# Section Two: Chapter 9: Central and Peripheral Nervous Systems

The nervous system is anatomically and functionally divided into two parts, the **Central Nervous System** (the brain and the spinal cord) and the **Peripheral Nervous System** (ganglia, 12 pairs of cranial nerves and 31 of pairs of spinal nerves). The Peripheral Nervous System (PNS) can be further delineated into the **Somatic Nervous System** (SNS) which integrates control over skeletal muscle, and the **Autonomic Nervous System** (ANS) which for the most part automatically regulates vital internal systems.

We have been introduced to the concept of homeostasis in physiology, that is, the maintenance of a stable internal environment. A recurrent theme in physiology is how homeostasis is maintained by feedback loops, which was covered in the first section of this course. The Central Nervous System (CNS) often plays a significant role as the **integration center** within these feedback loop mechanisms for maintaining homeostatic balance. This indicates that information processing, analysis and interpretation is a key function of the CNS.

As detailed below, each region of the brain and spinal cord have distinct physiological functions and help to regulate intricate and complex processes which are elegantly integrated with all of the other body systems. First we will consider some general roles of the brain then move to more specific functions of various regions of the brain. We will also cover the important functions of the spinal cord. After that, we will be ready to cover the Peripheral Nervous System (PNS).

## The Central Nervous System: The Brain

We can divide the brain into six (6) parts in terms of physiological functions: **1.** Cerebrum; **2.** Diencephalon; **3.** Midbrain; **4.** Cerebellum; **5.** Pons; and **6.** Medulla oblongata.

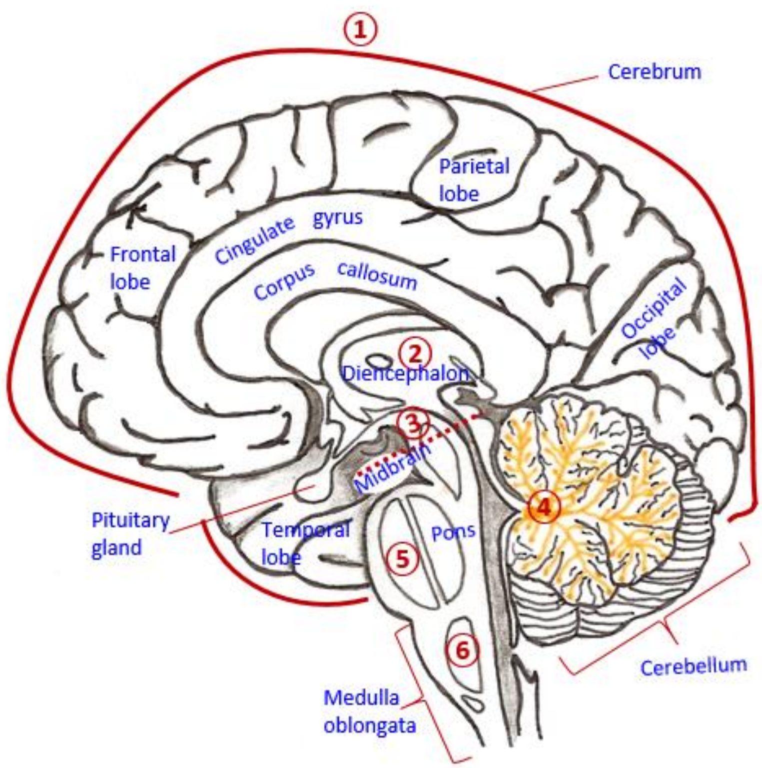



**Figure 9.1** This is a mid-sagittal section of the brain showing various regions and the six major divisions (red circled numbers) of the human brain from the highest to lowest information processing.

## 1. Cerebrum

The cerebrum is the largest most developed area of the human brain (see **Fig. 9.1** above) and is considered to be the center of the highest functions. Its major functions include: Awareness of sensory perception; voluntary control of movement (regulation of skeletal muscle movement); language; personality traits; sophisticated mental activities such as thinking, memory, decision making, predictive ability, creativity and self-consciousness. The cerebrum is composed of **5 lobes**, here is some basic information about them:

**The Frontal Lobe** – The **largest** and most **complex** of the 5 lobes, it is concerned with higher intellectual functions and is involved in the many behavioral aspects of humans. It inhibits certain primitive behaviors. The Primary motor cortex controls the movement of the rest of the body while the premotor cortex just adjacent to it is concerned with the initiation, activation, and performance of the actual movement.

**The Parietal Lobe** - This lobe is primarily concerned with the interpretation and integration of **sensory** inputs. The Somatosensory cortex is associated with reception and perception of touch, vibration, and position sense of the body. It is involved in body senses. This lobe also functions in spatial orientation, movement coordination, some visual perception, reading and writing and mathematical computation.

