The brain is the control center of the nervous system and, along with the spinal cord, forms the **central nervous system**. It occupies the cranial cavity and can be divided into four main parts: the **brainstem**, **cerebellum**, **diencephalon**, and **cerebrum**. It is covered by layers of fascia known as **meninges** and contains cavities filled with cerebrospinal fluid.

The gross appearance of the brain shows gray and white matter. **Gray matter** contains the neuronal cell bodies and is found in the surface of the cerebral and cerebellar hemispheres, as well as in several deep nuclei (ganglia). **White matter** is formed by myelinated neuronal axons and forms most of the brain, connecting it to the spinal cord and cranial nerves.

### Brainstem

The brainstem consists of the **medulla oblongata**, **pons**, and **midbrain**. It lies medially and inferiorly and is continuous inferiorly with the cervical spinal cord at the foramen magnum. Its fibers connect the peripheral and central nervous systems. It contains the nuclei from which most **cranial nerves** originate, as well as the **vital centers** that regulate breathing, digestion, heart rate, blood pressure, and consciousness.

#### Medulla oblongata

The medulla oblongata is 3 cm in length and is the most inferior portion of the brainstem. It is continuous with the spinal cord and extends superiorly from the foramen magnum to the pons where the border is marked by a groove.

It displays the following surface features:

<table>
<thead>
<tr>
<th><strong>Pyramids</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The pyramids are two club-like enlargements on the anterior surface of the length of the medulla. They taper towards the spinal cord and contain the <strong>corticospinal tracts</strong>, of which 90% of their fibers cross over to the opposite side to form the <strong>pyramidal decussation</strong>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Olive</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The olives are two bulges located on the anterolateral side of the medulla, just lateral to the pyramids. Each contains the <strong>inferior olivary nucleus</strong> which relays sensory information to the cerebellum via the inferior cerebellar peduncles.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Gracile fasciculus</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The gracile fasciculus lies on the posterior aspect of the medulla, on either side of the posterior median septum. It is formed by the gracile nucleus which relays sensory information from the lower body to the <strong>thalamus</strong>, via the <strong>medial lemniscus</strong>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Cuneate fasciculus</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The cuneate fasciculus lies on the posterior aspect of the medulla, lateral to the gracile fasciculus. It is formed by the caudate nucleus which relays sensory information from the upper body to the <strong>thalamus</strong>, via the <strong>medial lemniscus</strong>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Anterior median fissure</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The anterior median fissure is a groove that runs along the midline of the anterior surface of the brainstem.</td>
</tr>
</tbody>
</table>
Internally, the medulla oblongata contains the following nuclei:

<table>
<thead>
<tr>
<th>Cardiac center</th>
<th>Regulates the heart rate and force of contraction.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory center</td>
<td>Regulates respiratory movements.</td>
</tr>
<tr>
<td>Vasomotor center</td>
<td>Regulates blood vessel diameter.</td>
</tr>
<tr>
<td>Special senses nuclei</td>
<td>The nuclei of the following cranial nerves are located in the medulla oblongata:</td>
</tr>
<tr>
<td></td>
<td>- Gustatory nucleus (IX)</td>
</tr>
<tr>
<td></td>
<td>- Cochlear nuclei (VIII)</td>
</tr>
<tr>
<td></td>
<td>- Vestibular nuclei (VIII)</td>
</tr>
<tr>
<td>Cranial nerve nuclei</td>
<td>The nuclei of the following cranial nerves are located in the medulla oblongata:</td>
</tr>
<tr>
<td></td>
<td>- Glossopharyngeal (IX)</td>
</tr>
<tr>
<td></td>
<td>- Vagus (X)</td>
</tr>
<tr>
<td></td>
<td>- Accessory (XI)</td>
</tr>
<tr>
<td></td>
<td>- Hypoglossal (XII)</td>
</tr>
</tbody>
</table>

**Pons**

The pons is a bulge located on the anterior surface of the brainstem, in front of the cerebellum. It is 2.5 cm in length and forms the origin of the middle cerebellar peduncles.

It consists of fibers descending from the cerebrum to the cerebellum and spinal cord, ascending fibers to the thalamus, and fibers that connect the two lobes of the cerebellum.

Internally, the pons contains the following nuclei:

<table>
<thead>
<tr>
<th>Pontine nuclei</th>
<th>Located anteriorly in the pons, they connect the cerebrum to the cerebellum and co-ordinate voluntary movement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranial nerve nuclei</td>
<td>The nuclei of the following cranial nerves are located in the posterior part of the pons:</td>
</tr>
<tr>
<td></td>
<td>- Trigeminal (V)</td>
</tr>
<tr>
<td></td>
<td>- Abducens (VI)</td>
</tr>
<tr>
<td></td>
<td>- Facial (VII)</td>
</tr>
<tr>
<td></td>
<td>- Vestibulocochlear (VIII)</td>
</tr>
</tbody>
</table>

**Midbrain**

The midbrain is the smallest part of the brainstem measuring 1.5 cm. It is responsible for the visual and gustatory response, as well as the co-ordination of movement.

It displays the following features:

<table>
<thead>
<tr>
<th>Tectum</th>
<th>The tectum forms the dorsal surface of the midbrain and the roof of the cerebral aqueduct.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It contains four nuclei which form four mounds, collectively known as the <em>quadrigeminal bodies</em>:</td>
</tr>
</tbody>
</table>
**Superior colliculi**
The superior colliculi are the two superior quadrigeminal bodies and they control the visual response.

**Inferior colliculi**
The inferior colliculi are the two inferior quadrigeminal bodies and they control the auditory response.

**Cerebral crus**
Located inferior to the tegmentum, the cerebral crus consists of descending tracts from the cerebrum to the spinal cord and cerebellum.

Internally, the midbrain contains the following nuclei:

**Tegmentum**
The tegmentum forms the inner mass of the midbrain and lies between the substantia nigra and the reticular formation. It contains ascending tracts from the spinal cord to the brain and the red nucleus. It controls fine motor functions.

**Substantia nigra**
The substantia nigra is a pigmented lamina located between the tegmentum and cerebral crus that helps to coordinate movement.

**Red nuclei**
The red nuclei make up a highly vascular area that contains cell bodies of fibers traveling from the cerebrum and cerebellum to control subconscious movement.

**Medial lemniscus**
The medial lemniscus is a continuation of the gracile and cuneate tracts of the brainstem and spinal cord.

**Cranial nerve nuclei**
The nuclei of the following cranial nerves are located in the central part of the midbrain:
- Oculomotor (III)
- Trochlear (IV)

**Central gray substance**
The central gray substance surrounds the cerebral aqueduct and controls our perception of pain.

**Reticular formation**
The reticular formation is a series of important nuclei that are scattered throughout the brainstem and upper spinal cord. They receive sensory information from the body, and motor signals from the cerebrum. They are important in the arousal and maintenance of consciousness and the sleep/wake cycle.

---

**CEREBELLUM**

The cerebellum is located in the posterior part of the cranium and consists of two hemispheres. It controls muscle coordination, maintains balance and equilibrium, and fine tunes movements at the conscious and subconscious levels.

It displays the following characteristics:

**Vermis**
The vermis is a worm-like band running down the midline, connecting the two cerebellar hemispheres.
The surface area of the cortex of the cerebellum is greatly increased by folds known as folia. This increases the number of neurons that can be contained within the cortical layers.

Within the white matter of each hemisphere are four deep nuclei, through which all information leaving the cerebellum passes.

The cerebellum is connected to the brainstem by three tracts:

**Inferior cerebellar peduncle**
- The thin inferior peduncles connect the cortex of the cerebellum to the **medulla oblongata**.
- They consist of both motor and sensory fibers; ascending and descending tracts from the spinal cord.

**Middle cerebellar peduncle**
- The middle peduncles are the largest and connect the cerebellar hemispheres to the **pons**.
- They consist mainly of motor and sensory tracts connecting to the pons.

**Superior cerebellar peduncle**
- The superior peduncles connect the deep nuclei of the cerebellum to the midbrain, diencephalon, and cerebrum.
- They consist mainly of motor fibers leaving the cerebellum to reach the brain.

The cerebellum is separated from the pons and medulla oblongata anteriorly by the **fourth ventricle**. The roof and floor of the ventricle are formed by the superior and inferior medullary velum.

The cerebellum receives information from the cerebral cortex, eye, ear, and the muscles of the body. It monitors the intentions for movement and the actual movements that occur, combining this information to evaluate how the body is performing. It then sends feedback to the cortex to initiate any necessary adjustments via the **thalamus**. This process helps to smooth and co-ordinate complex movements, and regulates balance. It also stores this data which allows for the learning of skilled activities.

**HISTOLOGY IMAGES**

The thumbnail below shows a photomicrograph of the cerebellar cortex. Note the large neurons known as Purkinje cells with their complex dendritic arborizations, and the densely packed neuronal cell bodies.

**DIENCEPHALON**

The diencephalon lies between the brainstem and the cerebrum. It surrounds the third ventricle and is formed by the thalamus, hypothalamus, and epithalamus.
### THALAMUS

The thalamus is a pair of oval masses of gray matter that lie beneath the cerebrum and form most of the diencephalon. The masses are connected to one another by the intermediate mass. Each is made up of four groups of nuclei which are separated by a Y-shaped sheet of white matter.

#### Anterior group of nuclei

- The anterior group of nuclei forms the anterior portion of the thalamus and functions as part of the **limbic system**, helping to control mood.

#### Lateral group of nuclei

- The lateral group of nuclei forms the lateral portion of the thalamus. The lateral group are linked to the **association areas** and the **limbic system**.

#### Medial group of nuclei

- The medial group of nuclei forms the medial portion of the thalamus. The medial group is involved with **emotions** and is connected to the prefrontal cortex.

#### Ventral group of nuclei

- The ventral group of nuclei forms the ventral portion of the thalamus. It is involved in motor functions and connects the basal nuclei and the motor cortex. There are five nuclei in the ventral group:
  - **Ventral anterior nucleus**
    - Connects the basal ganglia and the motor cortex and controls movement.
  - **Ventral lateral nucleus**
    - Connects the cerebellum and basal ganglia with the motor cortex and controls movement.
  - **Ventral posterior nucleus**
    - Relays somatic sensation to the cortex.
  - **Lateral geniculate nucleus**
    - An eminence formed by the lateral geniculate nucleus on the posterior surface of the thalamus. The lateral geniculate nucleus receives **visual information** from the optic tract, which it relays to the visual cortex.
  - **Medial geniculate nucleus**
    - An eminence formed by the medial geniculate nucleus, located on the posterior surface of the thalamus. The medial geniculate nucleus relays **auditory information** from the lateral lemniscus to the auditory cortex.

The thalamus is a major relay center and receives fibers from the following three pathways:

#### Sensory fibers

- Receives sensory input from the spinal cord and brainstem. These fibers relay and continue to the cerebral cortex.

#### Motor fibers

- Receives motor input from the cerebellum. These fibers relay and continue to the cerebral cortex.

#### Intercerebellar fibers

- Relays fibers from one area of the cerebral cortex to another.

### HYPOTHALAMUS

The hypothalamus is a small area of the brain that lies inferior and lateral to the anterior aspect of the third ventricle. It is constricted anteriorly by the optic chiasma and posteriorly by the mammillary bodies. Its inferior portion is stretched into a hollow stalk that attaches the **pituitary gland**.
It constitutes a large number of neurosecretory cell bodies, divided into a number of small nuclei, all with varying functions.

**Infundibulum**

The infundibulum is a narrow, hollow stalk that connects the hypothalamus to the pituitary gland. It extends from between the mammillary bodies and the optic chiasma to the posterior lobe of the gland.

**Mammillary bodies**

The mammillary bodies are a pair of pea-sized white lumps protruding from the posterior surface of the hypothalamus. They are continuous superiorly with the fornix. They function in recognition memory especially with regards to smell memory.

Through connections to the limbic system, hippocampus, striatum, and brainstem it regulates emotions, autonomic control, hunger, satiety, immunity, memory input, and anger control.

**Autonomic control**

Regulates and controls the output of the autonomic nervous system. Thus, it is involved with the regulation of visceral activities.

**Emotional response**

Functions as part of the limbic system and is involved in both negative and positive emotions.

**Thermoregulation**

Functions as the body's thermostat, stimulating the autonomic nervous system to promote or reduce heat loss.

**Control of the endocrine system**

Secretes releasing and inhibiting hormones which either stimulate or inhibit the release of hormones from the anterior pituitary gland. Also, neurons from the hypothalamus produce hormones that travel along their axons to the posterior pituitary gland, stimulating it to release hormones.

**Hunger and satiety**

Controls the feelings of hunger and fullness.

**Water balance and thirst**

Responds to increase in concentration of extracellular fluid, stimulating the feeling of thirst.

**Sleep/wake cycle**

When darkness is detected by the retina, the suprachiasmatic nucleus of the hypothalamus stimulates the pineal gland to release *melatonin*. Melatonin regulates the body clock by promoting sleepiness.

**EPITHALAMUS**

The epithalamus is a small area of tissue that lies posterior to the third ventricle and contains the habenular nuclei. The pineal gland protrudes from its posterior aspect.

**Habenular nuclei**

Habenular nuclei are involved in the emotional response to olfaction.

**Pineal gland**

A small, round endocrine gland that lies above the tectum of the midbrain, posterior to the third ventricle and between the superior colliculi. When darkness is detected by the retina, the suprachiasmatic nucleus of the hypothalamus stimulates the pineal gland to release *melatonin*. Melatonin regulates the body clock by promoting sleepiness.
The cerebrum is the largest part of the brain and is divided into *left* and *right hemispheres* by a longitudinal fissure that runs along the median sagittal plane.

The outer layer of the cerebrum is composed of gray matter and is called the **cerebral cortex**. It is responsible for the analysis of sensory input, memory, learning, and cognitive thought.

Each cerebral hemisphere can be divided into lobes, the names of which correlate with the bones that protect them as follows:

<table>
<thead>
<tr>
<th><strong>Frontal lobe</strong></th>
<th>The frontal lobe is the largest lobe and is found at the front of the brain, protected by the <strong>frontal bone</strong>. It is separated from the parietal lobe posteriorly by the central sulcus and from the temporal lobe inferiorly by the lateral sulcus.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas</td>
<td>Primary motor area (movement). Motor association area (movement). Primary olfactory cortex (smell). Broca’s area (motor speech production).</td>
</tr>
<tr>
<td>Function</td>
<td>Cognitive thought and memory. Control of voluntary movements.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Temporal lobe</strong></th>
<th>The temporal lobe is located at the side of the brain and is protected by the <strong>temporal bone</strong>. It is separated above from the frontal lobe by the lateral sulcus.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas</td>
<td>Primary auditory area (hearing). Auditory association area (hearing). Wernicke’s area (speech comprehension).</td>
</tr>
<tr>
<td>Function</td>
<td>Special senses (hearing, smell). Learning and memory (retrieval). Emotions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Parietal lobe</strong></th>
<th>The parietal lobe is located at the top of the brain and is protected by the <strong>parietal bone</strong>. Anteriorly, it contains the postcentral gyrus and is separated from the frontal lobe by the central sulcus. Posteriorly, it is separated from the occipital lobe by the parietal-occipital sulcus.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas</td>
<td>Primary somatosensory area (cortex). Sensory association area (general senses).</td>
</tr>
<tr>
<td>Function</td>
<td>Body orientation. Primary gustatory cortex (taste).</td>
</tr>
</tbody>
</table>
### Occipital lobe

Located at the back of the brain protected by the **occipital bone**.

**Areas**
- Primary visual area (cortex).
- Visual association area (vision).

**Function** Visual interpretation.

### Insula

The insula is the smallest lobe of the brain and located deep in the cerebrum, deep to the parietal and temporal lobe.

**Function**
- Special senses (taste, hearing).
- Visceral sensation.

Each hemisphere is greatly folded, forming folds and creases known as **gyri** and **sulci** that increase the surface area of the cerebral cortex. Although the exact location of the sulci and gyri varies between different individuals, there are a number of large gyri and deep sulci which can be identified as constant landmarks.

The main features have been listed below:

<table>
<thead>
<tr>
<th><strong>Longitudinal fissure</strong></th>
<th>A large fissure running from back to front along the sagittal plane. It divides the cerebrum into left and right cerebral hemispheres.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Central sulcus</strong></td>
<td>Descending downwards and forwards from the top of the hemisphere. It divides the frontal and parietal lobes.</td>
</tr>
<tr>
<td><strong>Parietal-occipital sulcus</strong></td>
<td>Descending downwards and forwards mainly inside the longitudinal fissure. It divides the parietal and occipital lobes.</td>
</tr>
<tr>
<td><strong>Precentral sulcus</strong></td>
<td>Forms the anterior boundary of the precentral gyrus.</td>
</tr>
<tr>
<td><strong>Precentral gyrus</strong></td>
<td>This is located at the posterior border of the frontal lobe, in front of the central sulcus. It descends downwards and forwards from the top of the hemisphere. It forms the <strong>primary motor area</strong> (cortex).</td>
</tr>
<tr>
<td><strong>Postcentral gyrus</strong></td>
<td>This is found at the anterior border of the parietal lobe, behind the central sulcus. It descends downwards and forwards from the top of the hemisphere. It forms the <strong>primary somatosensory area</strong> (cortex).</td>
</tr>
<tr>
<td><strong>Postcentral sulcus</strong></td>
<td>Forms the posterior boundary of the postcentral sulcus.</td>
</tr>
<tr>
<td><strong>Lateral sulcus</strong></td>
<td>Found on the lateral side of the brain, it is almost horizontal and ascends gradually from the front of the brain to the angular gyrus. It separates the temporal lobe from the frontal lobe above.</td>
</tr>
</tbody>
</table>

The majority of the cerebral mass is formed by **white matter**. It is composed of myelinated axons that form tracts, which connect the cerebrum to the other parts of the central nervous system.

There are three types of tracts defined by the areas they connect, **association fibers**, **commissural fibers**, and **projection fibers**:

<table>
<thead>
<tr>
<th><strong>Association tracts</strong></th>
<th>Association tracts connect gyri within the same hemisphere.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Commissural tracts</strong></td>
<td>Commissural tracts connect gyri in different hemispheres. Examples include:</td>
</tr>
</tbody>
</table>

| **Anterior commissure** | The anterior commissure is a tract of myelinated axons that connects the vestibular cortex of the two cerebral hemispheres. It passes across the midline in front of the fornix and grooves the inferior surface of the putamen. |
### Posterior commissure

The posterior commissure is a thin tract of myelinated axons that lie above the superior colliculi and connect the midbrain and diencephalon.

### Corpus callosum

The corpus callosum is a C-shaped bundle of myelinated axons that arches over the thalamus and ventricles, connecting the left and right cerebral hemispheres; it forms the base of the longitudinal fissure.

### Projection tracts

Projection tracts connect gyri with different areas of the CNS. Examples include:

#### Internal capsule

The internal capsule is a large sheet of myelinated axons connecting the cerebral cortex to the brainstem and cerebrospinal tracts of the spinal cord. In the cerebrum it separates the thalamus and caudate nucleus from the globus pallidus and putamen; superiorly it diverges to form the corona radiata. Inferiorly the fibers converge to form the cerebral crus in the midbrain, continuing to the pyramids of the medulla oblongata and passing to the opposite side in the pyramidal decussation.

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**Did you know?**

During the first three or four months after conception, the fetal brain has a smooth surface which is similar in appearance to that of an adult bird or reptile brain. As fetal development continues, the surface of the brain begins to fold until it takes on the walnut-like appearance of the adult human brain.

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### MOTOR AND SENSORY HOMUNCULI

The motor and sensory homunculi are disproportionate maps of the body used to demonstrate the relative portion of cerebral cortex dedicated to each area of the body.

The primary motor and somatosensory cortices in the cerebrum deal with motor and sensory information for the whole body. Each strip of cortex is arranged topographically i.e., different areas of the cortex deal with different pieces of information.

The more control that is needed over a body part, the more area of the cerebral cortex is dedicated to that part. For example, even though the thigh has more muscles than the hand, the hand requires more control because it is involved in more intricate skills, like writing, while the thigh is involved in less intricate skills, like walking. Therefore, more of the cerebral cortex will be involved in controlling the hand than in controlling the thigh.

The homunculus picture shows the relative amount of the cortex dedicated to the specific body area. If the area has a lot of control, then that part will be disproportionately larger; if there is less control it will be smaller. The feature works both for motor stimulation and for sensory feedback.
### Sensory homunculus

The tongue, lips, fingers, toes, and sex organs are shown as relatively large as they have high sensitivity and therefore have a relatively large portion of the somatosensory cortex attributed to them.

### Motor homunculus

The tongue, lips, hands, fingers, and toes are shown relatively large as they all have precise motor control and therefore have a relatively large portion of the motor cortex attributed to them.

### BASAL GANGLIA

The basal nuclei are three masses of cerebral gray matter embedded in the white matter surrounding the thalamus. The basal nuclei include the caudate, putamen, and globus pallidus.

#### Caudate nucleus

The caudate nucleus is a C-shaped nucleus that lies under the lateral ventricles. It has a large head that tapers posteriorly and is connected to the putamen by thin striations. It is involved in the sub-control of voluntary movement.

#### Putamen

The putamen is an oval nucleus located lateral to the internal capsule. It is connected to the caudate nucleus by thin striations. It is involved in the reinforcement and co-ordination of learned motor skills.

#### Globus pallidus

The globus pallidus is the most medial of the basal ganglia. It is a small nucleus that lies medial to the putamen and lateral to the internal capsule. It is involved in inhibiting muscular activity and reducing muscle tone.

The basal ganglia are important in co-ordinating muscle movement and posture; they suppress unwanted movements and control muscle tone.

### LIMBIC SYSTEM

The limbic system is the main area of the brain involved with emotion and learning. It influences the formation of memory by integrating emotional states with stored memories of physical sensations. It is also involved in linking smell and memory.

It exerts influence on the endocrine and autonomic nervous systems producing both negative and positive emotional responses. It is formed by a ring of structures which surround the diencephalon and include the following:
### Cerebral gyri

The cingulate gyrus of the frontal and parietal lobes runs above the corpus callosum within the longitudinal fissure. The dentate and parahippocampal gyri surround the hippocampus.

### Hippocampus

A gyrus that runs medially along the temporal lobe, beneath the diencephalon. It is connected to the inferior limbs of the fornix. The hippocampus is critical to forming new memories.

### Amygdala

The amygdala is a large swelling located at the anterior aspect of the hippocampus. It is involved with the emotions of fear and aggression.

### Septal nuclei

The septal nuclei are clusters of cell bodies found within the septum pellucidum, a thin sheet of gray and white matter that lies vertically in the midline between the two cerebral hemispheres. It joins the corpus callosum superiorly to the fornix inferiorly, and separates the left and right lateral ventricles.

### Mammillary bodies

Mammillary bodies protrude from the posterior of the hypothalamus. They are continuous superiorly with the fornix.

### Anterior thalamic nuclei

The anterior thalamic nuclei form the anterior portion of the thalamus.

### Olfactory bulbs

The olfactory bulbs receive information regarding olfaction.

### Fornix

The fornix is a fibrous band of myelinated axons that arches over the thalamus, connecting the hippocampus and the mammillary bodies.

### BLOOD SUPPLY TO THE BRAIN

The right and left **common carotid** arteries supply a large proportion of the head and neck with blood. These arteries ascend at the side of the neck and divide to form the **internal** and **external** carotids. For more information, see ‘Cardiovascular system: Vessels of the head and neck’.

The brain is supplied by two internal carotid arteries, and two vertebral arteries:

#### Internal carotid artery

The internal carotid artery is a deep artery of the neck that enters the skull to supply the brain, eyes, nose, and forehead. **Branches include:**

- Ophthalmic.
- Anterior cerebral.
- Middle cerebral.
Vertebral artery

The vertebral artery arises from the subclavian artery, and ascends the neck through the transverse foramen of the cervical vertebrae and enters the skull via the foramen magnum, where it unites with its opposite to form the basilar artery. The vertebral arteries are important as they supply the cervical vertebrae, brainstem, cerebellum, and the spinal cord with blood.

Branches include: Spinal, Posterior inferior cerebellar, Basilar.

The branches of the internal carotid and vertebral arteries form an arterial circle around the pituitary gland and optic chiasm at the base of the brain, called the ‘circle of Willis’.

This anastomosis means that if an artery supplying the brain becomes damaged, blood flow from the other vessels can often replace it.

Branches of the INTERNAL CAROTID and VERTEBRAL ARTERIES:

![Diagram of arterial circle]

BRAIN WAVES

Brain waves are an amalgamation of the many action potentials generated by the neurons in the brain. They represent the total electrical activity of neurons in the brain, as recorded by electrodes placed on the forehead and scalp. A recording of brain waves is called an electroencephalogram or EEG. Different patterns of neuronal firing in the brain produce four different brain waves: alpha waves, beta waves, theta waves, and delta waves. The frequency of a wave is measured in hertz (Hz), which represents the number of cycles per second.

<table>
<thead>
<tr>
<th>Wave</th>
<th>Frequency</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>9-14 Hz</td>
<td>Appear when awake and resting. Absent during sleep.</td>
</tr>
<tr>
<td>Beta</td>
<td>15-30 Hz</td>
<td>Appear when the nervous system is active, during sensory reception, and during mental activity.</td>
</tr>
<tr>
<td>Theta</td>
<td>4-8 Hz</td>
<td>Seen in children and adults under emotional stress. Also seen in individuals with brain disorders.</td>
</tr>
<tr>
<td>Delta</td>
<td>1-3 Hz</td>
<td>Seen in adults during deep sleep and in infants when they are awake. An indication of brain damage is seen in the EEG of an adult in a state of wakefulness.</td>
</tr>
</tbody>
</table>
SLEEP
Humans follow a 24 hour cycle of alternation between sleep and wakefulness known as a 'circadian rhythm'.

The suprachiasmatic nucleus of the hypothalamus is key to the generation and control of the circadian rhythm. Wakefulness is a state of consciousness, where one possesses the ability to react to various stimuli. Sleep is a state of partial unconsciousness, where one is less able to respond to stimuli. Two different types of sleep have been established: non-rapid eye movement sleep (NREM) and rapid eye-movement sleep (REM). An individual will alternate between NREM and REM sleep during the night.

Non-rapid eye movement sleep (NREM)
NREM sleep is controlled by neurons in the preoptic nucleus of the hypothalamus, basal nuclei, and medulla oblongata.
During NREM sleep, an individual will pass through the following three stages in under an hour.

<table>
<thead>
<tr>
<th>Transition stage</th>
<th>The period between wakefulness and sleep lasting for up to 7 minutes. A state of relaxation, with eyes closed and a wandering mind. An individual in this stage is easily awakened.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light sleep</td>
<td>Eyes are closed and may slowly roll in their sockets. Incomplete dreams may be experienced. An individual in this stage is a little less easily awakened.</td>
</tr>
<tr>
<td>Deep sleep</td>
<td>The final and deepest stage of sleep, during which sleepwalking may occur. A further drop in body temperature, a slight decrease in muscle tone, and a slowing of brain metabolism may be experienced.</td>
</tr>
</tbody>
</table>

Rapid eye movement sleep (REM)
REM sleep occurs in episodes, breaking up NREM sleep.

An individual will typically have five episodes of REM sleep, at 90 minute intervals, during an 8 hour sleep period; they will get progressively longer, with the first lasting about 10-20 minutes and the last about 50 minutes.

During REM sleep, eyes move around rapidly and continuously under closed lids. Neuronal activity in the brain is high. REM sleep is triggered by neurons in the pons and midbrain.

The majority of dreaming occurs during REM sleep, producing EEG readings comparable to those of someone in a state of wakefulness. Sleep paralysis may be experienced when an individual is awoken from REM sleep which is due to the inhibition of motor neurons controlling skeletal muscle.

LEARNING AND MEMORY

Learning is acquiring new information or skills through experience. Memory is the ability to store and retain this information within the brain for future retrieval. Plasticity is the term used to describe the structural and functional changes in the brain, through which learning and memory are attained. Plasticity occurs in response to stimuli from both internal and external environments, and involves changes in synaptic connections such as an increase in the number of and enlargement of presynaptic axon terminals, growth of new dendrites, and synthesis of new proteins in particular brain regions.

Immediate memory
Immediate memory is the capacity for recalling snippets of information over a few seconds, for example, dialing a phone number that was just told to you.

Short-term memory
Short-term memory, also referred to as active or primary memory, is the capacity for holding small amounts of information over a short period of time.

Long-term memory
Long-term memory is the capacity for storing information for much longer periods of time. This information can usually be retrieved at any point.

Memory consolidation
Memory consolidation is the process by which memories become more established through frequent retrieval.
Long term potentiation (LTP) is the lasting amplification of synaptic transmission between two neurons, resulting from high-frequency stimulation. LTP is essentially the ability of a synapse to change its strength and therefore, it is thought to be one of the mechanisms underlying learning and memory.