THE HUMAN BRAIN *

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THE brain is confined in the cranial cavity as if in a closed box and its tail or spinal cord extends into the spinal canal. For its protection from injury during the normal movements of the body, the brain and spinal cord are suspended from its covering buffered by a fluid known as the cerebro-spinal fluid.

The brain and spinal cord consist of billions of nerve cells. Anatomists estimate that the brain alone, not including the peripheral nervous system, contains some 10 billion nerve cells or neurons. These in turn are sheathed or supported by some 100 billion glial cells. But the main operative unit is the neuron, the most remarkable of specialised cells. The neurons are further differentiated into 3 broad types—motor neurons, which bring about the contractions of muscles of the entire body ; the sensory neurons which receive and transmit light, heat, pressure and all other sense impulses ; and thirdly, the interconnecting neurons which are the most numerous. The connections to and from each neuron run into thousands producing a network of unsurpassed mystery and complexity.

Each nerve cell has a cell body with its dendrites which form 80% of the neuronal surface, and axons. The axons are the nerve fibres while the dendrites are the dominant part of the receptive surface of the neuron. Each nerve cell gets connected with other nerve cells with dendrites or axons. These connections are called synapses. Some of the synapses have an inhibitory function while the others have an excitatory function. The peripheral axons join together in bundles to form the nerves which supply each and every part of our body. Therefore, the most important fact that we have to recognise is that for the normal working of any tissue in our body, the brain and the spinal cord have an essential part to play. Even the complicated hormones which are produced by various tissues in the body are controlled by the master-gland, the pituitary gland or hypophysis situated in the base of the brain. Each neuron in maintaining its activity can be compared to a battery because there is a continuous electrical potential gradient in each one of them brought about by the specialised properties of its cell membrane. How the potassium sodium pump of the membrane is maintained and how propagation and maintenance of its activity is continued would be very interesting to a biochemist.

The billions of nerve cells in the brain and spinal cord are arranged in a fascinating manner. The nerve cells are all aggregated together and they are commonly known as the grey matter and the axons or nerve fibres form the white matter in the brain. The intricate network of these axons connecting with its various processes form an integrated whole.

Phylogenetically, the function of the nervous system will fall into various levels. All the newly acquired abilities and talents come at the highest level and interestingly enough the new cells that control such functions are at the cortex or periphery of the brain while the aggregates of neurons cluster themselves into the central part of the brain and manifest functions that are absolutely essential for life.

I want to begin by discussing some aspects of the physiology of perception. Electrophysiological methods are adding fundamentally to our knowledge of the physiological basis of perception. Microelectrodes demonstrate the response to different kinds of sensory stimuli from single neurons at different levels of the nervous system. For some years it has been known that in the retina and optic nerve there are some units which respond to the onset of illumination and some others which respond to its cessation while a different set responds to both. This is known as the "on and off system". Again it has been established that some units respond to movement in one horizontal direction but not to that in the opposite. It has also been shown that even though the visual cortex corresponds to a restricted retinal area, convergence from a considerable retinal field makes itself to a single cortical unit. Also, it is known that the retinal fields have excitory and inhibitory

* Public lecture delivered at the 32nd Annual Meeting of the Indian Academy of Sciences at Madurai on 22nd December 1966.

regions. It has been shown that within the receptive field, the summation of various stimuli provide a basis for the specificity of shape, size and orientation. It was further demonstrated that the lateral geniculate body had the same responses and these resembled the retinal configuration more than that of the striate cortex. Thus, it has been shown that perceptual discrimination in vision depends upon physiological organisation in the receptor organ, the retina. And, this in turn upon the anatomical fact that a large number of retinal receptors converge upon a single optic nerve fibre. There is also a spontaneous activity in the sense-organs. The interpretation of these stimuli finally by the cortex is related to learning memory and understanding.

Before considering the more difficult question of human consciousness let us see how the coded information works in simpler brains. The frog's reaction to seeing a fly is to aim its tongue at it. What the coded information derived from the retina of the frog does is to evoke the appropriate action. For this to happen afferent impulses must first convey information about the quality and position in space of the object, which is the fly; and, the frog must also receive information about its own position. In other words, the frog reacts to a fly because of the information processed by its visual system together with that of other information derived from other sources. Even these simple creatures learn by experience. Awareness of the passage of time seems to involve the retention of past experiences against which the ever-changing present is perceived as a novelty until it too becomes the past.

We can hardly consider perception without mentioning memory. But as this is too large a subject, only some aspects of this will be dealt with later. For the maintenance of consciousness the rhinencephalic and diencephalic mechanisms must act with appropriate parts of the cerebral cortex as well as with the upper brain-stem mechanisms. Even a discriminative activity or thought process is not solely a function of the cortex or any single area. Many factors and parts of the brain are concurrently involved.

Let us consider the intricate mechanism of speech. What is it that enables me to speak to you and enables you to translate my words and understand my meaning? I select the words that are symbols of my thought. You receiving these symbols convert them into thought but hold short sequences of my words within the focus of your attention for a fleeting moment long enough for conscious consideration and you add your own interpretation. That is perception of my speech. But an astonishing complex process takes place. A succession of nerve impulses flows out of my brain along the nerves in such a pattern that appropriate muscles contract while others relax, and I speak. An idea has found expression in electrical energy, movement and vibrations in the air. The boundary which separates philosophy from neurophysiology and physics has been crossed. When the sound reaches your ear drums it is again converted into nerve impulses by the receptor organs and are conducted along the auditory nerves into your brain. This stream of nerve impulses results in a secondary mental process in you, that is, again, perception. Thus, mind-brain frontiers have been crossed twice in succession. However, this perception becomes possible in your mind only because of its integrated function, integrating with previous experience, memory and intelligence.

Every intricate activity of the human being is controlled by the brain, spinal cord and nerves through a complicated mechanism that can be described in general terms as cybernetics. All our sensations, movements, actions, behaviour, thought process, memory—in other words, the entire personality of the individual—is through these complicated networks and their functions in the brain and spinal cord.

Comparisons have been made between the human brain and electronic computing machines on at least three different levels—components, coding and logical organisation, and information processing. Attempts have been made to apply these notions to describe and interpret information processing in biological systems. When making such comparisons the brain is viewed as an information-transforming device which accepts data from the external world, interprets and operates on these data and produces control information. In the jargon of the computer engineer the brain is a black box which receives input signals. The receptors from the various sensory organs operate on these signals to generate other output signals which finally go to effectors causing appropriate muscles and glands to function. The information loop is closed *via* the external world and thus the brain is interpreted as a complex,

automatic, regulating device which allows its owner to react so as to maintain a certain stability of success in his interaction with the local environment. Given this interpretation of the brain as a complex computer, attempts have been made to describe the information flow-paths and the logical organisation of its major sub-systems.

There is also the question of memory and how past events are coded and recorded in the brain. Some workers have made estimates as to the total information capacity of the brain. Obviously it varies with individuals thus making one more intelligent than the other. Various types of experiments suggest that a very large proportion of our experiences are coded, recorded and, under certain conditions, subject to recall. Some of these conditions need not be normal or normal function but pathological. Let me give you an example in the form of a case history.

A 26-year old girl had lost her mother at the age of 8. From the age of 18 she would suddenly feel that she was sitting near her mother who was singing a lullaby to put her to sleep. This phenomenon would last for a minute or two. Following this episode she would have some automatic behaviour without her knowledge. Such episodes occurred 5-8 times a year during the next three years. Then she started to get these episodes preceding major convulsive attacks of unconsciousness and convulsions. On investigation, this patient had an activating focus of abnormal electrical discharges in the right anterior temporal lobe. In other words, she started a temporal lobe epilepsy phenomena at the age of 18. When this particular area of the brain was exposed and stimulated by minute electrical currents one could reproduce the same attack which she had been experiencing for 8 years.

Obviously the storage of this experience which she had in her childhood was being brought into activity by the abnormal electrical discharges that were taking place in that specific part of the storage mechanism.

Fixation of experience is a wider topic than learning. It includes changes in the individual system, at all levels from molecule to society, that have become irreversible under single or repeated experiences and so have left some material record of a past activity and it includes racial changes that have cumulated over generations. Behavioural science represents the transient or functional responses of the system to stimuli or stress imposed by the environment and are reversible so that the system essentially reverts after the situations have passed. However, when such stimuli are sufficiently intense or meaningful or repetitive so as to leave an irreversible change, the system undergoes a secular change of fixed experience. The irreversible changes of individual units at the molecular level can include gene mutations and adaptive enzymes. At the cellular level there can occur the whole process of cellular differentiation. At the organ level inductions and gradients and even mechanical forces can mould the particular organ during development. Engrams within the nervous system are entirely comparable residues of experience in the brain. At the individual level come the collective process of aging, perceptual and motor habits, conscious memories and the like. And at the group or social level, cultures create customs, languages and the whole pattern of society. Behavioural attributes can change over many generations. Pressures from an environment will produce evolutionary changes only when the stock is malleable and can respond to pressures. Thus one can inherit not only mutated genes but genes that are more mutable. Adaptive enzymes come into being when both the genetic potentiality and the environmental substrate are present. Thus an organism not only can learn but it can also learn to learn. It is important to realise that even in this process of learning, though a specific area of the brain is central, its relationship with other areas is essential.

