The Human Brain: Functional Anatomy

Skull Anatomy

The skull is a rounded layer of bone designed to protect the brain from penetrating injuries.

Interior Skull Surface

The base of the skull is rough, with many bony protuberances. These ridges can result in injury to the temporal lobe of the brain during rapid acceleration.

Injury from contact with skull

Blood Vessels of the Skull

The brain requires a rich blood supply, and the space between the skull and cerebrum contains many blood vessels. These blood vessels can be ruptured during trauma, resulting in bleeding.

Groove for middle meningeal artery

Arteries of the Brain

The human brain requires a constant supply of oxygen. A lack of oxygen of just a few minutes results in irreversible damage to the brain.

The Neuron

Dendrites: Collects information from other neurons. Axon: Transmits information to other neurons.

Cell Body
The Meninges

The meninges are layers of tissue that separate the skull and the brain.

Skull
Dura mater
Arachnoid Layer
Pia Mater
Brain

Brain Evolution

- Subcortical structures (thalamus, hypothalamus, basal ganglia, amygdala, cerebellum) have been around for a long time (reptilian brain). We share our reptilian brain with all animals that have a backbone.
- The cortex appeared fairly late in evolution (mammalian age). An structure for storing the experienced-based memories was developed: hippocampus.
- Mammalian brain became the human brain by development of neocortex which accounts for 85% of the human brain and has almost two identical hemispheres.

<table>
<thead>
<tr>
<th>Mammal</th>
<th>Body weight (kg)</th>
<th>Brain weight (kg)</th>
<th>brain/body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue whale</td>
<td>60,000</td>
<td>6</td>
<td>0.01%</td>
</tr>
<tr>
<td>Lion</td>
<td>200</td>
<td>0.2</td>
<td>0.1%</td>
</tr>
<tr>
<td>Rat</td>
<td>0.2</td>
<td>0.0002</td>
<td>1.5%</td>
</tr>
<tr>
<td>Human</td>
<td>70</td>
<td>1.3</td>
<td>1.9%</td>
</tr>
</tbody>
</table>

- Though, not really a good indication of intelligence!
- See here to learn more on intelligence comparison: http://serendip.brynmawr.edu/bb/kinser/Home1.html

Brain Evolution

- Mammals have the neocortex. But we, as humans, suddenly have got the large prefrontal cortex that is believed to be uniquely of humans.
- Our prefrontal cortex is estimated to be about 29% of our cortex, whereas it is about 17% in chimpanzees, 7% in dogs and 3.5% in cats.

The Brainstem

The brainstem is the most primitive part of the brain and controls the basic functions of life: breathing, heart rate, swallowing, reflexes to sight or sound, sweating, blood pressure, sleep, and balance. The brainstem can be divided into three major sections.
Brainstem Divisions

**Midbrain**

**Pons**

**Medulla Oblongata**

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The Medulla Oblongata

The medulla oblongata merges seamlessly with the spinal cord and creates the base of the brainstem. The medulla is primarily a control center for vital involuntary reflexes such as swallowing, vomiting, sneezing, coughing, and regulation of cardiovascular and respiratory activity. The medulla is also the origin of many cranial nerves.

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Brainstem Components

- At the level of the medulla the fibers from these tracts start to cross over, or switch sides. This is called the decussation. Thus at the level of the cerebral hemispheres the left hemisphere senses and moves the right side of the body, and the right senses and moves the left.
- According to neurologist Dr. Gregory Dardas: "This is true when considering sensory fibers carrying pain and temperature information, and it usually takes one or two levels to cross over. Position and vibratory information ascend ipsilaterally up to the level of the medulla. There they too decussate after synapsing at the nucleus gracilis (leg) and nucleus cuneatus (arm). This point is of value in terms of localization of spinal cord injuries, particularly incomplete ones, when the patient may have ipsilateral loss of position and vibratory sense at the level of the lesion, and contralateral loss of pain and temperature loss, a spinal level or two below the level of the lesion."

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Autonomic Functions

The brainstem controls the basic functions of life. Damage to these areas of the brain are usually fatal:

- The **pons** plays a critical role in respiration.
- The **medulla oblongata** is responsible for respiration and cardiovascular functions.

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The Pons

The pons is the rounded brainstem region between the midbrain and the medulla oblongata. In fact, pons means "bridge" in Latin. The main function of the pons is to connect the cerebellum to the rest of the brain and to modify the respiratory output of the medulla. The pons is the origin of several cranial nerves.
The Cranial Nerves

I. Olfactory nerve
II. Optic nerve
III. Oculomotor nerve
IV. Trochlear nerve
V. Trigeminal nerve
VI. Abducens nerve
VII. Facial nerve
VIII. Vestibulocochlear nerve
IX. Glossopharyngeal nerve
X. Vagus nerve
XI. Accessory nerve
XII. Hypoglossal nerve

Cerebrospinal Fluid

Cerebrospinal fluid is a colorless liquid that bathes the brain and spine. It is formed within the ventricles of the brain, and it circulates throughout the central nervous system. Cerebrospinal fluid fills the ventricles and meninges, allowing the brain to "float" within the skull.

The Cerebral Hemispheres

The cerebrum is the largest portion of the brain, consisting of two hemispheres that are connected together at the corpus callosum. The cerebrum is often divided into five lobes that are responsible for different brain functions.

The Cerebrospinal Fluid

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The Ventricles

The ventricles are a complex series of spaces and tunnels through the center of the brain.

The Cerebral Hemispheres

The ventricles are complex spaces and tunnels through the center of the brain. They secrete cerebrospinal fluid, which suspends the brain in the skull. The ventricles also provide a route for chemical messengers that are widely distributed through the central nervous system. The ventricles are the transition between the brain stem and the forebrain. The walls of the 3rd ventricle has thalamus and hypothalamus.

Lobes of the Cerebrum

The cerebrum consists of two hemispheres that are connected together at the corpus callosum. The cerebrum is often divided into five lobes that are responsible for different brain functions.
There is a hierarchy in the functionality of the brain. This hierarchy has nothing to do with physical location of the brain regions. The lowest of the functional regions in the cortex is the primary sensory area: primary motor cortex, M1 (Area 4 & 6), where it receives sensory information from the cortex. The highest of the functional regions is the prefrontal cortex, which is also called “the executive brain” by Dr. Elkhonon Goldberg.

Most important subcortical structures:

- **Thalamus**: it is like a relay station for all the incoming sensory information.
- **Hypothalamus**: in charge of maintaining internal homeostasis, controlling food intake and body temperature.
- **Basal Ganglia & Cerebellum**: both modify movements on a continuous manner by communicating to the cortex through thalamus. The output of cerebellum is excitatory, while that of the basal ganglia is inhibitory. The balance between these two systems allows for smooth, coordinated movements. They both learn and store the motor commands for movements.
- **Amygdala**: is part of the basal ganglia but it is so crucial for survival that is discussed separately.

The limbic system is the area of the brain that regulates emotion and memory. It directly connects the lower and higher brain functions.

- A. Cingulate gyrus
- B. Fornix
- C. Anterior thalamic nuclei
- D. Hypothalamus
- E. Amygdaloid nucleus
- F. Hippocampus

Thalamus means “inner room” in Greek, as it sits deep in the brain at the top of the brainstem. The thalamus is called the gateway to the cerebral cortex, as nearly all sensory inputs (except smell) pass through it to the higher levels of the brain.
Hypothalamus

The hypothalamus sits under the thalamus at the top of the brainstem. Although the hypothalamus is small, it controls many critical bodily functions:
- Controls autonomic nervous system
- Center for emotional response and behavior
- Regulates body temperature
- Regulates food intake
- Regulates water balance and thirst
- Controls sleep-wake cycles
- Controls endocrine system

The hypothalamus is shaded blue. The pituitary gland extends from the hypothalamus.

Basal Ganglia

This is the least well known of all the structures because of its depth in the brain. It has a major role in motor movements, specifically regulating the intensity of movements, involuntary movement (i.e., talking with hands).

