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Jose Delgado's "Physical Control of the Mind"

Experimental Control of Brain Functions in Behaving Subjects

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In our present technological environment, we are used to the idea that machines can be controlled from a distance by means of radio signals. The doors of a garage can be opened or closed by pushing a button in our car; the channels and volume of a television set can be adjusted by pressing the corresponding knobs of a small telecollimand instrument without moving from a comfortable armchair; and even orbiting calmules can now be directed from tracking stations on earth. These accomplishments should familiarize us with the idea that we may also control the biological functions of living organisms from a distance. Cats, monkeys, or human beings can be induced to flex a limb, to reject food, or to feel emotional excitement under the influence of electrical impulses reaching the depths of their brains through radio waves purposefully sent by an investigator.

This reality has introduced a variety of scientific and philosophical questions, and to understand the significance, potentials, and limitations of brain control, it is convenient to review briefly the basis for normal behavioral activity and the methodology for its possible artificial modification, and then to consider some representative examples of electrical control of behavior in both animals and man.

Physicochemical Bases of Behavioral Activity

In the vegetable as well as in the animal kingdom, the dynamics of biological processes are related to ionic movements and electrical changes across the membranes which separate cells from the surrounding medium. For example, during the process of photosynthesis, the leaf of a tree captures energy from the sun and a negative potential is created on its receptive surface. In a similar manner, activation of a squid axon, a frog muscle, or the human brain is accompanied by a negative wave which invades cellular membranes and then disappears. This transmembrane change of potential induces a flow of electrical currents into the cellular cytoplasm and surrounding conducting fluids. Cellular activity may therefore be investigated by recording the electrical potentials appearing across the membranes or by detecting differences in potential which appear in the extraceiltilar fluid, even if the recording electrodes are placed at a considerable distance from the electromotive source. This is the basic principle of recording electrical activity of the heart (electrocardiogram = EKG) through electrodes placed on the extremities, or of studying electrical potentials of the brain (electroencephalogram = EEG) by means of leads attached to the scalp. If electrodes are placed closer to the source of negativity, for example in the depth of the brain, recordings will be more accurate and may reveal the location of generators of

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electrical activity. Conversely, by using an external potential, an electrical field may be established through the extracellular fluid, and some of this current flows through the cellular membranes, modifying their charge and permeability and producing the self-propagating process called "stimulation."

In order to stimulate, it is necessary to reduce quickly the positive charge which normally exists on the surface of a resting cell until it reaches a critical point of local depolarization. Then the ionic permeability of the membrane is modified, triggering a pre-established sequence of electrical and chemical phenomena. Excitation takes place in the vicinity of the iterative electrode (cathode) because the application of negative charges will neutralize the normally existing positivity at the external part of the cellular membrane. When stimulation is over, the positive polarity is re-established on the membrane surface with the aid of energy provided by specific chemical reactions, and the cell is ready for a new stimulation. The relatively simple processes of depolarization and repolarization of cell membranes are the essential elements of neuronal excitation, and they are responsible for the extraordinary complexity of all behavioral performance.

Our knowledge gap between understanding electrical events at the cellular level and deciphering the chain of phenomena taking place during the response of a whole organism is certainly formidable. How can we explain activities such as walking, problem solving, or ideation in terms of polarization and repolarization of membranes? Behavior certainly cannot occur without concomitant spike potentials and ionic exchanges, but the same statement holds true for oxygen and sugar consumption, and we must differentiate the mechanisms supporting basic nonspecific cellular activities, such as metabolic requirements, from the mechanisms more specifically related to behavioral responses. Electrical activity of the neurons seems to have the dual role of indicating nonspecific activity and transmitting coded information. This ability to transmit coded information is the most important and least understood property

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of the nerve cell, and it represents the functional unit for nervous communication. In architecture, given a number of brick units an infinite number of different houses can be constructed. We need to know both the properties of the individual bricks and the pattern of their organization in order to ascertain the properties and qualities of the final building. The characteristics of behavioral responses are determined by the combination of many depolarization phenomena, organized in space and repeated sequentially in time. Their arrangement is often so cornplex that it defies experimental analysis, and we must begin by examining very simple phenomena. The squid axon was for years a popular object of investigation in neuropliysiology, Great caution should be observed, however, when applying experimental results with that preparation to the understanding of motor responses or mental activity. We should remember that knowledge of the letters of the alphabet will not explain the meaning of a phrase or reveal the beauty of a poem.

In addition to investigating the spontaneous changes in membrane potentials, we can artificially depolarize membranes by electrical stimulation of cerebral neuronal pools in order to investigate their functional organization and behavioral consequences for the whole organism. Both of these experimental approaches should be used simultaneously in order to correlate cellular functions with behavioral results. Our present knowledge of the physicachemical bases of biological activity, which has an extensive bibliography (23, 182, 203), permits statement of the following principles: (1) All behavioral manifestations including their mental aspects require the existence of waves of negativity accompanied by electrical and chemical changes at the cellular level. (2) Membrane depolarization, artificially induced by electrical or chemical means, may be followed by observable behavioral manifestations. (3) While the complexity of these responses is extraordinary and many of their aspects are unknown, explanations of motor behavior and psychic activity do not require "vital spirits" or any other metaphysical principle because they are related to physical and chemical laws which can be investigated experimentally.

The classical experiments of Galvani, showing that the legs of a decapitated frog contract in response to electrical stimulation, are repeated many times every year in high school and college laboratories. These simple experiments demonstrate that a process of life, muscle contraction, can be elicited at the will of the investigator as many times as electricity is applied to the tissue. In the absence of stimulation, the legs do not contract. If the cells of the muscle are dead, excitability and contractability are lost and the preparation does not respond. The contraction of the frog's legs is similar regardless of whether the muscle is stimulated directly through its motor nerve or through the brain, and this muscle action is also comparable to its activation during voluntary movements of the intact frog. The applied electricity does not create the limb movement but acts only as a depolarizing agent, starting a chain of events which depends on the properties of the stimulated organ.

The reliability and apparent simplicity of the muscle contraction may be misleading because in reality the contraction depends on tremendously complex processes Nvhich include: depolarization of the testing membrane, changes in its permetbility, precipitous exchange of potassium, sodium, and other ions, creation of electrical fields, reorientation of proteic molectiles within the muscle fiber with a shortening in the length of its chain, decomposition and synthesis of adenosin triphosphate, exchange of phosphoric acids, degradation of hexosapliospliate into lactic acid, and many other enzymatic and biochemical reactions which follow each other according to a genetically determined plan within the muscle fiber and independent from the agent which initiates them. The *mechanisms for contraction and relaxation of the muscle fiber are pre-established in the biological structure of the cells. Electricity, like the nervous system itself, acts as a trigger for these processes*. This principle is fundamental for an understanding of the electrical control of

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biological functions. Organisms are composed of a large number of biological sequences, some of them inherited and others learned through experience. When a chain reaction has started, it proceeds according to an intrinsic plan which can be modified by feedback or by the arrival of new stimulations. In some cases the trigger may be nonspecific and, for example, muscular contraction can be initiated by mechanical, thermal, osmotic, chemical, electrical, or neuronal stimulation. In investigations of the brain as well as the muscle, electrical activation is preferable because it is not harmful for the cells and permits repeated studies of the same biological processes. By applying electricity we can activate pre-established functional mechanisms of a structure and discover its possible role in spontaneous behavior, By means of ESB (electrical stimulation of the brain) it is possible to control a variety of functions - a movement, a glandular secretion, or a specific mental manifestation, depending on the chosen target. Necessary methodology and examples of selected results are discussed in the following chapters.

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