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Jose Delgado's "Physical Control of the Mind"

Inhibitory Effects in Animals and Man

The existence of inhibitory functions in the central nervous system was described in the last century by Sechenov (198), Pavlov (171), and other founders of Russian psychology. Inhibition is a well-known phenomenon, and it has been the main theme of several recent symposiums (14, 63, 77). In spite of its importance, information about inhibitory mechanisms has not yet been integrated into the general body of scientific knowledge, and no chapter is devoted to this subject in most neurophysiological, psychological, and pharmacological textbooks. This lack of interest is surprising because as Morgan (158) wrote eighty years ago, "When physiologists have solved the problem of inhibition they will be in a position to consider that of volition," and modern investigators maintain that inhibition and choice, rather than expression and learning, are the central problems of psychology (63). A shift in interest among scientists seems necessary to give inhibition its deserved importance, and the layman should also be aware of the decisive role of inhibition in the performance of most of our daily activities.

The sound of a theater crowd at intermission is a continuous roar without intelligible meaning. During the performance, however, noises and, individual conversations must be inhibited so that the voices of the actors can be heard. The brain is like a monumental theater with many millions of neurons capable of sending messages simultaneously and in many directions. Most of these neurons are firing nearly continuously, and their

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sensitivity is like that of an enormous synaptic powder barrel which would explode in epileptic convulsions in the absence of inhibitory elements (122). During the organized performance of behavioral responses, most neurons and pathways must remain silent to allow meaningful orders to circulate toward specific goals. Inhibition is as important as excitation for the normal physiology of the brain, and some structures have specialized inhibitory functions. It should therefore be expected that, in addition to inducing the many types of activities described in previous sections, ESB can also block performance of such activities by exciting pools of neurons whose role is to inhibit these specific responses.

To behave is to choose one pattern among many. To think we must proceed in some orderly fashion repressing unrelated ideas; to talk we must select a sequence of appropriate words; and to listen we need to extract certain information from background noise. As stated by Ashby, we must "dispose once and for all of the idea...that the more communication there is within the brain the better" (6). As we know by personal experience, one of the problems of modern civilization is the confusion produced by a barrage of sensory inputs. We aye optically and acoustically assaulted by scientific literature, news media, propaganda, and advertisements. The defense is to inhibit the processing of sensory stimuli. Conscious and unconscious behavioral inhibition should not be considered passive processes but active restraints, like holding the reins of a powerful horse, which prevent the disorderly display of existing energies and potentialities.

Within the central nervous system, the reticular formation seems to be especially differentiated to modulate or inhibit the reception of sensory impulses, and some other cerebral structures including the thalamus, septum, and caudate nucleus also possess important inhibitory properties which can be activated by ESB. Three types of inhibitory processes may be induced by electrical stimulation: (1) sleep, which usually starts slowly and can easily be interrupted by sensory stimuli; (2) general inhibition, which

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affects the whole body, starts as soon as ESB is applied, and persists in spite of sensory stimulation; and (3) specific inhibition, which appears immediately, affects only a determined pattern of behavior such as aggression or food intake, and may or may not be modified by sensory impulses.

One example of sleep induced in a monkey by application of ESB is shown in Figure 18. After 30 seconds of stimulation in the septal area, the animal's eyes started closing, his head lowered, his body relaxed, and he seemed to fall into a natural state of sleep. In response to noise or to being touched, the animal would slowly open his eyes and look around with a dull expression for a few seconds before falling asleep again. Similar results have been obtained in free-ranging monkeys stimulated by radio. In this situation there was a gradual diminution of spontaneous activity, and then the animals began to doze, closing their eyes and assuming a typical sleeping posture with heads down and bodies curved over the knees. Theoretically it should be possible to treat chronic insomnia by brain stimulation, or to establish an artificial biological clock of rest and activity by means of programed stimulation of inhibitory and excitatory areas of the brain, but these challenging possibilities still require further investigations.

Motor arrest is an impressive effect consisting of sudden immobilization of the experimental animal in the middle of ongoing activities, which continue as soon as stimulation is over. It is as if a motion picture projector had been stopped, freezing the subjects in the position in which they were caught. A cat lapping milk has been immobilized with its tongue out, and a cat climbing stairs has been stopped between two steps.

Other types of inhibitory effects are more specific and restricted to only one determined behavioral category. Typical examples are the inhibition of food intake, aggressiveness, territoriality, and maternal behavior. As these specific inhibitions influence general activities, they could pass unnoticed do not if the experimental situation was not properly arranged. Obviously inhibition of appetite cannot be demonstrated in the

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Figure 18
Sleep induced by electrical stimulation of the brain is similar to spontaneous sleep. Above, control. Below, the monkey falls alseep under ESB.

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absence of food, nor can changes in maternal behavior be investigated when no babies are present. One example of how a hungry monkey loses appetite under the influence of brain excitation is presented in Figure 19. At the sight of a banana, the animal usually shows great interest, leaning forward to take the fruit, which he eats voraciously and with evident pleasure. However, his appetite is immediately inhibited as soon as the caudate nucleus is electrically stimulated. Then the monkey looks with some interest at the banana without Teaching for it, and may even turn his face away, clearly expressing refusal. During stimulation the animal is well aware of his surroundings, Reacting normally to noises, moving objects, and threats, but he is just not interested in food. If a monkey is stimulated when his mouth is full of banana, he immediately stops chewing, takes the banana out of his mouth, and throws it away.

Close to the hunger inhibitory area there is a region which is involved in inhibition of aggressive behavior. When this part of the caudate nucleus is stimulated (Figure 2o), the normally ferocious macacus rhesus becomes tranquil, and instead of grabbing, scratching, and biting any approaching object, he sits peacefully and the investigator can safely touch his mouth and pet him. During this time the animal is aware of the environment but has simply lost his usual irritability, showing that violence can be inhibited without making the animal sleepy or depressed. Identification of the cerebral areas responsible for ferocity would make it possible to block their function and diminish undesirable aggressiveness without disturbing general behavioral reactivity.

Similar results have been obtained in chimpanzees, and one example is presented in Figure 19. Chimpanzee Carlos was an affectionate animal who enjoyed playing with the investigators and had learned a variety of tricks including throwing and catching a ball. Enticed by an expected food reward, he sat voluntarily in the restraining chair where recordings and experiments were conducted. Like most chimpanzees, Carlos was

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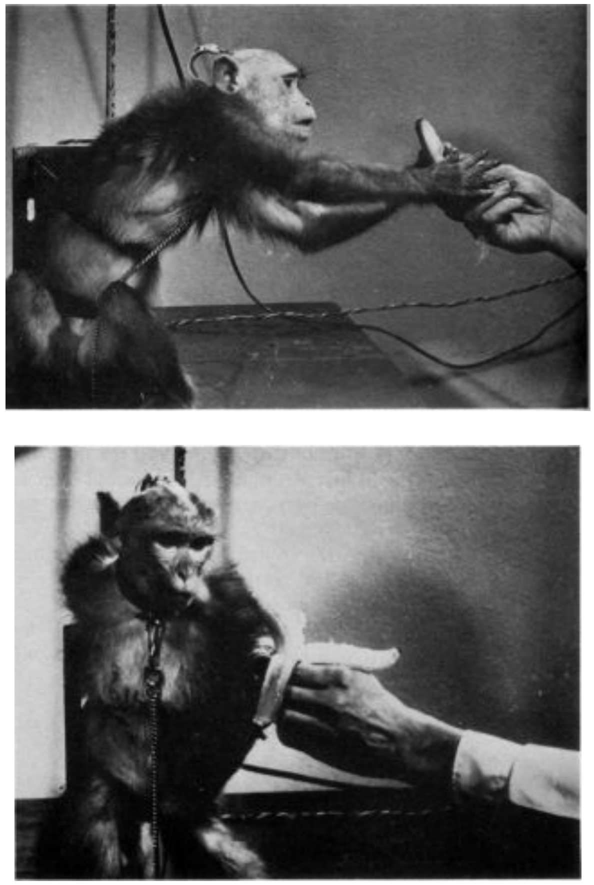


Figure 19
The normal reaction of a monkey is to stretch its arms and body to take an offered banana (above left). Appetite is immediately inhibited by stimulation of the caudate nucleus (below left). The monkey is not interested in food (above) and even turns away from the fruit (53). Photo: Erick Schaal.

