

## **A**ction Potential

Electrical signal that is the basic unit of communication for transmitting information throughout the nervous system. Capable of traveling at speeds faster than 250 mph, action potentials whisk electrochemical messages from neurons to muscles, organs, and other neurons to control our movements, emotions, perceptions, thoughts, and actions.

Particles in our body that are electrically charged are called ions. To set up an action potential, positively charged sodium ions and potassium ions and negatively charged chloride ions and protein molecules are arranged so there are different amounts of these ions on different sides of a semipermeable neuron membrane.

## 2 ACTION POTENTIAL

This creates an electrical potential difference between the inside and outside of a neuron. When a neuron is not sending a signal, the inside of a neuron is negative relative to the outside because sodium ions do not move easily across the membrane and a protein pump sends three sodium ions out of the neuron for every two potassium ions it puts in. In fact, the inside of most neurons is about 70 mV more negative relative to its outside.

When a neuron sends a signal down an axon, the rapid exchange of sodium and potassium ions across a neuron's membrane creates an electrical signal called an action potential. During an action potential, sodium ions rush into a neuron through channels (openings) in the neuron membrane. This causes the inside of a neuron to become more positive. A short time later, different channels open to let potassium ions flow out of a neuron across the neuronal membrane, and the sodium channels start to close. This causes the neuron to return to the more negative state. Eventually, the concentrations of all ions go back to their original levels inside and outside of the neuron. The entire process takes only a few milliseconds. Also, the action potential is “all or none”—meaning that if it gets started, it will remain at the same size as it moves down the axon.

Alan Lloyd Hodgkin (1914–1998) and Andrew Fielding Huxley (1917–2012) shared the 1963 Nobel Prize in Physiology or Medicine for their foundational research about the action potential. These scientists used the giant axon of the squid to learn how ions flow across the neuronal membrane to create an action potential.

*See also* Axon, Squid Giant; Neuron; Neurotransmitters

## **Ageusia**

Complete loss of the sense of taste. Although the inability to taste is not fatal, it can cause a lower appetite and the loss of one of life's simple pleasures. Many people have a reduction in their sense of taste as they get older, but it is rare that someone loses their ability to taste completely.

Ageusia can be caused by damage, infection, or injury to the sensory nerves of the tongue (facial nerve and glossopharyngeal nerve). Radiation therapy used to treat cancer in the head or neck can result in ageusia by damaging taste buds, nerves, or salivary glands. Ageusia is also a known side effect of some antibiotic, stimulant, and antipsychotic medications. Some people regain their sense of taste when they stop taking a particular medication or when an injury heals.

The loss of taste is included on the symptom list for a severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) infection (COVID-19) by public health organizations. Although the most commonly reported symptoms of COVID-19 infections are fever, cough, and fatigue, severe reductions in taste have been reported in about 40% of COVID-19 patients.<sup>2</sup>

*See also* Coronavirus Disease 2019 (COVID-19); Cranial Nerves

## **Alcohol**

Central nervous system depressant created by fermenting grain, fruit juice, or honey. Alcohol (ethanol) has been consumed by people for thousands of years, making it the world's oldest drug. After alcohol is consumed, it enters the bloodstream through the stomach and small

#### 4 ALCOHOL

intestine. The heart then pumps the alcohol to the brain, where it acts to produce relaxation, lower inhibitions, slow reflexes and reaction time, and affect coordination. In other words, it makes people drunk. Although small amounts of alcohol may cause people to make fools of themselves, excessive consumption of alcohol can result in trouble breathing, loss of consciousness, and even death.

The alcohol molecule is small and soluble in lipids and water, so it crosses the blood-brain barrier easily. Chronic alcohol use can reduce brain size, increase cerebral ventricle size, and cause a B<sub>1</sub> (thiamine) vitamin deficiency. A thiamine deficiency may cause Wernicke's encephalopathy or Korsakoff's syndrome—neurological disorders characterized by memory impairment, confusion, and movement disorders. Infants exposed to alcohol during development may be born with fetal alcohol syndrome.

Alcohol affects multiple brain areas and several neurotransmitter systems. Alcohol binds to the receptors for serotonin, glutamate, and GABA and leads to a release of dopamine. The symptoms of intoxication are the result of alcohol's effect on a specific area of the brain. For example, alcohol interferes with the ability of the (1) hippocampus to form memories, (2) cerebellum to control balance, and (3) frontal lobe to manage judgment. The overall effect of alcohol is to depress the nervous system.

Humans are not the only animals with a taste for alcohol. Pen-tailed tree shrews drink alcohol from fermented bertam palm flowers.<sup>3</sup> However, these small mammals from Southeast Asia show no signs of drunken behavior and do not get into bar fights.