The nutrition of every neuron has to be maintained at its optimum for effective function ; and, obviously, the nutrition is maintained by the blood supply to the area. Again, the brain is so specialised that there is an effective blood-brain barrier which prevents unnecessary metabolites from adversely affecting the function of the brain. One is familiar with the condition of stroke where one half of the body gets paralysed. What happens to produce such a calamity ? The blood supply to one half of the brain might have been jeopardised and thereby that part of the brain cannot function. This illustrates that all activities of the body including motor function, sensations and such other functions are controlled and modulated by the brain. It is important here to emphasize that once a neuron is damaged irreversibly the function of that neuron cannot be taken over by any other neuron nor can that neuron regenerate.

There is a collection of neurons placed longitudinally in the central part of the brain, in the mesencephalon and diencephalon, which is called the reticular formation. The vital importance of this reticular formation of the brain stem has long been recognised. The interference with the function of this region produces respiratory, cardio-vascular, autonomic responses and also can interfere with the state of consciousness. It has been demonstrated that connections from all the known sensory systems enter the central core of the brain stem, the reticular formation, and a multi-synaptic pathway is formed over which impulses are conducted to wide areas of the cortex. In other words the reticular formation becomes the central controlling system for various vital functions and state of consciousness. When we are conscious we are aware of the things around us. The alteration between sleep and wakefulness appears to depend on fluctuations of stimuli, or suppression of stimuli that may affect, the reticular formation. Therefore if there is a lesion in the mesencephalon and diencephalon involving the reticular formation the state which commonly results resembles persistent sleep. It is the continuous bombardment of stimuli from all over the body that maintains the state of consciousness. There is also good reason to believe that cortico-fugal impulses may be capable of damping the reticular formation tending to produce sleep. If the normal waking consciousness depends on a continuously graded upward flow of facilitation from the reticular formation to the cortex and if sleep is manifest at times when that upward flow declines, then we should expect that there would be a continuous cerebral vigilance. We could expect therefore a gradually declining cerebral efficiency as high-grade alertness passes through relaxed indifference, drowsiness and light sleep to deep sleep if this sensory stimulus is withdrawn or dampened by other stimuli. I have touched on a few fundamentally different aspects of brain function. It would be obvious to the thoughtful that for the proper functioning of this gigantic network of neurons in a harmonious fashion, integration of all inputs and outputs will be essential at all levels of the neuraxis and we find that such is the integrated function of the brain.

The recent great discoveries in molecular biology are beginning to give a better understanding of the function of the brain. Science seems to be within reach of understanding not only the physio-chemical workings of the brain and nervous system but also the mysteries of consciousness, memory, learning and all other mental processes. Obviously it could have immense implication for all education and also of mental diseases. No less awesome are the potential dangers of intervening genetically in man's being. This explosive new development has come about when it was found that the total genetic information governing the form and function of every living cell and organism is chemically coded in giant linear molecules of deoxyribonucleic acid or commonly known as DNA. The ribonucleic acid or RNA acts in such a way to mould the thousands of specific proteins making up a particular cell. Different gene sequences are switched on and off in different levels according to a programme laid down in the DNA to form the different specialised tissues. Just as the DNA code determines the colour of the eye, the shape of the nose, the precise functions of such organs as the liver, so also it determines the cast of the mind. The new hypothesis is that DNA not only specifies the physical structure of the brain but it may also control directly or indirectly all brain processes and mental activity through a molecular code. If one can understand this molecular code in the working of DNA, that knowledge can be more devastating than the knowledge of atomic fission.

So far only 2 or 3 suggestive links have been found between DNA and brain activity but enough has emerged to excite in molecular biologists a feeling that this is going to be the next great area of discovery. The period of the study of structural anatomy, showing the connections and pathways and the description of their functions is over. The emphasis placed on the understanding of molecular biology including cell membrane and its functions, the physio-chemistry of the cell itself and the formation of the various molecules are drawing the attention of scientists. Sophisticated instruments including electron microscopes and all such other equipment are now available to help in investigation. So we can look forward to the future for a better understanding of the magnificent organ, the human brain.