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thalamus. This is not to say that these techniques are ineffective in dealing with higher functions such as memory. What can be and is being provided by neurophysiology is a precise description of the neural substrate within the brain.

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PAUL BLUM

BRAIN: EMOTION AND MOTIVATION

The year is 1800. Great changes are taking place in the way man views himself. For millenia he had believed his intellect to be a function of spirits entrapped in the cavities of his brain and his emotions to depend on the humors composing his blood. Suddenly these doctrines are being challenged by the anatomist, F. J. Gall and his assistant, J. Spurzheim who make the radical proposal that the brain substance controls the various faculties of mind. They adduce a great deal of evidence from the clinic, carefully documenting case history after case history. The challenge is so successful that a quarter of a century later laboratory experiments are underway to determine precisely the functions of anatomically distinct parts of the brain. By the end of the century the broad outlines of brain physiology have been drawn with sufficient accuracy that Sigmund Freud could base a comprehensive systematic account of *psychological* processes on this knowledge. Central to this account were the findings of some half century of research initiated by Claude Bernard that parts of the brain regulated the internal environment of the organism and that these internal controls operated automatically beyond the awareness of the individual. Rational man now had to face the fact that his behavior might stem, to some considerable extent, from such ordinarily "unconscious" processes. In his discomfort with the unknown, he began in earnest to analyze the mechanisms of these powerful but little understood "motivational" determinants of psychological processes and behavior.

Encephalization of Mind

William James, contemporary with Freud, applied the new knowledge of brain function to construct an even more detailed and comprehensive systematic account of psychological processes. James's "psychology" differed in emphasis from Freud's and provided a complimentary view most notable for distinguishing emotional reactions from motivations. James proposed that emotions were manifest when a reaction to an occurrence was contained within the organism, calling into play adjustments of the autonomic-visceral regulations of the internal environment, while motivations took the organism outside himself by controlled operations on his somatic musculature.

This is the legacy we inherit from the nineteenth century. Seventy-five years of additional research on the physiology of emotion and motivation has produced new data and a sharpened conceptualization. The nineteenth century trend toward understanding psychological processes in terms of *brain* function has been accelerated and today the average person uses the terms *mind* and *brain* practically interchangeably.

Several landmarks in this encephalization of mind can be distinguished. Walter Cannon's research showed that the regulation of the internal environment was accomplished by a mechanism sensitive to the chemical substance (e.g., blood sugar, osmolarity, or partial pressure of CO_2) or physical quantity (e.g., heat) that it controlled, and that this mechanism was located in the core of the brain stem (hypothalamus and midbrain). Cannon further showed that emotional reactions were a function of these core-brain control mechanisms and not, as James had thought, of the peripheral visceral processes that the mechanisms regulated.

A similar though less heralded development took place with regard to motor functions. The demonstration by Fritsch and Hitzig (c. 1870) of the production of movement by electrical stimulation of parts of the brain began the experimental study of motor control. This research culminated after World War II in the realization that a major regulatory system, centered on the basal ganglia, regulates postural adjustment, the base from which movement and action takes place, by a homeostatic-like process. Controls operate on proprioceptors (e.g., muscle spindles) and therefore on a *sensitivity* to forces exerted on the receptors, rather than on muscle contraction per se. Such load-adjusting operations are now generically termed as being performed by feedback, or *servomechanisms.*

Regulatory Mechanisms

The next major discovery was made by Horace Magoun and Donald Lindsley and extended both the anatomical locus and the functions of the core-brain regulatory mechanisms. Anatomically, the regulatory systems were shown to involve a considerable length of the core of the midbrain stem (the mesencephalic reticular system). Functionally the mechanism could alter the *level* of arousal and activation (or inhibition) of *all* regulatory functions, changing the set points around which the homeostatic and postural processes would adjust. These changes in arousal and activation ranged from sleep at one extreme, to wide gauge alertness at the other. Lindsley systematized these initial discoveries in a proposal that emotion simply reflected the *amount* of arousal or activation of the brain.

