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BRAIN

BRAIN AND SPINAL CORD. The brain is one of the most important parts of our body. It enables us to think and to be aware of our surroundings. When we relate to others, memories stored in the brain affect those relationships. When we become emotionally upset, it is because the brain's control over bodily functions has been stressed beyond its capacity. The brain is also capable of some strange things. It permits, for example, a person to experience phantom pain where an amputated limb once was. Drugs and surgery of the nerves leading to the brain often cannot remove traces of the phantom. Only brain surgery will eliminate it. The human brain regulates all the functions associated with human behavior. Moreover, this remarkable organ is formed from about 1,500 cc of nerve tissue having the consistency of dessert gelatin. In some ways, the brain is like a computer, although it is more intricately organized than the most complicated electronic computer (see Computers). Nerves carry signals from the eyes, ears, and other sense organs and from body receptors to the brain.

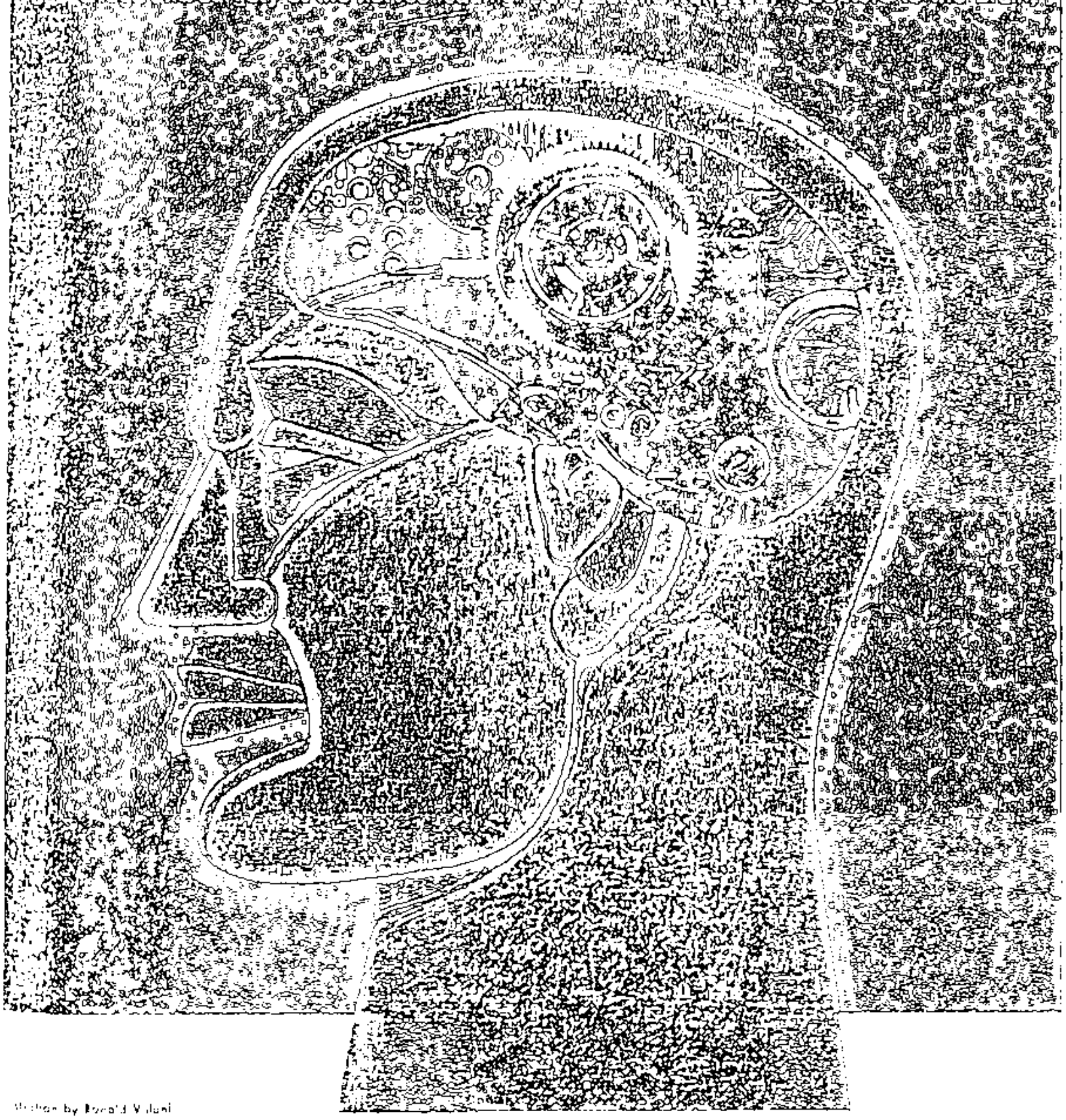
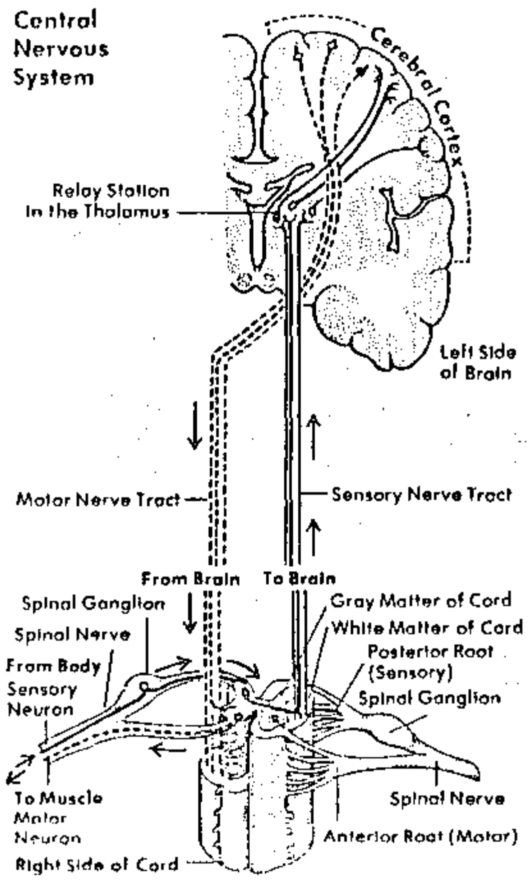


Photo by Ronald Viloni



Impulses travel up the spinal cord from sense organ to brain for processing and then back to a muscle for action.

a central control mechanism with tremendous memory storage capacity. On the basis of these input signals, computations are made in the brain and output signals are sent to effectors—muscles and glands—to carry out the behavior needed for survival, communication, or creative effort. Brain signals are electrical nerve impulses that are organized into patterns in somewhat the same way that the letters of the alphabet are organized into words and sentences (*see* Nerves).

The Nervous System

Biological information is processed in the central nervous system (CNS), which consists of the brain and the spinal cord. The nerve network in the CNS carries nerve signals to and from the brain and between its sections. The spinal cord is an elongated tube made of nerve tissue lying in the bony spinal column. The cord extends into the head through a large hole at the base of the skull. Inside the head the tube forms the brain stem, which in turn is capped at its uppermost end by the cerebrum—two mushroomlike hemispheres that make up the largest mass of human brain tissue.

The nerves that carry input signals to the CNS for processing are afferent nerves and those carrying output signals from the CNS are efferent nerves. The nerves connected directly to sense organs and receptors are sensory nerves, and those connected to muscles and glands are motor nerves. A special category of motor nerves belongs to the autonomic nervous system, which is connected to but somewhat independent of the CNS. Autonomic nerves regulate the muscles and glands that carry on vital processes such as breathing, blood circulation, and digestion. The autonomic nervous system, arranged on the outside of the spinal cord, is so named because the body's vital functions are greatly self-regulated and require only occasional adjustment by the CNS.

Homeostatic Regulation

Scientists once believed that all afferent, or input, nerves were sensory and that all efferent, or output, nerves were motor. This belief led to an overly simple view of how the nervous system works. Information from the outside world was thought to be processed through a reflex arc: input data→ central control mechanism→ output action. Recently, however, scientists discovered a new group of efferent nerves that carry information *from* the CNS to the sense organs and receptors, instead of the other way around. This means that when a person senses something from the outside, his brain has an influence on that sensation. For example, if you are willing to be tickled, you can be made to laugh and writhe, but if you are not willing to be tickled, you experience only touch, pressure, or even pain. For you to experience tickling, you have to be convinced through words and gestures to play along. Similarly, the touch of someone you love feels different from anyone else's. Furthermore, many scientists believe that pain is a type of selective control mechanism that alters the "setting" on the nerve cells in the spinal cord that receive sensory input from the skin, muscles, and internal body organs. In other words, a person's attitude could have an effect over the amount of pain experienced.

Discovery of efferent nerves to sense organs and receptors forced a revision of the reflex-arc idea. The nervous system is now thought to work in the same way that a wall thermostat controls a furnace. The thermostat has a number of temperature settings on its dial. Moving the dial changes the distance between two pieces of heat-sensitive metal in the thermostat. When warmed, they expand and make contact with each other. The contact closes an electrical circuit that stops the furnace. When the temperature drops, the metal contracts, the contact is broken, and the furnace starts. The entire system relies on a receptor mode of control; that is, the furnace is not controlled by a manual switch but by a

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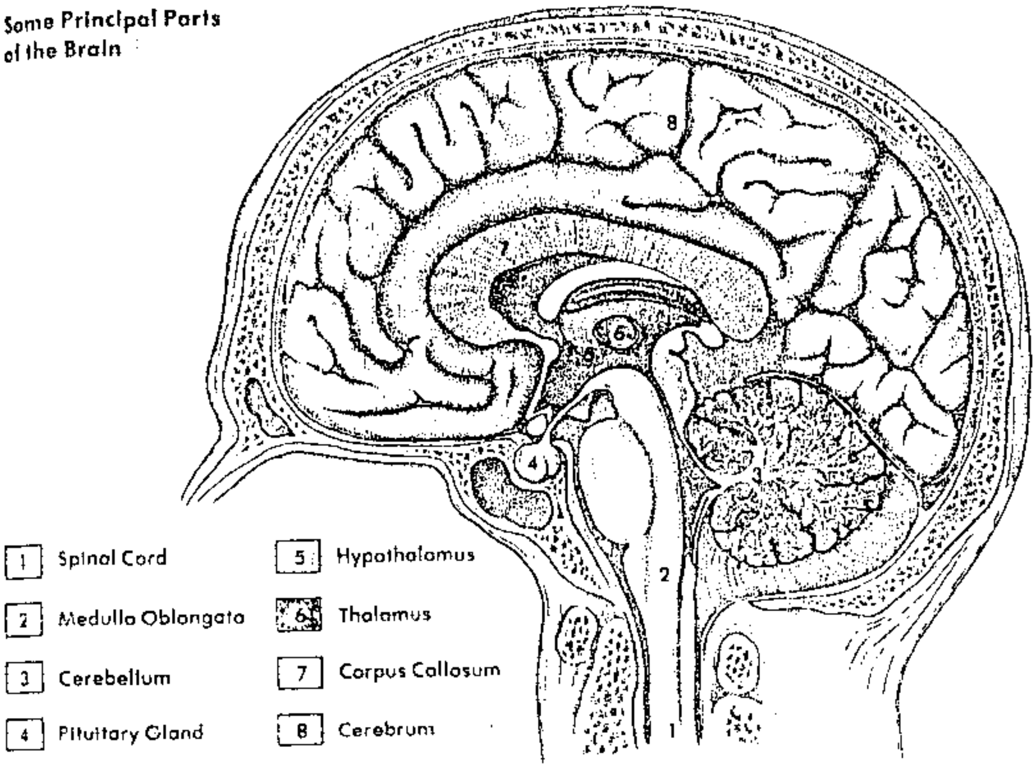
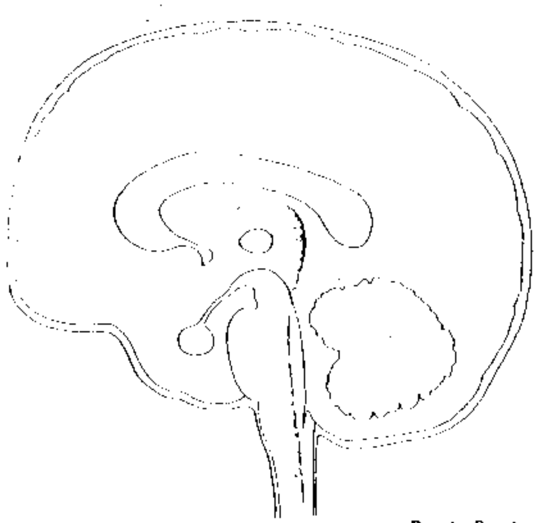
Some Principal Parts of the Brain



1. Spinal Cord—conducts nerve impulses to and from brain
2. Medulla Oblongata—contains regulators that control such basic functions as breathing and blood flow
3. Cerebellum—involved in coordinating muscle actions
4. Pituitary Gland—"master" gland that controls activities of many other endocrine glands
5. Hypothalamus—regulates many body actions, including sex functions, hunger and thirst, and body temperature; influences pituitary gland
6. Thalamus—"switchboard" of brain that relays sensory nerve impulses to cerebral cortex
7. Corpus Callosum—links both hemispheres of cerebrum
8. Cerebrum—"thinking" portion of brain where complex associations occur



[ ] Limbic System

Limbic System—mediates basic body functions, such as breathing, digestion, heartbeat, biological rhythms, and sex functions; also processes memory; includes the hypothalamus and portions of the basal ganglia and of the thalamus

[ ] Reticular Activating System

Reticular Activating System—triggers "awareness," or acute consciousness; includes core of brain stem and portions of the thalamus and hypothalamus

Basic Systems of the Brain

thermostatic receptor that responds to changes in room temperature.

In the same fashion, the brain controls the way a person responds to environmental changes by sending information that changes the "settings" on his receptors. Homeostatic regulation, as this is called, allows for economic memory storage. In the furnace analogy, a person need not consult a long and involved checklist showing when to turn the furnace on and off to maintain constant room temperature when the weather is changing. He only has to set a temperature from the short list of set-point numbers engraved on the thermostat dial. In a similar fashion, "lists" of informative features of the environment can be stored in the brain and called for when needed.

Brain Homeostats Regulate Vital Functions

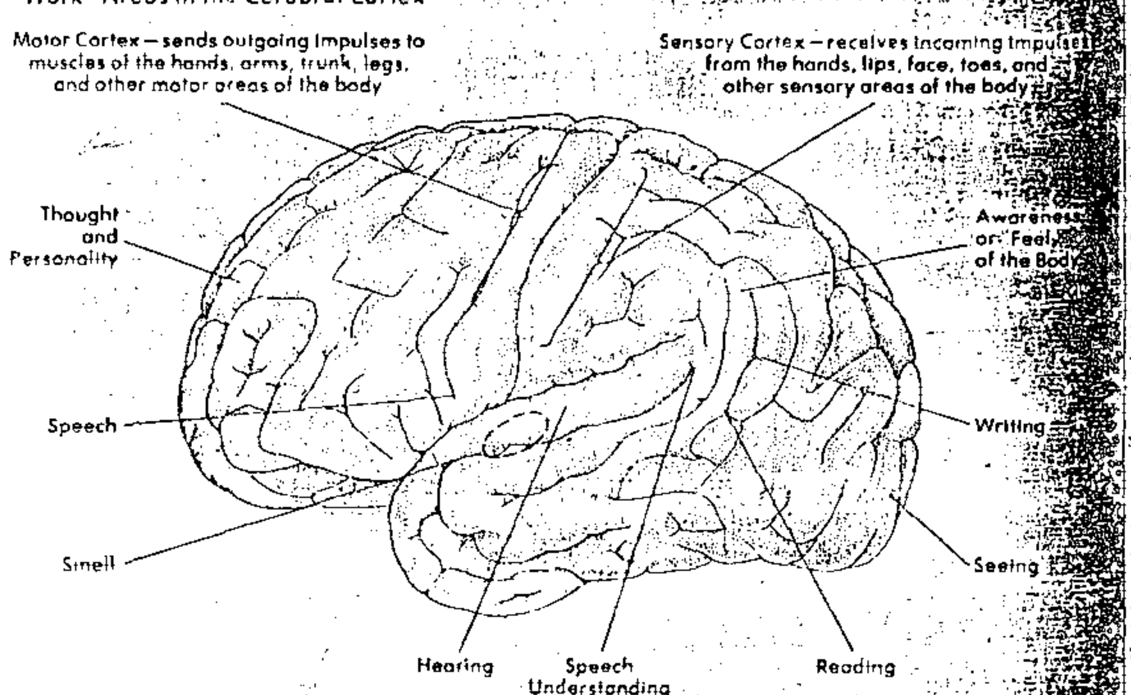
Nerves are the information-processing homeostats of the brain and its stem. Each neuron, or nerve cell, in the nervous system consists of a cell body and wirelike "tentacles" that sometimes reach three feet in length. Masses of nerve cells have a grayish color. They form the gray matter of the brain, brain stem, and spinal cord. Gray matter accumulations are called nuclei or centers because they contain many nerve connections. When they are spread out in thin sheets, however, they are called cortex. By contrast, masses of nerve trunks look white because they contain myelin, a fatty insulating material. Nerve trunk accumulations are called tracts or pathways. In the spinal cord and brain stem, gray matter lies in the center, surrounded by white matter. In the cerebral cortex, however, gray matter lies on the outside.

Many of the nervous system's most vital regulatory functions are carried out by homeostatic centers in the brain stem. The homeostat that regulates breathing, for example, is in the medulla oblongata, the hindbrain just above the area where the spinal cord extends into the skull.

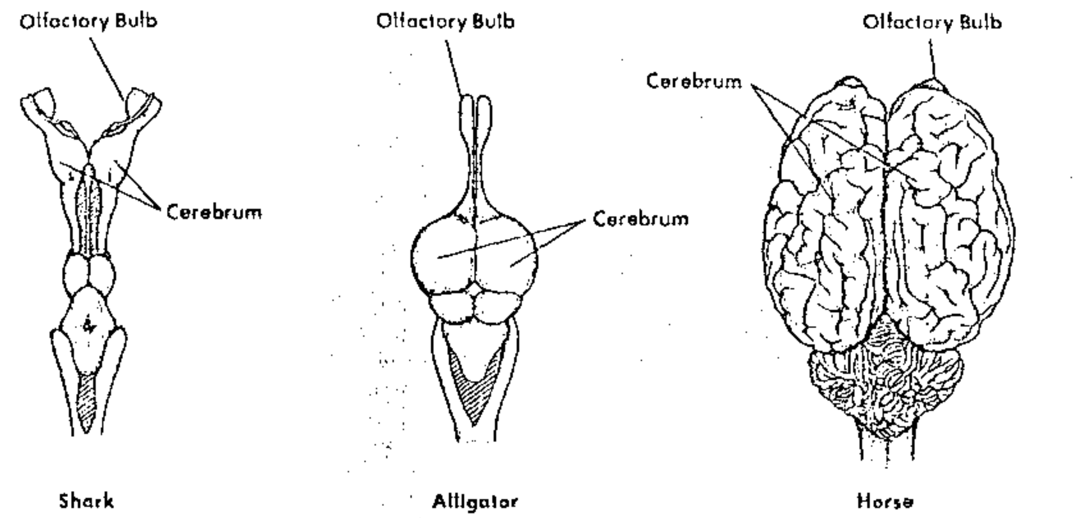
The homeostats that regulate sleep and wakefulness are located in the mesencephalon, or midbrain, which is slightly in front of the medulla but is still part of the brain stem. These homeostats also control such moods as elation and depression. Moods are influenced by body chemicals acting on receptors in the midbrain. Many of these chemicals are secreted by nerve endings to improve communication between nerves at their synaptic points of contact, which appear well-developed in the midbrain. Drugs that influence the mood-regulating homeostats are widely used in psychiatry to ease manias and depressions.

Still further forward in the brain stem lies another series of homeostats packed closely together in the hypothalamus, which is part of the diencephalon, or between-brain. Homeostatic neurons in the hypothalamus regulate sex functions, hunger and thirst, body temperature, and general body activity. They regulate some of these activities through neurosecretions, or nerve-cell chemicals, which make them glands as well as nerves. The neurosecretions di-

"Work" Areas in the Cerebral Cortex



Evolutionary Advances in the Size of the Cerebrum



...dging by the shark's large olfactory bulbs, smell is very ...portant to its survival. The cerebrum, associated with advanced behavior, is larger in the alligator; and in the horse and other mammals it outshadows the rest of the brain.

...tly influence the pituitary gland, the body's "mas...er" endocrine gland that lies immediately under the ...ypothalamus (*see* Hormones).

The brain's thalamus lies just above the hypothalamus. It receives and processes information from ...ceptors and sense organs through pathways in the ...wer brain stem and in the spinal cord. By con...ast hypothalamic, midbrain, and hindbrain mech...anisms process information only from inside the body.

Sensory and Motor Functions of the Brain

The back portion of the thalamus is the last ...tation reached by information from the body sur...face before it is relayed to the cerebral cortex for ...rocessing. Information about touch, pressure, pain, ...nd muscle and joint senses merges in the thalamus. Information that leads to seeing and hearing is also ...rocessed by thalamic nuclei. Afferent-efferent con...nections between the thalamus and the cerebral cortex ...orm a two-way street that closely coordinates their ...ctions.

The most forward part of the brain stem contains ...group of structures called the basal ganglia. They ...egulate muscle-control homeostats by adjusting the ...et points of those homeostats. Diseases of the basal ganglia produce muscle tremors and severe and un...controllably repetitive movements. In addition, evi...dence suggests that all homeostatic mechanisms are influenced by the basal ganglia.

The cerebellum is another structure intimately involved in movement control. It is an outgrowth of the balancing mechanism that has receptors in the inner ear (*see* Ear). Although it was originally in...volved only with inner-ear balance, the cerebellum eventually evolved a large cortex in man and other primates to help compute trajectories required for jumping from tree to tree or the many other complex movements primates can perform. Computations by the cerebellum are sent through the thalamus to movement homeostats in the cerebral cortex. Information from the basal ganglia also adjusts the set points of the movement homeostats. Thus, once an activity has begun, information from the cerebellum continuously fine-tunes, or redefines, the set points until the activity is completed.

The Cerebral Cortex

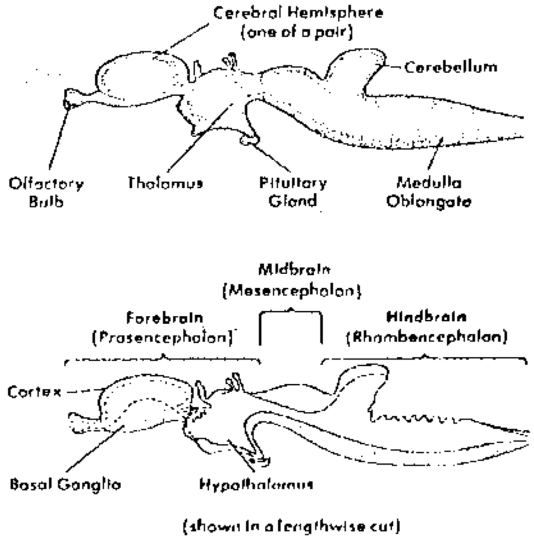
The uppermost part of the brain—composed of the cerebral hemispheres—is also the most dominant part. The cortex of the cerebral hemispheres is hooked up with the other parts of the brain. It receives information relayed through the thalamus. In turn, the cortex controls its input by transmitting signals through efferent fibers to the thalamus and points below. Furthermore, it is closely linked with the cerebellum and the basal ganglia. As a matter of fact, the cerebral hemispheres develop in the embryo from nerve cells that migrate from the basal ganglia.

An intriguing riddle about the cerebral cortex is how it retains most of its powers of perception and memory after it is extensively damaged. Brain tumors and strokes hardly alter these powers as long as a critical mass of brain tissue is not destroyed. This is also true of epileptic scarring, which makes nerve cells in the brain fire convulsively instead of in a tightly organized way. A person who suffers a stroke—the leakage or blockage of a blood vessel in the brain—might lose three fourths of the visual area of his brain. As a result, he would experience a hole in his visual field, that is, he would be unaware of the objects or scenes occurring in the blocked-out visual surroundings. But with the remaining quarter of his visual field, he would continue to experience all he already knew; that is, he would not suffer a proportional three-quarters loss of memory. He would come home to a family of four and recognize all and not just one member.

In their search for the way the brain stores memories, brain scientists have uncovered a possible explanation of the memory riddle. Perhaps information becomes distributed in the sensory systems in much the same way that information is stored in holograms. Holograms are interference patterns of light on film (*see* Color; Laser and Masers). Although they bear no images, three-dimensional images can be reconstructed from the interference patterns. Like the brain's visual system, holograms can be damaged extensively and yet produce a complete image from what remains. Holograms share other information storage properties with the brain, such as vast capacity, ease of information retrieval, and cross-correlation of input information.

The cerebral cortex is divided into a number of areas. Some are hooked up with peripheral sensory-motor and core homeostatic mechanisms. Others are involved with advanced behavior. For many years, scientists thought that the cerebral cortex was organized as a reflex-arc pathway. Sensory information, according to this belief, was sent to the sensory areas of the cortex, was then associated and abstracted in the association cortex, and finally was sent from the motor cortex to the muscles and glands. Recent data suggest, however, that the sensory areas of the cortex—those that receive information from sensory receptors—can effectively guide behavior even when completely isolated from the rest of the cortex. Also, the motor areas of the cortex—those that trigger muscle contractions when electrically stimulated—primarily process information coming from muscle receptors and then use this information to alter the set points of those and other receptors. Furthermore, the association cortex can to some extent by altering or filtering sensory input, perhaps through the basal ganglia, enabling attention to be given to one or more sources of sensory information. By studying electroencephalograms, or brain wave recordings, scientists can determine whether a monkey, for instance, is attending to the color or to the pattern of a cue with several components even before the monkey outwardly reacts to one or the other.

The Developing Brain



Key parts and major divisions of a vertebrate embryo's brain are shown above at an early stage of development. Technical names of the three major divisions are in parentheses.

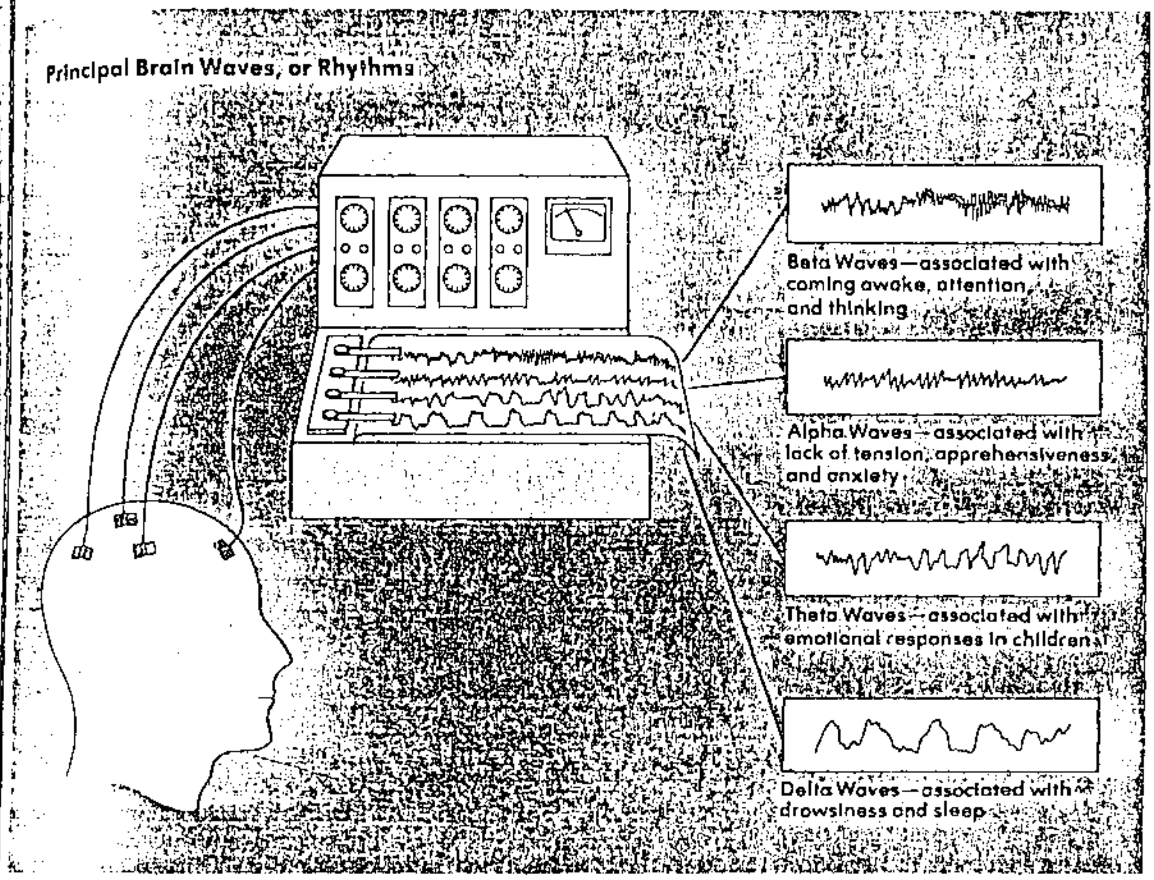
Experiments such as this suggest that what we see, hear, feel, and perceive is determined by homeostatic brain processes, as are the bodily functions. The central processing of these experiences, however, requires afferent-efferent neural loops that are longer and encompass larger masses of brain tissue than those involved in the bodily functions. Much of the central organization relies on interaction between the cerebral cortex and the lower parts of the brain and the spinal cord, rather than solely on reflex-arc action between areas of the cortex.

The reticular core of the brain stem is one of the most effective places for input control. The chemical receptor sites that regulate sleep and wakefulness, alertness, and elation and depression are found there. These core brain stem sites, in turn, influence visual, auditory, and somatic sensory input as it enters the spinal cord and brain stem. For example, it is more difficult for a person to pay attention to something when he is tired than when he is rested and alert.

We can envision the cerebral cortex as being broadly organized along two intersecting axes. The outer cortex lies along the first axis. The front part of it deals with motor action, while the back part deals with sensory input. The outer cortex is involved with the "world out there," including such memory functions as recognizing persons and places and remembering motor skills. The limbic cortex, or the side-to-side core portion, lies along the second axis. It deals with information from the "world within." The limbic cortex is involved with such memory functions as recalling familiar as well as unique experiences, for memories are tied in with our vital functions.

The Brain and Human Language

The two axes of the cerebral cortex intersect in the portion that receives and sends information to the ears, mouth, tongue, and throat. This is also the center of the human language control mechanism. Scientists have wondered what quality of the human brain provided for the development of language. One hint comes from the unique ability of each of the human cerebral hemispheres to control different information-processing systems. The right hemisphere deals largely with spatial relationships, musical abil-



Brain wave recordings are made by an electroencephalograph. Recordings of the principal brain waves are shown above. Subjects of "biofeedback" experiments try to maintain a steady output of alpha waves, which indicate a calm state of mind.

ties, and other nonverbal functions. The left hemisphere processes linguistic information. In all mammals, each hemisphere receives information from and controls the opposite side of the body. Signals to move the right hand, for example, come from the left cerebral hemisphere. Only in man, however, has specialization proceeded to the point where an all-important function such as speech is localized almost exclusively in the left hemisphere. Speech specialization is not present from birth, however. A child who has had surgery or injury to his left hemisphere before the age of seven ordinarily recovers all his language abilities, which then become localized in the right hemisphere.

Anyone reared in total isolation from other people does not develop the organization of sounds and gestures that constitutes language. The observations that hemispheric specialization develops slowly over years and that an isolated brain does not produce a language suggest that the human brain gradually becomes programmed. Other animals, such as the birds, have "wired-in" programs that guide behavior with little change from birth (*see* Animal Behavior). In humans, the strings of nerves that make up "lists" of variable length can influence each other to produce programs much as computer languages produce computer programs. Future research should uncover exactly how the information contained in the lists of homeostatic mechanisms becomes processed into human language. (*See also* Computers; Language; Learning; Nerves.)

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