can be judged from what is positively known of the action of the encephalic centres, the pain under these conditions is perceived by some nerve-centre, probably in the pons Varolii, but the impression is not conveyed to the cerebrum and is not recorded by the memory.

Taking all the experimental facts into consideration, the following seems to be the most reasonable view with regard to the action of the pons Varolii as a nerve-centre:

It is an organ capable of originating impulses giving rise to voluntary movements, when the cerebrum, corpora striata and the optic thalami have been removed, and it probably regulates the automatic voluntary movements of station and progression. Many voluntary movements, the result of intellectual effort, are made in obedience to a stimulus transmitted from the cerebrum, through conducting fibres in the pons Varolii, to the motor conductors of the cord and the general motor nerves.

The gray matter of the pons Varolii is also capable of perceiving painful impressions, which, when all of the encephalic ganglia are preserved, are conducted to and are perceived by the cerebrum, and are remembered; but there are distinct evidences of the perception of pain, even when the cerebrum has been removed.

Directions of the Fibres in the Cerebrum.—Fibres pass from the cerebral hemispheres to the cerebellum. Commissural fibres connect the cerebrum and certain of the basal ganglia on the two sides. Fibres connect the gray matter of the cerebral convolutions on the same side with each other. Fibres pass from the inner surface of the gray matter of the cerebrum to the internal capsule, corpora striata, optic thalami and pons Varolii, to the medulla oblongata and thence to the spinal cord. The directions of these four sets of fibres have been quite accurately described.

1. *Fibres connecting the Cerebrum with the Cerebellum.*—(A) Fibres from the gray matter of the frontal lobe, in front of the anterior central convolution, pass through the anterior division of the internal capsule and thence through the inner portion of the outer layer of the crus cerebri (crusta) to the pons Varolii, where they seem to go to the cells of the gray matter. From the pons, fibres go to the lateral and posterior regions of the cerebellum on the opposite side. This connection, therefore, is crossed. (B) Fibres from the occipital and temporo-sphenoidal lobes of the cerebrum pass in the outer portion of the crusta and go to the upper portion of the cerebellum, near the middle lobe. This connection is probably crossed. (C) Above the pyramidal tract of the crusta, is a small tract of fibres which connect the caudate nucleus of the corpus striatum with the cerebellum (Gowers).

2. *Fibres connecting the Two Sides of the Brain.*—(A) Fibres coming from the inner surface of the gray matter of the cerebral convolutions pass from one side to the other, through the corpus callosum, and connect the two cerebral hemispheres with each other. These are the transverse fibres of the corpus callosum. (B) Fibres from the gray matter of the temporo-sphenoidal lobe on either side pass through the corpora striata to the anterior commissure. These fibres connect the temporo-sphenoidal lobes, and probably also the corpora striata, on the two sides. (C) Fibres from the deeper portion of the crus cerebri (tegmentum) pass to the optic thalamus on either side and thence to the temporo-sphenoidal lobes. These fibres form the posterior commissure and connect the temporo-sphenoidal lobes and the optic thalami of the two sides.

3. *Fibres connecting Different Cerebral Convolutions on the same Side.*—(A) The so-called arcuate fibres, passing in a curved direction from one convolution to another, connect adjacent convolutions. (B) Other fibres, called longitudinal or collateral fibres, connect distant convolutions with each other. The fibres of the fornix connect the optic thalamus with the hippocampus major and the unicate gyrus. Fibres in the corpus callosum connect the anterior and posterior extremities of the gyrus fornicatus. These are the longitudinal fibres of the corpus callosum. Other longitudinal fibres, connecting parts more or less distant from each other, are found in the tænia semicircularis, the unicate fasciculus, the fillet of the gyrus fornicatus and the inferior longitudinal fasciculus. The last-mentioned fasciculus connects the gray matter of the temporo-sphenoidal and occipital lobes.

4. *Fibres connecting the Brain with the Spinal Cord.*—If these fibres be followed from the cortex of the brain downward, they are called converging, and if they be followed from below upward, they are called radiating fibres.