This early view of the functions of the reticular formation has since been modified by a deluge of research results, some of them from Lindsley's own laboratories. The reticular formation was found to be host to a variety of neurochemical receptors which, in keeping with their homeostatic regulatory function, were shown to be the origins of specific neuroanatomical systems extending forward in the core brain to regulate the activities of other, core-brain structures. Most of these neurochemical substances are amines, such as serotonin, an indole amine, and norepinephrine (noradrenaline), a catecholamine. Psychiatric and psychopharmacological research laboratories throughout the world are now engaged in studying how the interactions of these brain amines within the reticular formation and beyond in more rostral neurochemical systems (such as the dopamine system—a catecholamine system connecting the substantia nigra with the basal ganglia) produce different types of sleep and alertness and such mood changes as depression and elation, and even disturbances such as schizophrenia. Arousal and activation are turning out to be as neurochemically multifaceted as are the more specific emotions and motivations. The humors have returned, but they are now known to be neurohumors.

The Forebrain

Another major discovery embraces the mechanisms influencing homeostatic processes in the opposite direction, into the forebrain. Here again the core portions—the limbic formations—became the focus of interest. The close anatomical connectivity with core-brain stem systems (hypothalamic and reticular) sparked this interest. An initial contribution was the proposal by James Papez, later amplified by Paul MacLean, that the limbic formations serve as a "visceral" brain supplanting Cannon's thalamic locus for emotional experience and expression. Dramatic changes in the reactivity of laboratory animals were in fact obtained by Heinrich Klüver and Paul Bucy in initial experimental invasions of limbic structures. An analysis of these effects initiated and carried on by Karl Pribram and supplemented by research originating from other points of departure has shown that the limbic forebrain modulates and coordinates the regulatory core-brain stem mechanisms to make possible attentional and intentional processes. Such processes are characterized by their sensitivity to a wider range of variables in time and space than can be utilized by feedback, homeostatic organizations. The experimental results suggest that the limbic forebrain serves as a control on more primary emotional and motivational homeostatic processes constituted by the operations of thalamic (hypothalamic), basal ganglia, and reticular core-brain stem structures.

Self-Stimulation

These discoveries concerning the core portions of the brain stem and forebrain are highlighted by two others which introduce some continuity into the apparently disparate and diverse mosaic of homeostatic regulations. Continuity is given by the finding that the core-brain systems are intimately involved in the experiencing and the reaction to pleasure and to pain. The seminal discovery was that by James Olds and Peter Milner that animals would press a lever in order to turn on electrical stimulation to their brains. Olds carefully mapped the locations effective in producing self-stimulation and found them to be restricted to core-brain stem and limbic placements. Further research showed that the amount of self-stimulation interacted with a variety of homeostatically regulated processes. Thus the appetitive aspects of homeostasis and of self-stimulation appear to share a common locus in the brain. In addition, it was quickly established that these animals would also press a lever to stop ongoing electrical brain stimulation, indicating that the satiety aspects of homeostasis are similarly related. The stop-and-go mechanisms, though often intermingled, were in some locations clearly separable, and this separation was also found by a variety of techniques aimed to discern the organization of specific homeostatic mechanisms (i.e., hunger and thirst). Considerable definitional sense is made when, on the basis of these findings, stop mechanisms are considered the basis of emotion (James's definition that the control operations involve only internal regulations), while go mechanisms (in going outside the body by virtue of essential involvement of the somatic musculature) became the origins of motivations.

Equally important insights have come from stimulations of the hind parts of the core-brain stem. Here electrical stimulation of the stop locations would often produce grimacing, vocalizing, and other signs of discomfort. Yet at other times, with the electrodes placed in the same or only slightly adjacent locations, or with different stimulation parameters, the animal would turn on the electric current with apparent relish.

Pain

Clarification of these initially puzzling findings has come recently from studies of the pain mechanism. Neurosurgeons, on the basis of clinical evidence, have for years sectioned the lateral spinothalamic tracts in the spinal cord and lower brain stem to produce *analgesia* in patients suffering from intractable pain. When these tracts are sectioned in experimental animals, about one-third of their fibers can be traced to the thalamus, the remaining two-thirds ending in the core-brain stem in and around the reticular system. A special concentration of such fibers ends in the periaqueductal grey, a centrally located nucleus within the reticular formation. One would expect, therefore, that lesioning of the structure in which the pain tracts terminate would produce analgesia. This expectation is *not* confirmed; instead Liebeskind, Moyer, and Akil found that electrical *stimulation* of the periaqueductal grey produced the analgesic effect. Next it was found that analgesic pharmaceutical chemicals, such as morphine, are selectively absorbed by the cells of the periaqueductal grey. Finally, evidence is just beginning to be obtained that these "analgesic receptor" cells, under normal conditions, apparently *secrete* a morphine-like pain protective substance, or concentrate such a substance secreted elsewhere.

Pain thus comes under the control of a homeostatic system, a system that regulates the quantity of a chemical analgesic substance. Perhaps the self-stimulation effects obtained by Olds are due to excitation of this pleasurable, hedonic system which protects the organism from pain by producing analgesia.

Epicritic and Protocritic

How can we simply summarize this wealth of knowledge which has accumulated over the past two centuries? Clearly, the brain has been shown to be the organ critical to emotional and motivational experience and expression. However, not all parts of the brain are equally involved. The core portions of the brain stem and forebrain have been found especially important, and the question arises as to how to characterize their importance. Introspectional psychology once came to the conclusion that experience could be classified along three primary dimensions: a spatial, a temporal, and an intensive. Neuroscientists have succeeded to a remarkable extent in spelling out the sensory and perceptual brain mechanisms involved in the spatial dimension (called *epicritic* in clinical neurology, a term coined by Henry Head). Now it appears that the brain sciences may be making equally important strides in delineating the core-brain mechanisms involved in the intensive dimension, which can be labelled *protocritic* (again following Head's lead).

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See also PAIN

KARL H. PRIBRAM

BRAIN DAMAGE AND MENTAL RETARDATION

Mental retardation has many facets and cannot be regarded as a unitary condition. However, brain damage and mental retardation have been traditionally, medically, and behaviorally associated with each other. However, not all brain injured persons are retarded, nor are all mentally retarded individuals organically involved. The relationship is one of "associated with," that is, mental retardation associated with or following a whole host of conditions which may result in the destruction and/or structural aberrations of brain cells. These, in turn, yield varying degrees of intellectual subnormality ranging from the multiply-handicapped, profoundly retarded person to those within the borderline category.

Incidence of Mental Retardation and Brain Damage

The occurrence of this condition has been estimated at 3% of the population or approximately 6.5 million children, adolescents, and adults. Of these 20% are characterized as severely retarded. They contribute more than their proportionate share to the resident population of tax supported and private facilities for custodial care and training in the basic skills of daily life activities (Witkin, 1974). The average daily cost, if this condition is reducible to dollars and cents terms, is approximately ten dollars per person per day or about $700 million for those in tax supported institutions (Allen and Cortazzo, 1970). This figure does not include those in private facilities and those lost in the anonymity of the adult population.

Conceptualization

The range of behavioral adequacy is, like the intellectual aspect, a function of the locus and extent of the brain damage. The more severely involved people are also classified as cerebral palsied. The latter term is applied to those whose encephalopathy is manifested by some motor dysfunction(s). However, only about 30% of the cerebral palsied population is truly retarded. Of the remaining 70% approximately 40% are of average intelligence or higher even though functionally incapacitated in varying degrees, and 30% behave *as if* they are retarded due to their limited experiences in assimilating from and accommodating their environment.

Mental retardation may be seen from several vantage points: theoretical, behavioral, and developmental. The latter usually includes the first two and will be presented in some detail.

With specific regard for the brain injured retardate, the more appropriate developmental model is that promulgated by Piaget. His view is sequential in both time and stages. That is, "a major approach to cognition . . . describe(s) in explicit terms the sequence of concept development in children from birth to adolescence" (Suppes, 1974, p. 14).

While the onset is before birth, the accounting starts at birth with Piaget's Sensorimotor Stage which takes the infant through the first two years of life. For approximately 20% of the organically involved retardates, this is the stage at which they remain fixated, not passing beyond the mental age of two years, IQ rating of 20 to 25, and extremely minimal scores on the Adaptive Behavior Check List using the two-fold criterion for mental retardation: