the breath, because with the cessation of breathing the life and soul of the organism cease to exist or at least leave the body. Other observers, their attention attracted to the movement of the heart as the most significant bodily function, assumed this organ to be the seat of life and consciousness. Thus Aristotle considered the brain the coldest and most bloodless of the organs, its chief purpose being to temper the excessive heat of the heart, the true organ of the mind. Though the soul, as the vital principle of the entire organism, may be connected more particularly with some one organ of the body, nevertheless every organ, and indeed every object of nature, according to the animistic doctrine, functions through its endowment with a conscious vitalizing principle. Every physiological process and certainly every bodily movement is, from this point of view, the work of a rational and intelligent, though not always conscious or reflective spirit or soul. The animistic hypothesis is one that appears throughout the history of the organic sciences in many different guises. It is the progenitor of the doctrine of animal or vital spirits, and at almost all periods has inspired theories of psycho-physiological generalization such, *e.g.*, as that advocated by Pflüger as late as the middle of this century.

It must not, therefore, be supposed because Pythagoras maintained the brain to be the seat of the mind and intellect and Hippocrates speaks of the brain as the index and messenger of the intellect that they had arrived at these conclusions from a careful observation of facts. These are rather lucky guesses which subsequent research substantiated. Doubtless a few had observed the effect of concussion of the brain and had even referred idiocy to brain deficiency. It is stated that Hippocrates commented upon the loss of mental function following disease and injury of the brain, and that Polybos claimed the brain to be a centre for the nerves and the organ of the mind. Erasistratus is said to have taught that sensory nerves arise from the brain membranes and motor nerves from the cerebral substance. Herophilus, according to Celsus, maintained that vital forces resided in and circulated from the ventricles of the brain, and Galen stated definitely that the seat of the soul and intellect is in the brain and that the animal spirits have their origin in the ventricles of the brain and pass thence to the heart through the arteries. The Christian writers adopted Galen's view and conferred on it a theologic sanction which made correction difficult. As late as the thirteenth century Gordon, professor of medicine in Montpellier, placed common sensation and the reception of impressions in the anterior cornua of the lateral ventricles, imagination and intellection in the posterior, judgment in the third ventricle, and memory in the fourth. Rhazes (1554) localizes imagination in the second lateral ventricle, reason in the middle ventricle, and memory in the posterior. Willis (1622–1675) considered the brain substance as the dynamic source or storehouse of the animal spirits. He placed memory and will on the convoluted surface of the cerebrum, and associated imagination with the corpus callosum, sense perception with the corpus striatum, impulse and emotion with the basal parts about the crura, vision with the thalamus, and involuntary acts with the cerebellum. These somewhat suggestive attempts to state the psycho-physiological functions of the brain were rendered futile and bereft of all inspiration to experimental discovery by the persistent belief in the doctrine of animal spirits. When some anatomists of the seventeenth century attacked vital spirits resident in the ventricles (Alexander Benedictis as early as 1527 was so bold as to doubt that the spirits existed at all), they were regarded as revolutionary by the great majority of the seventeenth and eighteenth century medical writers. The vital spirits, however, were gradually losing their psychical attributes and were at this time generally defined as like to "little flames" or in a still more material way as those "very subtle particles" (Willis). Moreover, anatomical investigations were indicating the nerves rather than the arteries as the conductors of these animal spirits.

Descartes (1596–1650) first presented a psycho-physiological theory which contained possibilities for future advance. With him began a new era in physiological speculation. His chief contributions were (1) a consistent theory of a sensorimotor mechanism; (2) a clear distinction between the automatic or reflex functions of the cerebro-spinal system and its conscious functions; (3) a description of the sensorimotor arc as composed of afferent and efferent nerves and of a central system capable of reflecting sensory impulses from the brain to motor nerves mechanically and unconsciously, or even in spite of the will. Although it cannot be claimed that Descartes discovered spinal reflexes, for he considered the brain as the centre for both conscious and reflex movements, he nevertheless was far ahead of his time in justly appreciating the reflex capacity of the central nervous mechanism. He made the error of assuming that there must be a single point in the brain at which sensory impulses are transformed into sensations and the will exercises its determining influence upon the body. Even those who scorn this philosopher's attempt to find the seat of the soul in the pineal gland are not seldom guilty of a similar assumption, although they may perhaps assign it a different location.