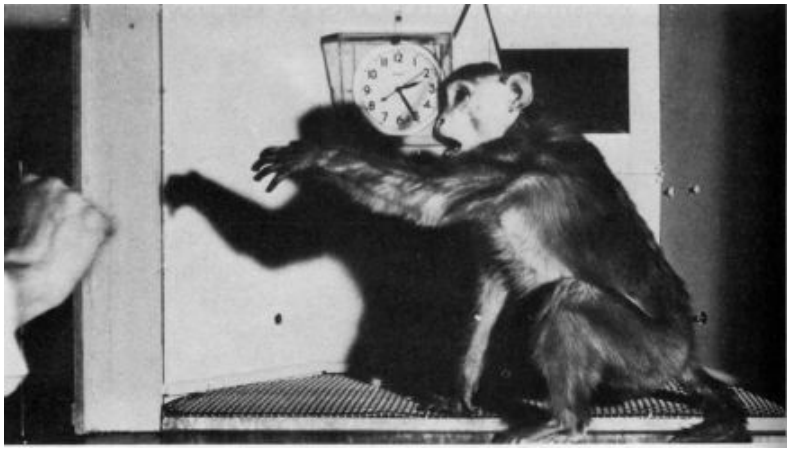
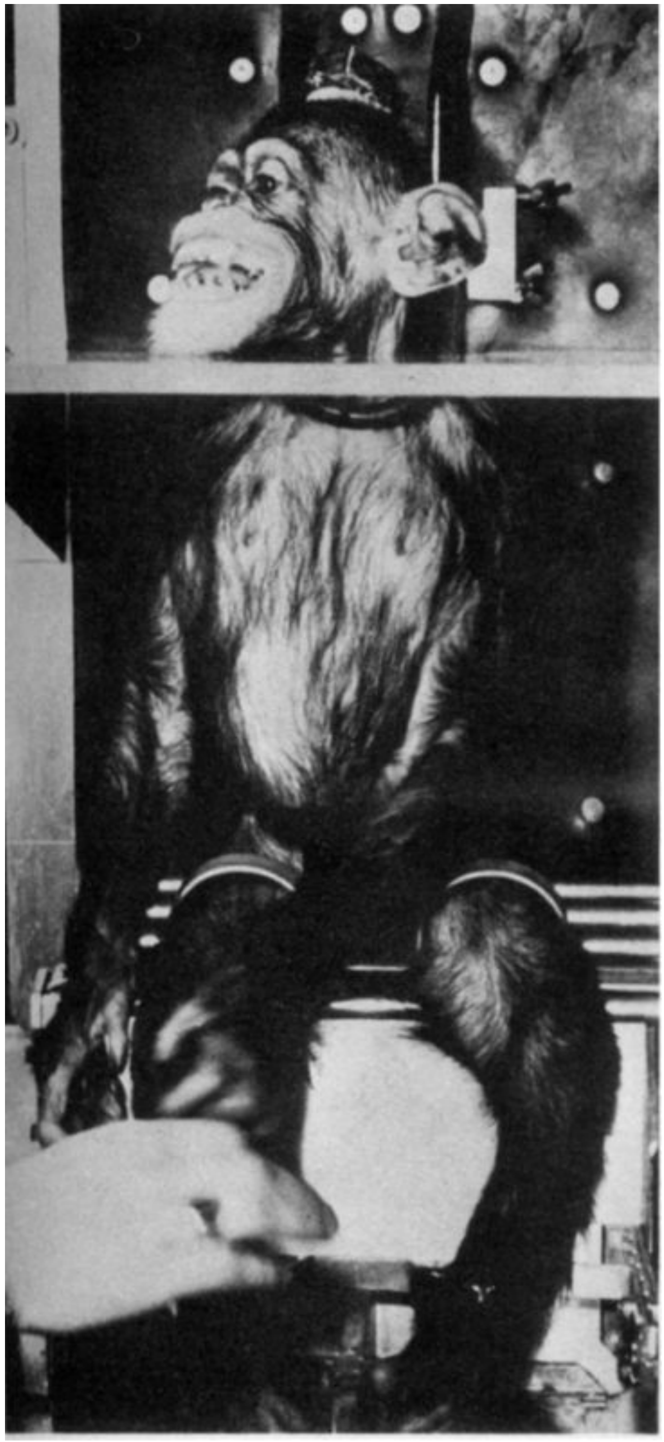


Figure 20
Rhesus monkies are usually ferocious and will often launch attacks, trying to catch and bite the observers (above). This ferocity is inhibited during stimulation of the claudate nucleus, and then (below) it is safe to touch the animal, which extends its arms to meet the observer's hands without making any threatening gestures. (53).



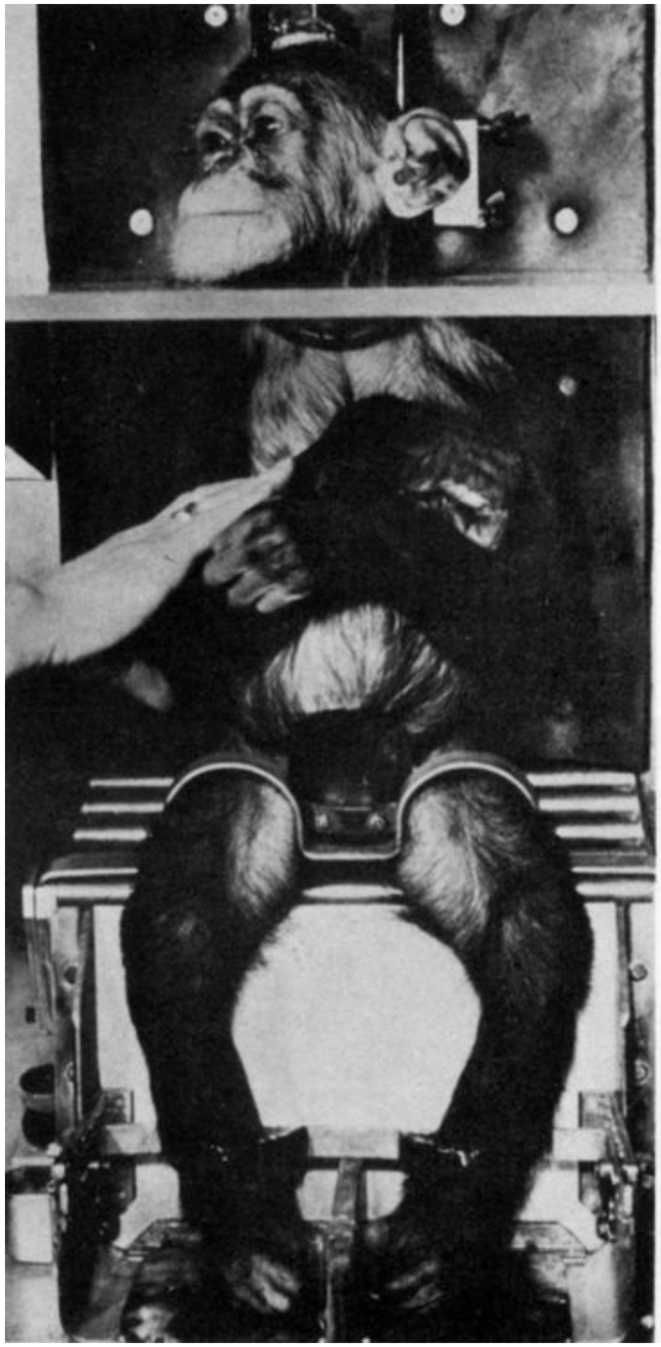


Figure 21
Chimpanzee Carlos reacts with offensive-defensive manifestations when touched by a sranger (left). During claudate stimulation, the chimpanzee is inhibited and can be teased without evoking any response.

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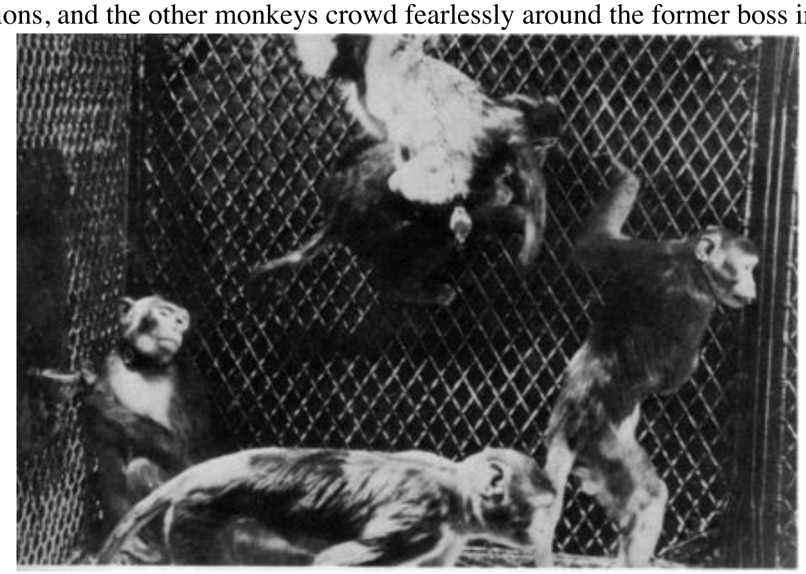
rather temperamental and was easily provoked into a tantrum by being punished, frustrated, or merely teased. He liked to be touched by people he knew but not by strangers. Figure 21 (left) shows his defensive, anxious reaction when approached by an unfamiliar investigator. His fear and aggressive manifestations were, however, completely inhibited during electrical stimulation of the caudate nucleus, as shown in Figure 21 (right). The animal displayed no emotion, appeared peaceful, and could be teased without any resulting disturbance.

Other experiments in monkeys have also confirmed the pacifying possibilities of ESB. In the autocratic social structure of a monkey colony the boss enjoys a variety of privileges such as choosing female partners, feeding first, displacing other animals, and occupying most of the cage while the other monkeys avoid his proximity and crowd together in a far comer (s ee Figure 22). This hierarchical position is maintained by subtle communication of gestures and postures: a boss may look directly at a submissive member of the group who will glance only furtively at his superior, and the boss may paw the floor and threaten by opening his mouth or uttering a warning cry if any low-ranking animal does not keep a suitable distance. This social dominance has been abolished by stimulation applied for 5 seconds once a minute for one hour to the caudate nucleus in the boss monkey. During this period the anirnal's facial expression appeared more peaceful both to the investigator and to the other animals, who started to circulate freely around the cage without observing their usual respect. They actually ignored the boss, crowding around him without fear. During the stimulation hour, the boss's territoriality completely disappeared, his walking time diminished, and he performed no threatening or aggressive acts against other monkeys in the colony. It was evident that this change in behavior had been determined by brain stimulation because about ten minutes after ESB was discontinued, the boss had reasserted his authority and the other animals feared him as before. His territoriality was as well established as during control periods, and he enjoyed his customary privileges.

Figure 22
Monkey colonies from autocratic societies in which the territorially of the boss is clearly shown. He occupies more than half of the cage (above). Radio stimulation of an inhibitory area of the brain (below) modifies the boss's facial expressions, and the other monkeys crowd fearlessly around the former boss in his own corner.



The old dream of an individual overpowering the strength of a dictator by remote control has been fulfilled, at least in our monkey colonies, by a combination of neurosurgery and electronics, demonstrating the possibility of intraspecies instrumental manipulation of hierarchical organization. As shown in Figure 23, a monkey named Ali, who was the powerful and ill-tempered chief of a colony, often expressed his hostility symbolically by biting his hand or by threatening other members of the group. Radio stimulation in Ali's caudate nucleus blocked his usual aggressiveness so effectively that the animal could be caught inside the cage without danger or difficulty. During stimulation he might walk a few steps, but lie never attempted to attack another animal. Then a lever was attached to the cage wall, and if it was pressed, it automatically triggered a five seconds' radio stimulation of Ali. Front time to time some of the submissive monkeys touched the lever, which was located close to the feeding tray, triggering the stimulation of Ali. A female monkey named Elsa soon discovered that Ali's aggressiveness could be inhibited by pressing the lever, and when Ali threatened her, it was repeatedly observed that Elsa responded by lever pressing. Her attitude of looking straight at the boss was highly significant because a submissive monkey would not dare to do so, for fear of immediate retaliation. The total number of Ali's aggressive acts diminished on the days when the lever was available, and although Elsa did not become the dominant animal, she was responsible for blocking many attacks against herself and for maintaining a peaceful coexistence within the whole colony.

Appeasement of instinctive aggressiveness has also been demonstrated in an animal species which for generations has been bred to increase its ferocious behavior: the brave bull. Some races of bulls have been genetically selected for their aggressive behavior just as others have been bred for farm work or meat supply. Brave bulls are stronger and more agile than their tamer relatives, and these differences in appearance and behavior must be supported at the neurophysiological level by different

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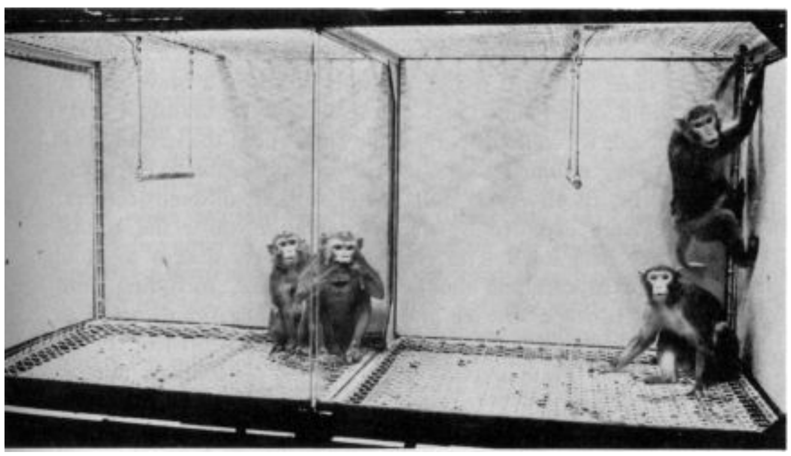
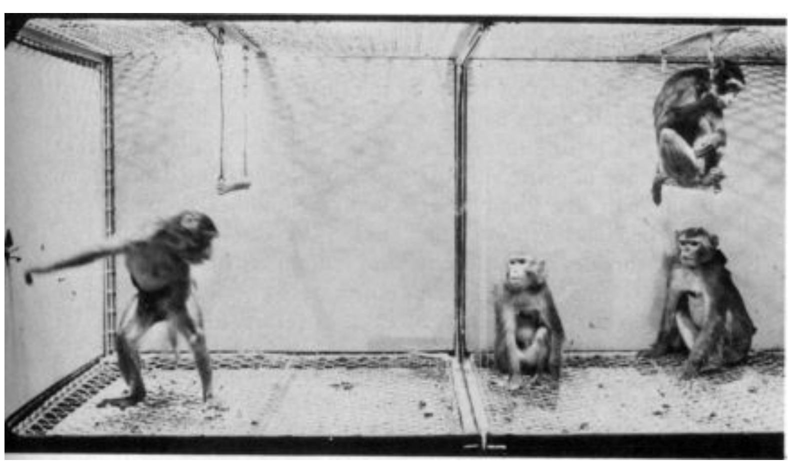


Figure 23
Above, Ali, the boss of the colony, expresses his ill temper by biting his own hand. Below, a submissive monkey, Elsa, has learned to press a lever which triggers radio stimulation of Ali, inhibiting his aggressive behavior (51).



mechanisms of responses. The sight of a person, which is neutral for a tame bull, will trigger a deadly attack in a brave one. If we could detect functional differences in the brains of these two breeds we could discover some clues about the neurological basis of aggression. This was the reason for implanting electrodes in the brains of several bulls. After surgery, different cerebral points were explored by radio stimulation while the animal was free in a small farm ring. Motor effects similar to those observed in cats and monkeys were evoked, including head turning, lifting of one leg, and circling. Vocalizations were often elicited, and in one experiment to test the reliability of results, a point was stimulated too times and too consecutive "moo's" were evoked.

It was also repeatedly demonstrated that cerebral stimulation produced inhibition of aggressive behavior, and a bull in full charge could be abruptly stopped, as shown in Figure 24. The result seemed to be a combination of motor effect, forcing the bull to stop and to turn to one side, plus behavioral inhibition of the aggressive drive. Upon repeated stimulation, these animals were rendered less dangerous than usual, and for a period of several minutes would tolerate the presence of investigators in the ring without launching any attack.

Maternal behavior is one of the instincts most widely shared by mammals, and a baby rhesus monkey enjoys the first months of his life resting in the arms of the mother, who spends most of her time hugging, nursing, grooming, and taking care of him. If the pair are forcibly separated, the mother becomes very disturbed and expresses her anxiety by prowling about restlessly, threatening observers, and calling to her baby with a special cooing sound. It is promptly reciprocated by the little one, who is also extremely anxious to return to the protective maternal embrace. This strong bond can be inhibited by ESB, as demonstrated in one of our colonies, consisting of Rose and Olga with their respective babies, Roo and Ole, plus a male monkey. Maternal affection was expressed as usual without being handicapped by the presence of electrodes implanted in

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both females (Figure 25). Several simple motor effects evoked by ESB (such as head turning or flexion of the arm) did not disrupt mother-infant relations, but when a 10-second radio stimulation was applied to the mesencephalon of Rose, an aggressive attitude was evoked with rapid circling around the cage and self-biting of the hand, leg, or flank. For the next eight to ten minutes, maternal instinct was disrupted, and Rose completely lost interest in her baby, ignoring his tender calls and rejecting his attempts to approach her. Little Roo looked rather disoriented and sought refuge and warmth with the other mother, Olga, who accepted both babies without hesitation. About ten minutes after ESB, Rose regained her natural maternal behavior and accepted Roo in her arms. This experiment was repeated several times on different days with similar disruptive results for the mother-infant relation. It should be concluded, therefore, that maternal behavior is somehow dependent on the proper functioning of rnesencephalic structures and that short ESB applied in this area is able to block the maternal instinct for a period of several minutes.

Information about inhibitory effects induced by electrical stimulation of the human brain is more limited than our knowledge about inhibition in animals. The subject has great importance, however, because one of the primary aims of human therapy is to inhibit undesirable sensations or excessive neuronal activities. Some patients experience a type of "intractable pain" which cannot be alleviated by the usual analgesic drugs, and their unbearable suffering could be blocked by direct intervention in brain structures where sensations reach the perceptual level of consciousness. Illnesses such as Parkinson's disease and chorea are characterized by continuous involuntary movements maintained by neuronal discharges originating in specific cerebral structures which could be inhibited by suitable therapy. Assaultive behavior constitutes one of the most disturbing symptoms of a group of mental illnesses and is probably related to the abnormal reactivity of limbic and reticular areas of the brain. Epilepsy is caused by explosive bursts of electrical dis-

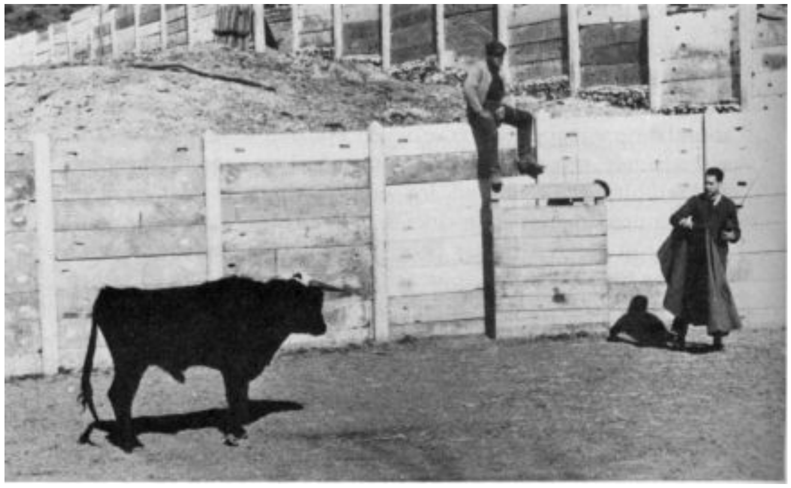


Figure 24
Brave bulls are dangerous animals which will attack any intruder into the arena. The animal in full charge can be abruptly stopped (above) by radio stimulation of the brain. After several stimulations, there is a lasting inhibition of aggressive behavior.

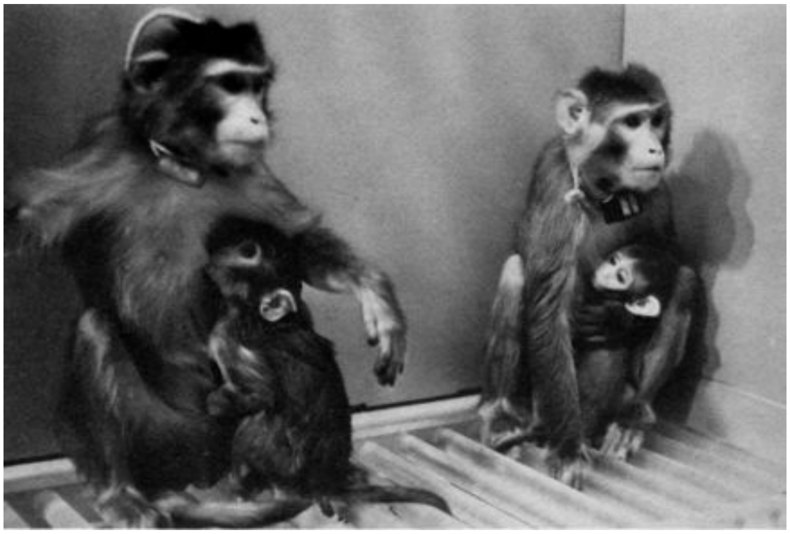
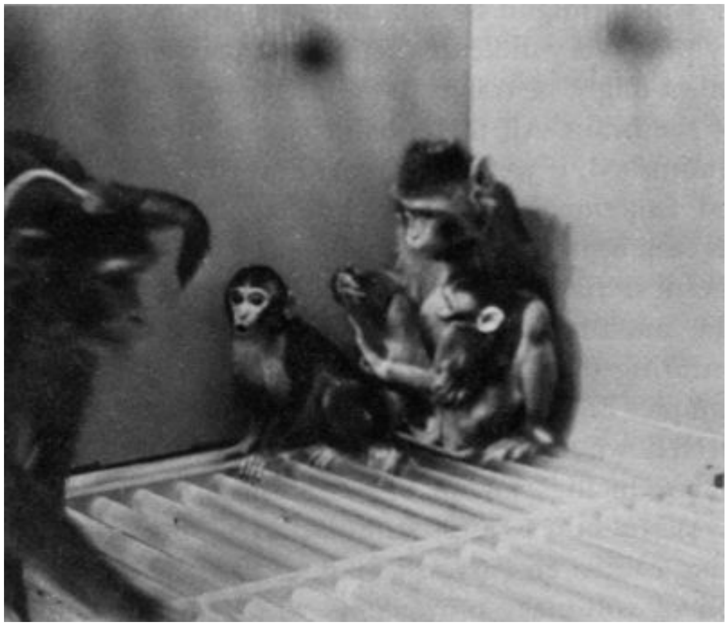


Figure 25
Above, maternal behavior is tenderly expressed by both mother monkeys, Rose and Olga, who hug, groom, and nurse their babies, Roo and Ole. Below, radio stimulation of Rose for ten seconds in the mesencephalon



evoked a rage response expressed by self-biting and abandoning her baby, Roo. For the next ten minutes Rose has lost all her maternal interest (above), ignoring the appealing calls of Roo who seeks refuge with the other mother.
Below, Rose is sucking her foot and still ignoring her baby.