*See also* Blood-Brain Barrier; Cerebellum; Dopamine; Fetal Alcohol Syndrome; Frontal Lobe; GABA; Hippocampus; Serotonin

### **Alien Hand Syndrome**

Rare neurological disorder characterized by involuntary movement of a hand accompanied by the perception that the movement is not controlled by its owner. In 1964, Stanley Kubrick (1928–1999) produced and directed the film *Dr. Strangelove* with scenes of its title character, played by Peter Sellers (1925–1980), losing control of his right arm while his left arm tries to restrain it. This film gave alien hand syndrome the alternative name *Dr. Strangelove syndrome*.

People with alien hand syndrome make purposeful movements of their hands, but they believe that they are



not controlling their limbs and act as if the limb does not belong to them.<sup>4</sup> Some people have even given names to the “alien” hands. The condition may arise after stroke, trauma, or disease of the corpus callosum, frontal lobe, or parietal lobe. One theory proposed for the cause of alien hand syndrome is that brain regions responsible for planning and controlling movement are disconnected. When these connections are lost, these different brain areas work independently so that physical movement of a body part is no longer associated with the conscious perception of actually controlling the body part.

Most treatments for alien hand syndrome focus on behavioral therapy to help people cope with their condition. Such therapy can provide ways for people to regain control of their daily lives. Some people with alien hand syndrome benefit from learning how to distract themselves from their affected hand or to visualize taking control of their hand.

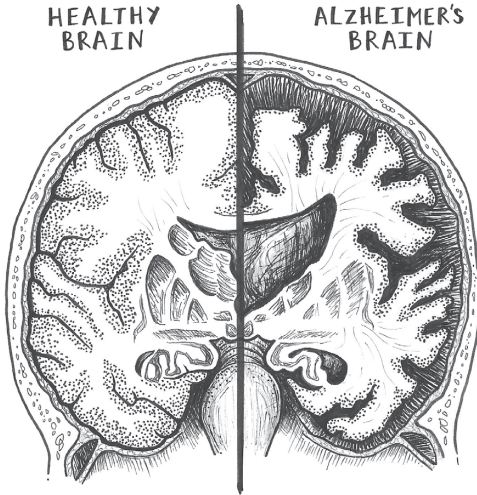
The first mention of alien hand syndrome was made by Kurt Goldstein (1878–1965) in 1908. Goldstein described the case of a fifty-seven-year-old woman whose left hand grabbed her own neck and choked her.

*See also* Corpus Callosum; Frontal Lobe; Parietal Lobe

### **Alzheimer's Disease (AD)**

A progressive, degenerative brain disease characterized by memory loss and disorientation. When is forgetfulness a normal sign of aging and when is it a symptom of a neurological disorder, such as AD? Everyone sometimes forgets where they placed their keys or cannot remember an item on a shopping list. Those types of memory loss do not affect a person's daily life. However, memory loss that disrupts a person's ability to work, communicate properly, control emotions, and make decisions may be a sign of AD. Dementia, the characteristic feature of AD, is the general term for this gradual and persistent loss of cognitive, linguistic, and emotional abilities.

The vast majority of people who develop AD are over the age of sixty-five years. Although the specific causes of AD have not yet been identified, genetic and environmental factors are likely involved. AD results in a slow



and irreversible attack on the brain that destroys neurons and the connections between neurons. This brain damage appears to be caused by abnormal buildup of beta-amyloid proteins called plaques and tau proteins called tangles. The accumulation of plaques and tangles may trigger inflammation, interfere with messaging between neurons, and kill neurons. The cerebral cortex and hippocampus, areas of the brain involved with thinking, learning, language and memory, are especially damaged.

Although there is no cure for AD, some medications and therapies can treat symptoms and improve the quality of life of people who suffer from AD. For example, some drugs that target the acetylcholine or glutamate neurotransmitter systems can help with memory loss and other signs of dementia. Nonpharmacological



treatments, such as behavioral therapy, can help some people with AD gain control of their daily activities.

Celebrities who have been diagnosed with AD include singers Glenn Campbell (1936–2017), Perry Como (1912–2001), and Tony Bennett (1926–); basketball coach Pat Summitt (1952–2016); actors Charles Bronson (1921–2003), James Doohan (1920–2005), Charlton Heston (1923–2008), Rita Hayworth (1918–1987), Burgess Meredith (1907–1997), Estelle Getty (1923–1998), Peter Falk (1927–2011), James Stewart (1908–1997), and Eddie Albert (1906–2005); former US president Ronald Reagan (1911–2004); painter Norman Rockwell (1894–1978); and boxer Sugar Ray Robinson (1921–1989).

*See also* Cerebral Cortex; Hippocampus; Neurotransmitters

## **Amphetamine**

A synthetic central nervous system stimulant. Amphetamines are a group of stimulant drugs that include Benzedrine, dextroamphetamine, and methamphetamine. The first amphetamines were developed to treat asthma, sleep disorders (narcolepsy), and hyperactivity. These drugs were used during World War II and later military conflicts to keep soldiers and pilots alert and to fight off combat fatigue.<sup>5</sup>

Amphetamines excite the central nervous system and sympathetic division of the peripheral nervous system primarily by increasing the activity within the dopamine and norepinephrine neurotransmitter systems. For example, amphetamines (1) cause the release of dopamine and norepinephrine from axon terminals, (2) block dopamine and norepinephrine reuptake, (3) inhibit the

storage of dopamine in synaptic vesicles, and (4) inhibit the destruction of dopamine by enzymes. These actions increase the availability of dopamine and norepinephrine within synapses where the neurotransmitters can bind to receptors.

People who use amphetamines usually experience a rise in heart rate and blood pressure, reduced appetite, widening of their pupils, and increase in alertness soon after the drug is ingested, smoked, or injected. Prolonged use of amphetamines can result in sleep disturbances, hallucinations, and tremors. Some people also become addicted to the effects of amphetamines and show tolerance to the drug when they must increase the amount they take in order to feel the effects.

The US Drug Enforcement Agency currently classifies amphetamines as Schedule II stimulants, meaning that products approved by the Food and Drug Administration that contain amphetamines have acceptable medical uses, but they also have a high potential for abuse.<sup>6</sup>

*See also* Autonomic Nervous System; Narcolepsy; Neurotransmitters; Synapse

## **Amygdala**

Almond-shaped brain structure located in the temporal lobe of the brain. As part of the limbic system, the amygdala has important roles in emotional behavior, memory, anxiety, and fear. Neurons in the amygdala respond to emotional faces and unpleasant odors, tastes, and feelings.<sup>7</sup> These complex functions require that neurons in the amygdala process information from all the senses and from organs inside the body through input from the hypothalamus, thalamus, cerebral cortex, and brainstem

areas. Signals sent from the amygdala feed back to the hippocampus, thalamus, and brainstem.

The role of the amygdala in fear was discovered when researchers observed that animals with damage to the amygdala did not learn to be afraid of new fears. This observation suggests that the amygdala helps organisms learn and remember the emotional significance of an event. Fear is not the only emotion processed by the amygdala. Some portions of the amygdala are involved with motivation, reward, aggression, maternal behavior, and sexual behavior.

The importance of the amygdala and its relationship to emotional behavior is strengthened by the behavior of people with a strange neurological disorder called Klüver-Bucy syndrome. Klüver-Bucy syndrome develops after people have suffered damage to their temporal lobes, including the amygdala and hippocampus, on both sides of their brain. People with Klüver-Bucy syndrome display hyperorality (putting things in their mouth), hypermetamorphosis (touching everything they see), hypersexuality, amnesia, and lack of fear and anger. There is no cure for Klüver-Bucy syndrome, but some people can learn to manage their symptoms.

*See also* Hippocampus; Temporal Lobe

### **Amyotrophic Lateral Sclerosis (Lou Gehrig's Disease)**

Progressive and fatal neurological disease characterized by a slow degeneration of brain and spinal cord neurons that control movement. In 1939, baseball star Lou Gehrig (1903–1941) knew that his performance on the field was suffering. He did not have his usual hitting power and he had difficulty running the bases.

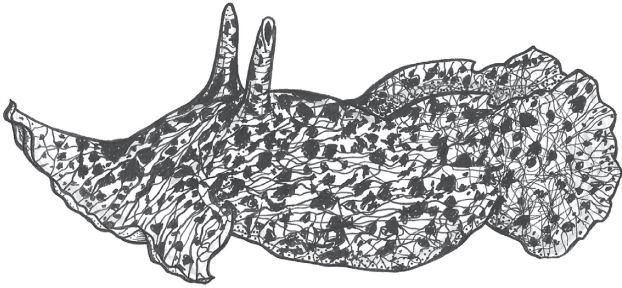
Later that year, the problem was identified: Gehrig had amyotrophic lateral sclerosis (ALS). Even today, ALS is best known as Lou Gehrig's disease, named after the longtime New York Yankee first baseman.

When motor neurons die, messages are no longer sent from the brain and spinal cord to control muscles for movement. The death of motor neurons causes progressive paralysis, leaving a person unable to move. Eventually, a person with ALS has trouble speaking, breathing, and eating. ALS usually does not affect memory, personality, or the senses. The disease is not contagious and there is no known cause for the majority of cases, but an inherited form of ALS is responsible for 5%–10% of the cases. Unfortunately, there is no cure for ALS, but some drugs (e.g., riluzole, edaravone) and therapies can improve the quality of life for people suffering from the disease.

In addition to Gehrig, physicist Stephen Hawking (1942–2018), actor David Niven (1919–1983), actor/playwright Sam Shepard (1943–2017), football player Dwight Clark (1957–2018), and former senator Jacob Javits (1904–1986) were all diagnosed with ALS.

### **Aplysia (Sea Hare)**

Marine mollusk used by neuroscientists to study neuron function. The sea hare (*Aplysia californica*) deserves a special honor in the archives of neuroscience for its contributions to our understanding of the nervous system. With approximately ten thousand neurons in its entire body (compared to eighty-six billion neurons in the human brain), the *Aplysia* has provided neuroscientists with a model organism to study the neural basis of behavior, especially memory and learning.



Starting his work in the 1960s, neuroscientist Eric Kandel used *Aplysia* to study the neuronal mechanisms responsible for the siphon withdrawal reflex.<sup>8</sup> This response involves the withdrawal of the animal's siphon (a tube that directs water out of the body) when it is touched. The neuronal circuit responsible for the withdrawal response is relatively simple, and the neurons in the pathway are large and easy to find in different *Aplysia*. The behavior can also be modified by learning. Using this system, Kandel and his coworkers provided an excellent way to demonstrate how learning and memory affect the strength of synaptic connections between neurons.

Kandel was rewarded for his work about neuronal signal conduction with the 2000 Nobel Prize in Physiology or Medicine.

*See also Synapse*

### **Aristotle (384–322 bc)**

Greek philosopher and student of Plato who expounded on topics including biology, physics, logic, politics, and the arts. Aristotle's teachings set the foundation for Western philosophy and the method of scientific inquiry.<sup>9</sup>

Although Aristotle is without question a towering historical figure who made important contributions to Western culture and science, he was wrong about the basic functions of the brain. Aristotle believed that the brain served merely to cool heat generated by the heart. He argued that the heart, not the brain, was responsible for intelligence, consciousness, and sensation. Aristotle's observations that the heart was located in the middle of the body and that it was the first organ to develop in chicken embryos may have contributed to his cardiocentric bias. The great philosopher also made errors about neuroanatomy. For example, he stated that the brain does not fill the entire cranium and that the back of the head was empty. These mistakes may be chalked up to the likelihood that Aristotle never dissected a human body to look inside. He may have based his neuroanatomical knowledge on studies of nonhuman animals, such as fish and reptiles.

Although we no longer think of the brain simply as a refrigerator or radiator to cool blood and the heart as the seat of intelligence and emotion, we nevertheless pay respect to this long-ago way of thinking each time we learn “by heart” or send our “heartfelt thanks” or suffer a “broken heart.”

### **Attention Deficit Hyperactivity Disorder (ADHD)**

Common neurodevelopmental condition characterized by inattention, hyperactivity, and impulsivity. ADHD affects millions of children each year, and the symptoms of the disorder can continue into adulthood.

Behavior that may indicate that a child has ADHD includes inattention (being easily distracted; being for-

getful; problems following directions), hyperactivity (problems sitting still), and impulsivity (inability to control impulses; acting without thinking). Because children may show these behaviors for reasons other than ADHD, a clinician must examine a child carefully before making a diagnosis.

The exact cause of ADHD is not known, but research suggests that genetic and environmental factors likely contribute to the condition. The possibility of a genetic link is strengthened by research showing the incidence of ADHD is more common in identical twins than in fraternal twins. Other factors that increase the chances that a child will develop ADHD include low birth weight, prenatal exposure to toxins, and brain injury.

Medications and behavioral therapy are often used to treat the symptoms of ADHD, but there is no cure. Surprisingly, central nervous system stimulants (e.g., Ritalin) can often reduce hyperactivity and impulsivity.<sup>10</sup> The beneficial effects of these drugs may be related to their ability to increase brain levels of the neurotransmitter dopamine, which is important for attention. Therapy to teach children and adults ways to keep organized and manage behavior can also help people function in school and at work.

Intelligence is not linked to ADHD, and the condition is not caused by watching too much TV, food allergies, or eating too much sugar.

*See also Dopamine*

### **Autism Spectrum Disorder (ASD)**

Developmental brain condition affecting how people socialize and communicate with other people. The US

Centers for Disease Control and Prevention estimate that one out of every fifty-four children is born with autism spectrum disorder.<sup>11</sup> The severity of symptoms of ASD varies from person to person, but the characteristic signs of the condition include communication problems, repetitive movements, and difficulty with social interaction.

People with ASD may experience difficulties in verbal communication, and some are entirely nonverbal; they may also have trouble interpreting what other people are saying or doing. Health care professionals diagnose ASD by looking for these behaviors and ruling out other disorders.

The exact cause of ASD is not known, but multiple factors appear to be responsible. Strong evidence supports a genetic factor as a contributor to ASD. Identical twins are more likely to both have ASD than either fraternal twins or nontwin siblings. A genetic variable may make someone more susceptible to environmental factors, such as a chemical or infection that may cause ASD.

Treatments for ASD seek to reduce the symptoms of the disorder and help people with their daily activities. Therapies to manage behavior sometimes help to improve skills and reduce unwanted behaviors. Cognitive therapy can help people with autism identify thoughts and feelings that lead to problem situations. Although there is no drug to cure ASD, some antidepressant, antipsychotic, stimulant, antianxiety, and anticonvulsant medications can reduce some symptoms of ASD.

*Rain Man*, a 1988 film starring Dustin Hoffman and Tom Cruise, tells the story of a man who has ASD in combination with savant syndrome (exceptional mem-



ory, rapid calculating ability). The film raised awareness about ASD in popular culture, but received some criticism about the depiction of savant syndrome because only about one in ten people with ASD show those extraordinary abilities.<sup>12</sup>

### **Autonomic Nervous System**

The part of the peripheral nervous system that helps maintain functions of internal organs, such as digestion, respiration, and heart rate. The autonomic nervous system is composed of the sympathetic, parasympathetic, and enteric nervous systems. The autonomic system works in the background because it functions in an involuntary and reflexive manner; it comes into play during emergencies (“fight or flight” situations) and in nonemergencies (“rest and digest” situations).

When a person walks around a corner and comes face-to-face with a snarling dog, should the person run away or prepare to fight? The heart pounds faster, blood pressure rises, digestion of food slows. That is the sympathetic nervous system in action. The sympathetic nervous system is activated when the body mobilizes for defense or in response to stress. In defensive situations, the heart rate increases, the lungs expand to hold more oxygen, the pupils dilate, and blood flows to the muscles.

Lounging at the park, resting on a bench, enjoying the sunshine: in these situations, a person’s digestion kicks into gear, blood pressure decreases, and the heart rate slows. That’s the parasympathetic nervous taking control. The enteric system is a network of neurons in the gut that also helps regulate digestion.

In general, the functions of the sympathetic nervous system and parasympathetic nervous system work in opposition to each other. However, these systems are always working to keep the body in balance.

### **Avicenna (980–1037)**

Persian physician. Avicenna was a medical doctor who contributed to our understanding of the anatomy and physiology of the nervous system as well as the diagnosis and treatment of neurological and psychiatric disorders. Avicenna's primary work, *The Canon of Medicine*, includes the diagnoses and treatments of disorders such as epilepsy, stroke, headache, meningitis, and head injury.<sup>13</sup> *The Canon of Medicine* was used as a medical guide for hundreds of years after Avicenna's death.

Avicenna may have been centuries ahead of his time in the approach he took to treat disease. He recommended a change in diet and advocated for physical exercise as therapy for many diseases. He also emphasized the importance of sleep in managing psychiatric disorders. In addition to suggesting changes in lifestyle to manage disease, Avicenna prescribed herbs or other medications for neurological conditions. Perhaps the first use of electrical stimulation to treat psychiatric disorders can be attributed to Avicenna: he suggested that depression could be cured by placing a live electric fish (torpedo ray) onto a patient's forehead.

### **Axon**

The part of the neuron that transmits information away from the cell body. The axon, which is connected to the cell body by the axon hillock, sends action potentials

toward synaptic terminals. Some axons are very short (less than 1 mm), while others, such as one stretching from the spinal cord to the foot, can be very long (~1 m; 3.3 ft). The diameter of an axon also varies in size from about 0.1 to 20 microns.

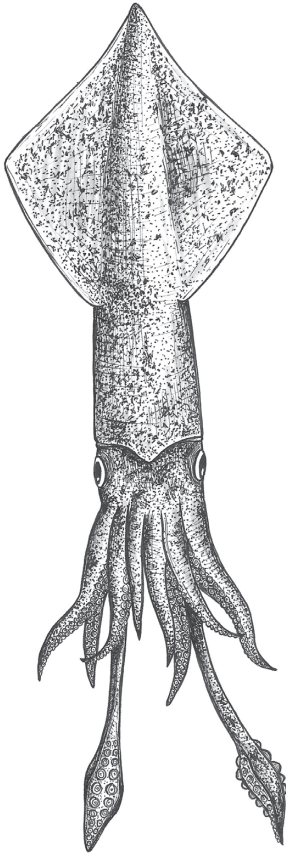
Larger-diameter axons conduct action potentials at faster speeds than smaller-diameter axons. To increase the transmission speed of action potentials, some axons are surrounded by myelin insulation. Action potentials in small-diameter, unmyelinated axons travel at speeds between 0.5 and 2.0 m/s (1.8–7.2 km/hr) while action potentials in large-diameter, myelinated axons travel at speeds between 80 and 120 m/s (288–432 km/hr).

*See also* Action Potential; Axon, Squid Giant; Myelin; Saltatory Conduction; Synapse

### **Axon, Squid Giant**

Large extension from a squid's nerve cell body. Like the sea hare (*Aplysia*), the squid is another invertebrate that deserves our gratitude for its important contributions to our understanding of the nervous system. The giant axon of the squid, part of the animal's water jet propulsion system, has been used to help neuroscientists understand how neurons send electrical signals.<sup>14</sup> These giant axons are so large (0.3–1.0 mm in diameter) that they can be seen without a microscope. The large size and location of giant axons make it easy for scientists to study these nerve fibers.

In the 1930s, English physiologist John Zachary (J. Z.) Young (1907–1997) described the structure of the giant axon in the squid *Loligo*. Later, Alan Lloyd Hodgkin (1914–1998) and Andrew Fielding Huxley (1917–2012)



used the squid giant axon in their 1963 Nobel Prize–winning work to describe how action potentials are conducted. Because of the large size of the squid giant axon, an electrode can be placed completely inside the giant axon to measure the voltage difference between the inside and the outside of the axon. Also, the cytoplasm of the axon can be squeezed out like toothpaste from a tube and replaced with solutions containing different concentrations of ions (e.g., sodium, potassium, chloride). Using this experimental setup, scientists were able to demonstrate how the exchange of ions across a neuron’s membrane was responsible for the conduction of action potentials.

Later experiments with toxins and drugs such as tetrodotoxin (TTX) and tetraethylammonium (TEA), which block the exchange of sodium and potassium ions, respectively, confirmed the importance of these ions and set the foundation for

our understanding of the generation and propagation of action potentials.

So the next time you are enjoying a plate of calamari, give thanks to the squid for its contributions to neuroscience.

*See also* Action Potential; *Aplysia*; Neurotoxin

## **B**lind Spot

Area of the retina lacking photoreceptors; also called the optic disk or optic nerve head. The retina of the eye contains cells (photoreceptors) that respond when they are exposed to light. The photoreceptors are connected to other cells that send their axons in the optic nerve to the brain. However, one small place on the retina is devoid of photoreceptors because axons of the optic nerve and blood vessels that exit the eye take up space. Light that falls on this area does not strike any photoreceptors, and therefore there are no signals sent to the brain about that light.

With two eyes, having a blind spot is not an issue because light strikes different areas of each retina so the brain receives a complete picture. Even with one eye, a blind spot rarely causes any problems because the brain fills the information gap with what it expects to be there.

How the brain makes up for missing information can be demonstrated simply by centering objects on the blind spot (see illustration). To find your blind spot, hold this book about 50 cm (20 in) from your face, close your right eye and look at the + sign in the image with your left eye. You should be able to see the O on the left side in your peripheral vision. Slowly move the



book closer to your face while you focus on the +. At some point the O will disappear. When it does, you have focused the image of the black circle on your blind spot.

*See also* Retina

### **Blood-Brain Barrier (BBB)**

A semipermeable system of astrocytes and capillaries in the brain that restricts the flow of some substances from crossing out of the bloodstream into the brain's circulatory system.

Think of the BBB as the brain's border guard, allowing entry to some materials and restricting entry to others. Endothelial cells that line capillaries in the brain fit together tightly to reduce the flow of large molecules, low fat-soluble molecules, and high electrically charged molecules across blood vessels. Glial cells (astrocytes) may help in the development and maintenance of the BBB. The restrictive barrier provided by this system protects the brain from substances in the blood that may damage the brain. The BBB also regulates brain levels of hormones and neurotransmitters that are released into the blood from other parts of the body and maintains a stable chemical environment for the brain.

The BBB can be weakened (opened) by hypertension, high concentration of a substance in the blood, microwaves, radiation, infection, trauma, ischemia, and inflammation. Also, before birth, the BBB is not fully developed. Several areas of the brain, called circumven-

tricular organs, have a BBB where substances can more easily cross into the brain. Circumventricular organs include the pineal body, posterior pituitary, area postrema, subfornical organ, vascular organ of the lamina terminalis, and median eminence.

*See also* Glia

### **Brain, Development**

Prenatal and postnatal growth and modification of the brain. The brain originates from embryonic tissue called the ectoderm. Approximately two weeks after conception, the ectoderm forms a neural plate. Within a week or so, a fold is formed in the neural plate to create a neural groove. By three weeks, the edges of the neural groove fold to form the neural tube. The front of the neural tube goes on to develop into the brain, and the remainder of the neural tube develops into the spinal cord.

A newborn baby's brain weighs just under 400 gm (0.9 lb) and contains almost all of the neurons it will ever have. In fact, adults have fewer neurons than babies. During development, neurons are overproduced. As a child grows, those neurons that are not used die. Although some neurons in a few parts of the brain, such as the hippocampus, may develop after childhood, most neurons are not replaced when they die. The brain continues to grow after birth with the addition of glial cells that divide and multiply. The average adult human brain weighs about 1,400 gm (3 lb).

During some prenatal stages of development, the brain adds about 250,000 neurons every minute. By the age of two years, a child's brain is about 80% of its adult size.

### **Brain Initiatives**

International efforts to better understand the physiology and anatomy of the brain, develop new methods to study the brain, and discover new therapies and treatments for neurological disorders. On April 2, 2013, then president Barack Obama stood at a lectern in the White House and announced the start of the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative. With an initial federal investment of \$110 million and additional financial contributions from several private foundations, BRAIN Initiative researchers would develop new methods to investigate how neurons interact to understand how brain function is linked to behavior. A few months after the BRAIN Initiative began, the Human Brain Project (HBP) started with funding from the European Union. Like the BRAIN Initiative, the HBP was established to create new technologies to better understand brain function and its relationship to cognition. Soon the governments of Australia, Canada, China, Japan, and Korea followed with their own efforts to support brain research and discover new ways to treat neurological disease. These large-scale brain research programs not only invested resources into basic scientific studies, but also were concerned with ethical and societal issues that may arise from their discoveries.

The various brain initiatives have created important innovations, such as new technologies to stimulate and record from the nervous system, new databases of neuron cell types, novel brain maps (brain atlases), and an ethical framework to design and conduct neuroscientific research. However, the tremendous progress made through these efforts has not been without con-



trovery.<sup>15–18</sup> For example, the share of project funding available to individual researchers compared to large collaborative funding has come under scrutiny. The European Union HBP has received criticism for setting unrealistic goals, poor organization and leadership, and wasteful spending.

Although it is difficult to measure the overall impact of these large research projects, these brain initiatives do provide hope for the millions of people affected by neurological disorders.

*See also* Neuroethics

## **Brainstem**

The central core of the brain, connecting the spinal cord and brain. The brainstem is composed of the medulla, pons, and midbrain. Together these areas help regulate basic life processes, such as respiration, heart rate, sleep cycle, and digestion. Damage to the brainstem, for example, by trauma or stroke, is often lethal. The brainstem also contains the pathways that send information between the brain and spinal cord.

The top of the spinal cord gradually merges with the medulla (medulla oblongata). The top of the medulla forms the bottom of the fourth ventricle, a chamber containing cerebrospinal fluid. Areas within the medulla are responsible for regulating respiration, heart rate, and blood pressure and controlling reflexes for swallowing, vomiting, coughing, and sneezing. The pons is located just in front of the medulla. Some neurons in the pons function to control sleep while other neurons process sensory information from the head or send signals to control muscles for eye movement,

facial expression, chewing, and swallowing. The midbrain is found above the pons. Within the midbrain are two paired structures, called the superior colliculus and the inferior colliculus, that are important for processing visual and auditory information, respectively. The substantia nigra, a major source that produces the neurotransmitter dopamine, and the raphe nuclei, a major source of the neurotransmitter serotonin, are also found in the midbrain.

The pons gets its name from the Latin word meaning “bridge” because of its connection between the medulla and the midbrain. The medulla also comes from a Latin word meaning “marrow” because of the inner location of the structure. Although the names of areas within the midbrain were derived from Latin (for example, colliculus means “small hill”), the midbrain just means “middle brain.”

*See also* Dopamine; Serotonin

### **Broca, Paul (1824–1880)**

French neurologist. In the mid-1800s, debate raged about whether the cerebral hemispheres functioned as a single unit or if different areas were specialized for different functions. Broca was fortunate to study a patient who contributed to the debate.

