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BRAIN MODELS OF MIND

KARL H. PRIBRAM, M.D.

INTRODUCTION

For two centuries brain models of mind have fascinated scientists and the lay public alike. The intense interest began with the pioneering correlations between brain pathology and characteristic personality histories of patients inaugurated by Francis J. Gall. As with every major advance in understanding the mind-brain relation, Gall's demonstrations became a popular fad in the form of phrenology, reading bumps on the skull. Today a similar fad involves the application of the findings regarding hemispheric specialization: educators and politicians alike exhort people to use their right brains, lest the human race fall forever into sinister damnation.

Brain models of mind show a remarkable coherence during the 19th and 20th centuries, despite the often acrimonious bickering regarding emphasis on this or that phenomenon to the exclusion of a comprehensive analysis. When carefully considered, each of the often opposing views captures important aspects of the issues, and reconciliation devolves on making distinctive definitions and reading the proposals in their original form with those definitions in mind.

Gilbert Ryle provided a definition of mind: mind comes from minding, paying attention. In old English *gemynd*, akin to remind, was derived from terms indicating to warn and to intend. The Sanskrit *manas* means to think.

THE MIND-BRAIN RELATION

A case-history highlights this definition. A neurosurgeon is called regarding a 14-year-old girl who had fallen out of a rapidly moving automobile. She had sustained a head injury and multiple scalp lacerations. She was several hundred miles away, and transporting her to the surgeon's hospital, although considered, was thought to be too risky to an already traumatized head. So the neurosurgeon drove to where she was bedded. Her head was swathed in bandages, through which some blood had oozed, making them appear bright red. By contrast, the girl looked green. The neurosurgeon said to her: "Hello, Cathy. You look like a Christmas package, all dolled up in your bandages." She smiled and said, "Hello, Doctor." The girl's brain was intact. She minded, even with a sense of humor. A thorough examination revealed a broken rib and a puncture to one lung, giving her a green color. Chest bandages and a brief time in an oxygen tent quickly allowed healing to commence.

The diagnosis rested on the truism that scrambled brains result in scrambled minds. But the truism, because of its pervasive validity, can blind one to the subtle aspects of the mind-brain relation. For instance, the close association of mind to brain may lead one to suspect uncritically that mind and brain are the same. That would be as absurd as stating that the islets of Langerhans of the pancreas are the same as insulin regulation of glucose metabolism. Minding is a function of the entire organism's interacting with its environment, just as glucose metabolism is a function of the organism's metabolizing environmentally derived nutrients. What is common to brain and mind is their organization, much as what is common to a computer's hardware and the various levels of programming software is the information being processed.

On the whole, people accept the special relation between brain and conscious experience but are not at all agreed on the subtleties inherent in the nature of the relation or on the consequences that the understanding of that nature may have on their understanding of themselves and their relationships to others. In that respect people have apparently come no further than the philosophers of the past two millennia.

Each of the philosophical stances toward the mind-brain relation has merit as long as it is restricted to the database that defines the stance. Thus what becomes important is the special relation between various brain processes and the variety of mental processes. On the other hand, what is ontologically neutral to the material brain and mental (psychological) processes is order, order as measured scientifically in terms of energy, entropy, and information.

With respect to the special relation between brain processes and the variety of mental processes, the ontological neutrality is expressed by showing that conscious and unconscious processes are coordinate with identifiable brain processes occurring in identifiable brain systems. That is, at some level the descriptions of brain processes and the descriptions of mental processes become homomorphic.

An example from computer science illustrates what is meant by homomorphic: One uses a computer as a word processor by typing English words and sentences. The word-processing system converts the keyboard input to binary, which is the language of the computer. Nothing in the description of English and in the description of binary machine language appears to be similar. Nevertheless, by virtue of the various transformations produced in the encoding and decoding operations of the various stages leading from typescript to binary, the information (the form within) of the typescript is preserved in the binary language of the operation of the computing machine.

In a similar fashion, little in conscious experience resembles the operations of the neural apparatus with which it has such a special relation. However, when the various transformations (the transfer functions, or the codes that intervene between experience and neural operations) are sufficiently detailed, a level of description is reached in which the transformations of experience are homomorphic with the language used by the brain. That language is the language of the operations of a microprocess taking place in synaptodendritic fields, a mathematical language similar to what describes processes in subatomic physics.

At the microprocessing level, therefore, an identity describes the relation between brain and mental processes. At remote processing levels that encompass large-event structures (assemblers, operating sytems or their counterparts in computer or brain systems), pluralism and eventually (at the natural language level) dualism characterize the relation.

The special relation between brain and mental processes is thus not unitary, except in implementation at the microprocessing level. At the neuronal level and even at the neural-system level, several types of relations with psychological processes can be discerned.

First, neurochemical states of neuronal assemblies determine and are determined by states of consciousness. The field of psychoneuropharmacology is replete with evidence of relations between catechol and indole amines acting in specified brain locations to produce states of consciousness, such as wakefulness and sleep, depression and elation, and perhaps even dissociated states, such as those seen in schizophrenia. The relations between relative concentrations of blood glucose and osmolarity and hunger and thirst, between sex hormones and sexually characteristic behaviors, and between such peptides as the endorphins and the enkephalins and the experiences of pain and stress are all well documented.

Second, the relations between the sensory systems of the brain and the sensory aspects of perception, such as the contents of consciousness, have been described in detail. States of consciousness often determine contents and are often determined by them. When hungry a person tends to be aware of restaurant signs; smelling the aroma of freshly baked bread while walking past a bakery whets the appetite. The connection between states of consciousness and the contents of consciousness is mediated by a process ordinarily called *attention* (the control of sensory input), *intention* (the control of motor output), and *thought* (the control of remembering). An understanding of those processes of minding is critical to the understanding of the special relation between brain states and the contents of conscious experience.

VARIETIES OF BRAIN ORGANIZATION

LOCALIZATION AND DISTRIBUTION OF FUNCTION

Gall brought the issue of localization of function to the fore by correlating local brain pathologies with the histories of the cadavers he autopsied. Although often wrong in detail, Gall was correct in the methods he carefully detailed. He was naive in delineating the faculties of mind for which he sought localization, but the systematic classification of mental functions is still elusive despite half a century of operational behaviorism. Today it is popular to discuss the modularity of mind and component systems of the brain and to relate them, in both the clinic and in the laboratory, by crafting experimental designs and behavioral and verbal testing procedures. The use of these techniques can be traced directly to Gall's enterprise.

The excesses of phrenology brought a reaction. First, the question was raised as to which brain system brought together the various faculties into a conscious self. The unity of being, the soul, was challenged by breaking mentation into a mere collection of faculties. Furthermore, experimental evidence showed a relation between, on the one hand, impairments in complex behaviors and verbally reported experiences and, on the other hand, the amount of brain tissue destroyed, regardless of location. In the recent past Karl Lashley became the exponent of that mass-action view.

However, if one reads Lashley carefully, one finds the seeds of conciliation. In a letter to Fred Mettler, Lashley once stated his exasperation with being misinterpreted. He knew, of course, that the front of the brain does something different from the back end. The visual sensory input terminates in the occipital lobes. Electrical stimulations of the pre-Rolandic areas elicit movements and the front parts are more enigmatic in their functions. But these observations beg the issue.

What concerned Lashley was that certain selected mental functions appeared to be related to brain processes that are nonlocal. For instance, he pointed out that sensory and motor equivalences could not be accounted for even by a duplication of brain pathways:

> "Once an associated reaction has been established (e.g., a positive reaction to a visual pattern), the same reaction will be elicited by the excitation of sensory cells which were never stimulated in that way during training. Similarly, motor acts (e.g., opening a latch box) once acquired, may be executed immediately with motor organs which were not associated with the act during training."

An example of motor equivalence was reported by A. A. Ukhtomski. A dog was conditioned to raise his right hind leg at the sound of a tone. After that conditioned response was well-established, his right motor cortex (which controls the left side of the body) was exposed. Then, during the performance of the conditioned reaction, a patty of strychninized filter paper (which chemically excited the cortical tissue) was placed on the area that controls the left forepaw. Immediately, the dog switched the responding leg: He now raised his left forepaw to the conditional signal. A temporary dominant focus of excitation had been established in the cortex by the chemical stimulation. E. Roy John summarized the experiments that demonstrate such shifts in cerebral dominant foci in Figure 3.6-1 (the experiment by Lev Abramovich Zal'manson in the illustration is the one reported by Ukhtomski).

The distributed aspect of brain function becomes most evident in memory storage. Even with large deletions of brain tissue, such as those resulting from cerebrovascular diseases and resections for tumor, specific memories, or engrams, are seldom lost. When amnesias do occur they are apt to be spotty and difficult to classify. That fact suggests that memory is stored in a distributed and statistically more or less random fashion. The storage process dis-members the input, which is then re-membered when recognition and recall became necessary. The retrieval processes, in contrast to storage, are localized, at least in such systems as those that are sensory-specific. When such systems are damaged, sensory-specific and even category-specific agnosias result. Thus, with regard to memory, both distributed and localized processes can be identified, depending on which property of the process is being considered.

HIERARCHY AND HETERARCHY The fact that a temporary dominant focus in the cerebral cortex can take control of the expression of a learned behavior indicates that hierarchical control operates in the central nervous system. Equally persuasive is the evidence for control over spinal cord activity by the brainstem and the forebrain. Neuronal activity in the spinal cord displays a high rate of spontaneous impulse generation. These generators are modulated by inhibitory local circuit neurons in such a way that the resultant activity can be modeled in terms of coupled ensembles of oscillatory processes.

The ensembles of oscillators become organized by brainstem systems that consist of cholinergic and adrenergic neurons. The cholinergic set regulates the frequency of a wide range of tonic rhythmic activities, such as those involved in locomotion, respiration, cardiovascular responses, and sleep. The cholinergic system is coupled to an adrenergic set of neurons that segment the rhythmic activities into episodes. Both systems are subject to further hierarchical control by the dopaminergic system of the basal ganglia.

Clinically, the loss of hierarchical control becomes manifest

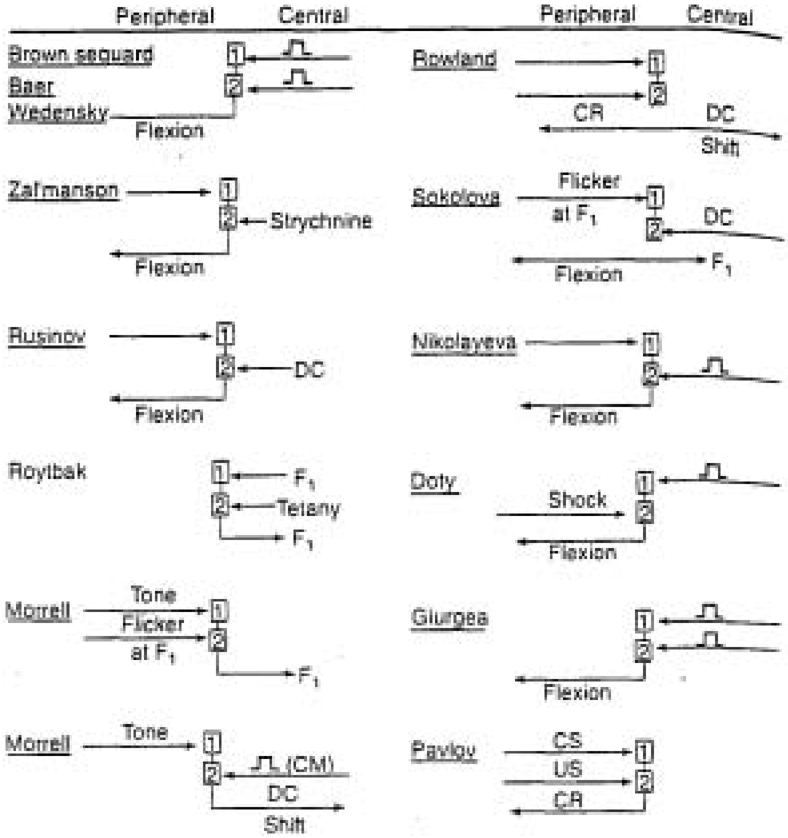

FIGURE 3.6-1 *Methods of conditioning that have been used by various investigators to establish and produce shifts in cerebral dominant foci. The example in the text refers to Zal'manson's experiment. (Figure from K. Pribram:* Languages of the Brain: Experimental Paradoxes and Principles in Neuropsychology, *p. 79. Random House, New York, 1971. Used with permission.)*

in an exaggeration of the normally present, almost subliminal tremors that, under extreme conditions, lead to spastic paralysis, hyperreflexia, and uncontrollable fits of oscillatory muscular spasm.

But the evidence from the experiments that showed temporary dominant foci can be viewed from another perspective: The flexibility demonstrated by the shift from one controlling locus to another shows the organization of the cortical system to be heterarchical. Any locus within the system can become dominant if sufficiently excited. Warren McCulloch used the following story to illustrate the nature of heterarchical organization.

After the 1916 battle of Jutland during World War I, in which the British navy took a beating, both the British and American navies were reorganized to change from hierarchical to heterarchical control. Battleships no longer had to await orders from a central command source to engage in defensive maneuvers.

During World War II the American fifth fleet was stationed in an only slightly dispersed mode of operation somewhere in the Pacific Ocean when it was attacked from two directions by separate air squadrons. Sightings of the attackers were made from two locations in the fleet by observers on the ships closest to one or the other of the attacking squadrons. In essence, the sailor who made the sighting became a dominant focus, and his ship and those in his proximity took off to defend against the attackers. However, since the attack came from two directions, two dominant foci were created, each commanding parts of the fleet to steam away in opposite directions. That left the ship at the center of the fleet, which housed its admiral, haplessly unprotected and, since no sightings were made by the admiral's ship, at a momentary loss as to what to do. Fortunately, both attacking squadrons were defeated and turned back without any damage accruing to the fifth fleet.

Thus, a penalty may be paid for the flexibility achieved by a heterarchical dominance, albeit temporary, over processing.

SERIAL AND PARALLEL PROCESSING Ordinarily, hierarchical control is conceived to be accomplished by way of a serial process. When control is direct, a causal connection exists between the controller and the controlled. Causality implies that the origination of the control signal precedes its effect on the system being controlled. Seriality remains when feedback loops are present. However, when feedforward operations are inserted into the process, seriality is no longer as clear-cut. In a thermostat or in homeostasis, if one lowers the temperature or the blood sugar, the sensor closes a circuit, and the effector responds: a serial process. But if one places a control dial or other bias on the process, the sensor can be adjusted in two or more ways. One can reset the thermostat's dial; thus the sensor has parallel inputs one from the dial and the other from the heat in the room. Herman von Helmholtz is credited with pointing out that voluntary processes, such as those by which people move their eyes, are constituted of such feedforwards: parallel corollary discharges to the effectors. Control can be hierarchical yet dependent on a parallel process.

Heterarchical organization, by definition, involves the potential for parallel processing. However, when control is exerted over other systems, a serial process becomes implemented. In general, the brain is composed of hierarchies of heterarchical systems.

Processing in the cerebral cortex is massively parallel. Simulations of those parallel cortical processes have been implemented on personal computers to such an extent that the endeavors have been dubbed a cottage industry.

Computer simulations of neural networks are capable of pattern recognition, language learning, and decision making that are remarkably true to life. Single-layered simulations have given way to three-layered computations, which involve an input layer, an output layer, and a hidden layer. All the elements of the network are interconnected, each element with all the others. In several such simulations the input is fed forward through the net and the output is compared with one that is desired; the difference between the actual and the desired is fed back to the net. The process is repeated until the desired output is achieved.

Variations on that theme abound, each variation being better adapted than its alternatives for a particular purpose.

Relevant to the issue of localization and nonlocal processing is the fact that information contained in the input becomes fragmented and distributed in the elements of the layers. The simulations are said to be parallel-distributed processes. That makes them akin to the optical information-processing systems, such as holography and tomography, from which they were derived.

ROLE OF BASAL BRAIN SYSTEMS IN ORGANIZING MIND

BASAL FOREBRAIN SYSTEMS William James noted that the delineation of minding—that is, consciousness—devolves on processes usually referred to as attention and intention (volition). Thought should be added. Controls on attention determine the span of sensory processing; controls on intention determine the span over which action becomes effective; and controls on thought determine the span of memories that become considered.

The neural processes in the control of attention involve three mechanisms: One mechanism deals with short phasic responses to an input (arousal-familiarization); a second mechanism relates to the organism's prolonged tonic readiness to respond selectively (activation-selection); and a third mechanism (effort-comfort) acts to coordinate the phasic (arousal) and tonic (activation) processes. Separate neural and neurochemical systems are involved in these processes: The phasic process is centered on the amygdala; the tonic process is centered on the caudate nucleus, while the coordinating system critically involves the hippocampus, a phylogenetically ancient part of the neural apparatus.

Evidence from the analysis of changes in the electrical activity of the brain evoked by brief sensory stimulation has shown that the arousal and activation systems operate on a basic process centered on the dorsal thalamus, the way station of sensory input to the cerebral cortex. Brain electrical activity evoked by sensory stimulation can be analyzed into components. Early components reflect processing by systems that directly (through the thalamus) connect sensory surfaces with cortical surfaces. Later components reflect processes initiated in the thalamocortical and related basal ganglia systems that operate downward onto the brainstem (tectal region), which influences a thalamic gate that modulates activity in the direct sensory pathways. The activity reflected in these later components constitutes activation.

The thalamic gate is, however, also regulated by input from the system centered on the amygdala, the arousal system. That system, when stimulated, produces an effect on the gate that is the opposite of the effect of the activation system.

The evidence also indicates that the coordination of phasic (arousal) and tonic (activation) attentional processes often demands effort. When attention must be paid the hippocampal system becomes involved; it influences the arousal system rostrally through frontal connections with the amygdala system and the activation system caudally through connections in the brainstem. At that juncture the relation of attention to intention—that is, to volition (will)—comes into focus. William James pointed out that a good deal of what is called voluntary effort is the maintaining of attention or the repeated returning of attention to a problem until it yields a solution.

Emotion and motivation William James apposed will to emotion and motivation (which he called *instinct*). Beginning with Walter Cannon's experimentally based critique of James and followed by Lashley's critique of Cannon, the anatomically based suggestions of James Papez, and their more current versions by Paul MacLean, brain scientists have been deeply concerned with the processes that organize emotional and motivational experience and expression. Two major discoveries have accelerated the ability to cope with the issues and have placed the early speculative accounts into perspective. One of the discoveries is the role of the reticular formation of the brainstem and its chemical systems of brain amines that regulate states of alertness and mood. Donald Lindsley proposed an activation mechanism of emotion and motivation on the basis of the initial discovery and detailed the pathways by which such activation can exert control over the brain processes. The other discovery is the system of brain tracts that, when electrically excited, results in reinforcement (that is, an increase in the probability of recurrence of the behavior that has produced the electrical brain stimulation) or deterrence (that is, a decrease in the probability that such behavior will recur).

To organize these discoveries and other data that relate brain mechanisms to emotion, one must distinguish between those data that refer to experience (feelings) and those that refer to expression and must distinguish emotion from motivation. Feelings encompass both emotional and motivational experience—emotional as affective processes and motivation as readiness. The affective processes of emotion are based on arousal, the ability to make phasic responses to input that stop the motivational processes of activation that maintain selective readiness. Feelings are based on neurochemical states (dispositions or moods) that become organized by appetitive (motivational, go) and affective (emotional, stop) processes.

James is almost universally misinterpreted as holding a peripheral theory of emotion and mind. Throughout his writings he emphasized the effects that peripheral stimuli (including those of visceral origin) exert on brain processes. Nowhere did he identify emotions with bodily processes. Emotions are always the resultant effect on brain states. However, what James failed to take into account is the role of expectations (the representational role of the organization of arousal-familiarity and activation-selection) in the organization of feelings. Those representations, or neuronal models, of prior experience entail the functions of the basal ganglia, including the amygdala.

Nonetheless, James was explicit when he discussed the nature of the input to the brain from the viscera. He pointed out two possibilities: emotions are processed by a separate brain system, or they are processed by the same systems as are perceptions. Today, both possibilities are known to play a role: parts of the frontolimbic forebrain (especially the amygdala and related systems) process visceroautonomic bodily inputs, and the results of processing are conveyed to brainstem systems that distribute to and diffusely influence the perceptual systems.

In addition, James defined the difference between emotions and motivations: Emotional processes take place primarily within the organism; motivations reach into the organism's environment. James may have overemphasized the visceral determination of emotional experience, but he did occasionally include attitudinal factors as depending on sensory feedback from the somatic musculature.

The distinction between the brain mechanisms of motivation and will were less clearly enunciated by James. He grappled with the problem and set the questions that must be answered. Clarity did not come until the late 1960s, when several theorists began to point out the difference between feedback, homeostatic motivational processes on the one hand and voluntary programs—which are feedforward, homeorrhetic processes—on the other hand. Feedback mechanisms depend on error processing and are, therefore, sensitive to perturbations. Programs, unless completely derailed, run themselves off to completion, regardless of the obstacles placed in their way.

Voluntary and involuntary behavior Clinical neurology classically distinguished the mechanisms involved in voluntary behavior from those in involuntary behavior. The distinction rests on the observation that lesions of the cerebellar hemispheres impair intentional (voluntary) behavior, but basal ganglia lesions result in disturbances of involuntary movements. Damage to the cerebellar circuits are involved in a feedforward mechanism, rather than a feedback mechanism.

The cerebellar hemispheres may operate by performing calculations in fast time—that is, extrapolate where a particular movement would end if it were to continue and send the results of such a calculation to the cerebral motor cortex, where they can be compared with the target to which the movement is directed. Experimental analysis of the functions of the motor cortex has shown that such targets are composed of images of achievement, constructed in part on the basis of past experience.

Just as the cerebellar circuit serves intentional behavior, the basal ganglia are important to involuntary processes, such as the readiness of the organism to respond selectively (activation). Lesions in the basal ganglia grossly amplify tremors at rest and markedly restrict expressions of motivational feelings. Neurological theory has long held that these disturbances are due to the lesion's interference with the normal feedback relations between the basal ganglia and the cerebral cortex. In fact, surgical removal of the motor cortex has been performed on patients with basal ganglia lesions to redress the imbalance produced by the initial lesions. Such resections have been successful in alleviating the often distressing continuing disturbances of involuntary movement that characterize basal ganglia diseases.

CEREBRAL CORTEX AND MINDING

Reflective consciousness and unconscious processes

The distinction between the systems that control intentional behavior and those that control involuntary behavior extends to the control of sensory input and the processing of memory. With regard to sensory input, the distinction between the contents of awareness and the person who is aware was delineated by Franz Brentano and called *intentional inexistence*. The dualism of a minding self and objective matter (the brain) was already present in the writings of Ernst Mach and René Descartes. Although Cartesian dualism is perhaps the first overt nontrivial expression of the issue, the duality between subject and object and some causal connection between them is inherent in language once it emerges from simple naming to predication. Eric Neumann and Julian Jaynes suggested that a change in consciousness (that is, in distinguishing an aware self from what the self is aware of) occurred somewhere between the time of the *Iliad* and the time of the *Odyssey*. That occurrence may be linked to the invention and promulgation of phonemically based writing. Prehistory was transmitted orally-aurally. Written history is visual-verbal. In an oral-aural culture a great share of reality is carried in memory and is personal; once writing becomes a ready means of recording events, they become a part of extrapersonal objective reality. The shift is especially manifest in a clearer externalization of the sources of conscience, the gods no longer speak personally to guide individual humans.

The process of ever-clearer distinctions between personal reality and extrapersonal objective reality culminates in Cartesian dualism and Brentano's intentional inexistence, which Edmund Husserl shortened to *intentionality*. That reading of the subject-object distinction is what philosophers ordinarily mean when they speak of the difference between conscious processes and unconscious processes.

Sigmund Freud had training in both medical practice and philosophy. When he emphasized the importance of unconscious processes, was he implying the medical definition or the philosophical definition? Most interpretations of Freud suggest that unconscious processes operate without awareness in the sense that they operate automatically, much as do respiratory and gastrointestinal processes in someone who is stuporous or comatose. Freud himself seems to have promulgated that view by suggesting a horizontal split between conscious, preconscious, and unconscious processes, with repression operating to push memory-motive structures into deep layers, where they no longer have access to awareness. Still, in "Project for a Scientific Psychology," memory-motive structures are neural programs located in the core portions of the brain that gain access to awareness by their connections to the cortex, which determines whether a memory-motivated wish comes to consciousness. When the neural program becomes a secondary process it comes under voluntary control, which involves reality testing and consciousness. To use language as an example, one may well know two languages but at any one time connect only one language to the cortex; thus the other language remains unconscious and voluntarily unexpressed.

The linking of reflective consciousness to the cortex is not as naive as it first appears. As recently reported cases have shown, blind-sight results when patients are subjected to unilateral removal of the visual cortex. Such patients insist that they cannot see anything in the field contralateral to their lesion, but, when tested, they can, by guessing, locate and identify large objects in their blind hemifield with remarkable accuracy. Furthermore, some patients have unilateral neglect after suffering parietal lobe lesions. Neglect patients can often get around by using their neglected limbs appropriately. A still different syndrome giving the same type of result was observed in a patient who sustained an amygdala-hippocampal resection; when he was trained in operant tasks the effects of the training persisted without decrement for years, despite protestations from the patient that he did not recognize the situation and that he remembered nothing of the training. Monkeys with such lesions have shown almost perfect retention of training after a two-year period, and the retention was better than that shown by controls. Those monkeys and the blind-sight patients are clearly conscious in the medical instrumental sense. What went wrong was their ability to reflect on their behavior and experience, an inability within the impaired sphere of clearly distinguishing personal from extrapersonal reality. They were left with impaired consciousness in the philosopher's sense: Behavior and experience were no longer intentional.

The thrust of most recent thinking by psychoanalysts and experimentalists is in the direction of interpreting the conscious-unconscious distinction in the philosophical sense. For instance, Ignacio Matte Blanco proposed that consciousness be defined by the ability to make clear distinctions, to identify alternatives. Making clear distinctions includes being able to tell personal reality from extrapersonal reality. By contrast, unconscious processes, according to Matte Blanco, are composed of infinite sets "where paradox reigns and opposites merge into sameness." When infinities are being computed the ordinary rules of logic do not hold. Thus dividing a line of infinite length results in two lines of infinite length—that is, one = two. Being deeply involved allows love and ecstacy but also suffering and anger to occur. In keeping with this, Carl Gustav Jung defined unconscious processes as those involving feelings. Bringing the wellsprings of behavior and experience to consciousness means making distinctions, providing alternatives, making choices, becoming informed in the sense of reducing uncertainty.

Unconscious processes as defined here are thus not completely submerged and unavailable to experience. Rather, unconscious processes produce feelings that are difficult to localize in time or in space and difficult to identify correctly. The unconscious processes construct the emotional dispositions and motivational context within which extrapersonal reality and personal reality are constructed. As the classic experiments of Seymore Schachter and Jerome Singer showed, feelings are to a large extent undifferentiated; people tend to know and label them according to the circumstances in which the feelings were manifested.

It is in this sense that behavior comes under the control of the unconscious processes. When people burst out in anger, they are aware that they have done so and are aware of the effects of the anger on others. They may or may not have attended the buildup of feeling before the blowup. And they may have projected the buildup onto others or introjected it from them. But they could have been aware of all that (with the guidance of a friend or a therapist) and still found themselves in uncontrolled anger. Only when the events leading to the anger become clearly separated into alternative or harmoniously related distinctions is unconscious control converted into conscious control. People with obsessions or compulsions are aware, in the instrumental sense, of their experience or behavior, and they feel awful. But they cannot, without aid, cope, that is, differentiate controls on the behavior generated by their feelings.

Cerebral dominance and the unity of consciousness As noted above, the topic of hemispheric specialization is currently fashionable not only in the behavioral neurosciences but also among the public at large. Three important discoveries fueled this interest. First, the rediscovery during the latter half of the 19th century of the fact that, in most right-handed persons, speech is controlled by the left hemisphere. That fact was already known to Hippocrates and may well have been learned by him from the Egyptians. Running from back to front, comprehension, grammar, and fluency are affected by lesions centering on the sylvian fissure. But dominance is not as complete in women as it is in men, nor is it pervasive in cultures that do not use phonemic writing.

Second, what is new in the appreciation of hemispheric specialization is the realization that the non-speech-dominant hemisphere has its own characteristic modes of processing. The left hemispheres of right-handed persons being taken over by an aural-oral dimension may have been due to the fact that the right hemisphere was used by primates to process visual-spatial relations leaving the right hand free for further manipulations. *Spatial* here means the space defined by the body in motion—egocentric and allocentric, as differentiated from occulocentric and object-centered spaces.

These specializations in processing modes refer primarily to the semantic and syntactic aspects of language. With regard to the emotional tone of language (prosody), right-sided frontal lesions result in monotone speech. Right-sided posterior lesions leave the patient unable to understand those aspects of communication that depend on intonation and emphasis (these syndromes are known as "aprosodias").

The third and most pervasive and persistent focus of interest has been a theme that also organized a debate regarding localization of function in the 19th century: the unity of consciousness. When the corpus callosum was severed in patients who had suffered severe unilateral epileptic seizures to prevent the involvement of the healthy hemisphere, testing revealed that what was sensed by the right hemisphere could be expressed only nonverbally by that hemisphere. The left, verbal, hemisphere appeared to be ignorant of what had transpired. It seemed as though consciousness had been split when the hemispheres were sundered. The assumption that there is ordinarily a unity to consciousness received support in that this unity had been ruptured.

These observations led to the conception that civilization suffers from left-brain dominance and that training for brain balance would restore balance to civilization. Of course, that is pure rot. All but the most rudimentary processing involves both hemispheres, as innumerable studies have demonstrated. Even in language, the appreciation and the expression of emotional communication involves the right hemisphere, and extreme specialization is limited to right-handed men raised in a phonemic literary environment.

Although the popular overgeneralization is to be deplored (as is the overgeneralization that led to phrenology), the original observations did renew interest in the question of whether consciousness can be divided. Sir John Eccles has argued that consciousness is tied to language, an argument also made by Freud, and that the right, speechless, hemisphere is essentially unconscious. However, the right hemisphere clearly communicates with left-handed, nonverbal instrumental responses to the input presented to it. The nonverbal hemisphere obviously has a mind of its own. But conscious minding is of two sorts: instrumental and intentional. Eccles's proposal is tenable if what is meant is intentional consciousness. Brain facts as they relate to behavior, mind, and consciousness often spring surprises on the unwary.

VARIETIES OF CONSCIOUS EXPERIENCE

OBJECTIVE CONSCIOUSNESS

Posterior cerebral convexity Surrounding the major fissures of the primate cerebral cortex lie the terminations of the sensory and motor projection systems. These systems have been labeled extrinsic because of their close ties (by way of a few synapses) with peripheral structures. The sensory surface and the muscle arrangements are mapped more or less isomorphically onto the perifissural cortical surface by way of discrete, practically parallel lines of connecting fiber tracts. When a local injury occurs within these systems, a sensory scotoma or a scotoma of action ensues. A *scotoma* is a spatially circumscribed hole in the field of interaction of the organism and the environment—for example, a blind spot, a hearing defect limited to a frequency range, or a section of the skin where tactile stimuli fail to elicit a response. Those are the systems where what Henry Head called epicritic processing takes place. The extrinsic sensory-motor projection systems are so organized that movement allows the organism to project the results of processing away from the sensory and muscular surfaces where the interactions take place and out into the world external to the organism, much as a stereo effect is obtained by adjusting the phase between the output of two speakers. Processing within the extrinsic systems constructs an objective reality for the organism.

In between the perifissural extrinsic regions of the cortex lie other regions of the cortex variously named association cortex, uncommitted cortex, and intrinsic cortex. These names reflect the fact that there is no apparent direct connection between peripheral structures and those regions of the cortex that make up most of the convexity of the cerebrum.

Corporeal reality and extracorporeal reality Lesions of parts of the intrinsic cortex of the posterior cerebral convexity result in sensory-specific agnosias in both monkeys and humans. Research on monkeys has shown that the agnosias are due not to a failure to distinguish cues from one another but a failure to make use of those distinctions in making choices among alternatives. The ability to make use of those distinctions is the essence of information processing in the sense of reducing uncertainty. The sensory-specific posterior intrinsic cortex determines the range of alternatives, the sample size that a particular informative element must address. A patient with agnosia can tell the difference between two objects but does not know what the difference means. As Charles Peirce once noted, what people mean by something and what they mean to do with it are synonymous. In short, alternatives, sample size, choice, cognition, information, and meaning are closely interwoven concepts. When agnosia is severe, it is often accompanied by what is termed neglect. The patient appears not only not to know that he does not know but to actively deny the agnosia.

Typical is a patient who repeatedly had difficulty in sitting up in bed. Her physician pointed out to her that her arm had become entangled in the bedclothes. She acknowledged that fact momentarily, only to "lose" that arm once more in a tangled environment. Part of her perception of her body, her corporeal consciousness, seemed to have been extinguished.

Such observations can readily be conceptualized in terms of an extracorporeal and corporeal *objective* reality. For a time it was thought that corporeal (egocentric) reality (personal body space) depended on the integrity of the frontal intrinsic cortex and that the posterior convexal cortex was critical to the construction of extracorporeal (allocentric) reality. That scheme was tested in experiments with monkeys and human patients and was found wanting. In fact, the corporeal-extracorporeal distinction involves the parietal cortex. Perhaps the most clear-cut example comes from studies showing that cells in the parietal cortex respond when an object is within view but only when it is also within reach. In essence, studies have been unable clearly to separate the brain locations that produce agnosia from those that produce neglect. Furthermore, the studies indicate that agnosia is related to meaning as defined by corporeal use.

In monkeys the disturbances produced by restricted lesions of the convexal intrinsic cortex are also produced by lesions of the parts of the basal ganglia (implicated in activation, selective readiness) to which those parts of the cortex project. That finding takes on special meaning from the fact that lesions of the thalamus (which controls the relaying of sensory input to the cortex) fail to produce such effects. The special connection between the posterior intrinsic (association) cortex and the basal ganglia further clarifies the intentional process that those systems make possible—the distinction between an objective egocentric corporeal self (the me) and an extracorporeal allocentric reality (the other).

NARRATIVE CONSCIOUSNESS

Frontolimbic forebrain Frontal lesions were produced for a time in an effort to relieve intractable suffering, compulsions, obsessions, and endogenous depressions. When effective in pain and depression these psychosurgical procedures portrayed in humans the now well-established functional relation between the frontal intrinsic cortex and the limbic forebrain in nonhuman primates. Furthermore, frontal lesions can lead either to perseverative, compulsive behavior or to distractibility in monkeys and in humans depending on environmental circumstance. A failure to be guided by the consequences of their behavior can account for both effects. Extreme forms of distractibility and obsession are due to a lack of sensitivity of the activation (selective readiness) process to feedback from consequences. Both the results of experiments with monkeys and clinical observations attest to the fact that those with frontal lesions—whether surgical, traumatic, or neoplastic—fail to be guided by the consequences of their behavior.

Consciousness as conduct and narrative *Consequences* are the outcomes of behavior. In the tradition of the experimental analysis of behavior, consequences are reinforcers that influence the recurrence of the behavior. Consequences are thus a series of events (Latin *ex-venire*, out-come), outcomes that guide action and thereby attain predictive value (as determined by confidence estimates). Such con-sequences—that is, sequence of events—form their own confidence levels to provide contexts that, in humans, become envisioned event-ualities.

Confidence implies familiarity. Experiments with monkeys and humans have shown that repeated arousal to an orienting stimulus habituates—that is, the orienting reaction gives way to familiarization. Familiarization is disrupted by limbic (amygdala) lesions and frontal lesions. Ordinarily, familiarization allows continued activation of selective readiness; disruption of familiarization leads to repeated distraction (orienting) and thus a failure to allow con-sequences to form. When the process of familiarization is disrupted, the outcomes-of-behaviors, events, become inconsequential. When intact, the familiarization process is segmented by orienting reactions into episodes within which confidence values can become established.

In such an episodic process the development of confidence is a function of coherences and correlations among the events being processed. When coherence and correlation span multiple episodes, the organism becomes *committed* to a course of action (a prior intention, a strategy), which then guides further action and is resistant to perturbation by particular orienting reactions (arousals). The organism is now *competent* to carry out the action (intention-in-action, tactic). Particular outcomes now guide competent performance; they no longer produce orienting reactions. In humans coherent competence provides the basis for ethical behavior. Thus in several languages the meaning of consciousness and conscience are conflated.

The cascade that characterizes episodic processing leads ultimately to considerable autonomy of the committed competence. Envisioned events are woven into coherent subjectivity, an "I," whose story is a narrative, the myth by which the person lives. The narrative composes a practical guide to action in achieving (temporary) stability in the face of a staggering range of variations of events.

Consciousness is manifest (by verbal report) when familiarization is perturbed, when an episode is updated and incorporated into a larger contextual scheme (the narrative) that includes both the familiar episodes and the novel episodes. Consciousness becomes attenuated when actions and their guides cohere; the actions become skilled, graceful, and automatic.

TRANSCENDENTAL CONSCIOUSNESS The contents of consciousness are not exhaustively described by the *qualia* of feelings of familiarity and novelty that are the basis for episodic and narrative consciousness nor by those of extracorporeal allocentric and corporeal egocentric consciousness. The esoteric tradition in Western culture and the mystical traditions of the Far East are replete with instances of uncommon states that produce uncommon contents. Those states are achieved by a variety of techniques, such as meditation, yoga, and Zen. The contents of processing in such states appear to differ from ordinary feelings and perceptions. Experiences are described as oceanic, a merging of corporeal reality and extracorporeal reality, or as out-of-body—that is, corporeal reality and extracorporeal reality continue to be clearly distinguished but are experienced by still another reality, a meta-me. Or an "I" that becomes transparent: a throughput experiencing everything everywhere; there is no longer the segmentation into episodes; nor do events become enmeshed in a narrative structure.

All these experiences have in common a transcendental relation between ordinary experience and an encompassing organizing principle. That relation is ordinarily termed "spiritual." The spiritual contents of consciousness can be accounted for by the effects of excess excitation of the frontolimbic forebrain (ordinarily involved in narrative construction) on the dendritic microprocess that characterizes cortical receptive fields in the sensory extrinsic systems (ordinarily involved in the construction of objective reality).

In addition to the gross topological correspondence between cortical receptive fields and the organization of sensory surfaces that gives rise to the overall characteristics of processing in the extrinsic systems, a microprocess that depends on the internal organization of each receptive field comes into play. The internal organization of receptive fields embodies, among other characteristics, a spectral domain: receptive fields of neurons in the extrinsic cortex are tuned to limited bandwidths of frequencies of radiant energy (vision), sound, and tactile vibration.

The most dramatic data are those that pertain to vision. The cortical neurons of the visual system are arranged, as are the other sensory systems, so as to reflect more or less isomorphically the arrangement of the receptor surfaces to which they are connected. (Thus, the homunculi that Wilder Penfield and others have mapped onto the cortical surface of the extrinsic projection systems.) However, within that gross arrangement lie the receptive fields of each of the neurons—a receptive field determined by the dendritic arborization of the neuron that makes contact with the peripheral parts of the system. Thus, the receptive field of a neuron is that part of the environment processed by the parts of the system to which the neuron is connected. Each receptive field is tuned to approximately an octave of spatial frequency. The frequency-selective microprocess thus operates in a holographiclike manner.

Processing can be conceived to function somewhat like the production of music by a piano. The sensory surface is analogous to a keyboard. The keyboard and the strings are spatially related to provide the overall organization of the process. When individual strings are activated, they resonate over a limited bandwidth of frequency. The combination of the spatial arrangement and the frequency-specific resonance of the strings makes the production of music possible.

The gross organization and the microorganization of the cortical neurons in the extrinsic systems resemble the organization of a multiplex hologram. A multiplex hologram is characterized by a Gabor elementary function, which Dennis Gabor called a quantum of information. A Gaussian envelope constrains the otherwise unlimited sinusoid described by the Fourier transform to make up the Gabor function. Experiments have shown that electrical excitation of the frontal and limbic structures relaxes the Gaussian constraints that are manifested as inhibitory surrounds or flanks in the receptive field architecture. When the relaxation of the constraint is moderate as during ordinary excitation of the frontolimbic systems of the forebrain, processing leads to narrative construction. When frontolimbic excitation becomes overwhelming, experience is determined by a totally unconstrained holographic process.

Holograms of the type involved in brain processing are composed by converting (for example, by Fourier transformation) successive sensory images (for example, frames of a movie film) into their spectral representations and patching the microrepresentations into orderly spatial arrangements that represent the original temporal order of the successive images. When such conversions are linear (as when they use the Fourier transform), they can readily be reconverted (for example, by the inverse Fourier transformation) into moving (successive) sensory images. The spectral domain is peculiar in that information (in the Gabor sense) becomes both distributed over the extent of each receptive field (each quantum) and enfolded within it. Thus sensory-image reconstruction can occur from any part of the total aggregate of receptive fields. That gives the aggregate its holographic, holistic aspect. All input becomes distributed and enfolded, including the dimensions of space and time and, therefore, causality. That apparently timeless-spaceless-causeless aspect of processing, which can be instigated by overwhelming frontolimbic excitation, is responsible for the extrasensory dimensions of experience that characterize the esoteric traditions.

Because of their enfolded property, these processes tend to swamp distinctions, such as corporeal reality and extracorporeal reality. In the esoteric traditions consciousness is not limited to that type of reality.

A related development (because it deals with the specification of an encompassing, cosmic order) has occurred in quantum physics. Over the past 50 years it has become clear that there is a limit to the accuracy with which certain measurements can be made when other measurements are being taken. The limit is expressed as an indeterminacy. Gabor, in his description of a quantum of information, showed that a similar indeterminacy describes communication, thus leading to a unit of minimum uncertainty, a limit on the maximum amount of information that can be packed for processing. As a consequence there is a convergence of the understanding of the microstructure of communication—and, therefore, of observation—and the understanding of the microstructure of matter. The need to specify the observations that lead to inferring the properties of matter has led noted physicists to write a representation of the observer into the description of the observable. Some of those physicists have noted the similarity of that specification to the esoteric descriptions of consciousness.

A revolution in Western thought is therefore in the making. The scientific tradition and the esoteric tradition have been at odds since the time of Galileo. Each new scientific discovery and the theory developed from it have, up until now, resulted in the widening of the rift between objective science and the subjective spiritual aspects of human nature. The rift reached a maximum toward the end of the 19th century: people were asked to choose between God and Charles Darwin, and Freud showed that heaven and hell reside within people, not in their relation to the natural universe. The discoveries of 20th century science do not fit that mold. For once, the recent findings of science and the spiritual experiences of humanity are consonant. That augurs well for the coming millennium. A science that comes to terms with the spiritual nature of humanity may well outstrip the technological science of the immediate past in its contribution to human welfare.

SUGGESTED CROSS-REFERENCES

Neuroanatomy is discussed in Section 1.2, electrophysiology in Sections 1.7 and 1.8, perception and cognition in Section 3.1, psychoanalysis in Section 6.1, and psychosurgery in Section 31.27.

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