temporal convolution, the more likely is the injury to give rise to a loss of sensation only; and the nearer the injury is to the angular gyrus, the more likely is the result to be a loss of perception, ideas, and memories connected with sensory impression. And yet it is difficult, both on the physiological and on the psychological side, to distinguish a pure sensation from one with an admixture of memory images. What a sensation would be utterly divorced from integral connection with the consciousness of the individual it is impossible to say. The association centres of Flechsig are centres of perceptual and ideational integration. Through their activity, in conjunction with the functions of the sensory areas, the actions of the human being are able to reflect the influence of acquired individual experience.

The posterior association centre (see Fig. 897, page 305, and Fig. 900, page 308) is concerned chiefly with the intellectual processes. Injury to the cells of this centre is followed by various forms of psychical blindness, by apraxia, agnosia, amnesia, and sometimes a weakening of the imagination. The anterior association centre is most closely associated in function with the somæsthetic area, and hence also with the motor regions concerned in conduct, so that here in all probability is to be sought the anatomical mechanism by means of which the memory effects of all conscious bodily experiences, especially of acts of will, are retained. In injuries to this region, Flechsig maintains, interest in the external world is lost and the most marked alterations of character, attention, reflection, and inhibition are manifest. There may be symptoms of over-appreciation or of great self-depreciation; the speech may for a long time remain unaffected, but judgment as to what is right and wrong, beautiful and hateful, will be impaired, and there may be lack of self-command, even when uninfluenced by violent emotions, readiness to yield to sexual excitement, and finally imbecility. When the posterior association centres are mainly involved it is knowledge of the external world, rather than of his body and personality, that is impaired. Ideas regarding the objects of the external world are confused, there is a poverty of ideas or an inability to express them in words, yet with all this the patient may have perfect self-possession and a normal regard for himself and his friends.

These two association centres are not connected with each other excepting through the somæsthetic area. Flechsig, accordingly, seems to assume a more or less significant distinction between the intellectual processes and those of volition. The centres are bilateral and are richly connected by fibres of the corpus callosum. In this they are distinguished from the middle association centre, the island of Reil, which is very sparsely supplied with these commissural fibres. This centre seems to be for the one hemisphere only. It is the association centre more particularly for the cortical elements concerned in the speech function, situated, as it is, in such close proximity to the inferior frontal convolution and to the temporal convolution; it is therefore in connection with the portions of the posterior association centre that are connected with the visual and auditory speech functions. These functions are so closely connected with the intellectual processes that a few words on the most recent conclusions as to their nature and localization will assist toward a comprehension of the relation of the association centres to the rest of the nervous system.

The history of the study of the symptom complex known as aphasia throws an interesting sidelight on the localization of cerebral function. Mention has already been made of the conclusions of Wernicke, Kussmaul, and others. It is quite impossible to enter in this connection into an analysis of this very important chapter of cerebral localization. Collins' monograph on the "Genesis and Dissolution of the Faculty of Speech" gives a concise critical résumé of the various views, and sketches a theory of speech location essentially in harmony with that of Déjerine, and, in the opinion of the writer, most satisfactory from all points of view. By the time of Kussmaul the three elements involved in aphasic disturbance were well recognized—the motor emissive element, the visual element, and the auditory element. Charcot deserves the credit of emphasizing the fact that so-called motor aphasias are generally kinæsthetic aphasias, depending upon the loss of motor images. He believed that there was an articulate speech centre in the inferior frontal convolution, and a graphic kinæsthetic centre in the middle frontal convolution. An individual who depended in speaking or writing upon kinæsthetic images originated in these centres, Charcot called a moteur; one who depended on the visual elements was a visuel; and one who depended on the auditory elements was an auditif. The predisposition to belong to one of these three types might be inherited or might be acquired by education. The centres for the auditory and visual elements lay close together in the neighborhood of the angular gyrus. Charcot taught that these centres must act in harmonious co-operation in order that intellectual expression and conception should be complete. These centres were, however, independent, and an injury to one might remove certain elements without necessarily interfering with the others.

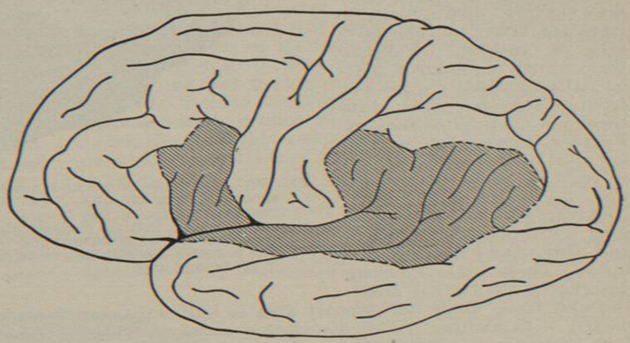

FIG. 902.—The Zone of Language, According to Déjerine. (From Mills.) The zone of language, as indicated by the shaded regions, comprises the portion of the third frontal convolution posterior to the ascending branch of the fissure of Sylvius and the lower extremity of precentral convolution, the upper portions of the first and second temporal convolutions, and the supramarginal and angular convolutions of the parietal and occipital lobes.

