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BRAIN STRUCTURE IN RELATION TO THE MIND.

Illustrated by new and original models.

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It is a widespread belief that the phenomena of the human mind are too complex to admit of their structural explanation or understanding. This belief is, however, only partially true, and overlooks much detailed and recent study of the nervous system, both in medical and biological science. This work is not usually accessible to the medical profession, and is published in technical and other works appertaining to embryology, human and comparative anatomy, neurophysiology and pathology, cyto-architectonics, etc., hence there is a natural failure to realize the progress which has recently been made in our understanding of the actual relationship between cortical brain-cells and mind. The new and original models to be illustrated to-night are an attempt to demonstrate this relationship in an ocular and understandable manner.

It will be generally admitted that current methods of teaching the anatomy and physiology of the nervous system are but little concerned with the relationship of brain-cells to mind. It is, therefore, necessary to

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approach the problem in a new way and to proceed from the simple to the complex. The first model to be described will thus be one familiar to all medical men—a simple spinal cord reflex, such as actuates the well-known phenomenon of the knee-jerk and, incidentally, also illustrates the fundamental principles of the nervous system of all vertebrates.

A SIMPLE SEGMENTAL THREE NEURONED REFLEX ARC (fig. 1).

The three structural nerve elements here concerned are (1) a receiving neuron, (2) a connectant neuron, and (3) an effector neuron. Each nerve element is entirely disconnected from the next in sequence, and the potential break between the elements is technically termed a *synapse*—a fact of considerable significance in the phenomena of normal and abnormal nerve conduction. As the nervous system is everywhere built up and compounded of such neurons in arcs and chains, it is important, if the relation of brain structure to mind is to be understood, that these elementary principles shall be constantly borne in mind.

The first or receiving neuron in the illustrative model is more generally known in medical practice as afferent or sensory.

The second or connectant neuron is almost invariably entirely overlooked, and yet it is the key to the problem.

The third or effector neuron is commonly known as the efferent or motor neuron.

In accordance with modern neurological thought it would be to the advantage of clinical medicine, and would certainly help to a better understanding of the relationship of brain structure to mind, were these obsolescent terms of 'afferent or sensory,' and 'efferent or motor,' dropped from medical literature and usage, and their simpler physiological substitutes—receptor and effector—employed. In the still more difficult study of brain structure in relation to mind, the terms *receptor* and *effector* are definitely preferable. The term receptor, as applied to such neurons, implies that they receive something. What then do they receive? Such neurons receive, and transmit centrally, impulses generated within them in response to stimuli, and these stimuli may be chemical, mechanical, or physical. The organs which respond to these stimuli form the 'senses' of the animal, and these senses differ in their numbers, nature, and intensity in different animals, according to their environmental requirements. Thus man, popularly believed to possess but five senses, has in reality about twenty-five such special receptor organs, which respond to the appropriate stimuli and so induce the corresponding receptor neurons to generate and transmit centrally induced nerve impulses.

These elementary principles are easily studied in figure 1. Here the receptor organ responds to a mechanical stimulus—the tap on the infra-

patellar tendon—and thereby induces the bipolar receptor neuron to generate and transmit an impulse centrally. The second, connectant or internuncial, neuron is stimulated in its turn, and so the nerve impulse bridges the synapse between it and the outgoing effector neuron, thus causing the latter to generate and discharge nerve impulse to the appropriate effector organ—in this case the quadriceps extensor muscle, which contracts slightly and so produces the knee-jerk.

The response to the original stimulus is thus immediate, inevitable, and invariable. In such a type of neuronic arc there is no appreciable interval

FIG. 1. The neuronic arc with single internuncial element.
'Path' conduction.

between the receipt of the stimulus and the immediate effector response, so that the reflex arc has an immediate summation in motion. In most of the lower animals the nervous system is almost entirely composed of such instantaneous reflex activities, as responses to the appropriate stimuli. In the higher animals such immediate response would often be disadvantageous to the animal's welfare and it becomes, therefore, essential to the well-being of both mammals and man to have a period of latency between the receipt of the stimulus and the motor reaction. This pause in the reflex action, this *period of latency*, furnishes an interval, as it were, for reflection and allows of a selection of the most advantageous motor reaction. This delay in the ultimate effector response to the stimuli will be effected most thoroughly by the substitution, in the nerve arcs concerned, of a large number of connectant or internuncial neurons and synapses between the receptor and effector limbs, in place of the single connectant neuron of the knee-jerk. If,

therefore (fig. 2) the single connectant neuron be removed and there be theoretically substituted a large number of minute, but perfect, neurons (those known technically as Golgi type II or 'granular' neurons), it will at once be observed that nerve-impulses from the receptor to the effector sides of the arc have now to traverse an infinite number of minute neurons—in the human brain running possibly into thousands or even millions—and hence a period of latency is induced and the effector response is delayed or even altogether inhibited and suppressed. This important faculty of delaying the effector responses to the incoming stimuli has attained its highest development in the brain of the normal man, and is, indeed, the essence of mind. Behaviour is thus no longer, as in the lower animals, a matter of instantaneous response to the stimuli, but is subjected to a certain degree of

FIG. 2. Theoretically constructed neuron arc with numerous granular internuncial neurons. 'Ripple' conduction.

supervisional review consequent on the degree of the period of latency and the power of delay or even inhibition. Is there then any portion of the nervous system of man where it can be shown that the connectant neurons between the receptor and effector limbs of the arcs concerned are entirely composed of the Golgi type II variety, instead of the long-axoned single kind just demonstrated in the spinal cord knee-jerk reflex arc? The answer is in the affirmative, for the cerebellum is so constructed.

