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Jose Delgado's "Physical Control of the Mind"

Electrical Activation of the "Will"

The theoretical considerations of the previous section may facilitate the understanding of so-called willful, free, or spontaneous behavior which to a great extent depends on pre-established mechanisms, some of them inborn and others acquired through learning. When a child takes his first steps or when an adult learns a new skill like tennis or typing, the initial movements are clumsy and require considerable attention and effort in every detail. Coordination progressively improves, unnecessary muscular tension diminishes, and the movements proceed with speed, economy, and elegance without being thought about. Acquisition of a skill means the automation of patterns of response with the establishment of spatial and temporal sequences. The voluntary aspects of willful activity are the purpose for it and the initiation of performance, while most of the details of complex movements and adaptation to changing circumstances are performed automatically. We may consider that the role of the will is mainly to trigger previously established mechanisms. Obviously the will is not responsible for the chemistry of muscular contraction, the electrical processes of neural transmission, or the intimate organization of responses. These phenomena depend on spindle discharges, cerebellar activation, synaptic junctions, reciprocal inhibitions, and many other mechanisms which are not only beyond consciousness but may be beyond our present knowledge and comprehension. The uniqueness of voluntary behavior lies in its initial dependence

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on the integration of a vast number of personal past experiences and present receptions.

Volition itself must be related to neuronal activities, and it may be asked whether either appropriate sensory perceptions or artificial electrical stimulation could induce neuronal pools involved in decision-making to discharge in a like manner. I shall not enter into the controversial issues of causality and determination of free behavior, but on the basis of experimental findings it is reasonable to assume that voluntary and electrical triggering can activate existing cerebral mechanisms in a similar way. If spontaneous and electrically evoked behavior involve participation of the same set of cerebral areas, then both types of behavior should be able to interact by modifying each others' inhibitory and excitatory influences. This possibility has been proved experimentally.

As described by Hess (107) and as observed also in our experiments, excitation of some points in the subthalamus of the cat induces a clockwise rotation of the head, and the effect of low intensity and low frequency (8 cycles per second) stimulation can be counteracted by the animal. The head starts rotating slowly and then is brought back to normal position by a quick voluntary jerk, the process repeating several times until stimulation ceases. If the intensity of stimulation is increased, the corrective movements disappear and rotation of the head progresses slowly but continuously, followed by rotation of the body on its longitudinal axis until the cat lies on its back. Then with a sudden jerk the animal abruptly completes the turn and springs to its feet. The explanation of these results may be as follows: During the initial part of the evoked head rotation, its abnormal position should produce normal proprioceptive and vestibular stimuli, starting a reflex reaction to slow down and counteract the electrically evoked effect. As soon as the cat is on its back, however, artificial and natural stimuli work together, the first to continue the turning, and the second to bring the animal to its usual horizontal position; the summation of these two actions would explain the sudden jerk. Interaction

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between evoked and spontaneous activity has also been observed during conditioning experiments with cats in which the animals often tried to suppress motor movements induced by ESB (89).

A clear example of algebraic summation between voluntary and evoked motility was observed in one of our cats with electrodes implanted in the left hidden motor cortex (48), Electrical stimulation induced an extension and raising of the right forepaw with proper postural adaptation. Offering of fish to the animal resulted in a similar extension and raising of the limb in order to seize the food. Simultaneous presentation of the fish and stimulation of the cortex produced a motor response of greater amplitude than usual; the cat miscalculated the necessary movement and overshot his target. He was unable to catch the food until he made a series of corrective adjustments, and then the fish was successfully captured and eaten. In addition to demonstrating the interrelation between evoked and spontaneous responses, this experiment also proved that the animal was aware of an artificial disturbance, and after a brief period of trial and error was able to correct its performance accordingly.