This view was a great improvement upon the complex schemes that had been evolved by the Germans, of whom Lichtheim showed that no less than fourteen different areas might be the seat of a lesion producing aphasia. Naming centres, ideational centres, propositionizing centres, and the like were thus cast aside. A tendency toward an extreme of localization for different phases of the faculty of speech was in this way checked. Déjerine made a great step in the direction of still greater simplicity. He established the dependence of sensory agraphia upon loss of visual memories in the angular gyrus, which causes alteration of internal language, due to loss of visual images associated with word-blindness. He maintained that writing with the hand was not a specialized function but simply the outward expression through the hand of visual images of various graphic symbols. This view is not accepted by some authorities, notably Mills, Gordinier, and Bastian, who still maintain the existence of a graphic centre. It may appear that in certain individual cases the cells in the second frontal convolution may be so trained by education that after adult life is reached the destruction of these cells may cause an inability properly to co-ordinate the muscles of the arm. The graphic-motor centre appears nevertheless to be less stably established as a specifically differentiated portion of the cortex than is the kinæsthetic speech centre in the left inferior frontal convolution. Déjerine also contended

against the functional independence of the three speech centres, mantaining that the language centre is really a zone constituted of portions of the temporal, parietal, and inferior frontal convolutions of which the three recognized speech centres were focal areas of most intense representation. The extent of this zone of language, which is shown in Fig. 902, is not strictly delimited. Collins says: "It varies in individual cases and at different periods of life in the same individual; namely, it is subject to phylogenetic and to ontogenetic variations as well, the latter depending somewhat upon the speech acquisition of the individual and on the range and number of avenues by which he receives or has schooled himself to receive information from language."

An injury to any portion of the zone of language will produce disorders of all the elements of speech function. This centre is emissive to the cortex of the Rolandic region, in which there are separate areas for the movements of respiration, vocalization, and lingual and labial action, from which proceed the true motor impulses. The centre in which are stored visual images is situated in the angular gyrus; the auditory centre occupies a position in the posterior part of the first temporal convolution immediately adjacent to the gyrus; the island of Reil may be involved. The speech zone receives and combines impulses coming into it from the auditory, visual, and kinæsthetic areas.

The views of Déjerine are in opposition to the theory of a cortical centre as a restricted area performing a certain specific psychical function and no other. Very similar are the views of Flechsig. The parts of the sensory areas which produce simple sensations have been shown to fade insensibly into the regions which perform functions related to more developed perception, and these shade off again into areas of ideation and conception, whose functioning constitutes a summation of impressions from all sense regions. For these areas I believe we may accept Flechsig's boundaries and name of posterior association centre. Perception, ideation, imagination, memory, thought, reason, etc., are not distinct psychical processes, but all are analyzable psychologically into associations or groups of ideas of more or less remote sensory origin. As these mental processes are revealed only through external expression, the cortical areas in which they are represented, of which the angular gyrus is the topographical centre, have a motor side also. In the same manner that the pyramidal tracts from the motor areas act ultimately upon the cells of the lower motor nuclei to induce more complex co-ordinations than are possible when spinal or basal centres act alone, so it is the function of the cells of the association area to act in a more complicated way upon the Rolandic neurones and other projection tracts. A part of this association area, Déjerine's zone of language, is shown to be connected with the association of those elements which constitute language, a function which has grown in the history of the race to have an amazing significance for man's intellectual life. Consequently I believe we may separate the zone of language (including the posterior third of the inferior frontal convolution, doubtfully the posterior third of the second frontal, the island of Reil perhaps, the angular gyrus, the upper part of the first and perhaps second temporal convolutions) from the rest of the association zone, as an area representing higher co-ordinations peculiarly significant for the processes of thought. We may designate the zone of language as a higher association area, or an association area of the second order. This specialized association area has a representation on only one side of the brain, whereas we have reason to believe that both cortical association areas take part in the simpler intellectual processes, although that on the left would appear to be somewhat more important. In special cases the right zone may perform language functions, even in right-handed persons, just as many persons learn to write with the left hand if the right has been injured or removed.

The prefrontal lobes have been variously designated as "silent" or "functionless" areas, as higher psychical centres, as centres of inhibition, as apperception centres, and as centres of the will and personality. So great is the misunderstanding of the nature of the functions of these lobes, even at the present time, and so often is positive evidence wrongly interpreted and even misquoted, that a somewhat extensive presentation of the facts and conclusions with respect to their functions is demanded.

The result of stimulation of these regions is negative, hence they are designated as silent areas. Ferrier, however, reports movements of the head and eyes, and early suggested that these might be movements characteristic of attention, which is the basis of intellection, and that these lobes might therefore be considered areas of higher psychical function. Extirpation of these prefrontal regions in dogs and monkeys by Hitzig, Ferrier, Horsley and Schäfer, and Goltz was accompanied by slight, hardly noticeable, mental deterioration. Munk and other observers, on the other hand, deny any loss of attention, perception, thought, or inhibitory power. Many authorities report areas for movements of the head and neck and of the trunk, and such centres are now assigned to the roots of the upper frontal convolution.

Bianchi (1888–95) contributed the first experimental demonstration conclusively pointing to the psychical functions of the frontal lobes. His experiments were made upon twelve monkeys and six dogs, all of which he subjected to very minute observations both before and after the operation, these observations extending in some cases over a period of years. To determine the boundaries of the prefrontal zone, Bianchi stimulated electrically all of the frontal region and excised all portions from 2 or 3 mm. in front of the excitable areas for the arm, face, jaw, and trunk. No special effort was made to preserve the olfactory bulb in the monkeys, but it was kept intact in the dogs. The results of electrical excitation agree with the conclusions of other observers.

Regions in front of the motor area of head, neck, and eyes were found to be unexcitable with a current of equal strength. Stimulation of the base of the upper frontal convolution produced slight rotation of the head to the opposite side and some lateral displacement of the trunk at the level of the lumbar region. Excitation of the inferior area caused raising of the eyelid together with dilatation of the pupil. The results which Bianchi obtained from unilateral extirpation may be summarized as follows:

1. During the first weeks were noted rotatory movements, concavity of the trunk toward the mutilated side, and paresis of the opposite arm (obvious in the more delicate movements). These symptoms disappeared at the end of two or three weeks. No oculo-motor disturbances were observed.

2. Tactile sensibility was normal except in one dog (diminished in opposite limb) and one monkey (hyperæsthesia in opposite ear and face).

3. In one monkey there was diminution of hearing on one side.

4. Taste and smell appeared normal.

5. In all cases there were visual disturbances. A piece of sugar was not seen with the right eye until it was nearly in a line with the visual axis. The left eye appeared to be normal.

6. There was no perceptible difference in behavior or psychical manifestations of animals mutilated on one side only. They were still susceptible of feelings and capable of new adaptations.

When both lobes were removed, there was apt to be a weakness of the left limbs and a tendency to rotate toward the right; but in some cases, after a time, all movements were perfectly performed, though in a listless, automatic fashion. Sensibility was not necessarily disturbed. There was a decided lack of interest, the habitual state seeming to be one of indifference, and the strongest feelings manifested were terror and the desire for food. Affection for the keeper and for the other animals disappeared. There was a lack of power to make new adaptations, to defend themselves, and to resist the influence of sensory stimuli. For example, the monkeys would pick up and eat a piece of plaster as readily as a piece of sugar. Even if they spit it out after breaking it up, as sometimes happened, they would return to the fragments and swallow them, apparently unable to resist the resemblance to sugar. Psychical life seemed to be reduced to the existence of actual sensations; there was no change or resource, and experience profited nothing. Perception seemed to lack some of the factors necessary to the formation of a complete judgment. There were crude sensations, but no co-ordination of simple presentations into representations of higher complexity.

Bianchi's conclusions are as follows: Paralysis of the trunk muscles does not always occur, and it is in any case but temporary. The phenomena observed upon destruction of the frontal lobes cannot be explained by the occurrence of a temporary trunk-muscle paralysis. Bianchi does not look upon Ferrier's hypothesis as satisfactory. The facts obtained point to more than a simple defect of attention correlated with paresis of ocular and cervical muscles.

Bianchi does not accept the view that the frontal lobes are distinctively inhibitory centres. On the contrary, he justly contends that every part of the nervous system becomes under different circumstances an inhibitory centre. When some particular area of the brain is excited there is an afflux of nervous waves into it, and this weakens the aptitude of other regions to fulfil their functions. If busy with a problem one becomes deaf and blind; if auditory or visual centres are strongly excited, the flow of ideas is weakened or arrested. Bianchi's final conclusion may be stated thus: In the frontal lobes, the incoming and outgoing products of sensory and motor areas are co-ordinated and fused with the emotional states that accompany perception; this area, therefore, determines what has been called the "psychical tone" of the individual.

From the time of Bouillaud many cases have been reported of injury to the frontal lobes without sensory or motor symptoms and with no apparent diminution of intellectual capacity. In the light of more recent knowledge of the effects of lesions in this region of the cerebral hemispheres, it is no doubt correct to infer that these cases were not carefully observed. For example, the American Crowbar Case, 1868, in reality a classical instance of conclusive evidence as to the peculiar functions of the prefrontal area, is still frequently misquoted and wrongly interpreted in medical literature, despite the critical analysis of Ferrier and Mills. The subject of this injury was a young man, twenty-five years of age. At the time of his injury, he was engaged in tamping a blasting charge in a rock with a pointed iron bar three feet seven inches in length, one and one-fourth inches in diameter, and weighing thirteen and one-fourth pounds. A premature explosion drove the bar clean through the frontal region of the skull, entering at the left angle of the jaw and passing out near the sagittal suture in the frontal region. The patient recovered and lived for twelve and a half years afterward. From a post-mortem examination of the skull it was clearly seen that the whole lesion was situated anterior to the coronal suture, and hence embraced only the prefrontal region. The following report, by Dr. Harlow, of the patient's mental condition after recovery from the injury presents a typical picture of mental decadence:

"His contractors, who regarded him as the most efficient and capable foreman in their employ previous to his injury, considered the change in his mind so marked that they could not give him his place again. The equilibrium or balance, so to speak, between his intellectual faculties and animal propensities seems to have been destroyed. He is fitful, irreverent, indulging at times in the grossest profanity (which was not previously his custom), manifesting but little deference for his fellows, impatient of restraint or advice when it conflicts with his desires, at times pertinaciously obstinate, yet capricious and vacillating, devising many plans of future operations, which are no sooner arranged than they are abandoned in turn for others appearing more feasible. A child in his intellectual capacity and manifestations, he had the animal passions of a strong man. Previous to his injury, though untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart business man, very energetic and persistent in executing all his plans of operation. In this regard his mind was radically changed, so decidedly that his friends and acquaintances said he was 'no longer Gage.'"

Corroborative evidence is contained in many subsequent observations. Lepine, in 1877, reported a case of abscess of the right frontal lobe in which the patient "was in a state of hebetude." He seemed to comprehend what was said but could scarcely be got to utter a word. Barabuc, 1876, reported a case of atrophy of the frontal convolutions in both hemispheres in which muscular power and sensation were unimpaired, but the patient was in a state of complete dementia, marching about restlessly the whole day, picking up what came in his way, mute and quite oblivious of all the wants of nature and requiring to be tended like a child. Davidson, 1876, reported a case of injury to both frontal lobes in which the only symptoms were of a psychical nature. Every action that this patient performed left the impression on the mind of the observer that it was purely automatic or machine-like. Cruveilhier reports a case of complete idiocy from birth until the age of fifteen, with atrophy of two-thirds of the frontal lobe. Ferrier states that the frequent association of idiocy with such defect of the frontal lobes is a generally recognized fact.

Williamson, 1896, presented five cases of gross lesions, tumors, and abscesses involving the prefrontal region of one or both hemispheres in which were noticed marked mental symptoms. He gives the following instructive summary of these and forty-five other cases recorded in recent medical literature:

A condition of mental decadence; a dull mental state; loss of power of attention; loss of memory; loss of spontaneity; the patient taking no heed of his surroundings; sleeping during the greater portion of the day, or being semicomatose. (In two of these it is noted that the patients were in a perplexed mental condition, and constantly appeared to be searching for something.)	32
Loss of memory; mental failure, but patient cheerful	6
Patient suspicious; suffered from delusion, and was occasionally violent	1
Patient irritable and violent	1
Patient generally asleep; irritable when awake	2
Patient ambitious, excitable; memory lost	1
Slowness of mental processes; patient simple and childish.	1
Mental anxiety; childishness; hallucinations; suicidal tendencies	1
Mental condition not stated	5
	50

It may be considered as having been demonstrated beyond the possibility of a doubt that injury to one frontal lobe probably, and injury to both lobes certainly, will cause mental deterioration. The amount and character of this deterioration can be ascertained only from a careful detailed examination of the antecedent and subsequent capacities of the individual. In general, the phenomena are slight intellectual degradation, moral and emotional perversion, deficiency of attention, and volitional inefficiency. The functions of these lobes seem peculiarly representative of the mental character and general conduct as these have been developed as the result of a lifetime of education and action. These areas may therefore be designated association areas of the third or highest order. They exercise no functions which are not performed by the other association areas in less degree of complexity. Wundt calls these areas, centres of apperception; an appropriate term if we remember that apperception is a synthesis or organized coordination of all the acquired intellectual and other responsive reactions of a brain to the environment of the individual possessing it. As pointed out by Waller, it is thus a "high-level neural synthesis"; similar syntheses of lower level being accomplished by other portions of the cerebral hemisphere. Hughlings Jackson presented a similar view in the suggestion of a hierarchy of neural processes.

