

Chapter 49

Nervous Systems

Lecture Outline

Concept 49.2 The vertebrate brain is regionally specialized.

- In all vertebrates, three bilaterally symmetrical, anterior bulges of the neural tube—the **forebrain**, **midbrain**, and **hindbrain**—form as the embryo develops.
- By the fifth week of embryonic development in humans, the three primary bulges have formed five brain regions.
- Three of these regions, derived from the midbrain and the hindbrain, give rise to the brain stem, a set of structures that form the lower part of the brain.
- The hindbrain also gives rise to another major brain center, the cerebellum.
- As embryogenesis proceeds, the most profound changes in the human brain occur in the *telencephalon*, the region of the forebrain that gives rise to the adult **cerebrum**.
 - Rapid growth of the telencephalon causes the outer portion of the cerebrum, called the **cerebral cortex**, to extend over and around much of the rest of the brain.
- Major centers that develop from the *diencephalon* are the thalamus, hypothalamus, and epithalamus.

The brain stem functions in homeostasis, coordination of movement, and conduction of information to and from higher brain centers.

- The adult **brain stem** consists of the midbrain, the **pons**, and the **medulla oblongata** or **medulla**.
 - The medulla and the pons transfer sensory information and motor instructions between the PNS and the midbrain and forebrain.
 - They also help coordinate large-scale body movements, such as running or climbing.
- In carrying instructions about the movement from cell bodies in the midbrain and forebrain to synapses in the spinal cord, most axons cross in the medulla from one side of the CNS to the other.
- As a result, the right side of the brain controls much of the movement of the left side of the body, and vice versa.
- The midbrain contains centers that receive and integrate different types of sensory information, sending coded sensory information along neurons to specific regions of the forebrain.
- Sensory axons involved in hearing terminate in or pass through the midbrain on their way to the cerebrum.
- In nonmammalian vertebrates, portions of the midbrain form prominent optic lobes that may be the only visual centers.
- In mammals, vision is integrated in the cerebrum, not the midbrain.
 - The mammalian midbrain coordinates visual reflexes, such as the peripheral vision reflex, in which the head turns to an approaching object without forming an image of it.

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- Signals from the brain stem affect attention, alertness, appetite, and motivation.
- The medulla contains centers that control several automatic, homeostatic functions, including breathing, heart and blood vessel activity, swallowing, vomiting, and digestion.
- The pons also participates in some of these activities; for example, it regulates the breathing centers in the medulla.
- Axons from the brain stem reach many areas of the cerebral cortex and cerebellum, releasing neurotransmitters such as norepinephrine, dopamine, serotonin, and acetylcholine.

The brain stem and cerebrum control arousal and sleep.

- Arousal is a state of awareness of the external world; sleep is a state in which external stimuli are received but not consciously perceived.
- Centers in the brain stem control arousal and sleep.
 - The **reticular formation**, a diffuse network of neurons in the core of the brain stem, acts as a sensory filter to choose which information reaches the cerebral cortex.
 - The brain often ignores certain stimuli while actively processing other inputs.
 - The pons and medulla contain centers that cause sleep when stimulated, and the midbrain has a center that causes arousal.
- All birds and mammals show characteristic sleep/wake cycles regulated by melatonin, a hormone produced by the pineal gland.
 - Peak melatonin secretion occurs at night.
 - Melatonin has been promoted as a dietary supplement to treat jet lag, insomnia, seasonal affective disorder, and depression.
 - Melatonin is synthesized from serotonin, which itself may be the neurotransmitter of the sleep-producing centers. Serotonin in turn is synthesized from the amino acid tryptophan.
 - Because tryptophan levels are relatively high in milk, drinking milk before bedtime may promote sleep by increasing the production of serotonin and melatonin.
- Sleep is essential for survival. Furthermore, sleep is an active state, at least for the brain.
 - EEG recordings show that the frequency of brain waves changes as the brain progresses through the distinct stages of sleep.
- Sleep and dreams may be involved in the consolidation of learning and memory.
 - Regions of the brain activated during a learning task become active again during sleep.
- Some animals display evolutionary adaptations that allow for substantial activity during sleep.
 - Bottlenose dolphins, which sleep with one eye open and one eye closed, swim while sleeping, rising to the surface to breathe air.
 - EEG recordings from the hemispheres of sleeping dolphins show that dolphins sleep with only one brain hemisphere at a time.

The cerebellum coordinates movements and balance.

- The cerebellum receives sensory information about joint position and muscle length, information from the auditory and visual systems, and input about motor commands issued by the cerebrum.
 - Information from the cerebrum passes first to the pons and from there to the cerebellum.
 - The cerebellum integrates this sensory and motor information as it carries out coordination and error checking during motor and perceptual functions.
- Hand-eye coordination is an example of cerebellar control; if the cerebellum is damaged, the eyes can follow a moving object, but they will not stop at the same place as the object.

- The cerebellum is also involved in learning and remembering motor skills.

The embryonic diencephalon evolved into three adult brain regions: the thalamus, hypothalamus, and epithalamus.

- The embryonic diencephalon is the forebrain division that evolved earliest in vertebrate history.
- The thalamus and hypothalamus are major integrating centers that act as relay stations for information flow in the body.
- The *epithalamus* includes the pineal gland, the source of melatonin, and also contains one of several clusters of capillaries that generate cerebrospinal fluid from blood.
- The **thalamus** is the main input center for sensory information going to the cerebrum.
 - Incoming information from all the senses is sorted in the thalamus and sent to the appropriate cerebral centers for further processing.
 - The thalamus also receives input from the cerebrum and other parts of the brain that regulate emotion and arousal.
 - The thalamus is formed by two masses, each roughly the size and shape of a walnut.
- The **hypothalamus** is one of the most important brain regions for the control of homeostasis.
 - The hypothalamus contains the body's thermostat as well as centers for regulating hunger, thirst, and other basic survival mechanisms.
 - The hypothalamus is the source of posterior pituitary hormones and of releasing hormones that act on the anterior pituitary.
 - Hypothalamic centers play a role in sexual and mating behaviors, the fight-or-flight response, and pleasure.

The hypothalamus regulates the biological clock.

- Specialized nerve cells within the hypothalamus regulate circadian rhythms, daily cycles of biological activity.
- Organisms from bacteria and fungi to plants, insects, birds, and humans display these rhythms.
- In mammals, the cycles controlled by the hypothalamus influence a number of processes, including sleep, body temperature, hunger, and hormone release.
- Circadian rhythms in mammals rely on a **biological clock**, a molecular mechanism that directs periodic gene expression and cellular activity.
 - Biological clocks can maintain a 24-hour cycle even in the absence of environmental cues.
 - Humans kept in a constant environment exhibit a cycle length of 24.2 hours, with little variation.
- In mammals, circadian rhythms are coordinated by a pair of hypothalamic structures called the **suprachiasmatic nucleus**, or **SCN**.
- In response to visual information, the SCN acts as a pacemaker to synchronize the body's biological clocks to the natural cycles of day length.
 - Animals whose SCN are removed lack rhythmicity in behaviors and brain activity.
- In 1990, Michael Menaker transplanted brain tissue between normal and mutant hamsters with faulty circadian rhythms and demonstrated that the SCN determines the circadian rhythm of the whole animal.

In mammals, information processing is largely centered in the cerebrum.

- The cerebrum develops from the embryonic telencephalon, an outgrowth of the forebrain that arose early in vertebrate evolution as a region supporting olfactory reception as well as auditory and visual processing.
- The cerebrum is divided into right and left **cerebral hemispheres**.
- Each hemisphere consists of an outer covering of gray matter, the cerebral cortex; internal white matter; and groups of neurons collectively called *basal nuclei* located deep within the white matter.
- The basal nuclei are important centers for planning and learning movement sequences.
 - Damage in this brain region during fetal development can result in cerebral palsy, a defect that disrupts the issuance of motor commands to the muscles.
- The cerebral cortex is particularly extensive in mammals, where it is vital for perception, voluntary movement, and learning.
 - In humans, the cerebral cortex accounts for about 80% of total brain mass and is highly convoluted.
 - Due to its convolutions, the cerebral cortex has a large surface area but still fits inside the skull: Less than 5 mm thick, it has a surface area of approximately 1000 cm².
- The cerebral cortex is divided into right and left sides, each responsible for the opposite half of the body.
 - The left side of the cortex receives information from, and controls the movement of, the right side of the body, and vice versa.
 - A thick band of axons known as the **corpus callosum** enables communication between the right and left cerebral cortices.
- The cerebrum is very plastic, especially early in development, and areas of the brain can take on novel functions.
 - A dramatic example of this phenomenon results from a treatment for the most extreme cases of epilepsy, a condition causing episodes of electrical disturbance, or seizures, in the brain.
 - Infants with severe epilepsy may have a cerebral hemisphere surgically removed.
 - Amazingly, recovery is nearly complete, as the remaining hemisphere assumes most of the functions normally provided by the entire cerebrum.
- Even in adults, damage to a portion of the cerebral cortex can trigger the development or use of new brain circuits, leading in some cases to recovery of function.

Some vertebrates demonstrate cognition.

- In humans, the outermost part of the cerebral cortex forms the *neocortex*, six parallel layers of neurons arranged tangential to the brain surface.
- Such a large, highly convoluted neocortex was thought to be required for advanced *cognition*, the perception and reasoning that form knowledge.
- Both primates and cetaceans possess an extensively convoluted neocortex.
- Birds lack a neocortex and were thought to have substantially lower intellectual capacity.
- In fact, birds are capable of sophisticated information processing.
 - Scrub jays can remember the relative period of time that has passed since they stored and hid specific food items.
 - New Caledonian crows are highly skilled at making and using tools, an ability otherwise well documented for only humans and great apes.

- African gray parrots understand relational concepts that are numerical or abstract, distinguishing between “same” and “different” and grasping the concept of “none.”
- The sophisticated cognitive ability of birds is based on an evolutionary variation on the architecture of the *pallium*, the top or outer portion of the brain.
- Whereas the human pallium—the cerebral cortex—contains flat sheets of cells in six layers, the avian pallium contains neurons clustered into nuclei.
 - This organization, likely ancestral in vertebrates, was transformed into a layered one early in mammalian evolution.
 - Connectivity was maintained during this transformation so that, for example, the pallium of both mammals and birds receives sensory input—sights, sounds, and touch—from the thalamus.
 - The result was two different arrangements, each supporting complex and flexible brain function.

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