In the play of forces between spontaneous and evoked responses, which one is more powerful? Will one of them be prepotent over the other? Experimental results demonstrate that when there is a conflict in the response, the stronger stimulus dominates. For example, stimulation of the left sulcus presylvius with 0.6 milliamperes in a cat named Nero caused a small flexion of the right foreleg. When Nero was jumping from a table to the floor, the same excitation did not produce any visible effect, and the animal landed with perfect coordination, showing good voluntary control of all his limbs. Electrical flexion of the foreleg had therefore been completely inhibited by tire peremptory need to use the musculature in the jump, If stimulation intensity was increased up to 1.8 milliamperes, flexion of the limb appeared even when Nero was air-borne in the middle of a jump, and landing was disrupted by the inability to use the right foreleg. In general, electrical stimulation of the

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brain was dominant over voluntary behavior, provided that its intensity was sufficiently increased.

It is known that reflexes are predictable responses, rigidly patterned and blindly performed. Similarly, electrical excitation of a peripheral motor nerve induces a stereotyped movement with little adaptation to external circumstances. In contrast, willful activity generally has a purpose, and its performance is adapted for the attainment of a determined aim, with a continuous processing of proprioceptive and exteroceptive sensory information, with the use of feedback mechanisms, with capacity for instantaneous readjustment of the central command to adapt to changes in the environment, and with prediction of the future which requires spatiotemporal calculation of speed, direction, and strategies of moving targets. Depending on the location of cerebral stimulation, the responses obtained by ESB may either be similar to a blind reflex or have all the above-mentioned characteristics of voluntary activity.

Stimulation of some points in the motor cortex and motor pathways in the cat, monkey, and other animals may produce simple movements, such as the flexion of a limb, which are completely stereotyped and lack adaptation. These effects may be interpreted as the activation of efferent structures where the pattern of response has already been decided. At this level, the neural functions are of conduction rather than of integration and organization, and only minor variations are possible in the circulating impulses, regardless of whether their origin was spontaneous or artificial. To the contrary, there is plenty of evidence that many of the effects evoked by ESB are oriented toward the accomplishment of a specific aim with adaptation of the motor performance to unexpected changes in environmental circumstances. The following examples substantiate this statement.

In the cat, electrical stimulation of the inferior part of the sulcus presylvius consistently induced licking movements with well-organized opening and closing of the mouth and phasic protrusion of the tongue. Under anesthesia, the licking was

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automatic and purposeless; but in the awake, free-moving animal the response was directed toward some useful purpose, and the cat searched for a target to lick-food, the hands of the experimenter, the floor, or its own fur. In this case, motor performance and posture of the whole body adapted to the experimental setting, and in order to lick the investigator's hand, for example, the cat advanced a few steps and approached the hand even if it moved slowly away. Another example of adaptation to the environment is the "avoidance of obstacles" (48). Stimulation of the middle part of the presylvian sulcus in the cat induced a contralateral turning of the head in the horizontal plane. The effect was reliable, but when the movement was interrupted by placing an obstacle such as a book in its path, the animal modified its performance and raised its head to avoid the interposed obstacle before continuing the evoked head turning.

The adaptability of artificially induced cerebral responses to changes in the environment has been clearly demonstrated by rhesus monkeys' aggressive behavior which was selectively directed by the animals against their natural enemies within the group with a motor pattern of chasing and fighting which continuously changed according to the unpredictable strategies of those under attack. In this case, ESB evidently did not evoke a predetermined motor effect but an emotional state of increased aggressiveness which was served by pre-established motor skills and directed according to the previous history of social relations (53).

Similar experiments have been performed in roosters (111). If the bird was alone, motor restlessness was the only observable effect of ESB, while the same stimulation of a rooster in a group produced a state of increased aggressiveness and attacks on other birds. Sharp fighting ensued with perfectly coordinated, typical patterns of attack and defense in the group.

We may conclude that ESB can activate and influence some of the cerebral mechanisms involved in willful behavior. In this way we are able to investigate the neuronal functions re-

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rated to the so-called will, and in the near future this experimental approach should permit clarification of such highly controversial subjects as "freedom," "individuality," and "spontaneity" in factual terms rather than in elusive semantic discussions. The possibility of influencing willful activities by electrical means has obvious ethical implications, which will be discussed later.

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