After the time of Descartes various observers soon began to report reflex phenomena, but it was not until a century had passed that Whytt (1714–1766), in an essay on "Vital and Other Involuntary Motions of Animals," reported the now classical experiment of Hales. A decapitated frog was shown to be capable of reflex movement for thirty hours after decapitation. When a needle was thrust down the spinal marrow, the animal was strongly convulsed and immediately afterward became motionless. Whytt concludes that the immediate cause of the contraction of the muscles of animals, or at least a necessary condition, is a certain power or influence lodged in the brain, spinal marrow, and nerves. Of this power he says: "If in compliance with custom I shall at any time give it the name of animal or vital spirits I desire it to be understood to be without any view of ascertaining its particular nature or manner of acting." Whytt demonstrated the special structures with which reflex functioning is connected. He believed, however, that no motion could take place in the body unattended by some degree of consciousness, thus rejecting the mechanical theory of Descartes and substituting a diffusion of consciousness wherever nerves are found.

Whytt's definition of the "power of nerves" was fixed for science by Haller (1708–1777), who maintained the existence of a similar power inherent in living muscle. This he called irritability or "vis in situ," which he considered to be independent of the sensibility of nerves. He also used the term "vis nervosa," but nevertheless takes for granted the existence of animal spirits and even debates what manner of fluid it may be.

The development of the concept of a force of gravity and the exploitation of the famous vibration theory of Newton made possible a detailed development of the mechanical theory of nervous reaction suggested by Descartes. Thus David Hartley (1649), the well-known psychologist, endeavored to explain the functions of the brain in connection with the association of ideas and sensations on a basis of the vibrations of the ether, a subtle fluid of the nerves. Indeed, Newton had himself, in the "Principia," advanced the opinion that all sensations and movements are excited by the vibrations of a very subtle spirit propagated through the solid capillamenta of the nerves from the organs of sense to the brain and from the brain to the muscles.

Unzer (1727–1799), taking up Whytt's results and point of view, distinguished more clearly between the sensory impulse which travels from the periphery to the brain, and the material idea, as he calls it, into which it is transformed in the brain, giving rise to an image in the soul. The sensory impulse on reaching the brain is reflected or turned back, giving rise to motion with conciousness. If it is reflected or turned back before reaching the brain it gives rise to motion without consciousness. Unzer, however, thought that the spinal ganglia were the structures in which this reflection took place.

Prochaska's work on reflex action (1749–1820) remained for fifty years an object of commendation. He was looked upon by Longet as the investigator who first made reflexes a distinct class of action. He clearly posited a vis nervosa as the cause latent in the nervous pulp, capable of producing certain effects when acted upon by a stimulus. "External impressions made on sensitive nerves are propagated with great velocity throughout their entire length to their origin. From this place, they are reflected according to a certain law and pass into certain and corresponding motor nerves by which again, being very quickly propagated to muscles, they excite certain and determinate movements. This place in which, as a centre, nerves of sense and motion meet and communicate, and in which the impressions of sensitive nerves are reflected into motor nerves, is called by a term already received by most physiologists, the 'sensorium commune.'" Prochaska even brought his central mechanism into line with biological conceptions of instinct, in maintaining that the law under which reflection takes place is "the preservation of the individual." Many physiologists had followed Newton in establishing a vibration theory for the nervous system; Prochaska, in turn, was influenced by Galvani's discoveries to look upon electricity as the physical condition for the manifestation of vis nervosa. Neither Prochaska nor Unzer made any lasting contribution to our knowledge of the localization of diverse centres of reflex and conscious reactions.

