Brain

Inside your head is a spongy, jelly-like organ that allows you to throw a ball, taste a pizza, talk to a friend, and remember your telephone number. That's right, this organ is your brain: it controls just about everything you do. The brain is your body's most complicated organ. It receives and processes sensory information from the outside world and sends messages to control muscles and glands. Your brain is also where you plan ahead, learn, and experience thoughts and emotions.

Cells of the Brain

The brain is composed of two main types of cells: nerve cells or **neurons** and glial cells or **glia**. Neuroscientists estimate that there are 100 billion neurons in the brain and ten to fifty times as many glial cells as neurons in the brain. Neurons and glia have different functions. Neurons are responsible for sending information throughout the nervous system. Neurons are some of the oldest cells in the body because they can last a lifetime. Some neurons are the longest cells in the body as they can be a few feet long. For example, some neurons can stretch from the tip of the toe all the way up to the brain. Glia, from the Greek word for "glue ", do not transmit information; rather, they insulate neurons, provide structural support for the nervous system, clean debris away from neurons and transport nutrients to neurons.

<insert figure of neuron about here>

The basic structure of a neuron is the same in a human, a cat, a frog and a fish. Neurons can by classified according to their function. **Sensory neurons** respond to environmental stimuli such as light, temperature, sound waves, smells, and touch. **Motor neurons** are responsible for controlling muscles. **Interneurons** are located between sensory neurons and motor neurons.

Although neurons vary in size and shape depending on their location in the nervous system, they all have four specialized features: 1) cell body or soma, 2) dendrites, 3) axon and 4) synaptic terminal. The central part of the neuron consists of the cell body. The cell body contains the nucleus of the cell and other organelles important for the function of the cell. The soma can vary in size from 4 μm to 120 μm in diameter. Thread-like extensions called **dendrites** branch from the neuron's cell body. Dendrites, from the Greek word meaning "tree," contain receptor zones for signals coming from other neurons. The dendrites bring information to the cell body. Also extending from the cell body is a single axon. The **axon** carries nerve impulses away from the cell body toward the **synaptic terminal**. At the synaptic terminal, information from one neuron is transmitted to another neuron. This area is called the **synapse**. An axon can branch multiple times to form synapses with many different neurons.

Neurons send messages using an electrochemical process. For instance, when you throw a ball, the neurons in your brain send messages to the nerves in your arm. These messages are electrical signals that travel on electrically charged chemicals called **ions**. In the nervous system, important ions are sodium, chloride, calcium and potassium. Differences in the distribution of ions inside and outside a neuron result in an electrical potential difference. When neurons become active, they generate a brief electrical signal by reversing this potential difference. This is called an **action potential** or a nerve impulse. Action potentials travel down the axon without a change in the shape or size of the electrical signal. Depending on the size of an axon and whether the axon is insulated with glial cells, action potentials can speed down an axon at rates between 0.2 and 120 meters/sec (0.7 - 432 km/hr = 0.4 - 268 miles/hr). A single neuron can generate hundreds of action potentials each second. It is the pattern of these electrical signals that makes up the message transmitted throughout the nervous system.

At the synaptic terminal, action potentials cause the release of chemicals called **neurotransmitters**. Many different neurotransmitters are involved in chemical ransmission. Examples of neurotransmitters are chemicals such as dopamine, norepinephrine, epinephrine, acetylcholine and serotonin. Neurotransmitters float across a gap between neurons and may attach themselves to receptor sites on other neurons. The response of the neuron receiving the chemical signal results in a change in this neuron's excitability. In other words, the neuron receiving the chemical signal will be either more or less likely to pass on the message.

<insert figure of synapse about here>

Organization of the Brain

Single celled organisms, such as the ameba, do not have a nervous system or a brain. However, these types of animals do react to light, heat and food. Simple, multicellular animals, like the sea anemone and jellyfish, have a primitive nervous system, but no collection of cells that can be called a brain. Instead, the nervous system of these animals is made up of a collection of interconnected nerve cells called a **nerve net**.

<insert figure of simple nervous systems about here>

In general, larger animals have bigger brains. In adult humans, the brain weighs about 1.4 kg (3 lb.), is 140 mm (5.5 in) in width, 167 mm (6.6 in) in length and 93 mm (3.7 in) in height. For a person who weighs 70 kg (154 lb), the brain is 2% of the total body weight. The brain, however, uses about 20% of the body's total oxygen supply. On average, men's brains are larger than women's brains. It is important to note that there is no relationship between intelligence and brain size: a genius does not necessarily have a larger than average brain. In fact, the great physicist Albert Einstein had a brain that weighed only 1.23 kg. The brain is isolated and protected from the outside world by several layers of tissue. First, there is the skin of the head (**scalp**). Under the scalp are the bones of the **skull**. Between the skull and the brain are a series of three special coverings called the **meninges**. The most outer layer of the meninges is called the **dura mater**. The dura is tough and thick. The middle layer is called the **arachnoid**. The innermost layer of the meninges, located on top of the brain, is called the **pia mater**. A clear, colorless liquid called the **cerebrospinal fluid** (CSF) flows between the pia mater and arachnoid. The CSF supports the brain, cushions it against sudden impacts, removes waste products, and distributes hormones to other parts of the body. CSF also flows through cavities in the brain called **ventricles**.

<insert figure of human brain about here>

Larger, more complex animals have developed centralized collections of neurons in ganglia and brains. The nervous system is divided into two main parts: **the central nervous system** and the **peripheral nervous system**. The brain, along with the spinal cord, makes up the central nervous system. The peripheral nervous system is composed of the nerves that extend out of the brain and spinal cord.

The brain consists of three main divisions: 1) the **cerebral hemispheres**; 2) **the brain stem** and 3) the **cerebellum**. The cerebral hemispheres are largest parts of the brain making up approximately 85% of the total brain weight in humans. The cerebral hemispheres are composed of the cerebral cortex, the basal ganglia, the amygdala and the hippocampus. The brain stem is subdivided into many parts including the thalamus, hypothalamus, midbrain, pons, and medulla. The cerebellum is located above the pons and midbrain. Although different areas of the brain may play a role in specific functions, brain areas interact to coordinate behavior.

Box 1: Average Brain Weights

Species	Weight (g)
Sperm whale	7,800
Elephant	6,000
Dolphin	1,500
Human (adult)	1,400
Walrus	1,126
Camel	762
Giraffe	680
Hippopotamus	582
Horse	532
Polar bear	498
Gorilla	500
Cow	440
Chimpanzee	420
Orangutan	370
Tiger	264
Lion	240
Grizzly bear	234
Sheep	140
Baboon	137
Rhesus monkey	90
Dog	72
Aardvark	72
Beaver	45
Cat	30
Porcupine	25
Squirrel monkey	22
Marmot	17
Rabbit	12
Platypus	9
Alligator	8
Squirrel	8
Opossum	6
Hedgehog	3
Owl	2
Rat	2
Hamster	1.4
Turtle	0.3
Bull frog	0.24
Viper	0.1
Lizard	0.08

The **cerebral cortex** makes up the outermost layer of the cerebral hemispheres. The thickness of the cerebral cortex varies from 1.5 mm to 4.5 mm. Looking down on the brain from the top, the external surface of the brain looks like a large, pinkish-gray walnut. It is wrinkled and divided into two halves or **hemispheres**. The right and left cerebral hemispheres are connected by a thick band of over 300 million nerve fibers called the **corpus callosum**. The wrinkles of the brain are the result of bumps and grooves on the cerebral cortex. Each bump on the brain is called a **gyrus (**plural = gyri**)**. Each gyrus is separated by a groove called a **sulcus (**plural = sulci**)**. Although most people have the same patterns of gyri and sulci, no two brains are exactly alike. The folding of the cerebral cortex increases the amount of cerebral cortex that can fit in the skull. The total surface area of the human cerebral cortex is about 2200 cm^2 (2.5 ft^2), about the size of a full page of newspaper.

Each hemisphere of the cerebral cortex is divided into four regions or **lobes** by various sulci and gyri. The **occipital lobes** are located at the back of the brain and are concerned with vision. The **temporal lobes**, located on the lower sides of the brain, have a role in hearing. The **hippocampus**, located within the temporal lobe, is important for transferring memories from short-term to long-term memory. The **parietal lobes**, found on the upper sides of the brain, are responsible for perceptions related to touch, pressure, temperature and pain. The **frontal lobes** are found in front of the temporal and parietal lobes and function in reasoning, planning, parts of speech, movement, emotions and problem-solving.

The basal ganglia are a group of structures located deep in the cerebral hemispheres. These areas, important for controlling movement, include the **caudate nucleus, putamen and globus pallidus**. The **amygdala** is sometimes included as one of the basal ganglia nuclei and is important in emotional behavior. The **substantia nigra** is also part of the basal ganglia, but it is located in the midbrain.

Located at the front end of the brain stem, the **thalamus** is a group of structures that processes information from all of the senses except olfaction on its way to the cerebral cortex. The thalamus also contains cell groups important for motor function. Below the thalamus at the base of the brain on the midline lies the **hypothalamus.** The hypothalamus is responsible for regulating basic autonomic, endocrine and visceral functions such as drinking and feeding, body temperature, sleep and emotions. The **pituitary gland** extends from the down from the hypothalamus and acts like a master control organ for other glands in the body.

The **midbrain** contains areas important for eye movements as well as visual and auditory reflexes. Other parts of the midbrain modulate pain and motor behavior. The **pons** ("bridge") contains areas that relay motor information from the cerebral cortex to other places in the nervous system.

The **cerebellum** ("little brain") is found at the back of the brain. It plays a role in movement and the learning of motor skills. To coordinate movement and maintain balance and posture, the cerebellum receives information from the senses. In adult humans, the cerebellum weighs about 150 g.

Autonomic functions such as heart rate, breathing and digestion are all regulated by the **medulla**. Other areas of the medulla are important for sleep and arousal.

Functions of the Brain

The brain is likely the most complicated structure in the universe. Its billions of interconnected neurons make movement, language, memory and perception possible. Some functions of the brain are established at birth. For example, babies are born with a set of **reflexes** that help them survive. Other more complicated behaviors develop as we grow, learn and communicate with other people.

> Box 2: Do we use only 10% of our brain?
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> A common misconception is that we use only 10% of our brains. Although different parts of the brain are more or less active during different behaviors, there is no evidence that only a small portion of the brain is used. Damage to only a small area of the brain can cause devastating effects such as amnesia, paralysis or loss of language. Some people, especially children, can recover after damage to or loss of part of the brain. This illustrates the tremendous capacity of existing parts of the brain to take over different functions, rather than showing that the brain had little use in the first place.

The Senses

The nervous system is equipped with special receptors to provide the brain with information about the environment. These receptors convert outside signals such as light, sound and pressure into electrical impulses. Receptors are specialized for one particular type of signal.

For example, receptors in the eye respond to light, but not to sounds. Electrical impulses generated by receptors are relayed into the central nervous system where a perception of the signal is formed. It is often said that humans have only five senses: touch, taste, sight, hearing and smell. However, the inner ear has receptors that provide information related to balance and joints and muscles have receptors that provide information about body position. Some animals have additional sensory systems or greater sensitivity to particular information compared to humans: fish can detect changes in water pressure; snakes can see into the infrared spectrum of light; the platypus can detect electrical currents.

The nervous system also monitors sensory signals inside of the body. Sometimes we are not aware of such internal sensory signals. For example, information related to body temperature and blood pressure is sent to the brain but we are often not conscious of such signals. These signals are monitored by the brain and used to maintain a normal internal environment.

Motor Behavior

A major function of the brain is to control movement. Incoming sensory information sent into the brain from the environment can be processed by the brain and converted into outgoing signals to control muscles and glands. It is the pattern of outgoing signals that is ultimately responsible for an organism's behavior.

Some movements do not require the brain. These automatic movements, called reflexes, require processing only in the spinal cord. For example, when a spot on your knee is lightly tapped, your leg will kick before the message is relayed to your brain. Although the information eventually does get to the brain, it is not required for the kick to occur.

More complex movements, such as talking, throwing a ball, and dancing, involve multiple areas of the brain. These brain areas include those involved with memory, perception, and planning. The primary motor cortex is a region of the brain that sends its axons to neurons the spinal cord to control muscles. The basal ganglia and cerebellum are two other brain areas important for movement, particularly planned movements and those requiring smooth control.

Learning and Memory

The brain is in a constant state of change. While exploring their environment, organisms learn about the world around them and form memories of events that have taken place. Learning and memory formation alters the structure of the nervous system primarily by affecting the strength of particular synapses.

Memories are stored in the brain in stages. Small pieces of new information are processed in **short-term memory** for only a few minutes. Memories may then be transferred to a more permanent form in **long-term memory**. The exact mechanisms by which the brain stores information are not known. It is likely that multiple areas of the brain, especially those in the temporal lobe, are important for memory. Electrical stimulation of parts of the cerebral cortex can evoke memories of past experiences. The hippocampus plays an important role in transferring information from long-term to short-term memory. Although damage to the hippocampus does not affect old memories, it can result in the inability to form new memories. For example, people with damage to the hippocampus can remember their own names, but they cannot remember the names of people whom they have just met.

Sleep

Each night for about eight hours you lie down with your eyes closed to rest. During this time you are not conscious of the world around you. Although you appear to be inactive, your brain is not at rest. Using a machine called the **electroencephalograph** to measure brain activity, scientists have discovered that at times during sleep, the brain displays patterns of activity similar to those when we are awake.

Sleep follows a predictable pattern of stages each night. There are two basics forms of sleep: slow wave sleep and rapid eye movement sleep. After falling asleep, people descend sequentially in different forms (stage 1 to stage 2, stage 3 and stage 4) of slow wave sleep, each stage characterized by different patterns of brain activity. After returning to stage 1 sleep, people enter rapid eye movement (REM) sleep that is characterized by brain activity similar to wakefulness. The cycle is repeated at intervals of about 90 minutes. During rapid eye movement sleep, most skeletal muscles are completely paralyzed. In the 1950s, scientists found that the eyes darted back and forth rapidly and that if people were awakened during rapid eye movement sleep, they often reported that they were dreaming. Although all of the brain mechanisms responsible for sleep are not known, circuits involving the brain stem, hypothalamus and cerebral cortex are important for sleep and wakefulness.

Box 3: **Time Spent Asleep**

Species	Time (hr/day)
Bat	19.9
Opossum	19.4
Python	18
Hedgehog	17.4
Armadillo	17.0
Human (infant)	16
Tree shrew	15.8
Hamster	15
Squirrel	14.9
Western Toad	14.6
Chimpanzee	13.7
Gerbil	13.1
Rat	12.6
Cat	12.1
Mouse	12.1
Rhesus Monkey	11.8
Rabbit	11.4
Duck	10.8
Dog	10.6
Dolphin	10.4
Human (adult)	8
Pig	7.8
Guppy (fish)	7
Seal	6
Human (elderly)	5.5
Cow	3.9
Sheep	3.1
Horse	2.9
Giraffe	2.0

Disorders of the Brain/Brain Imaging

Brain disorders have a tremendous emotional and economical impact on society. Early neuroscientists learned about the human brain by observing the behavior of people who had brain damage. In the 1940s and 1950s, Dr. Wilder Penfield applied small electrical shocks to the human brain to map the cerebral cortex. Technological advances now allow scientists to peer inside the living human brain to see the brain in action. These brain imaging methods include computerized tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET).

MORE ON IMAGING

Using these techniques, scientists can determine what part of the brain is damaged after an injury (e.g., trauma, stroke) or disease (e.g., Parkinson's disease, Alzheimer's disease) and to develop new methods to treat brain disorders. Brain imaging methods have also provided data concerning mental illnesses such as schizophrenia and depression as well as normal brain function.

MORE ON DISORDERS

<Insert MRI photograph>

Scientists have learned a great deal about the brain. Nevertheless, some of the most basic questions about the brain remain unanswered: why do we sleep?; what is consciousness?; what is the best way to treat neurological and mental disorders?; how do we remember and why do we forget?; what is the neural basis of addiction? These and other questions promise to challenge scientists as they attempt to understand the workings of the most complicated structure in the world: the brain.

Box 4:   Keeping Your Brain Healthy

Here are some simple tips to keep your brain functioning at top efficiency:

1. Wear a seat belt in the car.
   Seat belts significantly reduce the severity of injury and decrease the number of deaths in car accidents.

2. Wear a helmet when you bike, skate, snowboard and ski.
   Head injuries account for almost two-thirds of all bicycle-related deaths. Bicycle helmets reduce the risk for head injury by as much as 85% and reduce the risk for brain injury by as much as 88%.

3. Don't use illegal drugs.
   Drugs such as cocaine, marijuana, heroin, LSD and amphetamines alter the function of neurotransmitters in the brain and may lead to addiction.

4. Use proper safety equipment when you play sports.
   It is essential that protective headgear and safety equipment be used to prevent injury.

5. Eat a well-balanced diet.
   The brain requires energy to work efficiently.

6. Get enough sleep.
   To avoid drowsiness and irritability, get a good night's rest.

<insert photo of kid wearing helmet>

Did you know?

1. At times during brain development, new brain cells form at a rate of 250,000 per minute.

2. Adult humans have approximately 2 square meters (18-20 square feet) of skin that weighs about 2.7 kg (6 lb).

3. The third leading cause of death in the United States is a stroke ("brain attack").

4. The heaviest brain ever recorded weighed 2.3 kg (5 lb., 1.1 oz).

5. The smallest bone in the human body, the "stapes," is found in the ear.

6. The longest time anyone has stayed awake continuously is 264 hours (11 days).