In 1861, a man named Louis Victor Leborgne (1809–1861) was admitted to the hospital where he was cared for by Broca.<sup>19</sup> As a youth, Leborgne suffered from epilepsy and he lost his ability to speak when he was thirty years old. Although Leborgne could understand spoken language, he could speak just one word: tan. For this reason, many textbooks refer to Leborgne as Tan.

When Leborgne was fifty years old, he was paralyzed on the right side of his body, developed gangrene, and was transferred to Broca for care. Leborgne died just six days later. When Broca removed and examined Leborgne's brain during an autopsy, he found damage to the left cerebral hemisphere in the frontal lobe. In 1861, Broca made a presentation to the Society of Anthropology in Paris, where he proposed that the area of the brain damaged in Leborgne was responsible for the creation of speech. Broca continued to study other patients who could not speak and confirmed that these patients also suffered damage to the left cerebral hemisphere.

Broca's observations provided evidence that a specific region of the brain had a specific function. The area of the brain damaged in Leborgne and the other patients is now known as Broca's area, and the difficulty in producing speech is called Broca's aphasia. We now know that, to speak a word, information must first get to an area of the cortex (visual cortex for speaking a written word; auditory cortex for speaking a heard word) and then be transmitted to Wernicke's area. From Wernicke's area, information travels to Broca's area, then to the motor cortex.

*See also* Frontal Lobe; Wernicke, Carl

**Caffeine** Central nervous system stimulant in the xanthine chemical group; found naturally in coffee beans and tea leaves and added to some soft drinks and drugs. After caffeine is consumed, it is absorbed in the stomach and small intestine and then transported in the blood to the brain. In various areas of the brain,



caffeine interferes with the action of the neurotransmitter adenosine. Modification of adenosine's action can result in increased alertness and attentiveness. In other parts of the body, caffeine can increase heart rate, constrict blood vessels, and improve breathing.

Depending on the type of coffee and the brewing method, a cup of coffee has between 60 and 150 mg of

caffeine. The side effects of caffeine, such as insomnia, headaches, and nervousness, are well known to many people who enjoy their regular mug of coffee. Similarly, some people experience uncomfortable withdrawal symptoms when they suddenly stop their usual consumption of caffeinated products. Some people develop a tolerance to caffeine and must consume greater amounts of caffeinated beverages to achieve the same effects. Genetic factors appear to partially contribute to the tolerance to caffeine.<sup>20</sup> Massive doses of caffeine (about 10 grams or 80–100 cups of coffee) can be deadly.

The discovery of coffee is shrouded in mystery, but one legend claims that goats were responsible for unearthing the power of this stimulant. According to the story, around AD 850, goats belonging to an Egyptian goat herder named Khaldi did not return home one night. When Khaldi eventually found his goats, they were dancing around a shrub with red coffee beans. Like any conscientious goat herder, Khaldi tried some of the berries and he started to dance. After a bit of experimenting with brewing berries, coffee was born.

*See also* Neurotransmitters

### **Capgras Syndrome**

Rare neurological condition in which people believe that family members and friends are impostors; also called impostor syndrome.<sup>21</sup> Imagine that your spouse or significant other insists that you are not who you think you are, instead maintaining that you are an impostor who has replaced the “real” you. Such is the life of a person who lives or takes care of someone with Capgras syndrome.

Although Capgras syndrome is somewhat rare, people with dementia, Alzheimer's disease, Lewy body disease, Parkinson's disease, epilepsy, stroke, and schizophrenia make up the majority of cases with the disorder.<sup>22, 23</sup> A disconnection between brain areas involved with facial recognition and emotions is theorized to underlie the problem.

Capgras syndrome is not like prosopagnosia (face blindness). People with Capgras syndrome recognize a face, but they have the delusion that the face belongs to an impostor or double. Pets and inanimate objects are sometimes included in a delusion. Reasoning with people with Capgras syndrome does not eliminate the misbelief.

Antipsychotic or antidepressant medications or drugs used to treat dementia may reduce symptoms of Capgras syndrome in some people. Behavioral therapy can help patients feel at ease with people they see as impostors. Family therapy and counseling can also help a patient's loved ones cope with the condition.

French psychiatrist Joseph Capgras (1875–1950) and Jean Reboul-Lachaux first described the disorder in 1923.

*See also* Alzheimer's disease; Epilepsy; Lewy body disease; Parkinson's disease; Prosopagnosia; Schizophrenia; Stroke

### **Cauda Equina**

Bundle of spinal nerves at the base of the spinal cord. From the Latin words for "horse's tail," the cauda equina is a collection of nerves extending from the spinal cord that sends and receives information from skin and

*(continued...)*