**The Temporal Lobe** - The temporal lobe contains the **auditory** cortex for the reception and interpretation of sound information, and the **olfactory** cortex for the sense of smell. It also houses the language cortex in the dominant hemisphere (usually the left hemisphere) and participates in recognition and interpretation of language. Parts of the limbic system (the amygdala and hippocampus) are connected to the temporal lobe and aid in memory formation related to emotions, the sense of smell and sound.

**The Occipital Lobe** - This lobe contains the primary visual cortex for **visual** information interpretation. Vision is the ability to detect images of visible light. The eyes transmit this to the visual cortex, which then processes it to determine colors, identify objects, identify shapes, and other aspects of visual perception. Visual information is sent to the parietal lobes and temporal lobes for further processing. The occipital lobe is involved in functions including: Visual perception; color recognition; reading and reading comprehension; depth perception; recognition of object movement. The parietal lobes use this visual information in conjunction with motor processes to perform such tasks as opening a door or brushing your teeth. The temporal lobes help to connect the visual information received with retained memories.

**The Insula Lobe** – One known role of this lobe is for **visceral** perception, that being conscious awareness of internal organs and various bodily states. For instance, when the bladder is empty, most are not consciously aware of it, but that changes when it becomes full, we then become aware of that organ. There may be times that people become more acutely aware of the heart beating, this perception is because of the insular cortex. The insular lobe helps in motor control to a certain extent and most of the time we are able to read our own emotions and be aware of them as a function of the insula.

**The Limbic System – The Emotional Brain**

Still within the cerebrum, the **limbic system** is a group of structures on the medial aspect of each hemisphere and the diencephalon, and is more a functional system than an anatomical one. The limbic system is the "emotional brain", participating in the creation of emotional states such as fear, anger, pleasure, affection, arousal, etc. and processing vivid memories associated with those states. Various parts of the limbic system are complex, one example is the cingulate gyrus, it is involved in memory retrieval, planning, and processing spatial information. It allows us to shift between thoughts. It also functions to interpret painful stimuli as unpleasant, thus aiding in learning and memory.

The amygdala ('almond') is central in the limbic system for processing **fear** and stimulates a sympathetic response to it. The amygdala enables us to recognize menacing facial expressions in others and to detect the precise gaze of someone who is looking at us. It is also involved in the positive emotional recognition of faces, for instance seeing a picture of your grandmother and giving an emotional connection with it.

## Cerebral Lateralization

The entire body, including the brain, exhibits **bilateral symmetry**, meaning it can be divided into two equal left and right halves. The **two hemispheres** of the cerebrum have two symmetrical halves. The **cerebrum** represents about 7/8 of the mass of the brain and is divided into **left** and **right hemispheres**. Although anatomically the two hemispheres of the cerebrum look very similar, functionally the two sides are have different roles. Thus, the term **cerebral lateralization** is used to denote that the lobes of the two cerebral hemisphere have developed specific functions that are not necessarily shared by other lobes.

The two cerebral hemispheres are connected by a structure called the **corpus callosum**. In Latin this means callused body. It's tough, and is made of bundles of nerve fibers that share information between the two sides. The corpus callosum contains about **300 million** axons linking the two hemispheres, such that although they have differing functions, the two sides are highly integrated and coordinated.

## The Brain Controls the Opposite side of the Body

In case you did not know, the right side of the brain controls the left side of the body, and the left side of the brain controls the right side of the body! There is a 'swapping over' that occurs as nerve fibers traverse to and from the brain, and to and from the periphery. This is called **decussation** of the nerve fibers, which means the crossing of axons from one side of the brain to the opposite side of the body.

## How the Two Halves are Different

In general terms, the **left cerebral hemisphere** is more in control of **language**, **logic**, **analytical**, **sequential** and **verbal** tasks, while the **right cerebral hemisphere** is more related to **spatial perception**, **artistic** and **musical** endeavors and **visual imagery**. Specific regions of the brain tend to process certain types of information, however, both sides of the brain are involved in the majority of information processing.

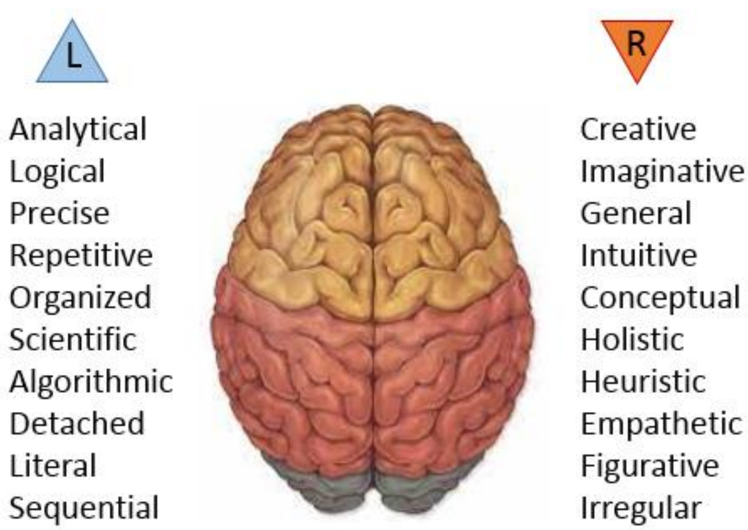



**Figure 9.2** Shows a superior view of the two cerebral hemispheres (the Left and the Right), with notation of their areas of focus. The frontal (yellow) parietal (rose) and occipital (grey) lobes can be seen. In general, these descriptions listed for the different functional elements of the Left (blue triangle) and Right (orange triangle) hemispheres are fair. The two hemispheres are different but complementary to one another.

### Examples of Cerebral Lateralization

In the past it has been the practice to call one cerebral hemisphere 'dominant', and that was customarily the left hemisphere. The term dominant is probably misleading, it does not mean that this side dominates anything. It was likely originally based on **handedness**. Most people are right handed, with about 90% of the population being right hand dominant. About 10 to 12% of the people are left-handed. Also, some people are **ambidextrous**, meaning they are able to use both hands with equal ease or dexterity, this is very uncommon with about a 1% prevalence.

Since most people are ***right*** handed and it is the ***left*** hemisphere which controls the *right hand*, then the left hemisphere was referred to as the dominant hemisphere. As it turns out, handedness is a useful relationship to examine and compare with other areas of control within the cerebrum.

### Functions of Speech and Word Recognition

The specific examples that are most obvious in demonstrating cerebral lateralization are regarding the functions of speech and word recognition. The primary cortical areas for language are **Broca's Area** and **Wernike's Area**. These two regions exist on the <u>left hemisphere only</u> if you are left-brain dominant, which roughly equates to people who are right handed.

- The **Broca's Area** (in the left frontal lobe) is responsible for speaking ability, the mechanics of skeletal muscle control for verbal articulation (sound production) within the mouth and throat.

- The **Wernicke's Area** (in the left juncture of parietal, temporal and occipital lobes) is concerned with understanding language, that is, for comprehension of the words that are read or heard.

There same regions on the right cerebral hemisphere are different in terms of functional areas. For example, the emotional aspect of language is controlled in the opposite hemispheres. Opposite Broca's area is the **affective language area**, which gives intonation to words, in order to modify their meaning. The area opposite Wernicke's is concerned with recognizing the emotion content of another person's speech. Think of someone saying "Oh great" with legitimate excitement and optimism, versus an "Oh great" with complete sarcasm and pessimism. These are the same words, with very different meanings based on ***affectation***, which is loading emotional feelings into the words that are being used.

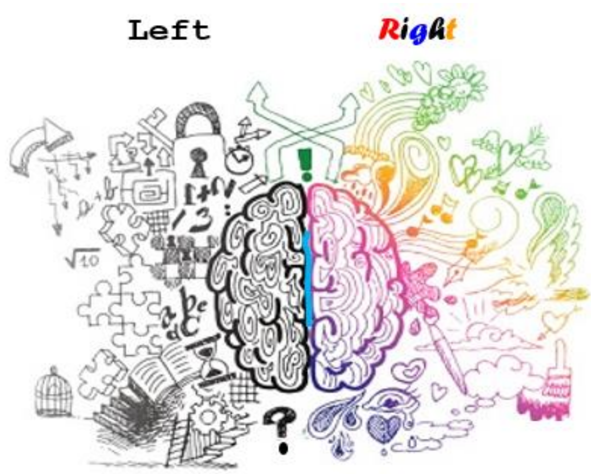



**Figure 9.3** Above is an artistic rendition of how the two cerebral hemispheres (the Left and the Right) are different from each other. The light blue line in the middle of the two hemispheres represents the corpus callosum, which contains about 300 million axons connecting the left and right sides for highly integrated cognition.

**Left Side**: Language, logic, analytical, sequential, verbal tasks (**fragmentary** information processing). "Thinkers"

**Right Side**: Spatial perception, artistic and musical endeavors (**holistic** information processing). "Creators"

These are useful ways to consider the functions of the two sides of our cerebrum, but also involves generalizations. Some research suggests that brain lateralization may be overemphasized and is not comprehensive for the cerebral hemispheres. It was proposed that women tend to use both sides of the brain more equally than men, however some researchers argue this is also misleading, and indeed that the brain is less lateralized than earlier believed. There is always more to learn and as we have already witnesses in the last section, it is not uncommon that 'discoveries' of former research and conclusions turn out to be extremely flawed and therefore inaccurate. It is important to keep an open mind and follow good honest science wherever it may lead us.

## The Limbic System

As already briefly introduced, there is a disparate anatomical group with critical functions and interconnecting structures (cortices and nuclei) within the cerebrum and diencephalon that are referred to collectively as the limbic system (see **Fig. 9.4** below). The term limbic means 'border or edge'. This group of structures is thought to be incredibly important in regulating **autonomic** and **endocrine** function, including responses to **emotional** stimuli.

This area of the brain is responsible for setting levels of arousal, and is involved in aspects of motivation, wherein it integrates this into behaviors, which is also related to reinforcing various behaviors.

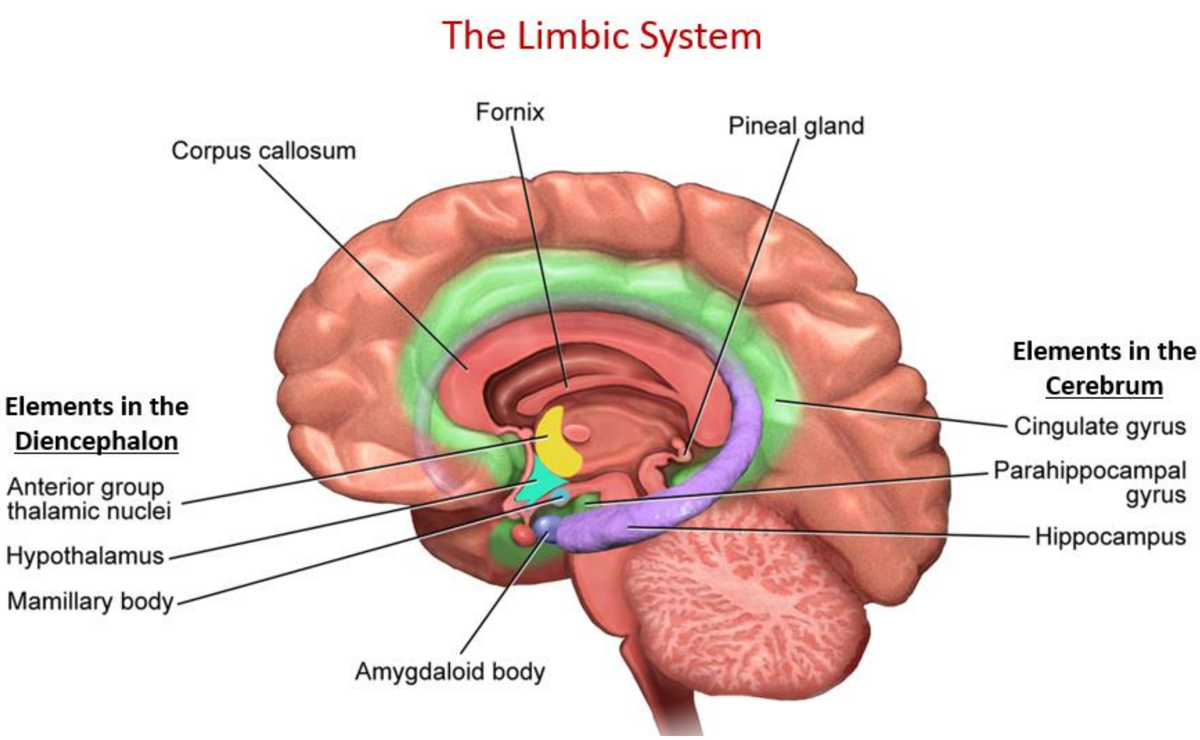



**Figure 9.4** This mid-sagittal section of the brain highlights and color-codes the elements of the limbic system that are from the cerebrum and the diencephalon. The fornix is to the limbic system what the corpus callosum is to the cerebral hemispheres, as the fornix inter-connects the two hemispheres of the limbic system.

**The Cingulate Gyrus**

The Cingulate gyrus lies on the medial aspect of the cerebral hemisphere. It forms a major part of the limbic system which has functions in emotion and behavior. The cingulate gyrus is an arch-shaped convolution situated just above the corpus callosum. Information processing for decision making, planning, allows us to shift between thoughts and inter-relate them. It also has a primary role which interprets pain as unpleasant. His is an integral part of learning and learned avoidance practice.

**The Hippocampus**

The hippocampus is a complex brain structure embedded deep in the **temporal lobe**. It is thought to have a major role in learning and memory. It's named after its resemblance to the **sea-horse** creature who pulled the Roman god of water Neptune's chariot. This structure is described as *plastic*, where **neuroplasticity** is the ability of the brain to create and reorganize new synaptic connections, especially in response to learning or after experiencing injury, since the hippocampus can become damaged by various stimuli. For example, high, prolonged levels of **cortisol** are associated with shrinkage of the hippocampus. Another way to think of it is that worrying too much can shrivel your brain. So worry less.

This area has a role in **spatial processing** and navigation, integrating spatial relationships and memories. This may explain why some people have a better sense of direction than others, in that their hippocampus is more integrated with their others senses. So let them have the map, it's just better for everyone. It also functions in consolidating information and memories during restorative sleep.

**The Amygdala**

The amygdala takes its name after the almond-shaped nuclei that is nestled within the **temporal lobe**, it is part of a collection of nuclei located deep in the temporal lobe.

Researchers hypothesize that the amygdala is at the core of a neural system for detecting and processing threatening stimuli, especially **menacing glances** or faces that represent **expressions of fear**. A neuroscientist researcher in the 1990's, Paul Whalen, showed that subjects presented with images of **fearful faces** triggered the amygdala. Scrambled unrealistic images of the same face elicited no response from the amygdala. After being stimulated, it assists in activating appropriate fear-related behaviors in response to threatening or dangerous stimuli, things like revving up the heart rate so you can do a few fancy karate moves if need be. Primarily, the amygdala activates areas involved in preparation for motor functions of **fight or flight**, i.e., the **sympathetic division** of the autonomic nervous system (ANS). It also triggers release of stress hormones cortisol and epinephrine.

The amygdala is also involved in tying emotional meaning to our memories. It's not all about fear, the amygdala also plays an important role in the storage and retrieval of **positive emotional memories**, such as the recognition and emotional happiness from seeing your grandmother's face. As an example, seen in **Fig. 9.5**, for the two facial expressions **a)** and **b)** in the image to the right, which do you think would trigger the amygdala to fire because it detects possible danger? Like **b)**, right? However it is worth noting that the amygdala could still be triggered by **a)**, if you recognized this face as someone you had a very positive emotional connection with.

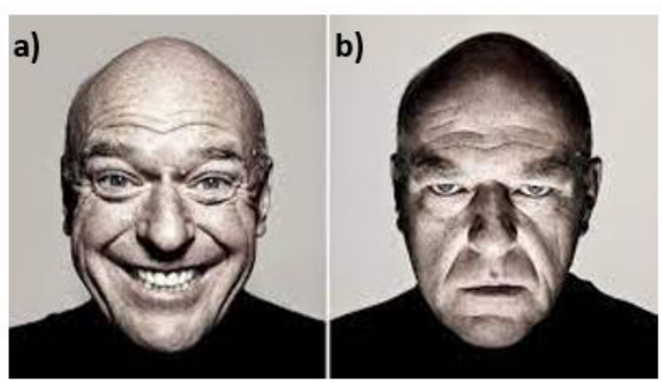



**Figure 9.5** The brain will react differently to **a)** the pleasant facial expression, compared to **b)** the kind of scary looking one.

**Neurotransmitters from Amygdala Output**

The output of the amygdala results in release of **norepinephrine**, **acetylcholine**, **dopamine**, **serotonin** throughout the brain - this makes the brain hyper aware and sensitive. In the body, it helps trigger release of the hormones **epinephrine** (adrenalin) and **cortisol**, both of which ready the body for danger. The firing of neurons that release **GABA** (GABAergic neurotransmission) **inhibits** the amygdala and prevents the generation of inappropriate emotional and behavioral responses. You can imagine that if a person does not have enough GABA they may be more easily frightened and therefore more anxious.

## Damage to Brain Areas

Language disorders caused by damage to specific cortical areas are known as **aphasias** (see appendix A for the etymology, a = without, phasis = to speak). Most aphasias are caused by strokes. A **stroke** can be defined as a "**cerebrovascular accident**", or a **CVA**. This can occur when a blood vessel in the brain (a cerebral blood vessel) is ruptured or is blocked by a clot. The result can be the sudden damage of some brain cells due to a lack of oxygen ($O_2$) in that region of the brain being supplied by the vessel, as well as a lack of glucose for neurons, which they require constantly in order to maintain order and function. Damage of the affected area can result in obvious symptoms or may be difficult to identify. The response of an induvial to any kind of stroke will depend on the area of the brain affected.

As nerve pathways cross over, the brain has control over the opposite side of our body. This explains why damage to one side of the brain can affect the functioning of the **opposite side** of the body. However, people who experience damage in an area of the brain dedicated to a specific function may begin processing information for that same function in another area of the brain. This is an example of **neuroplasticity**, where the brain is able to modify and adapt its structure and function throughout life, in response to experience and damage. Never discount the human body, it is a marvel and it literally works at its best for you 24/7, 365 days of the year. Its primary goal is to re-establish balance and function.

**Neuron Oxygen and Glucose Physiology**

As we know from the 2$^{nd}$ law of thermodynamics, every cell needs energy (E) to contend with entropy. The cellular energy **ATP** and there are 2 ways to make ATP in the body: **1)** with $O_2$ (aerobically) and **2)** without $O_2$ (anaerobically).

Neurons **cannot** make ATP anaerobically (without $O_2$), thus they need a constant supply of $O_2$ in order to make ATP. Neurons also require glucose (with $O_2$) to make ATP. Unlike most other cells, they cannot use other molecules such as lipids and proteins as fuel for ATP production. Furthermore, they have no stores of glucose (like muscle or liver tissue has), so they need a constant supply of both $O_2$ and glucose.

Why are we mentioning this here? Because this is a primary reason why **blood glucose levels** are important and so closely regulated by the body. Brain damage may result if this organ is deprived of its critical $O_2$ supply for prolonged periods, or if its glucose supply is cut off for more than 10 to 15 minutes.

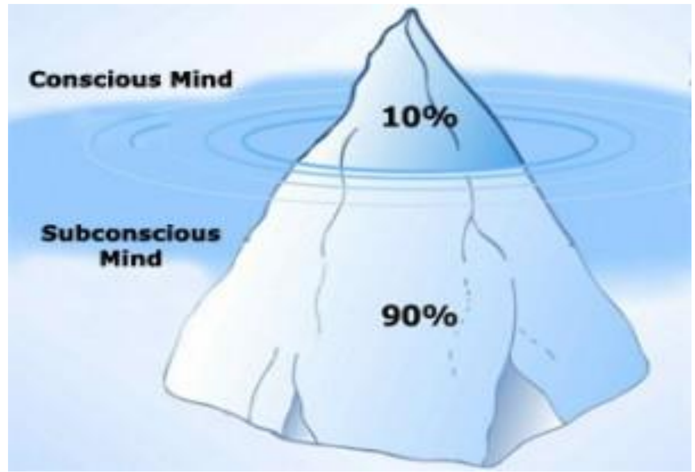
**Neurons are Not Insulin Dependent**

As we will see in discussions of the hormonal regulation of glucose, the peptide hormone **insulin** regulates glucose uptake by cells through glucose transporters, specifically via GLUT 4 and GLUT 8. There are some neuronal cell bodies, mainly in the hippocampus and amygdala, which use these glucose transporters; however, glucose enters the brain predominantly from the blood by crossing the blood brain barrier (BBB) through **GLUT 1** and **GLUT 3**. Importantly, insulin is not required for GLUT 1 or GLUT 3 mediated glucose transport, therefore **insulin is not needed for glucose transport into most brain cells**. Yay!

## The Subconscious Mind

Before we go further into the brain, it is worth mentioning that the concept of the **subconscious mind** relates heavily to the cerebrum, but is certainly not limited to it. Recall that of the six regions of the brain, the cerebrum accounts of **7/8**th of the total mass of the brain, and this indicates that quite a lot is going on in this region.

The subconscious mind is somewhat like a data bank for everything that has been experienced and contemplated by us. This is distinct from the conscious mind, which heavily filters the information it receives and therefore greatly affects the perception of an individual. The subconscious mind stores our beliefs, previous experience, memories and skills. Everything that we have seen, done or thought is contained there, if you will. It is also our guidance system as it can make rapid and complex computations that enable us to make accurate predictions, not to mention tap into feelings and intuition and pattern recognition very quickly.




**The Subconscious Minds Knows Everything**

The conscious mind represents about **10%** of the total activity of your mind, and very much like the tip of the iceberg (above right), it is that small portion above the surface that is easier to see and comprehend. Deeper, more vast and representing **90%** of your minds activity is the subconscious mind. It is the subconscious mind that is the target of advertisers and other programmers! This is because this portion of your mind is really controlling most of our actions and is willing to believe anything you allow it to believe. Examine the comparison of the conscious and subconscious minds in **Table 9.1** below.

**Table 9.1** Here are some basic differences between the **Conscious** and **Subconscious** Mind.

| Conscious Mind | Subconscious Mind |
|---|---|
| Processes **40** bits of info per second. (**40**/sec) | Processes **4 million** bits of info per second. (**4,000,000**/sec) |
| Sets **Goals** and **Judges** the results. Actively Analyzes. | Maintains **Habits** and **Routines** (Heart Rate, Breathing, Digestion) |
| Thinks **Abstractly** (happiness means very different things to different people). | Thinks **Literally**. Need to be very specific in communicating with it. **Resistant** to change through normal conscious processes. |
| Thinks in the **Past** and **Future**, not in the Present. | Exists in the **Present**. Everything is **NOW**! No such thing as past or future. |
| Processing capacity for **short term memories** is about 20 seconds, multi-tasking of about **1-3** events at a time. | Vastly expanded processing capacity, housing **long term memory**, multi-tasking **1,000's** of events at a time. |

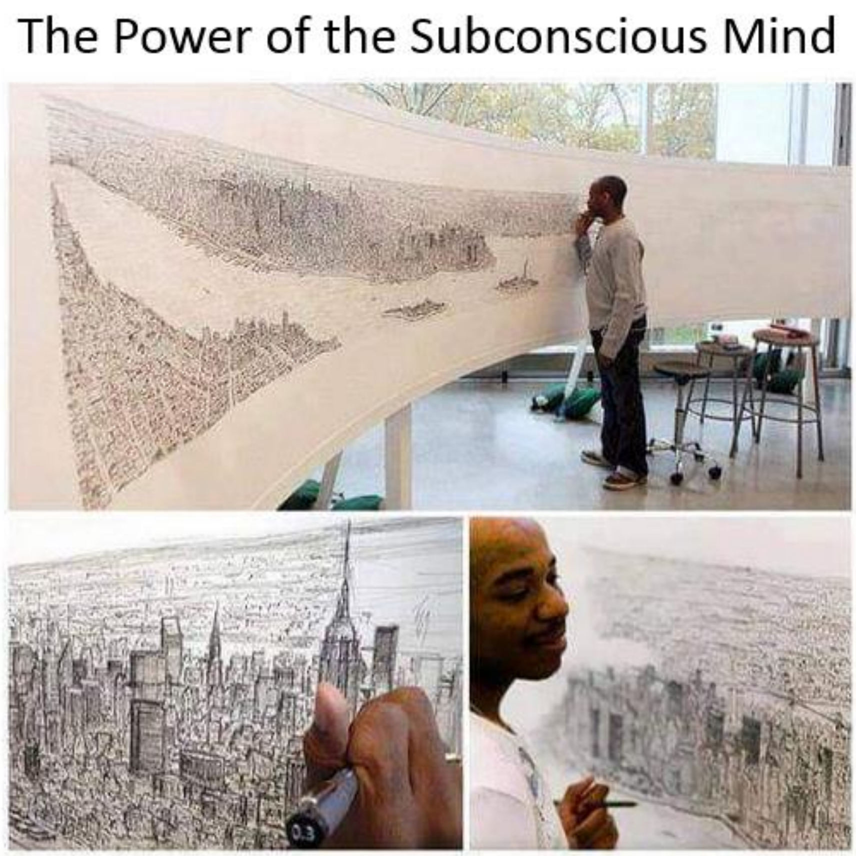



**Figure 9.6** Seen here is Stephen Wiltshire, an autistic savant architectural artist, known for his ability to draw landscapes from memory after seeing things just once. Above, after only a 20 minute helicopter ride over New York City, he was able to draw intricate details of the New York skyline from memory alone.

**What is a 'Savant' Anyway?**

A **savant** is typically a person with exceptional skills and aptitude in one particular area, often that of music, art or mathematics. They are considered extremely gifted in this area despite having significant impairment in other areas of intellectual or social functioning. Some time ago such people were called 'idiot savants', which was not very nice, but it was making the point that often time these were individuals who would have trouble tying their shoe laces yet could dismantle a complex car engine and re-assemble it perfectly with ease.

The man Stephen Wiltshire shown in **Fig. 9.6** above is such a person. In some realms he is affected with a developmental disorders, almost akin to an intellectual disability, and yet he clearly exhibits exceptional talent and skills in memory recall and reproduction of visual input in his amazing drawings.

It may be argued that any one of us could do these seemingly amazing things – if we could tap into all of that power in our subconscious mind, as that it the place or realm that seems to literally store everything we encounter! It could be a matter that these skills are facilitated by unique brain wiring. Or that this is actually hard-wired in all our brains and it then becomes a matter of tapping into it!

As you might be starting to realize, it is the **Subconscious Mind** that is really running the much of what we are constantly processing. Understanding this, it becomes more obvious why the **Beliefs** in the **Subconscious Mind** have an enormous impact on how you feel and consequently the way you behave.

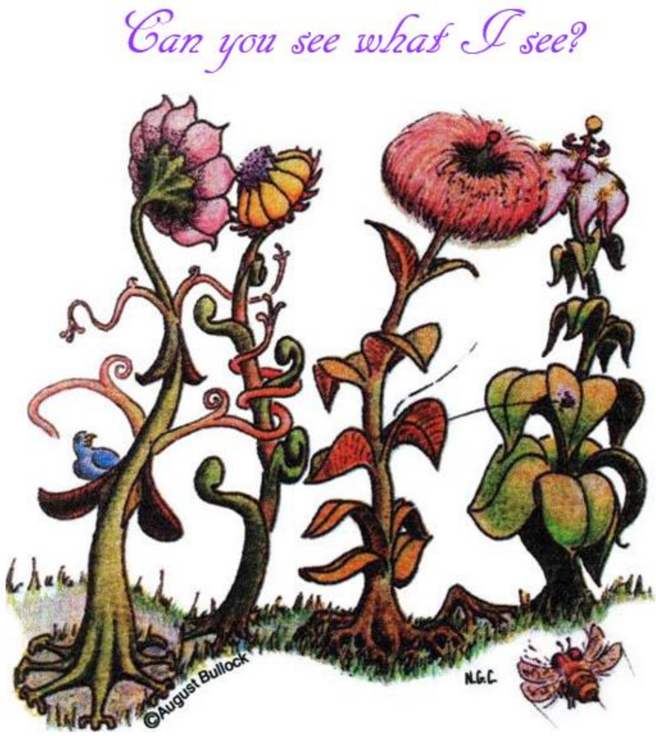



**Figure 9.6** This is just an image of some birds and bees, some flowers and trees… right? Can you see the hidden word? Your subconscious mind can see it right away and takes in that information.

**Subliminal Messages and Your Mind**

Hypnotized people can read reversed, mirrored and upside-down text at a normal rate. That is, the subconscious mind decodes any text, no matter how it's written. Recognition of **images** are even more powerful - since visual stimulation is paramount in our thinking and processing of information in terms of content and context. It must be understood that **advertisers and anyone else trying to manipulate you** knows this (and much more) about the human mind.