Arising from the internal, concave surface of the cortical substance of the cerebrum, the converging fibres, at first running side by side with the curved, commissural fibres, separate from the latter as they curve backward to pass again to the cortical substance, and are directed toward the corpora striata and the optic thalami. The limits of the irregular planes of separation of the commissural and the converging fibres contribute to form the boundaries of the ventricular cavities of the brain. In studying the course of the converging fibres arising from all points in the concave surface of the cerebral gray matter, it is found that they take various directions. The fibres from the anterior region of the cerebrum pass backward and form distinct fasciculi which converge to the gray substance of the corpora striata. The fibres from the middle portion converge regularly to the middle region of the external portions of the optic thalami. The fibres from the posterior portion pass from behind forward and are distributed in the posterior portion of the optic thalami. The fibres from the convolutions of the hippocampi and the fascia dentata are lost in the gray substance lining the internal borders of the optic thalami In the course of most of these fibres toward the corpora striata and the optic thalami, they pass through the internal capsule.

The fibres from the anterior and middle portions of the cerebrum, especially the middle portion, contribute largely to the formation of the anterior two-thirds of the posterior division of the internal capsule. The fibres from the posterior portion of the cerebrum are found in the posterior third of the posterior division of the internal capsule. The posterior fibres are probably sensory. The middle and anterior fibres are motor. The latter undergo descending degenerations following lesions of the anterior and posterior central convolutions (Charcot). A few of the converging fibres from the hemispheres pass directly through the internal capsule and have no connection with the corpora striata and optic thalami.

From the internal capsule, the fibres pass in the crus cerebri to the upper border of the pons Varolii. The motor fibres pass through the pons as lon-

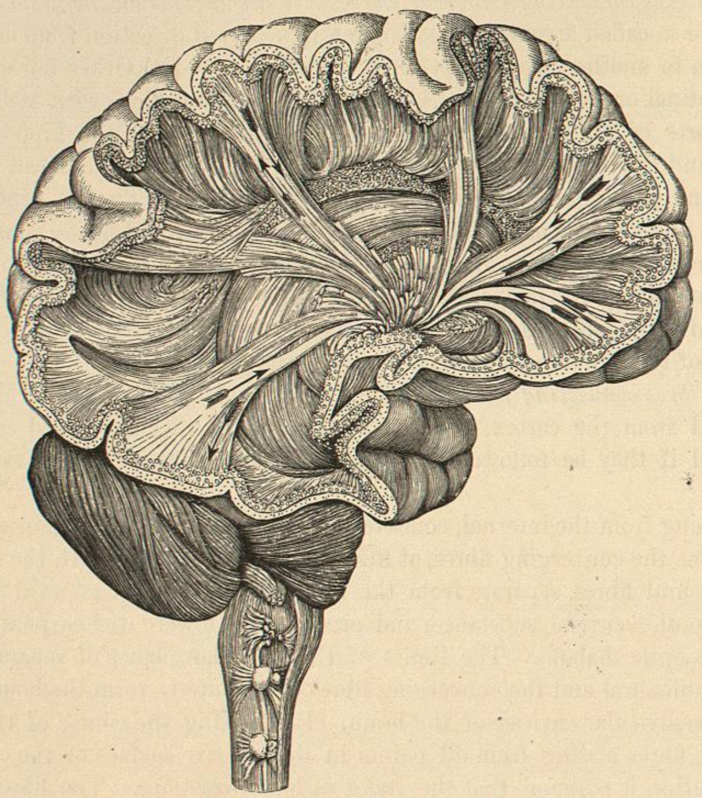

FIG. 225.—*Diagrammatic representation of the direction of some of the fibres in the cerebrum* (Le Bon).

gitudinal fibres, go to the anterior pyramids of the medulla oblongata, where most of them decussate, and thence to the pyramidal tracts of the spinal cord. The sensory fibres go to the posterior part of the cord. The converging cerebral fibres are re-enforced, in their downward course, by fibres from the tubercular quadrigemina and the gray matter of the pons Varolii. Certain fibres go to the olivary bodies in the medulla oblongata. A more extended description of these fibres will be given in connection with the physiological anatomy of the medulla.

Cerebral Localization.—The observations of Flourens (1822 and 1823) and his immediate followers, which seemed to show that the cerebrum was neither excitable nor sensible to direct stimulation, have been so completely contradicted by the experiments of Fritsch and Hitzig (1870), Ferrier, Munk, Horsley and many others, that the question of the existence of motor and sensory centres—especially motor centres—hardly admits of discussion. The negative results obtained by Flourens were probably due to severe hæmorrhage, which,

according to Ferrier, rapidly destroys the excitability of the motor cortical areas. Some of the experiments of Goltz, by which it has been attempted to prove that circumscribed and invariable motor areas do not exist, are answered by observations showing descending secondary degenerations following injury of certain parts of the cerebral cortex. The earlier observations on cerebral localization were made on dogs. Later, experiments have been made on monkeys, and the results of these have been to a certain extent confirmed by pathological observations on the human subject. Beginning with the observations in which descending degenerations have been noted as a consequence of destruction of parts of the cerebral cortex, it may be assumed that a distinct area exists which presides over certain localized muscular movements.

Motor Cortical Zone.—The motor cortical zone is on either side of the fissure of Rolando. It is usually described as including the anterior and pos-

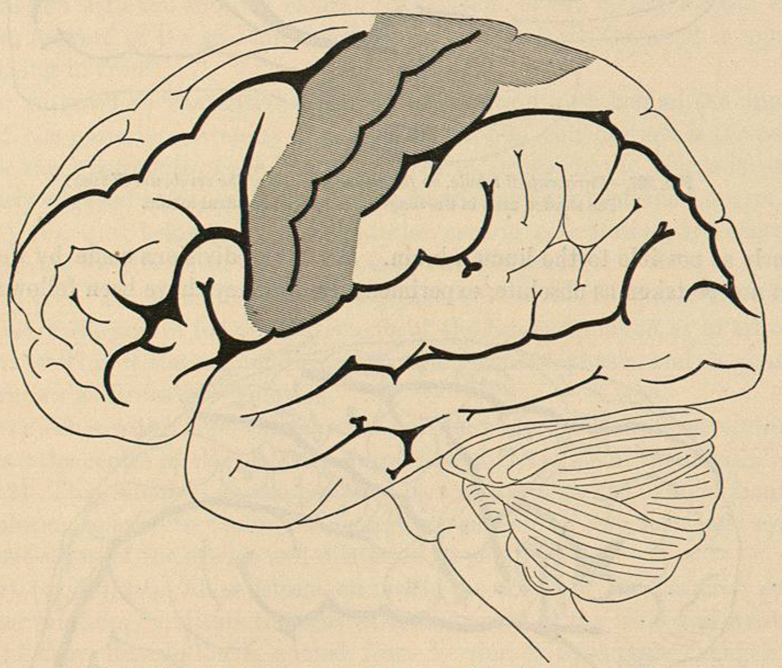

FIG. 226.—*Motor cortical zone, on the outer surface of the cerebrum* (Exner).

terior central convolutions (see Fig. 221) and the paracentral lobule (see Fig. 222). Faradization of parts in this zone is followed by localized muscular movements. In fact, the motor areas seem to be subject to nearly the same laws, as regards their reactions to Faradic stimulation, as are the motor nerves. Forty Faradic shocks per second produce a corresponding number of single muscular contractions. Forty-six shocks per second produce a tetanic contraction (Franck and Pitres). Destruction of motor areas is followed by partial loss of power in certain sets of muscles, and by descending secondary degeneration of nerve-fibres, extending through the corona radiata, the internal capsule, the crura cerebri, the anterior pyramids of the medulla oblongata and finally the pyramidal tracts of the spinal cord.

It remains now to locate the distinct motor areas. This has been done on the brain of the monkey, by Ferrier, who has applied his observations as

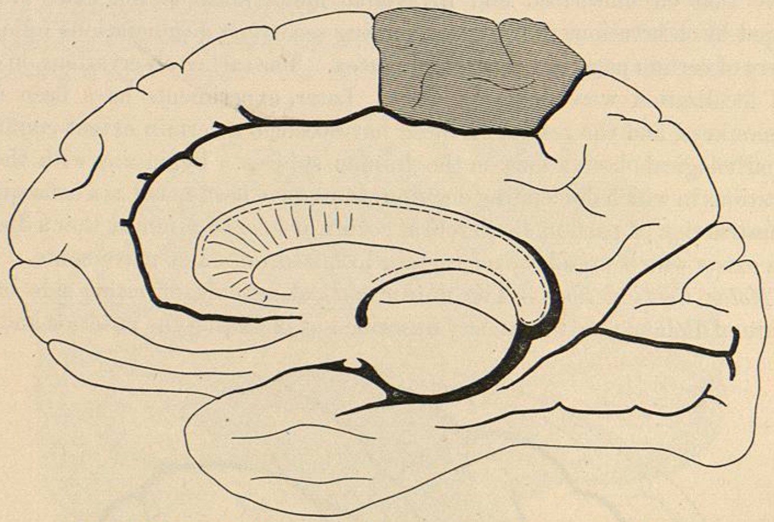

FIG. 227.—*Paracentral lobule, on the inner surface of the cerebrum* (Exner). The shaded area in the diagram is the paracentral lobule.

nearly as possible to the human brain. While the divisions made by Ferrier can not be taken as absolute, experiments on monkeys have been followed by

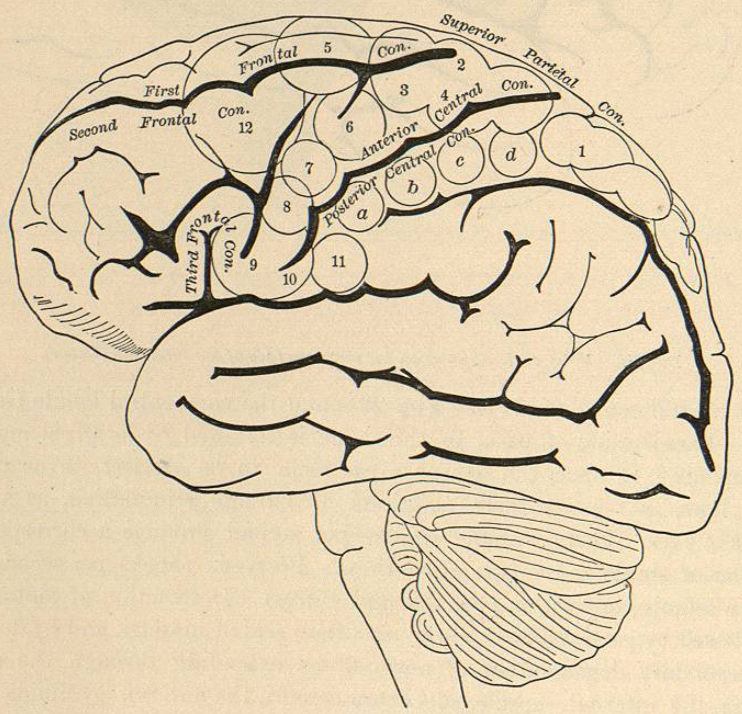

FIG. 228.—*Lateral view of the human brain, with certain motor cortical areas* (modified from Ferrier).

results so nearly constant, that the localizations may be accepted as nearly correct. In the diagram (Fig. 228) and descriptions, the centres for the special senses have been omitted, to be taken up in connection with the physiology of olfaction, vision, audition and gustation.

In the following description, the numbers and letters refer to Fig. 22:

(1). This, which is on the precuneus (compare Fig. 222), indicates the position of the centres for movements of the opposite leg and foot, such as are concerned in locomotion.

(2), (3), (4). These numbers, which are over the convolutions bounding the upper extremity of the fissure of Rolando (including the paracentral lobule—compare Fig 222), include centres for various complex movements of the arms and legs, such as are concerned in climbing, swimming, etc.

(5) Situated at the posterior extremity of the first frontal convolution, at its junction with the anterior central convolution, is the centre for the extension forward of the arm and hand, as in putting forth the hand to touch something in front.

(6) Situated on the anterior central convolution, just behind the upper end of the posterior extremity of the second frontal convolution, is the centre for the movements of the hand and forearm, in which the biceps is particularly engaged; viz., supination of the hand and flexion of the forearm.

(7), (8). Just below (6), on the anterior central convolution, are centres respectively for the elevators and depressors of the mouth.

(9), (10). These numbers taken together, on the third frontal convolution, mark the centre for the movements of the lips and tongue, as in articulation. " This is the region, disease of which causes aphasia, and is generally known as Broca's convolution."

(11). This, which is on the lower end of the posterior central convolution, marks " the centre of the platysma, retraction of the angle of the mouth."

(12) This, which is on the posterior part of the first and second frontal convolution, marks " a centre for lateral movements of the head and eyes, with elevation of the eyelids and dilatation of pupil."

(*a*), (*b*), (*c*), (*d*). These letters, on nearly the whole of the posterior central convolution, " indicate the centres of movement of the hand and wrist."

The above description is quoted from Ferrier, with certain changes in the nomenclature of the convolutions. Schäfer and Horsley in the main have confirmed and have somewhat extended the researches of Ferrier. These observers have shown that the centres on the outer surface of the cerebrum, near the great longitudinal fissure, extend to the inner surface. In the first frontal convolution, in front of the paracentral lobule, is a centre for movements of the trunk (Tr., Fig. 229), and in front of this, is a centre for the movements of the arm and shoulder. Other parts of the inner cerebral surface, except the paracentral lobule, are inexcitable.

In man lesions of parts of the motor-cortical zone produce localized paralysis, or what is called monoplegia, the action being crossed. " The following forms of monoplegia have been observed to attend localized cortical lesions: 1, oculo-motor monoplegia (isolated ptosis); 2, facial monoplegia, sometimes combined with paralysis of the hypoglossal nerve; 3, brachial monoplegia, or paralysis of the opposite arm; 4, crural monoplegia, or paralysis of the opposite leg; 5, brachio-facial monoplegia, or paralysis of the arm and face" (Flint's "Practice of Medicine").

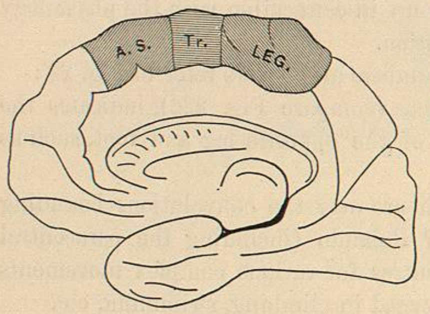

FIG. 229.—*Inner surface of the right cerebral hemisphere* (Schäfer and Horsley).

A. S., area governing the movements of the arm and shoulder; Tr., area for movements of the trunk; LEG. (paracentral lobule) area for movements of the leg.

It is possible that there may be sensory centres in the cerebral cortex, but they have not been satisfactorily localized, although attempts have been made to limit such areas by studying reflex phenomena following stimulation of certain parts. It may be stated in general terms that the occipital and temporo-sphenoidal lobes, the fibres from which pass through the posterior third of the posterior division of the internal capsule, are specially connected with sensation.

One of the most important of the cerebral centres is the centre for speech, which will be fully described after the consideration of the general uses of the cerebral hemispheres.

General Uses of the Cerebrum.

The cortical gray substance of the cerebral hemispheres not only is capable of generating motor impulses of the kind known as voluntary, and of receiving sensory impressions, including those connected with the special senses, but its anatomical and physiological integrity, and its connections, especially with sensory conductors, are essential to what are known as mental operations. The existence of the mind and the possibility of normal operations of the intelligence depend upon the existence of the gray matter of the cerebral cortex and its normal physiological condition and relations. This proposition does not imply that the mind is a force which operates through the brain, or even, strictly speaking, that the brain is the seat of the intellectual faculties. Mental operations involve a slight elevation of temperature and slightly increase some of the excretions. It is probable, therefore, that they involve changes of matter; and these changes, if they occur, can be effected only by the cells of the brain. Without defining or analyzing the intellectual faculties or attempting to locate different faculties in special parts, it is sufficient to state that certain of these faculties reside probably in that portion of the brain which is anterior to the motor cortical zone; that is, in the frontal lobes. These lobes, as far as is known, do not present motor or sensory areas.

The brain and the intellectual power of man are so far superior in their development to this organ and its properties in the lower animals, that some philosophers have regarded the human intelligence as distinct in nature as well as in degree. Although physiologists do not generally accept this proposition, regarding the intelligence of man as simply superior in degree to that of the lower animals, it is evident that this difference in the degree of development is so great as to render the human mind hardly comparable with the intellectual attributes of animals low in the scale. Still, there can be no doubt with regard to the identity of the nature of the faculties of the brain in man and in some of the lower animals, however much these faculties may differ in their degree of development. If this proposition be true, it is reasonable to apply experiments on the brain in the lower animals to the physiology of corresponding parts in the human subject.

Extirpation of the Cerebrum.—Experiments upon different classes of animals show clearly that the brain is less important, as regards the ordinary manifestations of animal life, in proportion as its relative development is smaller. For example, if the cerebral hemispheres be removed from fishes or reptiles, the movements which are called voluntary may be but little affected; while if the same mutilation be performed in birds or some of the mammalia, the diminished power of voluntary motion is much more marked. It would be plainly unphilosophical to assume, because a fish or a frog will swim in water and execute movements after removal of the hemispheres very like those of the uninjured animal, that the feeble intelligence possessed by these animals is not destroyed by the operation. It is not only possible but probable that in the very lowest of the vertebrates, the operations of the nervous centres are not the same as in higher animals. There is, for example, a fish (the lancet-fish, Amphioxus lanceolatus), that has no brain, all of the functions of animal life being regulated by the gray substance of the spinal cord. It is essential, therefore, in endeavoring to apply the results of experiments upon the brain in the lower animals to human physiology, to isolate, as far as possible, the distinct manifestations of intelligence from automatic movements.

Flourens (1822 and 1823) made a series of important observations upon the different parts of the encephalon. As regards the cerebral hemispheres, he found that the complete removal of these parts in living animals (frogs, pigeons, fowls, mice, moles, cats and dogs), was invariably followed by stupor, apparent loss of intelligence and absence of even the ordinary instinctive acts. Animals thus mutilated retained general sensibility and the power of voluntary movements, but were thought to be deprived of the special senses of sight, hearing, smell and taste. As regards general sensibility and voluntary movements, Flourens was of the opinion that animals deprived of their cerebral lobes possessed sensation, but had lost the power of perception, and that they could execute voluntary movements when an irritation was applied to any part, but had lost the power of making such movements in obedience to an effort of the will. One of the most remarkable phenomena observed was entire loss of memory and of the power of connecting ideas. The voluntary muscular system was enfeebled but not paralyzed. Removal of one hemisphere produced, in the higher classes of animals experimented upon, enfeeblement of the muscles upon the opposite side, but the intellectual faculties were in part or entirely retained.

The observations of Flourens have been repeated by many physiologists, and were in the main confirmed, except as regards the special senses. Bouillaud (1826) made a large number of observations upon pigeons, fowls, rabbits and other animals, in which, after removal of the hemispheres, he noted the persistence of the senses of sight and hearing. Longet finally demonstrated the fact that both sight and hearing are retained after extirpation of the hemispheres, even more clearly than Bouillaud, by the following experiments: He removed the hemispheres from a pigeon, the animal surviving the operation eighteen days. When this animal was placed in a dark room and a light was suddenly brought near the eyes, the iris contracted and the animal winked; "but it was remarkable, that when a lighted candle was moved in a circle, and at a sufficient distance, so that there should be no sensation of heat, the pigeon executed an analogous movement of the head." An examination after death showed that the removal of the cerebrum had been complete. An animal deprived of the hemispheres also opened the eyes at the report of a pistol and gave other evidence that the sense of hearing was retained.

With regard to the senses of smell and taste, it is more difficult to determine their presence than to ascertain that the senses of sight and hearing are retained. It is probable, however, that the sense of smell is not abolished, if the hemispheres be carefully removed, leaving the olfactory ganglia intact; and there is no direct evidence that extirpation of the cerebrum affects the sense of taste; indeed, in young cats and dogs, Longet has noted evidences of a disagreeable impression following the introduction of a concentrated solution of colocynth into the mouth, as distinctly as in the same animals under normal conditions.

Comparative Development of the Cerebrum in the Lower Animals.—It is only necessary to refer very briefly to the development of the cerebrum in the lower animals as compared with the human subject, to show the connection of the hemispheres with intelligence. In man the cerebrum presents a large preponderance in weight over other portions of the encephalon; and in some of the lower animals the cerebrum is even less in weight than the cerebellum. In man, also, not only the relative but the absolute weight of the brain is greater than in lower animals, with but two exceptions. Todd has cited a number of observations made upon the brains of elephants, in which the weights ranged between nine and ten pounds (about 4,000 and 4,500 grammes). Rudolphi gave the weight of the encephalon of a whale, seventy-five feet long (about 23 metres), as considerably over five pounds (about 2,300 grammes). With the exception of these animals, man possesses the largest brain in the zoölogical scale.

Another interesting point in this connection is the development of cerebral convolutions in certain animals, by which the relative quantity of gray matter is increased. In fishes, reptiles and birds, the surface of the hemispheres is smooth; but in many mammalia, especially in those remarkable for intelligence, the cerebrum presents a greater or less number of convolutions, as it does in the human subject.

Development of the Cerebrum in Different Races of Men and in Different Individuals.—It may be stated as a general proposition, that in the different races of men, the cerebrum is developed in proportion to their intellectual power; and in different individuals of the same race, the same general rule obtains. Still, this law presents marked exceptions. Certain brains in an inferior race may be larger than the average in the superior race; and it is frequently observed that unusual intellectual vigor is co-existent with a small brain, and the reverse. These exceptions, however, do not take away from the force of the original proposition. As regards races, the rule is found to be invariable, when a sufficient number of observations are analyzed, and the same holds true in comparing a large number of individuals of the same race. Average men have an advantage over average women of about six ounces (170 grammes) of cerebral substance; and while many women are far superior in intellect to many men, such instances are not sufficiently frequent to invalidate the general law, that the greatest intellectual capacity and mental vigor is coincident with the greatest quantity of cerebral substance. If the view, which is in every way reasonable, be accepted, that the gray substance alone of the cerebral hemispheres is directly connected with the mind, it would be necessary, in comparing different individuals with the view of establishing a definite relation between brain-substance and intelligence, to estimate the quantity of gray matter; but it is not easy to see how this can be done with any degree of accuracy.

It is undoubtedly true that proper training and exercise develop and increase the vigor of the intellectual faculties, and that thereby the brain is increased in power, as are the muscles under analogous conditions. This will perhaps explain some of the exceptions above indicated; but an additional explanation may be found in differences in the quality of brain-substance in different individuals, irrespective of the size of the cerebral hemispheres. One evidence that these differences in the quality of intellectual working matter exist, is that some small brains actually accomplish more and better work than some large brains. This fact may be due to differences in training, to the extraordinary development, in some individuals, of certain qualities, to intensity and pertinacity of purpose, capacity for persistent labor in certain directions, a fortunate direction of the mental efforts, opportunity and circumstances, etc.; but aside from these considerations, it is exceedingly probable that there are important individual differences in the quality of nervous matter.

Facial Angle.—It is not necessary to enter into an extended discussion of the relations of the facial angle to intelligence. It was proposed by Camper to take the angle made at the junction of two lines, one drawn from the most projecting part of the forehead to the alveolæ of the teeth of the upper jaw, and another passing horizontally backward from the lower extremity of the first line, as the facial angle. This angle is to a certain extent a measure of the projection of the anterior lobes of the brain. A number of observations upon the facial angle in different races has been made by Camper and by other physiologists and ethnologists. These show, in general terms,