A COMPLEX SUPRASEGMENTAL MULTINEURONED NERVE-ARC (fig. 3).

It is well known that the bodies of all vertebrate animals are built up of a series of segments, and so we speak of the 31 segments of the spinal cord of man. Such portions of the nervous system are, therefore, segmental in

origin, and the type of nervous system concerned is the neuronie reflex arc illustrated in fig. 1. But at the cephalic or head-end of such higher animals there is added a series of nerve structures which are not segmental in origin, and are therefore termed suprasegmental. The cerebellum is such a suprasegmental addition, and its type of neuronie construction differs entirely from that of the segmental spinal cord (fig. 3).

It may be well to recall that the cerebellum is described histologically as consisting from without inwards of three well-defined structural layers—molecular, middle, and internal. The external and internal layers are both composed of minute granular cells of the Golgi type II variety. These cells have somewhat unfortunately received in the past special names and are

FIG. 3. The supragranular neuronie arc as found in the cerebellum, with very numerous internuncial neurons of granular type.

known as cortical, stellate, basket, and granular cells, whereas actually and physiologically they are all granular in type. These two layers of the cerebellar cortex are sharply demarcated one from the other by the very distinctive layer of the cell-bodies of the Purkinje cells, which form the middle layer. Running more or less at right angles to the grey cerebellar cortex are certain medullated axons which have received the fanciful names of 'climbing' and 'moss' fibres, and commingled with these are the axons of the outgoing effector Purkinje cells.

Moss-fibres are the axons of receptor neurons conveying proprioceptive impulses from the locomotor system through the inferior cerebellar peduncles to the cerebellum. These impulses, on reaching the cerebellum, pass through

the innumerable granular cells, and finally discharge on to the Purkinje cells, which thus represent the outgoing effector neurons of any ordinary neuron arc. In fact, the Purkinje cells are the only effector neurons which the cerebellum possesses. Expressed still more simply, receptor neurons are represented by the so-called climbing and moss fibres; the internuncial or interposed junctional nerve tissue by the many basket, stellate, and granule cells; and the outgoing effector limbs of the cerebellar arcs by the Purkinje cells.

If this construction be now compared with the simple spinal cord reflex nerve arc represented in fig. 1, it is clear that the only difference in the suprasegmental cerebellum is that the single internuncial long-axoned cell of the knee-jerk arc is replaced by the very large numbers of minute granular cells of the Golgi type II variety. Hence the passage of nerve impulses through such arcs must be considerably slowed down or even arrested.

When we come to study the structure of the brain itself we are generally confronted with a series of obsolete histological diagrams which fail to convince us of the structural relations between nerve-cells and mind. Yet this relationship exists and can be shown to exist, provided the question of cerebral structure be approached from a different angle. To understand brain structure and its relation to mind it is necessary to remember particularly the differences in the junctional nerve tissues of the neuron arcs of the spinal cord and the cerebellum, for the human brain reproduces both types (figs. 1 and 2), but multiplies enormously the numbers of nerve-cells concerned.

As is well known, there pass to the brain certain well-defined 'sensory or afferent' tracts, and from it other equally well-defined 'motor or efferent' tracts. Amongst the former may be mentioned the exteroceptive tracts of vision and hearing, forming the retinal fibres of the optic radiation, and the central path of the cochlear nerve of hearing. Of the purely 'efferent' tracts the most generally well-known are the 'motor' pyramidal, lesions of which offer such obvious signs. These and all similar inflowing or outflowing pathways to and from the brain are obviously the equivalents of the receptor and effector limbs of the neuron arcs of the spinal cord and may, for the moment, be so collectively termed. But what of the cerebral tissue in between? What of the connectant neurons which, just as in the spinal cord reflex arc of the knee-jerk (fig. 1) are, and must be, interpolated between the receptor and effector limbs to complete the necessary neuron arcs of the brain? As a matter of fact these all are fully described in any good textbook of anatomy or physiology, but their significance as essential elements in the elementary structures of primitive behaviour is usually omitted. Some at least of the cerebral internuncial neurons of the principal receptor and effector channels of the brain are known and described as the short and long association fibres of the cerebral

cortex (fig. 4), and are, in the human brain, like those found in the spinal cord and serve the same purpose. They form quick-acting reflex arcs for immediate responses to the stimuli (fig. 5). The segmented type of reflex

FIG. 4. Some of the chief association tracts of the brain. These are the cerebral equivalents of the fasciculi proprii of the spinal cord, and therefore of the internuncial neurons of the segmented form of the neuronic arc.

FIG. 5. Model of brain showing spinal cord 'path' type of conduction in an infant's brain during the stage of echolalia. Many imbeciles retain this primitive type of cortical mechanism throughout life.

neuronic arcs is thus retained and elaborated in the human brain, and the elaboration is rendered necessary by the multifarious reactions to which the brain has to give effect. It is unnecessary, once the significance of the association systems in the human cerebral cortex has been realized, to bother with their anatomical names. What they essentially are is what matters, and clearly they are internuncial neurons interposed between receptor and effector limbs of nerve arcs so completing the functional arcs concerned, in much the same way as so many of the axons of the fasciculi proprii of the spinal cord form the connectant links between receptor and effector neurons of simple spinal cord reflex arcs.

'The association fibres link together different portions of the same hemisphere, many uniting adjacent areas whilst others connect parts widely separated. They are grouped, therefore, as long and short association bundles. With the exception of a narrow zone in the immediate vicinity of the upper end of the central sulcus the cerebral cortex at birth is unprovided with association fibres which have acquired their myelin sheath. Within the early months after birth, however, the myelinization of these, as well as other tracts, progresses rapidly, although this process is not even moderately completed until after the lapse of several years. Indeed, there is sufficient evidence to believe that myelinization of additional fibres continues so long as intellectual effort is progressive, the demands made by education and special mental exercise being met by a corresponding completion of additional association fibres.' (Piersol, *Textbook of Anatomy*.)

By this arrangement of a retention of the quick-acting spinal cord neuronic reflex arcs, with association internuncial neurons as the connecting links, the brain is enabled to give, where necessary, rapid responses to its many and varied incoming receptor stimuli.

But the human brain also incorporates within its minute structure the suprasegmental or cerebellar type of neuronic arcs, in which the interposition of extraordinarily numerous granulous cells between incoming receptors and outgoing effectors so delays, arrests, or inhibits the reactions to the stimuli, as to afford the physical basis of memory, mind, and language. That man differs so profoundly from even the nearest anthropoid ape is due to the fact that in him the numbers of these granulous cerebral cells and association systems considerably exceed that of any animal, and hence there is ample provision for the physical retention of stimuli in the form of nerve energy which may give rise to memory and speech.

The principles of the suprasegmental type of neuronic arcs, as seen in the human brain, are perhaps easily illustrated from an area of cortex to which much research has been devoted, namely, the visuosensory, situated in the occipital lobes.

THE VISUOSENSORY CEREBRAL CORTEX (fig. 8).

The visuosensory occipital cortex is a typical receptive area of the brain, for on to it are discharged the nerve impulses aroused by the stimulant

action of light waves on the retina. It is now known that all typically receptive areas of the cerebral cortex conform to the suprasegmental type of structure. There is an incoming band of medullated axons conveying receptor stimuli, discharging on to numerous granulous cells. For these reasons the visuosensory cortex is termed by von Economo a heterotypical granulous area.

The advantage of such a model (fig. 8) is that it clearly permits us to see with the naked eye the minute structural details of the brain itself. Thus, light waves falling upon the retina stimulate the rods and cones or receptor organs of the optic nerve. The axons of these nerves pass centrally, as the fibres of the optic radiations, through the brain substance to the visual cortex. In the model they can be seen passing upwards through the white matter into the grey cortex, there forming part of a radial bundle. In the middle of that cortex they turn at right angles to the brain surface, forming a well-marked white band variously known as the stria of Gennari or the outer line of Baillarger, and discharging their impulses on to the innumerable granular cells of Watson's granular cortex. A similar smaller band of medullated axons is also shown discharging on to the polymorphic cells of the infragranular cortex. As both the polymorphic cells and the small pyramidal cells of this visuosensory area are exceedingly minute, von Economo now regards the small pyramidal cells as granulous or receptive in type. The cells of this visuosensory area seem, therefore, to be comparable with those of the cerebellum and may be regarded, structurally, as forming internuncial or connectant cells between the incoming receptor axons of the optic radiation, and those of outgoing effector or associational neurons.

Of the intensely receptive nature of the visuosensory cortex, Ariëns Kappers says:—

'The granular layer is strongly developed in those regions of the neocortex that have an exquisite sensory function—the postcentral or sensory region the frontal cortex, the auditory and visual cortex. In the area striata (visual cortex) afferent (receptor) fibres running in the stria Gennarii and Vicq d'Azyr, end chiefly in the granular layer. This does not mean that the granular layer is the only layer which receives afferent (receptor) impulses. Afferent (receptor) impulses, among which are those transmitted by the corpus callosum, also reach the supragranular pyramids.'

von Economo says:—

'The granulous cortex corresponds to the sensory sphere of the cortex in respect of localisation; so that we may consider it to be the sensory cortex par excellence.'

But the problem arises, what exactly takes place in the granular cells in response to the receptor stimuli conveyed to them? That either the cells or their numerous synapses may delay, arrest, or inhibit the passage of nerve impulses through the neuronics in which they occur appears to be certain,

but do the cells themselves play any other part in the phenomena of mind? Elliot Smith, quoted by Herrick, says:—

‘The ability to learn by experience necessarily implies the development, somewhere in the brain, of a something which can act not only as a receptive organ for impressions of the senses and a means for securing that their influence will find expression in modifying behaviour, *but also serve in a sense as a recording apparatus for storing such impressions*, so that they may be revived in memory at some further time in association with other impressions received simultaneously, the state of consciousness they evoked, and the response they called forth.’

Howell, in the eleventh edition of his *Textbook of Physiology*, says:—

‘The greater mental activity in the higher animals is dependent, in part, upon the richer interconnection of the nerve cells. . . . A visual or auditory stimulus that in the frog, for instance, may call forth a comparatively simple motor response, may in man, *on account of the numerous associations with the memory records of past experiences*, lead to psychical and motor responses of a much more intricate and indirect character.’

Herrick, in *Brains of Rats and Men*, says:—

‘In the associational fields we have the machinery for registering in static form the structural modifications (engrams) left by the activation of every cortical associational pathway. *Every such associational pattern which has once been activated seems to be preserved, set as on a trigger, ready to be activated when some related or congruous system of subcortical activities again overflows into the cortical projection centres—the conventional theory of cortical memory* Many of the neurons involved in one memory may also be involved in a dozen other memories, but linked in different patterns In the associational zones there is sensual fusion, not only of present complexes of stimuli, but also of vestiges of previous similar activities which have been fabricated through facilitation of path and the retention of these acquired structural alterations—cortical memories, conscious and unconscious.’

Whilst the foregoing extracts, indicative of anatomical, physiological and neurological thought, are not solely referable to the granular cells of the visuosensory area but include many other similar cortical neurons and associational systems, they suggest that all three authorities quoted seem to be in agreement as to the functional properties of the brain-cells concerned, and regard them as doing something more than merely ‘delaying, arresting or inhibiting the passage of nerve impulses through them.’ ‘The storing of such impressions’ . . . ‘Memory records of past experiences’ . . . ‘Neurons involved in our memory involved in a dozen other memories’—whatever the language, the ultimate underlying thought appears to be the same—that these brain-cells are, in some way, the physical basis of memory, thought and language, and therefore of those phenomena we term the mind. As Herrick expresses it,

‘The influence upon present conduct of memories of particular past experience—this does seem to be in mankind a typically cortical sort of nervous action.’

For the further uses of this paper it will then be assumed, either rightly or wrongly, that

‘ Every mnemonic vestige, every engram, is represented by a complex web of interrelated neurons, each with a potential energy while in the resting condition, and when reactivated in recall (say by sensory or receptive stimuli) the reserve energy of this mnemonic complex is released and is available both to co-operate with the reactivating excitation in determining the nature of the response and also to intensify that response and inhibit or neutralise all other responses The cortex contains innumerable nervous elements with short axons (Golgi type II neurons) which seem structurally not well adapted to participate in the more extensive associational patterns of the usual memory vestiges, but are so situated as to be able to function in a non-specific way by discharging their reserve energy locally into any associational system that at the moment may be activated within their field . . . Type II neurons give to the human cerebral cortex its unique position as the master tissue of the body ’ (Herrick, *Brains of Rats and Men*).

The human brain thus combines within itself the segmental spinal cord machinery for quick localized reaction to incoming stimuli, as also a most efficient mechanism for the retention of potential energy, as transformed by neuronic reaction from physical stimuli until the opportune moment arrives for its discharge in the form of action, reaction, or speech indicative of ideas, which up to date in the evolutionary world are the highest form of mind, human or animal, known to us.

THE BRAIN AS THE ORGAN OF MIND (fig. 8).

It will be seen from fig. 8 that there are three chief receptive cortical areas—auditosensory, visuosensory, and somæstheticosensory—about equidistant from each other and all characterized, structurally, by the presence of exceedingly numerous minute granulous neurons. From birth onwards the cortical cells of these areas are constantly influenced by the effects of stimulation, conveyed to them by their own receptor nerves. Thus, the organ of Corti—that is, the receptor organ of hearing—is perpetually responding to sound waves, and so causes the receptor neurons of the cochlear nerve to undergo certain changes which apparently transmute sound waves into nerve impulses. Under this form they are transferred to the granulous cortical neurons of the auditosensory area which, as the result of the stimuli, becomes, as it were, converted into fully-charged live batteries—that is, charged with potential nerve energy, whereas if they do not become so charged, they remain in their neuroblastic, embryological and functionally useless state. The influence of stimuli in the production and phenomena of mind is thus very considerable. Precisely similar and synchronous changes also occur in the somæstheticosensory and visuosensory areas, as a result of which many millions of granulous neurons in the areas concerned become charged with potential nerve energy.

‘ All living substance in the resting condition has some unexpended potential energy. In the nervous system there is much accumulation of this sort, laid down in a characteristic iron-containing nucleoproteid which is chemically unstable, the chromophilic substance, or Nissl bodies The known

structure of the cortex indicates that ample reserves (of this energy) are available on demand for reinforcement of any cortical pattern of associational activity whatever.' (Herrick, *Brains of Rats and Men*).

From the primary receptive granulous cortical areas this charging of neurons with potential energy spreads to, and involves, those immediately adjacent portions of cortex known as the auditopsychic, visuopsychic, and somæstheticopsychic areas. *Pari passu* the short and long associational axons become myelinated and taken up into the ever widening network of functioning and activating cerebral neurons. A slow continuation of the same processes gradually involves that portion of cortex known as the parietal associational area, in which eventually become fused, synthetised and correlated, all those forms of potential nerve energy resulting from a stimulation of the three primary receptive areas by light, sound, and general sensibility.

It will be observed that this process of gradual infection of successive groups of cortical brain-cells, with the potential energy resulting from a constant stimulation does not in the least resemble that so generally believed, and which, as the 'path theory of cortical function,' Ashby has adversely and justly criticized. It is much better expressed in his own slightly modified simile of a cerebral pond in which many millions of successive ripples (successively charged neurons) are produced by a constant throwing in of stones (stimuli) at three independent points. Eventually these ripples fuse, coalesce, and weave themselves, within the parietal associational centre of the pond, into those innumerable kaleidoscopic neuronc patterns or engrams essential to the production of mental phenomena. The path theory of cortical function is not applicable, as Ashby points out, to *all* cerebral manifestations. What, however, may possibly have been overlooked is that the path theory *is* applicable to the associational tracts of the cerebral hemispheres, but not to the suprasegmental types of junctional cerebral nerve tissues just considered.

From what has just been stated it should be clear that at birth, and for some time after, there are relatively large areas of cerebral cortex (figs. 6 and 7) completely devoid of all function, for the simple reason that the majority of their cellular elements remain in the embryological neuroblastic non-functional state. These areas have been specially studied by Flechsig who, from his observations on the periods of time at which the axons assume their myelin sheaths, has been enabled to deduce with considerable accuracy the times at which these originally non-functional cortical areas become functional, or differently expressed, the dates at which cortical neuroblasts, especially those of association areas, become converted into fully functioning neurons. That they do become so converted under the influence of incoming exteroceptive and other stimuli seems beyond doubt, as does also the fact that if the conversion does not take place, as, for example, in the visuosensory

area of the congenitally blind, there is a corresponding diminution of the general intellectual level of the individual. The successive stages of the gradual diminution in the sizes of these non-functional cortical areas and

FIG. 6. Flechsig's primordial areas, in dotted zones.

FIG. 7. Flechsig's primordial and marginal areas in dotted zones. In both figures the non-myelinated, and therefore non-functional, portions of cortex are undifferentiated. In fig. 5 these non-functional cortical areas are diagrammatically shown in black. With normal development these areas should complete their myelination, but in the feeble-minded they may not do so.

their adoption into physiologically active mind-producing matter is well shown in the figures just referred to.

It is not, unfortunately, possible within the limits of the present demonstration to follow up the weaving of these innumerable cortical neurons (fig. 8) now charged with potential nerve energy into those manifold neuron patterns and engrams which still further explain, in their countless permutations and combinations, the production of mind from brain-cells.

FIG. 8. Occipital half of left cerebral hemisphere seen in two dimensions.

Upper part. Cortical surface. Primary receptor zones in circles; secondary receptor zones in triangles; association area in squares.

Lower part. Section through the cortex showing the construction, as modelled in beads, of the areas concerned. After von Economo's microscopic studies.

From left to right.

Auditosensory (somæstheticosensory) area.				Economo: Type 5 cortex	
Auditopsychic area	...	...	..	..	4 ..
Association area	...	...	..	..	3 ..
Visuopsychic area	...	...	..	..	4 ..
Visuosensory area	...	...	..	..	5 ..

It may, however, be pointed out that this discussion has only concerned itself with the *building up* of the cerebral structure of mind. Once these myriads of brain-cells have been converted, under stimulation, into energy-holding and -producing agencies, they may change that potential energy into kinetic energy, and may do so under any stimulus whatsoever,

whether arising from within or without the body. Once built up they obviously do not require rebuilding—in fact, a self-regulating mechanism has been set up—for from the one exposed negative many pictures may be obtained, and the human brain contains still more ‘unexposed negatives’ in the form of neuroblasts awaiting the necessary stimuli to convert them into activating and functional neurons.

CLINICAL APPLICATIONS.

Passing next to some clinical applications of the facts already recounted of the relationships between brain-cells and mind, there may be instanced the actual physical and neurological phenomena now taking place. Sound waves induced by the lecturer’s voice, and light waves reflected from the pictures on the screen are impinging on the corresponding receptor (sense) organs of the audience—that is, upon the organ of Corti and the rods and cones of the retina. These stimuli, transformed into nerve energy by the neurons of the cochlear and optic nerves, impinge on the myriads of cortical cells of the audiosensory and visuosensory areas of the cerebral cortex, inducing in them some as yet little-understood chromatolytic changes which result in an accumulation of potential energy. These changes spread, like ripples on water, to many other cerebral cells, especially those of the association areas, which thus accumulate and retain, in potential form, the nerve energy generated in response to the stimuli. It is obvious that, as yet, this potential energy has not given rise to any effector or other response on the part of the audience, which has, indeed, remained passive throughout. But the potential nerve energy which has so become accumulated in the brains of one’s hearers will not remain potential for ever. Sooner or later some other stimulus will come along and cause the potentially charged neurons of to-night to liberate energy in kinetic form, and effector responses will be manifested in the form of speech, discussion, and exchange of ideas relative to the events of the lecture.

But contrast this delayed reaction to the stimuli with the extremely rapid locomotor ones which this audience would instantaneously display were the lecturer suddenly and unexpectedly to produce a couple of automatic quick-firing guns and loose them off in accordance with the best practice of the racketeers of the North American continent. No longer would the audience fail to respond to the incoming stimuli of sight and sound, but would react both rapidly and effectively. Clearly then the human brain can adapt itself to two totally different series of requirements. It can absorb stimuli in the form of potential nerve energy until such time as it is most advantageous to utilize it, or the potential energy can be immediately and instantaneously converted into kinetic form, with appropriate locomotor or other effector responses to the stimuli. And this, it will be remembered, is

strictly in accordance with those structural details of brain construction, the outlines of which have already been set forth. For instantaneous responses to stimuli of sound, sight, or touch, the human brain utilizes the numerous spinal-cord types of neuronics arcs with which it is provided, the elements of which are the receptor nerves, the long association fibres, and the appropriate effector pathways (fig. 5).

For delayed reactions to the stimuli, the mechanism employed is the numerous small pyramidal, granular and polymorphic cells among which the production of potential energy delays, arrests, or even entirely inhibits the effector responses to the incoming stimuli (fig. 8). The *first* is the spinal-cord or segmented type of neuronics arc with 'path' mode of function, designed to give rapid and instantaneous reaction to the stimuli. The *second* is the suprasegmental or 'ripple' type of neuronics arc conduction, with extraordinarily numerous interpolated internuncial neurons between the receptor and effector limbs of the arcs, which delay, arrest or may even totally inhibit the reactions to the stimuli.

Although it is clear that there are two distinct types of mechanism in the completely developed brain, namely, the spinal-cord type for quick reaction, and the suprasegmental type for delayed response, it is apparent that in the fundamental whole these two types must co-operate in an intimate way. The reaction to the revolver episode can only occur when the sense of danger, i.e., the meaning of the total situation is first realized by the audience. It would appear, then, that even though the primitive effector (spinal type) response is used, it is not, in the fully developed brain, an isolated, purely reflex phenomenon, but is appropriately employed by a cerebrum acting as a whole. What can be conceived of as a primitive structure has, in fact, become incorporated into the fully developed nervous system.

SPEECH.

Of other practical applications of some of the foregoing facts of cerebral construction and the logical deductions therefrom, attention may be directed to their important bearing on the clinical significance of the acquisition of speech. Unfortunately, medical attention is mostly devoted to its loss, as in the aphasias, rather than to its acquisition, and yet in the mental phenomena associated with that lack of cerebral development termed mental deficiency it is not the loss of speech, but the failure to acquire it which is of such profound clinical significance.

During the first twelve months after birth the normal child is little more than a speechless automaton, yet during this period important changes occur in the brain, which prepare the way for all future mental development. Amongst these changes are those of conversion of functionless neuroblasts

into functioning neurons and the acquisition by them of myelin sheaths. At about the fourteenth month of normal development the child commences to utter meaningless words, which are nothing more than repetitions of the last sounds of syllables heard. This stage of *echolalia* (fig. 5) is thus described by Wyllie in his classical but seldom read work, *The Disorders of Speech*:—

‘It is in the cortical centre for hearing that the sound is first registered. By-and-by the motor area becomes trained or developed to reproduce the word heard. Thus the child reproduces many words that he hears, in parrot-like fashion, by echolalia, without making any attempt to understand them.’

Now it requires no very profound knowledge of the intricacies of the nervous system to understand the nerve mechanism involved in echolalia. The cochlear nerve of hearing represents the receptor limb of the arc, with the organ of Corti as the receptor or sense organ. The auditosensory area, with its innumerable minute receptive cortical neurons, is the chief cortical receptive centre. The polymorphic and other cells whose axons form the short association fibres passing from the auditosensory area to that part of the Rolandic motor area concerned with the muscles of the lips and larynx represent the internuncial neurons of the arc, whilst the neurons proceeding to the appropriate muscles form the effector limbs of the arcs, and so complete the nerve circuit. In echolalia the brain is obviously utilizing the simple segmented spinal-cord type of arc with ‘path’ conduction and immediate response, just as it did in the revolver episode previously mentioned, or as the spinal cord itself does in the knee-jerk.

But *pari passu* with this, a much more intricate process is going on in the developing brain of the normal child (fig. 8). Exteroceptive stimuli of sound, sight and touch are being constantly poured into the cerebral cortex, as a result of which the auditosensory, visuosensory, and somæstheticosensory areas are activated to the conversion of immature brain-cells into mature ones and the production of more and more potential nerve energy. This dual process is passed on, in the ‘ripple’ form of cerebral conduction, to the auditopsychic, visuopsychic, and somæstheticopsychic areas, and finally to the appropriate association area, in this case the parietal, where the various sense stimuli appear to be fused and retained in the form of potential nerve energy. This process affects many thousands, or more likely millions, of cerebral cells and processes, which later, and under suitable stimulus, liberate their potential nerve energy in the kinetic form, and so the child becomes transformed from a senseless automaton into a sentient, intelligent, human being.

The nerve mechanism here employed is entirely different from the reflex arc type which is the basis of echolalia, for it involves the many myriads of interposed suprasegmental internuncial cells with which the human brain abounds. The conversion of the numerous neuroblasts of these supra-

segmental cerebral arcs into functioning neurons, and the necessary myelination and connexions of their associational and commissural axons naturally take time and cover, or should cover, the first 18 or 20 years of life. Speaking generally, the earlier it ceases, the greater the mental deficiency, and the later it ceases the higher the intelligence.

But suppose these twin cerebral processes do not occur? Suppose that from any cause whatever the cerebral neurons remain developmentally imperfect and that neither the spinal-cord echolalia 'path' conduction arcs, nor the suprasegmental 'ripple' ones attain maturity? What happens? The child grows up as a physical and possibly a sexual adult, but mentally is, and must be, an idiot, devoid of speech and intelligence. Given accurate observation, by any intelligent general practitioner, of such a developing child during the years of infancy and childhood, a prognosis of future idiocy can be made with certainty from a study of its speech reactions alone. Cerebral cortical histology thus leads to a most important clinical dictum, which is, that unduly late acquisition of speech by a child is a certain indication of a future state of amentia. If, during the first five years of life, there is no attempt at speech, or no utterance of sounds other than the grunts and animal noises of early infancy, idiocy can be prognosticated with some certainty. A diagnosis of future imbecility can similarly be made if the child be found to remain permanently in a state of echolalia (fig. 5). But there is something more involved even than this purely clinical observation, important though that is. If what has been stated as to the two modes of cerebral conduction—'path' and 'ripple'—has been followed, it is clear that this failure to acquire adequate speech has given still more valuable information, for it affords the expert an adequate conception of the actual state of development and faulty neuron construction of the brain itself, and thus establishes an accurate basis upon which to found one's psychological and other medical studies of the patient.

FEEBLEMINDEDNESS.

Passing next to the higher grades of mental defectives—the feeble-minded—it is certain that in them the brain attains a much greater degree of development, with a mentality about equal to that of a normal child of from 7 to 10 years and a Binet I.Q. of from 50 to 70, the limits and range being subject to much individual variation. Here it is impossible to state, neurologically, exactly which part of the brain is lagging behind in its development, but it is almost certainly some part of the association areas, and specially concerns the pyramidal-celled or supragranular cortex (figs. 7 and 8). It has already been shown that, at birth, the association areas are not functional because, as Flechsig has proved, the axons are not myelinated. Under the influence of normal environmental stimulation from exteroceptive sources the cells of these areas become fully developed, their axons

myelinated, and they become taken up into the evergrowing network of neuronic arcs, patterns and engrams, until eventually all parts of these association areas are functioning, and normal mentality is attained. In feeble-mindedness this process of absorption of non-functional cortical areas into fully functioning brain matter becomes prematurely arrested, and the degree of feeble-mindedness presented depends entirely at what stage this process ceases. There are, of course, many clinical, psychological, intelligence, and other tests for determination of the grade or degree of feeble-mindedness, but from the neurophysiological standpoint a study of the patient's language and vocabulary is as illuminating and interesting as any. As regards the former it is, as a general rule, the consonants which present more difficulties to the feeble-minded than the vowels, and they frequently retain, in their language, some at least of its more infantile features. Amongst these may be mentioned 'smudging' or scamping of the syllables, as in baby speech, slurring and lalling, whilst some form of stammering is not uncommon. Speaking generally, disorders of speech and a retention of infantile features common to its acquisition are sign manuals of an underdeveloped cerebral cortex of greater or less degree.

Cortical studies of structure also seem to throw further light on epilepsy, fits, convulsions, and other similar manifestations of discharge of nerve impulse in an aberrant kinetic form. The cortical explanation would appear to be that either owing to an insufficiency of intracortical internuncial neurons between the receptor and effector limbs of the cortical arcs, or an excess of short associational junctional tissue, or both, nerve energy—the result of a summation of minute stimuli—is transmitted too directly to effector cells, thus causing in the latter a massive discharge of kinetic nerve energy, that is, a greater number of motor or effector cells are brought into prolonged activity. Whether this be or be not the explanation it supports the view that epilepsy is not a disease but a symptom of an imperfectly developed nervous system. Certainly the lower grades of mental defectives, in whom the nervous system is most imperfect, are those in whom epilepsy most frequently occurs. Consequently the legendary statements concerning some of the world's military and other geniuses popularly believed, on insufficient evidence, to have suffered from epilepsy, should be received with suspicion. As Wilson remarks:—

'There are many organic nervous states of which epileptic fits are a symptom; in fact, the epileptic fit is nothing else than a symptom. No such disease as epilepsy exists, or can exist.'

And modern cortical structural studies support this view.

It has been stated that feeble-mindedness appears to be due to a lack of development of the association areas, and specially concerns the pyramidal or supragranular cortex. Thanks to the work of G. A. Watson, Shaw Bolton, Mott, and others, it is known today that only the mammals have a true

neopallial cerebral cortex, and that in them this cortex is laid down on an infragranular basis (fig. 8). In the higher mammals, and especially in the anthropoids and man, the three-layered cerebral cortex of the marsupials becomes a five-layered one by the addition of layers of pyramidal cells. Hence it is not improbable that the human cerebral cortex functions in horizontal strata in addition to the localized 'centres' previously recognized. Howell, in the last edition of his well-known *Textbook of Physiology*, says:—

'It is pointed out that if we omit the outer or molecular layer the other cells of the cortex fall into three groups, namely, the granular layer, the supragranular layer—comprising the pyramidal cells external to the granular layer—and the infragranular layer—comprising the pyramidal and fusiform cells internal to the granular layer. Comparison of the cerebral cortex in the brains of the different vertebrates indicates that the supragranular cells have appeared relatively late in the phylogeny of the vertebrates, and have reached their greatest development in the human brain. The suggestion occurs, therefore, that these cells have a different functional significance from those in the infragranular layer. It has been supposed that the supragranular cells mediate the so-called higher psychical processes, which characterise man and the related mammalia as compared with the lower vertebrates. The infragranular cells, on the other hand, constitute a primitive layer which has obvious connection, through projection fibres, with the underlying parts of the brain and of the body at large. These cells form, therefore, a mechanism through which the brain is connected directly with the rest of the body, and through which the older instinctive reactions are controlled.'

It is difficult for any scientifically trained clinician to study the mentally defective without reaching the conclusion that there is much to be said for the laminar conception of cerebral function. If the supragranular pyramidal cells are deficient in numbers and development there must be a corresponding diminution of the medullated axons of the white matter, and therefore a diminished brain volume and a smaller head. An examination of over 2,000 mentally defective patients in both Australia and England, with accurately recorded head measurements, has convinced me that microcephaly or smallheadedness is almost pathognomonic of feeble-mindedness, as I have found it in about 80 per cent. of all cases.

Bolton has shown that in the lower grades of mental defectives we may expect to find a diminution in the thickness of both the infragranular and supragranular cortices with a resultant idiocy or imbecility. In the higher grades this diminution in thickness of cortical matter affects chiefly the supragranular cortex, hence the feeble-minded appear to derive whatever mentality or intelligence they may possess from their infragranular cortex, through which, according to Watson and Howell, the older instinctive reactions are controlled. And this, too, certainly reveals itself in the general reactions, instability, paucity of vocabulary, and more animal reactions of the feeble-minded. There is thus every reason to believe that cortical histology, carefully checked by clinical and scientific observations, is opening up new ground in the field of mental science.

Lastly, there is the still more recent work of von Economo, Jakob, and others, who have pointed out that in certain aberrant forms of mentality associated with the insanities there can be demonstrated an actual destruction of cortical cells in some of the different laminae. Even though none of these several observations be regarded as proven, they are, at least, all heading in the same direction, and that is, to brain-cells as the undoubted organs of mind.

Notwithstanding that the practitioner of medicine may, at first, imagine that cortical histology is a repellent subject, devoid of interest to any but the expert, it is to be hoped that this demonstration may have shaken his faith in his pessimism. Today, when all are so anxious to recognize mental disturbance as early as possible with a view to the adoption of more hopeful preventive measures, rather than the more hopeless curative ones, there is given to the general practitioner a great opportunity. To him and to him alone must we look for that careful study of the mental development of the infant and child which is so essential if mental disorder is to be recognized early enough for effective preventive measures, and to him too we look for a realization of the fact that the 'phenomena of the human mind are *not* too complex to admit of their structural explanation or understanding.'