Unzer had presented certain views on the localization of cerebral functions, and Prochaska in 1784 published in Vienna a work on the nervous system in which he developed a scheme of cerebral localization which establishes him as the immediate predecessor of Gall. Owing to the unproductiveness of the phrenologists and because of the dogmatism with which the system was asserted, it is customary to look upon Gall as having no place whatever in the development of the science of neurology. The excesses of phrenology are to be attributed to Spurzheim, Combe, and their followers. Their noisy advocacy of what they considered a philosophical system gave to it great popularity until the middle of this century, and its attendant ill-repute in scientific circles. Gall, it is true, embraces within his system the views of the physiognomists, who had remained somewhat outside the pale of science; but he is nevertheless a legitimate successor of the cerebrationists of his time. The advanced position which he held and the discussion to which it gave rise were a distinct impulse to the development of experimental work in neurology. Indeed, Gall and Spurzheim were among the first to give public demonstrations of the anatomy of the human brain, as also they were among the first to advocate that the cerebral cortex is the only organ of the mind. It is true that Gall and his followers contributed nothing to our knowledge of the localization of functions in the cerebral cortex, but they nevertheless pointed the way; those who followed, employing more legitimate scientific methods, initiated the discoveries that have led to the present status of the science. Gall's methods hark back to preceding modes of thought and demonstration, and hence he is the last significant figure of a line of speculators and investigators that began with Descartes. After him, the presumption has always been in favor of specialization of function, and of restricting the psychical functions of the nervous system at least to the cerebrum. His chief errors flowed from the acceptance of a psychological system, which viewed the mind as made up of separate faculties, and from his readiness to use insufficient evidence to arrive at far-reaching conclusions. Thus he placed the faculty of language behind the eyes, because he observed the protruding eyes of some of his school-fellows noted for their facility in language. The protrusion of the eyes and the various bumps upon the skull were to him indices of the growth of the convolutions immediately beneath. Gall recognized twenty-six different faculties or organs, and selected their place by examining the heads of friends, of inmates of jails and lunatic asylums, and of other persons who happened to be conspicuous for some special faculty or mental trait. These twenty-six organs were marked upon the skull by round enclosures with vacant interspaces. The common phrenological charts wherein the skull-cap is portrayed divided into oblate and coterminous areas are the production of Spurzheim and Combe, who increased the number of faculties to thirty-five and neatly filled out the entire area with an equivalent number of organs.

When Bell, in 1811, published the results of sectioning the anterior and posterior roots of the spinal nerves, he gave to the world the first satisfactory demonstration of the specificity of the function of motor and sensory nerves. He thereby initiated the era of experimental investigation and laid the foundation of modern nerve physiology. Simple as were the facts observed by Bell and clear as was the evidence, the embodiment of his results, known as Bell's law, was not accepted without challenge. On the one hand, he was accused of dissecting the brain to find the seat of the soul. It was probably for this reason that he privately published his conclu-

sions in a communication entitled "Idea of the New Anatomy of the Brain, Submitted for the Observation of His Friends." On the other hand, it was argued against Bell's law that the mechanical juxtaposition of fibres of specifically different function was as unscientific as the system of phrenology. As late as 1831 Lange and Beck maintained that Bell's law was as speculative as Gall's localization of cerebral functions. The labors of Magendie, Bellingeri, Panizza, and Van Deen confirmed Bell's conclusions. Müller's "Physiologie" (1834) established Bell's law in Germany, contributing to the facts of functional specificity by the galvanic irritation of both roots of the spinal nerves of the frog. Longet, in 1841, demonstrated Bell's law on higher animals.

Before the relation of the sensory and motor roots to the gray matter of the cord and cerebrum could be established, some intelligible hypothesis was necessary to explain the function of the cord in transferring a sensory stimulus to a motor nerve. Marshall Hall's "Memoirs on the Nervous System" (1837) elaborated a mechanical theory of reflex action. He maintained that the cord is composed of two parts very closely connected with each other; the first part is a bundle of nerves mediating sensation and volition, the central organ for these fibres being in the brain; the second part is the true spinal cord, generally though not invariably connected with the first part and distinguished by excito-motor nerves. He thus assumed the existence of two separate systems of nerves, an excito-motor system and a sensori-volitional system, both perhaps enclosed within the same nerve sheath. With the function of the excito-motor system nothing psychical was associated; he stoutly affirmed that brainless reflexes were unattended by sensation or by any other rudimentary form of consciousness even in the least degree. The excito-motor force he identified with Haller's vis nervosa, Müller's motor power, and Flourens' excitability. Kürschner, who translated Hall's work into German, maintained that sensory nerves ran in the posterior column and motor nerves in the anterior column. He distinguished single movements of flexion and extension that are produced in the cord from the coordinate movement of limbs produced in the cerebellum and cerebrum.

Many observations were made to determine the truth of Hall's statement that brainless animals never moved spontaneously. Volkmann, in Müller's *Archiv* for 1838, justly maintains that whether the cord has obscure sensations is not manifest, for experiments prove only that the part of the body furnished with a brain does not feel the irritation of that part which has been severed from its connection. He inclines to the view that the behavior of animals with cord and oblongata is not purely reflex, but rather of such character that it is impossible to deny the co-operation of a psychic principle, the degree of consciousness in such case being dreamlike, and marked by the presence of obtuse sensations and even obscure conceptions that help to determine the movements. Müller, on the other hand, maintained that if the sensory stimulus can pass on to the sensorium commune in the brain, it becomes a conscious sensation, but in case of section of the spinal cord it produces centripetal action in the cord only. In both cases reflex movements may result, but in one instance they are attended by conscious sensation, in the other not.

The last opponent to the theory of non-conscious spinal reflexes and of the localization of all psychical functions within the cerebrum was Pflüger (1853), who contributed so largely to our knowledge of reflexes and yet vitiated his conclusions with primitive metaphysical considerations. Consciousness for him is motion and exists wherever central nerve substance is found. It is divisible in all animals with its material substratum; hence the well-known theory of a spinal-cord soul. Reflex action is the operation of a neuro-psychic mechanism by means of which the peripheral sensory fibre, by whatever cause excited, causes through mediation of the spinal cord the ordinary state of excitation in motor nerves. The brain is not the only organ of sensation; the functions of the sensorium are extended throughout the cerebro-spinal system.

A consistent theory of the central neural mechanism was finally contributed in an acceptable form by Lotze in the article on "Instinct" in Wagner's "Handwörterbuch der Physiologie." He suggests that the reflexes, and probably the lower instincts also, are purely mechanical. These elementary reactions, he explains, are due to purely physical connections which have been established by nature, and which the mind can neither invent nor construct. After the mind learns these elementary movements, it may weave them into richer and more complicated patterns, just as letters may be combined by the mind into sentences. Physical changes set up in the peripheral ends of sensory nerves are therefore conducted unaltered in character to the brain. Here occur all those processes by which physical excitation is transmuted into the psychic forms of sensation, feeling, etc. The reflexes of Pflüger's decapitated frog are due not to sensation or intelligence present in the cord, but to the after-effects of these, for the motor states of the mind are transformed into nervous impulses in the brain alone, whence they are propagated through the efferent nerves to the muscles. By practice and training a secondary character which survives decapitation is imparted to subordinate centres. Lotze's mechanism is thus constituted of inherited and acquired habits. With Lotze's explanation of the neural basis of reflex, instinctive, and conscious reactions, the restriction of strictly psychical functions, at least, to the encephalon may be considered to have been at last decisively established.

Meanwhile, the evidence of the specificity of parts of the encephalon was being advanced by experimental physiologists in the first instance and by pathologists in the next. Flourens, in 1821, published his "Experimental Researches on the Character and Functions of the Nervous System"; a second edition in 1842 reported additional experiments. Longet and Vulpian, in 1866, and Goltz, in 1869, contributed experimental evidence. Flourens was the first to employ extensive ablations of various portions of the encephalic nervous system. He was thus able to locate a centre for the coordination of respiratory movements near the angle of the calamus scriptorius and to show that the medulla oblongata contained centres for movement of the face and for some forms of emotional expression. Vulpian demonstrated that a young rat deprived of all the encephalon above the medulla oblongata can yet move its limbs and emit a cry of pain when its toes are pinched. On destruction of the oblongata the cry ceases, but the reflex movements continue. Moreover, he correctly interpreted the cry as no real sign of pain, but only a reflex contraction of the laryngeal and expiratory muscles. The investigations of Flourens in 1828, and later of Goltz, proved that the semicircular canals are the peripheral organs of equilibration, and located the central organ of equilibration in the cerebellum. These demonstrations were made on pigeons, cats, dogs, and moles. In all cases, partial ablation of the cerebellum induced disturbances of gait and station, ranging from slight swaying or reeling to an apparently complete loss of station and locomotion. Similar experiments performed on the cerebral hemispheres seemed to show annihilation of perception, ideation, volition, and intelligence in general, but large tracts of the brain cortex could, according to Flourens, be removed without causing any apparent mental disturbance. The ablation of single areas produced a similar result. These results led Flourens to the formulation of the dictum of the equivalence of all parts of the cerebral hemispheres, each portion being capable of performing all the functions of the whole. Flourens believed, however, that sensation proper was destroyed by removal of the cerebral hemispheres. Vulpian, on the other hand, maintained that sensation continued, but was crude and obscure in comparison with the distinct sensation or perception of the cerebral hemispheres. Longet ascribed the crude sensation to the midbrain. Goltz does not decide the question, but ascribes to the midbrain an adaptive faculty and terms the reactive functions of