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charges which might be inhibited at their original source. Anxiety poses very difficult therapeutic problems, and its basic mechanism might be traced to the increased reactivity of specific areas of the brain. All these disturbances could be cured, or at least diminished, if we had a better knowledge of their anatomical and functional bases and could inhibit the activity of neurons responsible for the phenomena.

in the near future, important advances may be expected in this field, and already we have some initial clinical information demonstrating that ESB can induce inhibitory effects in man. For example, ESB applied to the supplementary motor cortex has slowed down or completely arrested voluntary motor activity without producing pain or any concomitant loss of consciousness (174). In other cases, stimulation of the frontotemporal region has caused an "arrest response characterized by sudden cessation of voluntary movements which may be followed by confusion, inappropriate or garbled speech, and overt changes of mood (128, 186). More interesting from the therapeutic point of view is the fact that abnormal hyperkinetic movements have been inhibited for the duration of the applied ESB, allowing patients to perform skilled acts which were otherwise impossible. In these cases, a small portable instrument could perhaps be used by the patient to stimulate his own brain in order to inhibit abnormal motility temporarily and restore useful skills (160).

Somnolence with inexpressive faces, tendency to lower the eyelids, and spontaneous complaint of sleepiness, but without impairment of consciousness, has been produced in some patients by stimulation of the fornix and thalamus (7, 199). In some cases, sleep with pleasant dreams has been induced, and occasionally sleep or awakening could be obtained from the same cerebral point by using a slow or high frequency of stimulation (96, 229). Diminished awareness, lack of normal insight, and impairment of ability to think have been observed by several investigators during excitation of different points of the limbic system (74, 120). Often the patients performed automatisms such . as undressing or fumbling, without remembering the incidents

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afterward. Some of our patients said they felt as if their minds were blank or as if they had been drinking a lot of beer. These results indicate that Consciousness may be related to specific mechanisms located in determined areas of the brain. They contrast with the full awareness preserved when other areas of the brain were stimulated.

Arrest of speech has been most common of all inhibitory effects observed during electrical stimulation of the human brain (8), and this fact is probably due to the extensive representation of the speech areas in the temporal lobe, and also to the facility of exploring verbal expression just by conversing with the patients. The most typical effect is cessation of counting. For example, one of our female patients was asked to count numbers, starting from one. When she had counted to fourteen, ESB was applied, and speech was immediately interrupted, without changes in respiration or in facial expression, and without producing fear or anxiety. When stimulation ceased seconds later, the patient immediately resumed counting. She said that she did not know why she had stopped; although she had heard the interviewer encouraging her to continue, she had been unable to speak, If the same stimulation was applied while the patient was silent, no effect could be detected by the observer or by the patient herself. In other cases, patients have been able to read and comprehend or to write messages that they were temporarily unable to verbalize (200).

It is known that ESB activation of pleasurable areas of the brain can inhibit pain Perception in animals (42, 146), and similar results have also been reported in man, with an immediate relief of pain following septal stimulation (98). Because of the multiplicity of pathways in the nervous system which can transmit disagreeable sensations, it is often not possible to block all of them, and to alleviate unbearable suffering it may be easier to inhibit the cerebral structures involved in the psychological evaluation of pain, blocking the components of anxiety and diminishing the subjective sensation of unpleasantness.

There are also a few reports indicating that abnormal violence may be reduced by ESB: Heath has a movie showing a patient who self-stimulated his own brain in order to suppress an aggressive mood as it developed, and we have described a case in whom crises of antisocial conduct during which the patient attacked members of his own family were considerably diminished by repeated stimulations of the amygdaloid nucleus (60).

We are only at the beginning of our experimental understanding of the inhibitory mechanisms of behavior in animals and man, but their existence has already been well substantiated. It is clear that manifestations as important as aggressive responses depend not only on environmental circumstances but also on their interpretation by the central nervous system where they can be enhanced or totally inhibited by manipulating the reactivity of specific intracerebral structures.

Violence, including its extreme manifestation of war, is determined by a variety of economic and ideological factors; but we must realize that the elite who make the decisions, and even the individual who obeys orders and holds a rifle, require for their behavioral performance the existence of a series of intracerebral electrical signals which could be inhibited by other conflicting signals generating in areas such as the caudate nucleus. Inhibitory areas of the central nervous system can be activated by electrical stimulation as well as by the physiological impact of sensory inputs which carry messages, ideas, and patterned behavior. Reception of information from the environment causes electrical and chemical changes in the brain substance, and the stimuli shape the functional characteristics of individual interpretation and integration, determining the degree and quality of his reactions. Human relations are not going to be governed by electrodes, but they could be better understood if we considered not only environmental factors but also the intracerebral mechanisms responsible for their reception and elaboration.

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