Stripping the individual, who has attained adult life, successively of his prefrontal lobes, the association zone of language, the other association areas, will successively reduce him to a lower grade of human being than he has come to be. The cells of the prefrontal lobes may be put to different uses in the brains of different persons. Loss of the frontal lobes might leave a Descartes still a fairly satisfactory college professor. The loss of these lobes and of portions of the other association areas might not unfit the college professor to live the normal life of a day laborer whose frontal lobes may be put to a strain to maintain his lower standard of activities.

It may be well to summarize the general conclusions of this article and to indicate the point of view from which these conclusions have been examined. It is customary to distinguish between sensory and motor functions of the nervous system, as though certain nerve elements performed the duty of supplying us with sensations, and others contributed an equal service by bringing about our movements. Waller has emphasized the objections to this view, maintaining that no centre is exclusively either motor or sensory, but that all centres are both sensory and motor. In this, he correctly interprets the facts, which show that brain centres physiologically perform their functions only when they both receive and emit stimuli. It would clear up many psychological notions, that are often confusedly interwoven with reports of the function of various centres, if it were kept constantly in mind that no centre, no neurone, and no nerve is motor, and on the other hand that no centre, no neurone, and no nerve is sensory.

All manifestations of life and consciousness are presented in the movements of the organism. These movements are, therefore, the immediate phenomena. A movement, even though it may possibly be restricted to a single muscle, is yet the summation of the contraction of its individual fibres. The function of any nerve fibre is not to produce a movement, but to stimulate or irritate a muscle fibre to exercise its inherent function of contracting. Similarly, it is the function of an afferent nerve fibre not to convey a sensory stimulus, but to innervate the neurone or neurones about which its central dendrites terminate. Even the simplest reflex action is the result of the co-ordination of at least two nerve elements which are intercalated between the peripheral point of application of a stimulus and the muscle fibres to which the motor neurones run. A single segment of the spinal cord, through the anatomical relationship of its neurones, is capable of serving as the reflex centre for complicated co-ordinated movements. The explanation as to why certain definite movements are elected to follow in response to a given stimulus is partly anatomical and partly physiological. In the first case, the answer ultimately reverts to biology to explain why neurones should be found so located as to be capable of mediating particular movements in response to definite stimuli. If we ascribe the cause to the functional habit of the neurones, we again must refer the question to biology to give an explanation of the inheritance of this congenital function, or to tell how neurones acquire during their existence in the organism a particular function or habit. When spinal centres comprise more than one segment, the problem remains the same; more neurones with their axis-cylinder processes have been intercalated, and the response of the peripheral neurones is now conjointly inspired by a larger group of neurones. The movements that result upon stimulation of more extensive centres will be characteristically different from those of segmental origination, but nevertheless these movements will still depend upon the interrelations of the neurons in the centres or upon an acquired or inherited habit.

The neurones, which are alone capable of stimulating muscle fibres, are located in the anterior horns of the cord and in the nuclei of the motor cranial nerves. These neurones may therefore be acted upon by peripheral neurones of afferent conduction alone, in which case they will respond with simple movements; or they may be acted upon by other additional central neurones. These constitute aggregated masses in the medulla oblongata, the cerebellum, the various basal ganglia, and the cortex of the cerebral hemispheres. As one mass after another is added, the peripheral motor neurones become the recipients of stimuli from larger and larger groups of central neurones, and the co-ordinated movements that follow will represent the combined or co-ordinated influence of their various cell elements. Thus, in the spinal cord, the neurones suffice to bring about simple reflexes; by adding the neurones of the cerebellum, more complex movements of locomotion are produced; adding the basal ganglia contributes the anatomical elements that render the reflex mechanism sufficiently complex to bring about the co-ordinated adjustment of the various sense organs to stimuli, and also to initiate the instinctive movements of the facial parts and body, which are interpreted as expressions of emotion. But these movements can all be accomplished without consciousness, and are apparently not acquirable in the lifetime of the individual. They represent instinctive or inherited reactions, simple if relatively few neurones take part in the co-ordination, complex and often apparently purposive if a greater number of neurones are involved. When to these neurones are added the neurones of the sensory areas of the cortex, of the association area, of the zone of language, and of the prefrontal lobes, the physiological problem is still merely the question of the anatomical connection of these neurones *inter se* and with the peripheral neurones. The evidence and the interpretation of what these neurones contribute to the production of complex bodily movements involve, however, two factors not necessary of consideration in connection with the functions of centres below the cortex, namely, the relation of consciousness to these processes and the development of acquired functions or habits.

Considered relatively, the functional activities of the cortex are largely the result of an ontogenic education, whereas those of the lower centres are the result of an inheritance of functions acquired in the course of organic evolution. But when anatomical and physiological connections have been established in a given adult brain, the physiological problem is then the same as before;—namely, "What additional complexities of movements are now possible from this additionally complex mechanism?" The existence in our minds of certain sensations due to the stimulation of particular areas may assist in establishing the functional relationships of these areas *inter se* and to lower centres, but the sensations themselves can form no part of a physiological explanation of the responsive movements that take place in consequence of such connections. The same principle must apply to the association centres as areas of higher psychical activity. The polite request "Please get off my toe" is as much a motor response of the peripheral neurones as the cry of pain. Experience shows that for the first reaction, certain cells of the cortex must have integral connection with the efferent pathway, which are not necessary for the much simpler movement. The psychologist cannot distinguish between perceptions and sensations as distinct entities, nor between intellect and imagination as diverse processes, nor does he regard the will as a faculty exclusive of other manifestations and processes of the mind. When it is maintained, therefore, that there are areas of higher level than the cortical sensory areas—first, an association area which is the anatomical *locus* for those cells whose functioning is responsible for the phases of consciousness distinguished by the terms knowledge, conception, imagination, thought; a second association area, the zone of language, which is the basis of the function of language as an intellectual and emotional instrument; and still a third region, the prefrontal lobes, which is essential for the preservation of high intellectual and moral character and for volitional effectiveness—it is not meant that these three centres contribute each a different mental element to consciousness, nor yet that they are the organs of three diverse mental faculties. The analysis suggests that a human being, who may manifest, at different times through speech, conduct, and bodily movement, intellectual capacity and moral character of different grades, must have these three areas intact, if he is to continue to evidence the highest attainment of which he is individually capable.

A question, often confusing, is frequently allowed to become involved with this psycho-physiological parallelism of increasing intellectual complexity and increasing integration of the cells of the central nervous system. On the one hand, the mere addition of neurones apparently forms a satisfactory explanation of the increased complexity of cortical reactions over that of the spinal reflexes. The psychical functions of the brain might therefore represent the result of a mere phylogenetic increase in nerve tissue, a product of cortical integration. On the other hand, in the human being and higher organisms, it is a common experience to find automatic actions developing from conscious actions, even becoming so set in the nervous system as to appear ineradicable reflexes. Many facts tend to suggest that conscious reaction has always presided over the phylogenetic development of reflex action; that psychical function thus preceded reflex function, and both helped to determine the course of organic evolution. This view was entertained by Cope, the eminent biologist, and is exploited as a fundamental philosophical hypothesis by Wundt, without doubt the leading psychologist of the day. Many difficulties present themselves to the acceptance of either theory. It is not necessary for us to take sides on this issue, when considering the localization of psychical function over the cortex of the cerebral convolutions; but it is desirable to keep this and similar psycho-physiological speculations from interfering with an acceptance of reported facts and conclusions.

It is not worth while to enter into a consideration of the various theories which have been propounded at different times to explain the specific nature of the nerve excitation which passes along the nerve fibres of a pathway of conduction. The crudest physical concepts have been called upon to do duty by way of explanation; thus the cell has been likened to a battery and the fibres to conducting wires; the nerve stimulus is frequently spoken of as a wave of nervous impulse, similar to but not identical with the electrical wave, propagated at an appreciable rate, flowing from nerve fibre to nerve fibre. Theories of electrical tension, of galvanism, of molecular vibrations, and of chemical explosions, are scientific fancies rather than hypotheses. When the nervous pathway was shown to be made up of unitary cellular elements, that were contiguous but not continuous, biological theory interpreted the conduction of the nerve stimulus as a series of amœboid movements. It may be said that no hypothesis has yet been formed that offers even the hope of becoming a sufficient explanation.

In addition to the original authorities, mentioned in the text, the writer has been much assisted by the critical abstracts of the literature to be found in the publications of Ferrier, Jackson, Macalister, Collins, Gordinier, and Barker, and especially by the "Sketches of the History of Reflex Action," by Hall and Hodge, in the *American Journal of Psychology*, from which have been drawn many statements of the established facts of the phenomena of reflex action.

Lightner Witmer.

BRAIN, GROWTH OF THE.—The following article aims to present a general account of the growth changes which occur in the human brain and cord, between the time of normal birth and the natural end of life, thus including those found in old age.

In dealing, as in this case, with data for the most part very incomplete, the danger of confusion arises from the tendency, on the one hand, to make a general application of special observations, and, on the other, to interpret the *absence* of positive as equal to the *presence* of negative evidence. With these words as a preface, however, we may spare ourselves the duty of showing in special instances the limitations of the observations cited.

In discussing the changes which occur in the neuraxis (brain and spinal cord = central nervous system), the following outline is employed:

A. Growth changes in the neuraxis and some of its divisions.

B. Growth changes in the neuraxis—considered as the resultant of changes in the cells which constitute it.

1. Number of neurones.
2. Size of neurones.
3. Changes in the cytoplasm of the cell bodies during growth.

C. Growth of the cerebral cortex.

A. GROWTH CHANGES IN THE NEURAXIS AND SOME OF ITS DIVISIONS.—The human encephalon varies widely in weight at maturity, even when members of the same race and the same social class are alone compared. Differences in the final weight must be looked upon as resulting from differences in the process of growth. The weight of the encephalon at maturity is illustrated by the accompanying table based on the observations of Dr. Boyd:[1]

TABLE I.—SHOWING IN GRAMS THE WEIGHT OF THE ENCEPHALON AND ITS SUBDIVISIONS IN SANE PERSONS, THE RECORDS BEING ARRANGED ACCORDING TO SEX, AGE, AND STATURE. (From Marshall's tables based on Boyd's records.)

SANE.

Males.					Females.				
Ages.	Encephalon.	Cerebrum.	Cerebellum.	Stem.	Stem.	Cerebellum.	Cerebrum.	Encephalon.	Ages.
Stature 175 cm. and upward.					Stature 163 cm. and upward.				
20–40	1409	1232	149	28	23	134	1108	1265	20–40
41–70	1363	1192	144	27	23	131	1055	1209	41–70
71–90	1330	1167	137	26	24	130	1012	1166	71–90
Stature 172–167 cm.					Stature 160-155 cm.				
20–40	1360	1188	144	28	26	137	1055	1218	20–40
41–70	1335	1164	144	27	26	131	1055	1212	41–70
71–90	1305	1135	142	28	24	128	969	1121	71–90
Stature 164 cm. and under.					Stature 152 cm. and under.				
20–40	1331	1168	138	25	24	130	1045	1199	20–40
41–70	1297	1123	139	25	25	129	1051	1205	41–70
71–90	1251	1095	131	25	25	123	974	1122	71–90

These records were obtained from 2,086 patients of the Marylebone Workhouse in London, representing, for the most part, the least favored class of persons native to Great Britain. For the purpose of weighing, the encephalon was divided into three portions: (1) The cerebrum, including all parts frontal to the midbrain; (2) the cerebellum, severed at the peduncles; and (3) the stem—the midbrain, pons, and bulb taken together.

Owing to the fact that these records are based on a workhouse population, it is probable that they represent brains less well grown and earlier subject to senile atrophy than would be the case among the more prosperous members of the community. The general relations to which we are about to call attention would, however, remain the same.

On comparing the sexes Table I. shows that the heavier brains belong to the males; on comparing those of different stature within each sex, that they belong to the tall individuals; and when those of the same sex and stature are compared, according to age, to those in the prime of life, *i.e.*, twenty to forty years of age. Sex and stature, then, are conditions which modify the weight which the brain will attain at maturity, and after the prime of life its weight diminishes.

Having indicated the weight at maturity under the conditions of the race and social class here chosen, we have next to determine the weight of the encephalon at birth, and the course of the changes by which it reaches its full size.

Vierordt has collected the most complete series of observations for the change in brain weight between birth and twenty-five years of age. The data are taken mainly from German records. They are printed in Table II.

TABLE II.—TO SHOW THE INCREASE IN BRAIN WEIGHT WITH AGE. ENCEPHALON WEIGHED ENTIRE WITH PIA. (Compiled by Vierordt.)

Age.	Males.		Females.	
	Number of cases.	Brain. Grams.	Number of cases.	Brain. Grams.
0 months	36	381	38	384
1 year	17	945	11	872
2 years	27	1025	28	961
3 "	19	1108	23	1040
4 "	19	1330	13	1139
5 "	16	1263	19	1221
6 "	10	1359	10	1265
7 "	14	1348	8	1296
8 "	4	1377	9	1150
9 "	3	1425	1	1243
10 "	8	1408	4	1284
11 "	7	1360	1	1238
12 "	5	1416	2	1245
13 "	8	**1487**	3	1256
14 "	12	1289	5	**1345**
15 "	3	**1490**	8	1238
16 "	7	1435	15	1273
17 "	15	1409	18	1237
18 "	18	1421	21	1325
19 "	21	1397	15	1234
20 "	14	1445	33	1228
21 "	29	1412	31	1320
22 "	26	1348	16	1283
23 "	22	1397	26	1278
24 "	30	1424	33	1249
25 "	25	1431	33	1224
Total	415		424	

When the data in Table II. are cast in the form of a curve representing the increase in weight according to age, we obtain the chart given below (Fig. 903).

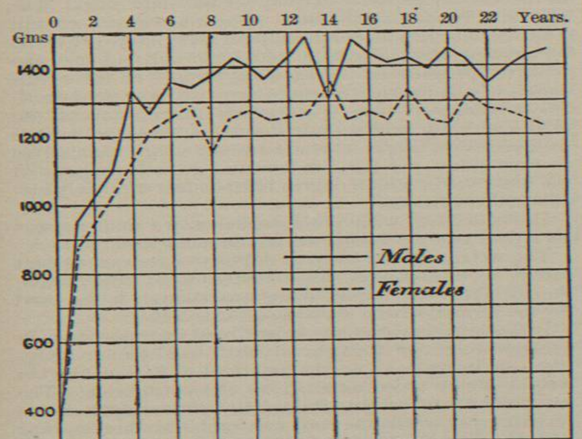

FIG. 903.—Curves Showing the Variations in Brain Weight During the First Twenty-Five Years of Life. Based on Table II.

In the records of Vierordt it appears that, except at birth and in the fourteenth year, the male has a greater brain weight than the female.*

In both sexes the most rapid increase in weight is during the first year; it continues to be rapid up to the fourth or fifth year, and then becomes slow till the seventh year, when the weight of the brain found in the adult is nearly attained. From this age on, there is a very slight and very slow growth up to maturity. At the time when nearly the final brain weight has been attained—namely, the seventh or eighth year—the full difference of 100 grams or more existing between the two sexes is evident. From this, it happens that the rapid growth of the brain has occurred while the body is still very immature, since boys of seven years weigh on the average only fifty pounds, and girls but forty-two pounds—this in both sexes being about one-third of the adult body weight; and that the differences characteristic of sex have been established before sexual maturity. The irregularities of the curve are to be explained as statistical mainly, and dependent on the comparative smallness of the number of cases available for each year. No significance is to be attached to the dip in the male curve at fourteen years. The very high averages for the males at twelve and fourteen years, and for the females at thirteen years, are to be noted, since they occur in other similar series.[5] These "premaxima" are most readily explained by assuming that an overgrowth of the brain during these years of beginning adolescence is one source of constitutional weakness, and hence the children dying at this period exhibit heavy brains. There is no reason to suppose that within the life cycle of the individual, the brain attains during these years a greater weight than that shown at maturity.

From the table of final weights (Table I.) as well as from that just presented on growth, it is plain that the difference in the weight of the encephalon according to sex is one exhibited at birth; that it increases during the growing period, and is maintained throughout life. In the first instance, this difference is most closely associated with the difference in the total body weight of the two sexes, and is so correlated in the mammalian series.

Table I. further shows us that the taller persons have the heavier brains, and this may probably be extended to mean the heavier persons, since when fairly compared, the taller are also probably the heavier. In old age in both sexes, the brain weight diminishes, as the result of shrinkage in the encephalon. There is some reason to think that this involutionary process is delayed in the more favored social classes.

It is an important fact that the differences in the weight of the encephalon according to sex, age, and stature are correlated with only very slight variations in the proportional development of the subdivisions of the encephalon as here examined. Table III. shows the percentage value of these subdivisions for different ages at all statures.

TABLE III.—SHOWING THE PERCENTAGE OF WEIGHT OF THE SUBDIVISIONS OF THE ENCEPHALON, THE RECORDS BEING GROUPED ACCORDING TO AGE. BASED ON TABLE I.

Males.					Females.				
Age.	Encephalon.	Cerebrum.	Cerebellum.	Stem.	Stem.	Cerebellum.	Cerebrum.	Encephalon.	Age.
20–40	100	87.52	10.49	1.91	1.96	10.9	87.13	100	20–40
41–70	100	87.00	10.6	1.94	2.02	10.8	87.14	100	41–70
71–90	100	87.33	10.6	1.98	2.11	11.16	86.4	100	71–90

Here there is a very slight falling off in the proportional value of the cerebrum in persons of advanced age. In general the value of the male cerebrum is slightly in excess. In the next table (IV.), where the comparison is made according to stature, there is a regular decrease in the value of the male encephalon with diminishing stature, and at all statures the male cerebrum is slightly in excess of the female.

* During the period of very rapid growth, a slight disparity in the average age of the cases compared easily reverses the weight relations according to sex. This is the probable cause of greater weight in the female at "birth," as reported by Vierordt. More careful determinations by Mies,[3] 1894, and Pfister,[4] 1897, show the male brain to be heavier.