Main diseases: Parkinson, Huntington Disease, Movement disorders

Side Note about Thalamus

- On the roof of the 3rd ventricle -or the epithalamus- there is the infamous pineal gland and several other poorly understood functions.
- The pineal gland is what Descartes thought was the place where the non-physical mind would be communicating with the brain. And this turns out to be extremely wrong because in people the pineal gland gets only a very tiny bit of visual information—basically light sensation. It also makes melatonin at night, which is important for sleep.
- Reference: Dr. Ginger Campbell, Brain Science Podcast #32

Amygdala

The amygdala is an almond-shaped structure in the brain; its name comes from the Greek word for “almond.” 2 amygdalae: each is located close to the hippocampus, in the frontal portion of the temporal lobe.

Responsible for feelings, emotions, fear; it modulates all of our reactions to events that are important for survival.

Assignment: Investigate the association of Amygdala and depression.

Cerebellum

The cerebellum is connected to the brainstem, and is the center for body movement and balance.

The Cerebral Cortex

Most of the cerebral cortex is neocortex; it has 6 layers. The neocortex is where all the higher brain functions take place.
The Neocortex

The cerebral cortex is a thin layer of cells about 1.5 to 4 mm thick. The cortex provides the connections and pathways for the highest cognitive functions, such as language and abstract thinking. The cerebral cortex contains about 25 billion neurons, more than 62,000 miles of axons, and 300,000,000,000,000 synapses.

The Neocortex

Neocortex' six layers contain between 10 and 14 billion neurons. Each cortical layer contains different neuronal shapes, sizes and density as well as different organizations of nerve fibers. 

1. Layer I is the molecular layer, which contains very few neurons; 
2. Layer II is the external granular layer; 
3. Layer III is the external pyramidal layer; 
4. Layer IV is the internal granular layer; 
5. Layer V is the internal pyramidal layer; 
6. Layer VI is the multiform, or fusiform layer.

Functionally, the layers of the cerebral cortex can be divided into three parts. The supragranular layers consist of layers I to III. The supragranular layers are the primary origin and termination of intracortical connections, which are either associational (i.e., with other areas of the same hemisphere), or commissural (i.e., connections to the opposite hemisphere, primarily through the corpus callosum). The supragranular portion of the cortex is highly developed in humans and permits communication between one portion of the cortex and other regions.

Frontal Lobe

The frontal lobe is the area of the brain responsible for higher cognitive functions. These include:

- Problem solving
- Spontaneity
- Memory
- Language
- Motivation
- Judgment
- Impulse control
- Social and sexual behavior.

Temporal Lobe

The temporal lobe plays a role in emotions, and is also responsible for smelling, tasting, perception, memory, understanding music, aggressiveness, and sexual behavior. The temporal lobe also contains the language area of the brain.

Brain Function

The frontal lobe plays a role in our sensations of touch, smell, and taste. It also processes sensory and spatial awareness, and is a key component in eye-hand co-ordination and arm movement.

The parietal lobe also contains a specialized area called Wernicke's area that is responsible for matching written words with the sound of spoken speech.
Occipital Lobe
The occipital lobe is at the rear of the brain and controls vision and recognition.

Vision
The visual cortex resides in the occipital lobe of the brain. Sensory impulses travel from the eyes via the optic nerve to the visual cortex. Damage to the visual cortex can result in blindness.

Basic Pattern of the Brain Anatomical Structure to Remember:
- At the level of the spinal cord the neurons are on the inside and the axons are on the outside.
- As we move up into the brainstem the neurons begin to be clustered into nuclei scattered among the white matter of axons.
- And at the level of the brainstem most of the cranial nerves come in.
- At the mid brain and forebrain areas the structure of brain changes.
- At lower parts, mid brain and deep of the forebrain, we have scattered neurons communicating with each other.
- At the forebrain, at the level of cortex, all the gray matter (the neurons) are on the outside, with the neurons in a sheet on the surface of the brain, with a 6-layer structure and columnar organization.

Taste
The gustatory complex (green circle) is the part of the sensory cortex (purple area) that is responsible for taste.

Brain Functions
- Vision
- Taste
- Cognition
- Emotion
- Speech
- Language
- Hearing
- Motor Cortex
- Sensory Cortex
- Autonomic Function

The neocortex, the way that it’s organized, the front of it seems to be devoted to action and the back to perception.

Cognition
The prefrontal cortex is involved with intellect, complex learning, and personality. Injuries to the front lobe can cause mental and personality changes.
Emotion
Emotions are an extremely complex brain function. The emotional core of the brain is the **limbic system**. This is where senses and awareness are first processed in the brain. Mood and personality are mediated through the **prefrontal cortex**. This part of the brain is the center of higher cognitive and emotional functions.

Speech
**Broca’s area** is where we formulate speech and the area of the brain that sends motor instructions to the motor cortex. Injury to Broca’s area can cause difficulty in speaking. The individual may know what words he or she wishes to speak, but will be unable to do so.

Hearing
There are two auditory areas of the brain:
- The primary auditory area (brown circle) is what detects sounds that are transmitted from the ear. It is located in the **sensory cortex**.
- The auditory association area (purple circle) is the part of the brain that is used to recognize the sounds as speech, music, or noise.

Language
**Wernicke’s area** is a specialized portion of the parietal lobe that recognizes and understands written and spoken language. Wernicke’s area surrounds the **auditory association area**. Damage to this part of the brain can result in someone hearing speech, but not understanding it.

Spatial Navigation
In Spatial Navigation 3 regions are involved, each in different ways:
- **hippocampus**
- **parietal cortex**
- **prefrontal cortex**

Spatial Navigation
- The hippocampus registers the past and current positions of the animal. The parietal cortex records the animal’s presence in particular parts of a path, no matter the animal’s position in the room. The prefrontal cortex combines multiple types of information about the animal’s actions and position with the animal’s expectation of reward. This region is regarded as an “associative” area because it receives convergent input from many other regions of the brain. Distinct patterns of activity can be seen in the prefrontal neurons depending on the size of the reward and how sure the animal is about the potential of receiving the reward.
Neocortex Function - Conclusion

The bottom line is that it appears that the older parts of the brain probably are modular but that the neocortex isn’t. Consider, for example, how our brain represents an object. The representations of objects are distributed over the cortex. A person can have brain damage (e.g. from a stroke) in which they can no longer tell what an object is by looking at it, but if they pick it up they can. And visa versa, they may not be able to tell a familiar object just by touch but if they can see it they can tell what it is. Therefore, they haven’t lost their knowledge of what the object is, they’ve just lost pieces of its mental representation.

There is evidence that language is also distributed. It appears that words that are associated with action seem to be in the frontal lobes and words that are associated with objects seem to be in the parts of the cortex associated with their representations. So, again, the cortical representation of objects seems to be highly distributed. Interestingly, it turns out that the ability to name living things may be more likely to be lost in brain damage than the ability to name inanimate objects, this implies that the mental representations of inanimate objects might be more widely distributed.

In brief, the frontal lobes know where stuff is and they decide when it’s needed. This selection of what information to use is also a key function of the frontal lobes. One paradox is that while the frontal lobes are critical for accessing and activating this important information, they do not contain the information. One of the consequences of this is that we can see frontal lobe function being affected by damage to other parts of the brain.

Sensory Cortex

The sensory portion of the cerebrum is illustrated here. Different areas of the brain are associated with different parts of the body. Injury to the sensory cortex can result in sensory disturbance in the associated body part.

Motor Cortex

The motor portion of the cerebrum is illustrated here. The light red area is the motor area, and is responsible for control of skeletal muscles. Different areas of the brain are associated with different parts of the body. Injury to the motor cortex can result in motor disturbance in the associated body part.

Hippocampus

Very useful site/notes:

Cna yuo raed ths?!

i cdnuolt blvieve taht I cluod aulaclty uesdnatnr bd ths I wsn andieg. Ths phaomneal pwer of th hmuan mnid, accondrg to a rshereach at Cmbregde Univertisy, ts dsnt mtoetr in woth oerdr tht the ttttesr in wrod rds, th olny iproamtnt tng is tht the frst nd lsat tttte r be in th rght pcls. Th rst cns b a taatl mses nd yu cns still rae tht whtut a pboerm. Ths is bcusess tht thm mns dos r naed ervey tttter fr istfl, but tht wrod s wlohe. Azanmg huh? yaeh nd I awyss tghuhot speling ws imoprant!
The following are excellent resources and were the basis of the anatomical and functional components of this presentation: