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Brain.

An assembly of neurons in the head that regulates behavior. An animal is a collective of cells (see CELL, biology) that moves through its environment to eat and avoid being eaten, in competition to reproduce itself. Within each collective are specialized cells (see NEURON) that grow long threads from their cell bodies, which provide rapid communication within the collective to coordinate and control its movements. Each neuron has an axon and a dendritic tree. The axon transmits pulses as its signal to thousands of other neurons or to muscle or gland cells. The dendrites integrate the pulses from thousands of other neurons. Groups of neurons form ganglia in chains along both sides of the body axis from head to tail. The largest of these paired groups, the brain, is in the head where the nose, eyes and ears are located. These "distance receptors" respond to smells, sights and sounds coming so far from a collective, that it has time to receive the inputs, interpret them as signals, plan an action before being overtaken by circumstance, and act while monitoring and correcting its action. These are the minimal functions of a brain.

The power of a brain lies not in its size but in the complexity of the connections among its functional parts. For example, on average the brains of men (1,450 grams) are larger than those of women (1,350 grams), corresponding with a difference in average body mass but not with overall brain capacity, which does not differ.

Brain parts. The three main parts of the brain in vertebrates are the cerebrum (Latin meaning "head wax", which describes well the soft consistency of fresh brain tissue), the cerebellum ("little cerebrum"), and the brainstem that connects them with each other and with the spinal cord (Fig. 1). The two cerebral hemispheres are separated by a mid-line fissure that is bridged by a massive bundle of axons running in both directions, the corpus callosum (Fig. 2). Each hemisphere has a core of groups of neurons, the basal ganglia; an outer shell of neurons in layers, the cerebral cortex (Greek for "tree bark"); and massive bundles of axons for communication within the cerebrum and with the rest of the brain. These bundles are called "white matter" because of the waxy sheaths of the axons (see NEURON). Destruction of myelin by antibodies in an autoimmune reaction causes paralysis (see MULTIPLE SCLEROSIS) by progressive disconnection of brain parts.

Basal ganglia have three main groups. The thalamus receives axons from all sensory systems and transmits to cortex. It also receives feedback from cortical neurons during sensory processing. The corpus striatum ("striped body" due to bundles of axons cutting through the groups of neurons) also has two-way communication with cortex and assists in the organization of body movement. The hypothalamus receives orders from the cortex and accordingly organizes the chemical systems that support body movement. One output channel is hormonal by which it controls the pituitary gland (hypophysis) controlling the endocrine system. The other channel is neural by axons coursing through the brainstem and spinal cord to the motor neurons of the autonomic nervous system, which regulate the heart, blood vessels, lungs, gastrointestinal tract, sex organs, and skin. The autonomic and endocrine systems are largely self-regulating, but they are subject to control by the cortex through the hypothalamus.

Cortex is called "grey matter" because it contains the axons, cell bodies and dendrites of neurons but little myelin. An index of the capacity of a brain is cortical surface area. In higher mammals the cortical surface increases during fetal development so much faster than the volume that wrinkles form. The convexities (gyri) and fissures (sulci) vary in their details from one brain to another, but they are sufficiently reliable to serve as landmarks to subdivide the cerebral hemispheres into lobes.

Four lobes comprise the shell of each hemisphere (Fig. 3). The lateral sulcus separates the temporal lobe from the parietal and frontal lobes, which are divided by the central sulcus. The pre-central gyrus has the "motor cortex". Its neurons are arranged in a orderly pattern of connections to motor neurons in the brainstem and spinal cord that control the muscles. The post-central gyrus has the "somatosensory cortex". Sensory receptors in the skin, muscles and joints send messages there through relays in the spinal cord and thalamus. Each cortex provides a "map" of the opposite side of the body. The area for each body part is related to the number of its muscles or receptors, not to its size. Thus the areas for the lips, tongue, and fingers are far larger than those for the trunk and limbs. The temporal cortex receives input relayed through the thalamus from the ears to its "auditory cortex". The occipital lobe has the "visual cortex" that receives thalamic input from the eyes.

Association cortex. These primary sensory and motor areas are a small fraction of each lobe in humans. The occipital lobe has many specialized areas for recognizing patterns of color, motion, and texture. The parietal cortex has areas that support perception of the body and its surrounding personal space. The temporal cortex has areas that provide recognition of faces and of rhythmic patterns, including those of speech, dance and music. The frontal cortex provides the neural machinery for constructing patterns of motor behavior into the future (foresight), and for understanding the personalities of others (insight) as the basis for social behavior. The rapid enlargement of the frontal and temporal lobes in human evolution over the past half million years has supported the transcendence of humans over other species. Here is located the capacity to create works of art, and also to anticipate pain and death. Insight and foresight are both lost with frontal lobe damage (lobotomy).

Motor Systems. A small part of frontal lobe output goes directly to motor neurons in the brainstem and spinal cord for fine control of search movements by the eyes, head and fingers, but most goes either to the striatum from which it is relayed to the thalamus and then back to the cortex, or to the brainstem from which it is sent to the cerebellum and then through the thalamus back to the cortex. In the cerebellum the cortical messages are integrated with sensory input predominantly from the muscles and joints but also from the eyes and inner ears to provide split-second timing for rapid and complex movements. The cerebellum also has its cortex and its core of nuclei to relay input and output. Their connections, along with those in the cerebral cortex, are subject to modification with learning in the formation of working memory (the basis for learned skills). The predominantly closed form of the cortico-striatal and cortico-cerebellar loops indicate that they prepare movements prior to execution by imagination and mental rehearsal.

Limbic Lobe. The cerebellum and striatum do not set goals, initiate movements, store temporal sequences of sensory input, or provide orientation to the spatial environment. These functions are performed by parts of cortex and striatum deep in the brain (Fig. 3) comprising the limbic system. Its entry is the entorhinal cortex, which receives input from all of the sensory cortexes including the olfactory system, combines it, and sends it to the hippocampus, phylogenetically the oldest cortex in the brain. Here it is integrated over time. Hippocampal output goes back to the entorhinal cortex, which returns it to all of the sensory cortexes and up-dates them to expect new sensory input. It also goes to the hypothalamus and part of the striatum, the amygdaloid nucleus, for regulating emotional behavior. Bilateral damage to the hippocampus results in loss of short term memory. Damage to the amygdaloid nucleus causes serious emotional impairment.

Split Brain. Each hemisphere has its own limbic, cortico-thalamic, cortico-striatal, and cortico-cerebellar loops together with sensory and motor connections. When isolated by surgical section of the callosum, each hemisphere shows independent function, as though two persons occupied the same skull, but with differing levels of skills in abstract reasoning and language. The right brain ("spatial") / left brain ("linguistic") cognitive differences are largely due to pre-eminent development of the speech areas in the left hemisphere in both right- and left-handed persons. These are Broca's area in the frontal lobe and Wernicke's area in the temporal lobe (Fig. 3), in which damage leads to loss of the ability respectively to speak (motor aphasia) or to understand speech (sensory aphasia) from a loss of declarative memory for facts and words.

Brainstem controls. Groups of brainstem neurons send axons that branch widely through each hemisphere carrying chemicals that bathe the cortical neurons and modulate their states of excitability and activity. The chemicals include neuroamines (norepinephrine and acetylcholine involved in changes of connection strengths with learning (see SYNAPSE); serotonin and histamine taking part respectively in suppression and arousal of cortex; and dopamine implicated in motor control and hedonic experiences); and neuropeptides (short amino acid chains controlling pain and regulating the growth of neurons). Hormones such as estrogen, progesterone, and thyroxin under hypothalamic control also modulate cortical function. These neuromodulators set the levels of cortical function that we experience as mood, affect, arousal, sleep, energy, etc. The chemical techniques for blocking and enhancing neuromodulators provide the main basis for biological psychiatry in treating mental illnesses.

Computation. Although long-range communication by neurons is by pulse trains, their pulses do not represent numbers. The brain is a dynamical system more like a hurricane than a digital computer. Memory is diverse and widely dispersed, and remembering is a process of constructing neural activity patterns rather than retrieving numbers from a fixed store. New forms of artificial intelligence deriving from mathematical models of brain connections and dynamics are still speculative. Few questions are now more vigorously debated than those concerning the site, nature, role, and existence of consciousness in humans, animals and machines.

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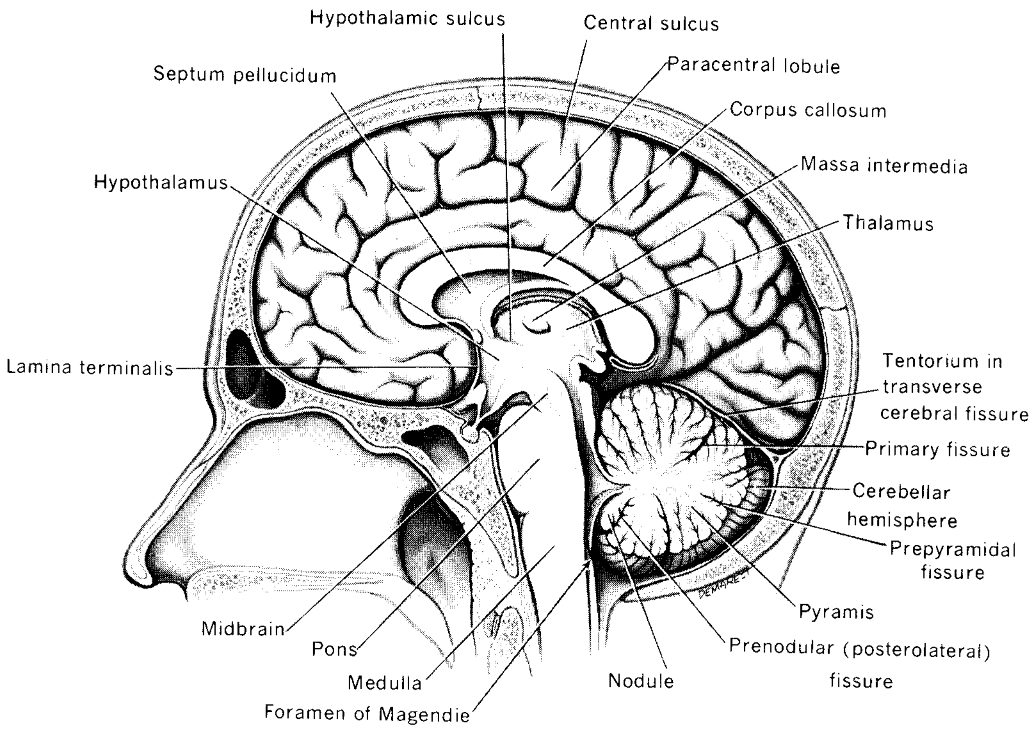

Fig. 1 Midsagittal (midline, median) section through brain, looking at medial surface to show the cerebrum, brainstem, cerebellum, corpus callosum, thalamus, hypothalamus, pituitary gland (hypophysis), visual cortex, and olfactory bulb. From Noback, 1981. Readers should copy these three figures and draw the cortico-thalamic, cortico-striatal, cortico-cerebellar, and limbic loops that are described in the text.

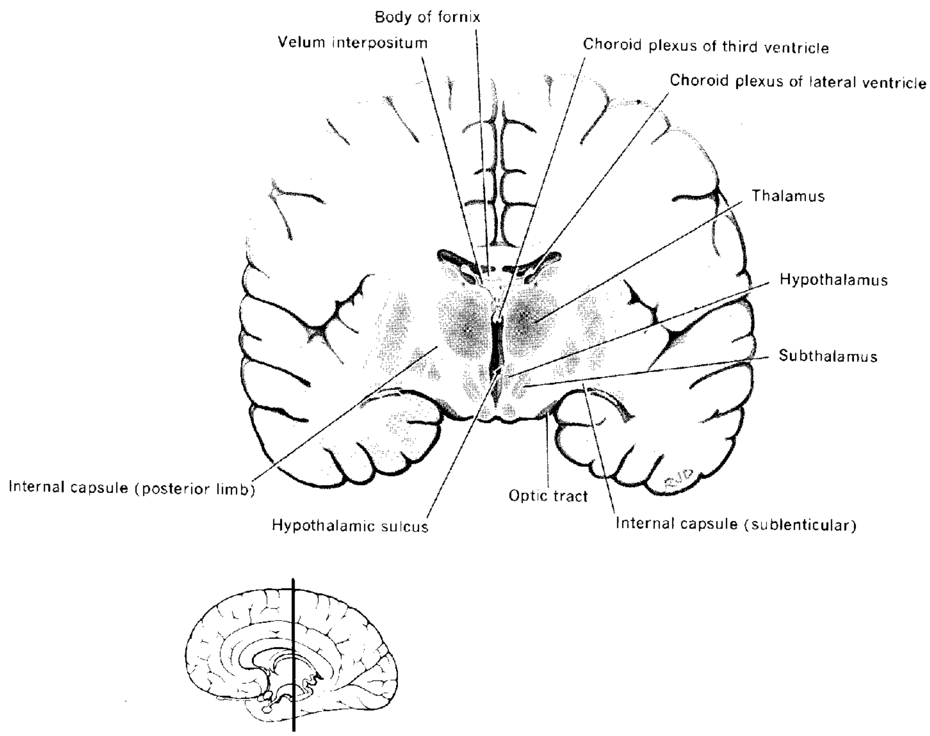

Fig. 2. Coronal (frontal) section of brain to show the the cortex (gyri and sulci), corpus callosum, the midsagittal sulcus, and basal ganglia (thalamus, striatum, hypothalamus). The limbic system (entorhinal cortex, hippocampus, and amygdaloid nucleus) are located in the medial temporal lobe below the internal capsule (sublenticular). From Noback, 1981.

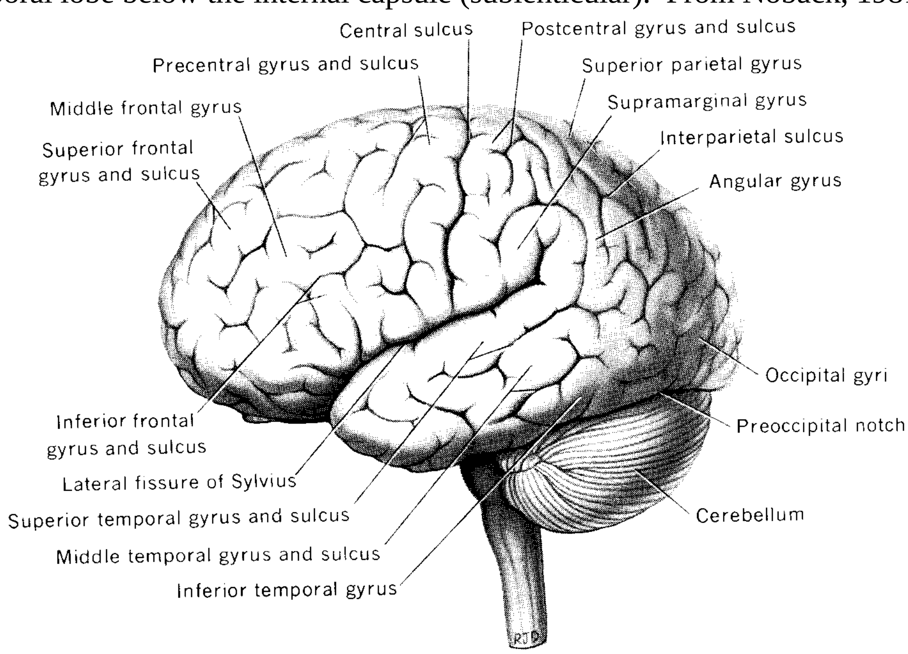

Fig. 3. Lateral view of cerebral hemisphere to show the lateral and central sulci, the four lobes (frontal, parietal, occipital and temporal), the primary cortices (motor, somatosensory, auditory and visual), Broca's area, and Wernicke's area. From Noback, 1981.