CHAPTER ONE

PHYSIOLOGY OF THE BRAIN

1.1 INTRODUCTION

Brain is the most fascinating part of the human body. All our actions are related to the working of our brains. An understanding of the brain should provide an insight into many mysteries of human nature. Brain theory is developing into a central focus among many disciplines. The functioning of the brain has long been prominent among topics of interest to biologists and physicists alike (Siddiqui, Kamal and Khan 1988). Yet the task seems so difficult because quantitative data about the nervous system are much more sparse than is desirable and it seems a major difficulty for attempts to build mathematical models of brain function. Brain is an extremely complex structure containing something of the order of 10^{10} - 10^{12} nerve cells with perhaps 10^{15} inter-connections (Griffith 1971).

With all these difficulties present mathematical models of brain have been constructed and applied to study various physiological states. Techniques from physics, mathematics and statistics have been employed to be able to try to understand this fascinating gray mass everyone carries in one´s head. The amazing computing and synthesizing power of brain has led scientists to think about powerful computing machines which employ parallel processing instead of serial processing. In the coming years neuroscience, therefore, would influence man´s lifestyle in many ways.

1.2 THE HUMAN BRAIN

The human brain is a large, bilaterally symmetrical, wrinkled organ (Fig. 1). The outer surface, called *cortex*, contains a large number of brain cells and the processes that connect one neuron to others. The brain cells are called *neurons*. Toward the rear of the brain the *cerebellum* can be found under the cortex. The cerebellum is a highly wrinkled tissue concerned mainly with the coordination of commands to the muscles (Teyler 1977). The major difference between the human brain and the brain of other mammals is in the number of neurons they possess and the interconnections among these neurons. Underlying the convoluted layer of cortical neurons are tracts of fibrous processes, called *axons*, that extend from and carry messages from cortical neurons to other neurons and vice versa. The lengthy axonal processes are often covered with a specialized insulating sheath, termed the *myelin sheath*, of fatty tissue which appears white. This insulating sheath is responsible for insulating one axon from its immediate surroundings.

1.3 REGIONS OF THE CORTICAL SURFACE

Generally each hemisphere of the cortex is divided into four *lobes* (Fig. 1):

(a) Frontal lobe

The frontal lobe contains motor areas for all of the

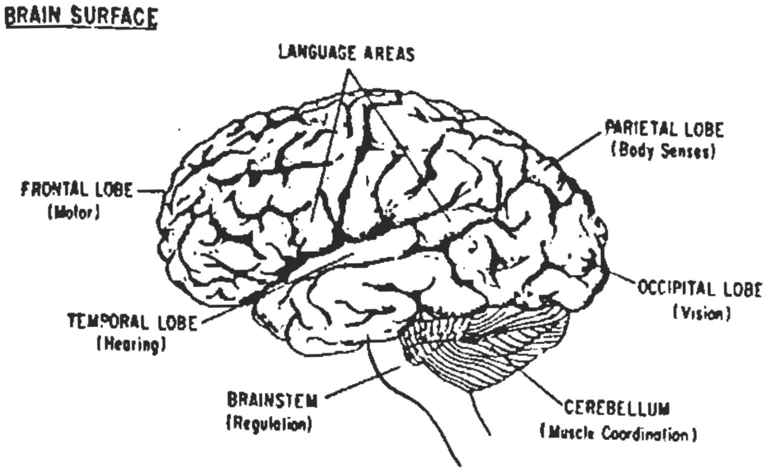


Fig. 1: *The surface of the left hemisphere of the human brain.*

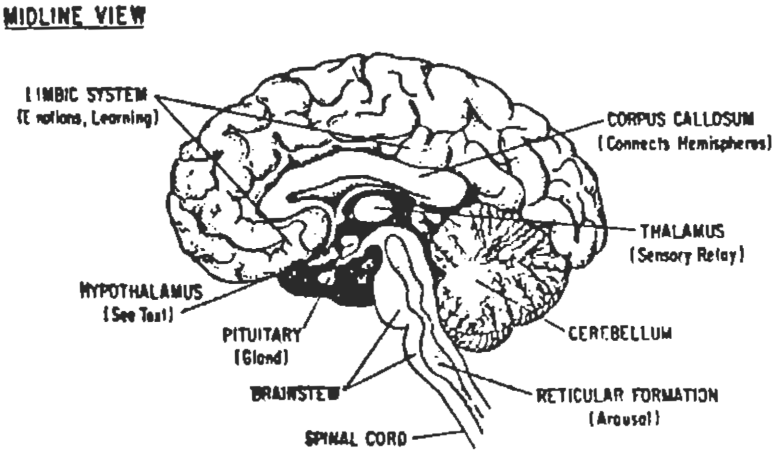


Fig. 2: *A midline view of the right hemisphere.*

skeletal muscles in the body. Cells in these zones send axons to neurons in other parts of the brain as well as long axons to neurons in the spinal cord which, in turn, send axons directly to muscles.

(b) **Parietal lobe**

These are bodily sense areas receiving axon projections from *subcortical* areas whose function is to process and pass on body sense information gained from receptors located in the skin, joints, and other tissue.

(c) **Temporal lobe**

These are auditory sense areas receiving information indirectly from the *cochlea* (a complex, coiled structure containing the sensory receptors for sound and located in the inner portion of the ear) of the ear. These are multiple auditory analyzers in the temporal lobe.

(d) **Occipital lobe**

These are cortical sensory analyzers for information from the retina of the eye.

All lobes, in human being, may be divided into (i) zones that are either *sensory* or *motor*, and (ii) zones that are termed *associational*. The sensory zones are areas for body sensation such as feeling of warmth or cold, tickling etc. The motor zones are regions dealing with control of muscular contractions. Neurons in the sensory zones receive information from sensory organs and further process this information; whereas axons influence the neurons in the motor area to produce movement.

The *association zones* function neither as sensory analyzers nor motor programmers. Very little is known about the precise functions of the association zones. They are involved with the understanding of language or the perception of complex sensory information. The increase in cognitive abilities across species nicely parallels the expansion of the association cortex. It is probably the association cortex that separates us from our fellow nonhuman creatures.

The midbrain, located in the middle of the brain, is made up of the *reticular formation* and the *hypothalamus* (Fig. 2). The reticular formation is a diffuse structure running up through the base of the brain and ending in the midbrain (Fig. 3). Located at the center of the *forebrain* (the highest and most prominent portion of the brain which has undergone the greatest evolutionary expansion of any nervous system region) there is a large structure, called *thalamus*, which is composed of many different collections of neurons. Thalamus plays an important role in relaying sensory, motor, and limbic information to the cerebral cortex and basal ganglia (cf. Fig. 2). Hypothalamus is a complex structure located at the base of the forebrain, immediately below the thalamus. It is composed of many different collections of neurons and is in direct contact with *pituitary* gland via neural and vascular connections. The hypothalamus is involved in modulating such basic behaviors as eating, drinking, sleeping, sexual activity, aggression as well as controlling body temperature and harmone secretions.

1.4 THE NEURON

The basic unit of the brain is neuron. Neurons come in a variety of shapes and sizes, some are with one or two processes extending from the cell body, others can have many branchings (Fig. 4). A neuron is like other cells in that it posses a cell membrane enclosing cytoplasm. Neurons have cell nucleus and the necessary metabolic machinery. They are specialized for the integration and transmission of information. The short branching processes extending from the cell body are dendrites. Dendrites receive information from other cells. The long process is the axon. The synapse refers to the region of communication between two neurons. The axon of one neuron does not touch the dendrite of the other. Instead, there is a gap - the synaptic gap - between them.

The entire surface of the cell is bounded by a membrane and the interior of the cell is negative with respect to the exterior. Cell membrane is selectively permeable to ions, the most important of which are Na^+, K^+ and Cl^-. The potential difference is given by Nernst equation, in terms of relative concentrations $C_{exterior}$ and $C_{interior}$ (Hodgkin 1965), as

$$(1.1) \qquad \mathcal{V} = \pm\ (RT/F)\ \log\ (C_{exterior}/C_{interior})$$

where R is the universal gas constant, T the absolute temperature and F the Faraday Capacitance. There is less sodium and

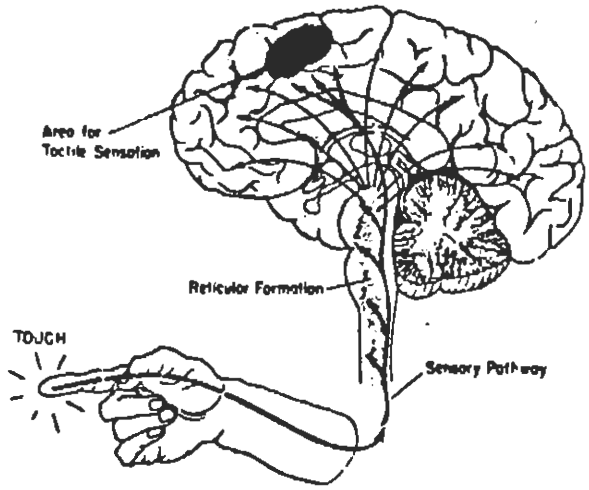


Fig. 3: *The reticular activating system*

cytoplasm.

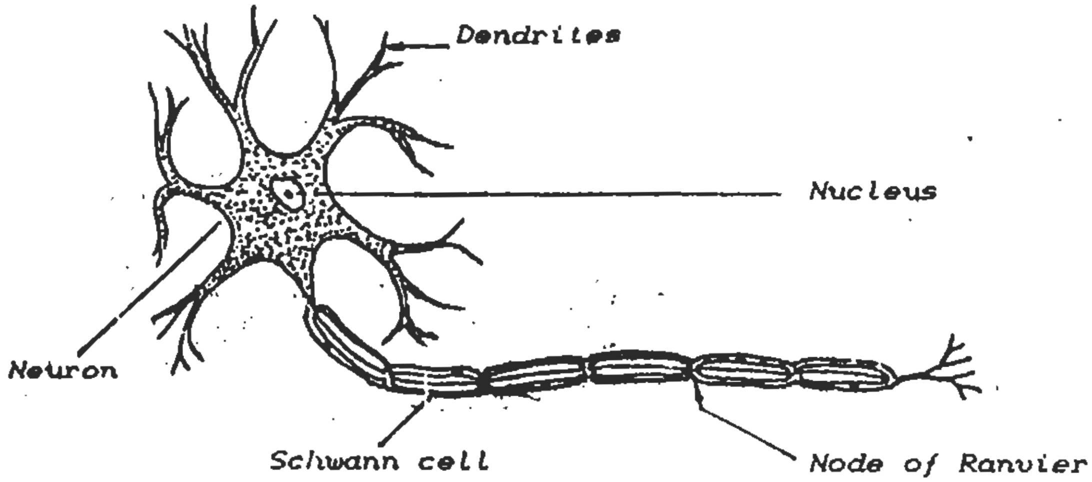


Fig. 4a: *Elementary structure of the neuron*

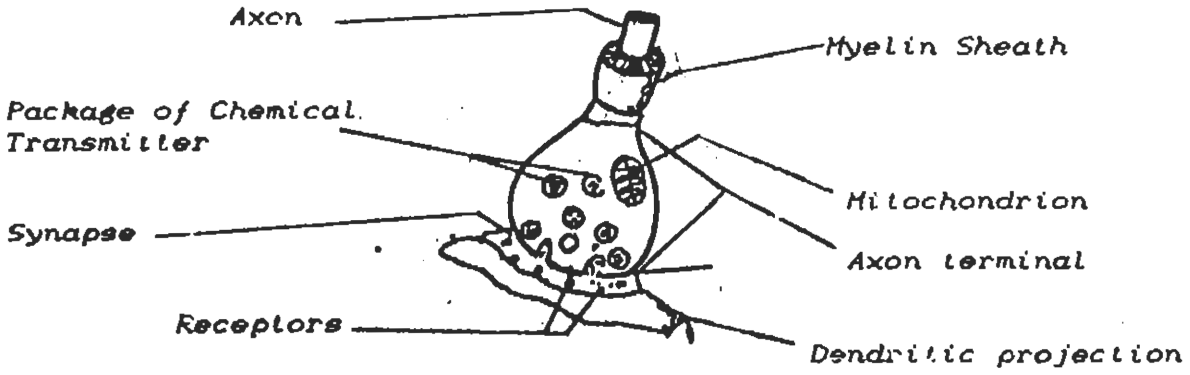
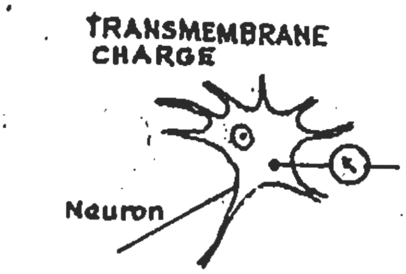


Fig. 4b: *The synapse*



Measure voltage between inside and outside of neuron

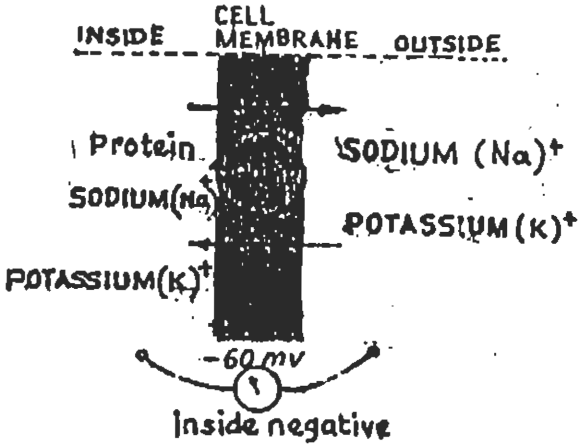


Fig. 4c: *Features of the resting neuron*

more potassium inside than the expected value. This disequilibrium defines a *steady state* (a steady state is defined as a state in which the probability of occupation in different levels is not equal, but does not change with time), called the *resting state of the nerve cell*. The potential difference corresponding to his state $\mathcal{V} = -70$ mV is called the *resting potential*. According to Hodgkin and Huxley (1952), the total current into the cell is given by

$$(1.2) \qquad \mathcal{I} = \mathfrak{C}\ (\partial V/\partial t) + g_{Na}(\mathcal{V} - \mathcal{V}_{Na}) + g_{K}(\mathcal{V} - \mathcal{V}_{K})$$

where $\mathcal{V}$ is the membrane potential, g_{Na} and g_{K} are conductivities for Na^{+} and K^{+} and $\mathfrak{C}$ is the capacity of the membrane. In resting state $i = \partial\mathcal{V}/\partial t = 0$ and so

$$(1.3) \qquad \mathcal{V} = (g_{Na}\mathcal{V}_{Na} + g_{K}\mathcal{V}_{K})/(g_{Na} + g_{K})$$

The above equation shows that g_{Na} and g_{K} are themselves dependent upon the potential difference $\mathcal{V}$. A threshold value $\mathcal{V}_{o}$ (-60 mV to -50 mV) exists in normal circumstances, above which the mutual interdependence of g_{Na} and $\mathcal{V}$ leads to increase of g_{Na} relative to g_{K}. The conductivity of potassium, g_{K} increases also but more slowly. Ultimately g_{K} again exceeds g_{Na} pulling $\mathcal{V}$ back to its resting value. The observed potential changes are called *action potential*. Let the axon be arbitrarily split up into a sequence of patches having resistance r between them. When g_{Na} is increased in one patch so that $\mathcal{V}$ across it rises from the resting value, a current flows through the next patch and depolarizes it so that the action potential moves from one patch to another down the

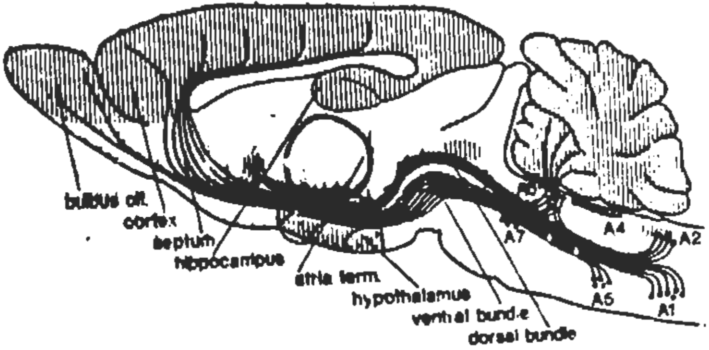


Fig. 4e: *A chemical map of noradrenaline neurons.*

axon. This is the method of propagation of the action potential along axons and the dendrites.

When an action potential has passed down an axon and reached a synapse, it normally stops there and does not jump immediately across to other neuron. It stimulates the release of a neurotransmitter, *acetylcholine* (ACh). It diffuses across the synaptic gap and alters the conductances of Na^+ and K^+, which in turn alter Ψ. Immediately after the generation of the new signal the ACh molecules are inactivated by the enzyme, *Acholinesterase*, hence the potential change due to an impulse arriving at a synapse does not persist indefinitely, but decays exponentially towards the resting potential.

1.5 ELECTRICAL ACTIVITY OF THE BRAIN

The constant flow of electrical signals along the nerve fibers suggest that some electrical activity might be observable in the brain (Elul 1972). The measurement of the brain activity is a limiting factor in our understanding of its functions. This is due to the limitations of the procedure and the intrusive effects of the recording device on the normal operation of the brain. Electrical activity can be recorded by simply attaching electrodes directly to the scalp. The recording called an *electroencephalogram* or EEG, must be made with proper electrical filtering in order to avoid confusing the record of the electrical signals of the brain with signals produced by muscle movement etc. (Fig. 5). The neurons are

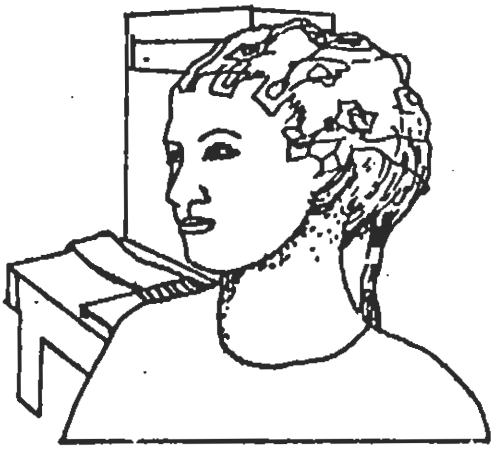


Fig. 5a: *Scalp electrode positions*

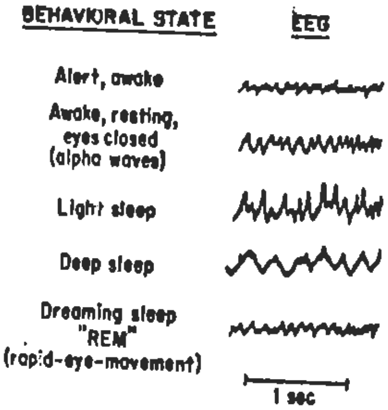


Fig. 5b: *General forms of EEG*

synchronously active, the resultant record shows rhythmic values of various frequencies. This is called spontaneous activity and is usually marked by the presence of a dominant frequency which can be used to characterize the EEG pattern (Nunez 1981). All EEG phenemena have a temporal behavior that lies in one of the following categories:

a. Non periodic (e.g. occasional spikes, random noise)

b. Nonsinusoidal and periodic (e.g. spike and wave, ECG)

c. Sinusoidal (e.g. alpha rhythm, sleep delta, sleep spindles)

We do not, however, xpect any EEG to be purely sinusoidal. The alpha rhythm (8-13 cps) typically consists of a continuous spread of frequencies over a fairly narrow band. Most theta (4-8 cps) and beta (above 13 cps) activity normally seen in EEG contains a brad range of frequencies, so these rhythms are not normally sinusoidal. An important aspect of EEG is its close correlation with cognition and behavior (Gevins, Zeillin, Yingling, Schaffer, Callaway, Yeager 1979).

The fact that the brain produces electrical currents in the conductive tissue implies that magnetic fields are set up. These magnetic fields are extremely weak (on the order of 10^{-9} gauss). *Magnetoencephalography* (MEG), measurement of the extracranial magnetic fields produced by electrical currents within the brain, requires the use of a *superconducting quantum interference device* (SQUID) in a magnetically shielded room (Rose, Smith, Sato 1987).

1.6 ELECTROCORTICAL ACTIVITY

If cortical cells are viewed as information processing networks, then electrocortical waves might be viewed as statistical shifts in average local depolarization. Determination of the laws of motion of these waves and their internal mechanisms of controls is a step towards an understanding of the brain. A major difficulty arises because of the complexity and the nonlinearity of the neural interactions (Cowan 1974). The gross electrocortical waves may, however, be represented as linear right, Kydd 1984). In the following chapters we are going to present a covariant model of global electrocortical activity.