For **Figures 9.6** and **9.7**, can you see the word 'sex', or the naked bodies or the word 'sex' in the ads for soda? Do you see skulls and dice, and body features in the imagery promoting those drinks, especially alcoholic beverages? The answers is **YES**. Those images, and more, are present. Just take the time to consciously look for them and they will start to appear. Why? Why would advertisers and programmers do this? Because they want to communicate with your **subconscious mind** and influence it without your conscious mind being aware of the manipulation. Sneaky!


**Figure 9.7** The images for **a)**, **b)** and **e)** are from advertisements promoting alcoholic beverages. Images **c)** and **d)** are ads for Coca-Cola. There are skulls, suggestive body parts, dice, and even the word sex etched in an ice cube. All of these images are for your subconscious mind to take in and make desired associations with these products.

But **Why**? Why would people do this? Here is a quick discussion of a reasonable suggestion.

These imbedded messages are for your **subconscious mind** (that's why they hide them), because, as shown above, your subconscious mind **sees everything** and takes into account incredible amounts of information, especially visually. The skulls are **death imagery**, to remind you that you're going to die, so why not have some fun, get blotto and do stupid things while you are drunk, because it's all meaningless anyway, and you might as well live a little. This is likely in contrast to what your conscious mind may be thinking – something more like, maybe I should be careful, perhaps that alcohol is toxic and harmful. Still, the skull continues to say 'So what, you're going to die anyway, let loose and just do it!'

Similarly, relating and connecting **sex** to everything (buying a car, cologne, soda, vodka, etc.) is still outwardly taboo to most, therefore implanting covert (hidden) **sexual imagery** in a product's ads and within its packaging is an attempt to link sex to that product in a veiled way. It is hoped that whomever encounters the imagery will act on that ***subconscious link***, not consciously knowing why they have selected that product. Impulse buying works at the subconscious level - and it does work - if you are not aware of the manipulation that is being practiced. If you think it does not work, then why is it constantly, relentlessly used? And if you think it's just about making money, you may want to think again. Lots of concepts are delivered to the subconscious mind for reasons of **control**, a concept that is far beyond any money!

Some will say that people see horses in the clouds, and no one 'placed' them there, it's just a human tendency to see things that are not really deliberate, so seeing a skull in an ice cube is the same thing! Furthermore, some people have disorders, believing they see things that are not actually real, therefore the subliminal stuff is meaningless. It is true that people can see objects in clouds. The important thing to realize is that this natural tendency in the human mind is well known, these 'conditions' have names (**apophenia** and **pareidolia**, see below). More importantly perhaps is that advertiser's etc. know all about this (and more) regarding how the human mind works, and thus they 'hide' images in adverts intentionally, knowing many will dismiss it as random, unrelated coincidence… When in reality someone is deliberately attempting to guide and manipulate your subconscious mind.


**Figure 9.8** Shown here are examples of pareidolia, **a)** some may see an eye, but it's just sudsy water going down a drain. For **b)** that sure looks like a horse in those clouds. And finally in **c)** if you can see faces in this picture, you may have facial pareidolia. This also indicates you have a well-wired brain.

**Apophenia** is a general term meaning the tendency of people to perceive a connection or meaningful pattern between seemingly unrelated or random things. It is thought to be a human ability and tendency to see shapes or make pictures out of things that are, or may appear to be random. **Pareidolia** (classified as a type of apophenia) is the tendency to perceive a specific, often meaningful image, especially **faces**, in a random or ambiguous visual patterns. See **Figure 9.8** just above for examples.

The purpose for exploring this topic in this section is because the human brain is extraordinarily complex, and it is worthwhile understanding the various ways that it can be influenced. In an interesting and revealing taste test experiment done in 2005, somewhat surprising results were found and it ties into the discussion about what factors tend to influence the brain and the mind (which are not the same thing – that's another story for another time).

The study (see **Fig. 9.9** below) conducted **taste tests** for unknown sodas A and B, which in the first trial were Coke and Pepsi. Guess what? There was no 'winner' in the subjects' preference, it was a 50% to 50% split down the middle. Should that surprise anyone? For all intents and purposes they are ***identical beverages***. However, in the second trial, one cup was labeled "Coke" and the second cup was labeled "Other", but both cups actually contained Coke. In this taste test there was an **85% preference** for the drink labeled "Coke". But its competitor was the exact same beverage, it just wasn't labeled Coke. Finally, in the third trial, again both drinks were the same, only this time it was Pepsi, with one of the cups was labeled "Pepsi" and the second cup labeled "Other" with both cups containing Pepsi. The result now was a 50% split between Pepsi and Other. What does this tell us? Does it tell us about the actual taste of the beverages? No, not really. Does it tell us about the ***perception*** that already exists in people's minds regarding the two beverages? Yes, this seems to be a key element of the study according to the setup of the experiment. Another thing it indicates to us is that Coke has a more successful marketing campaign than Pepsi.

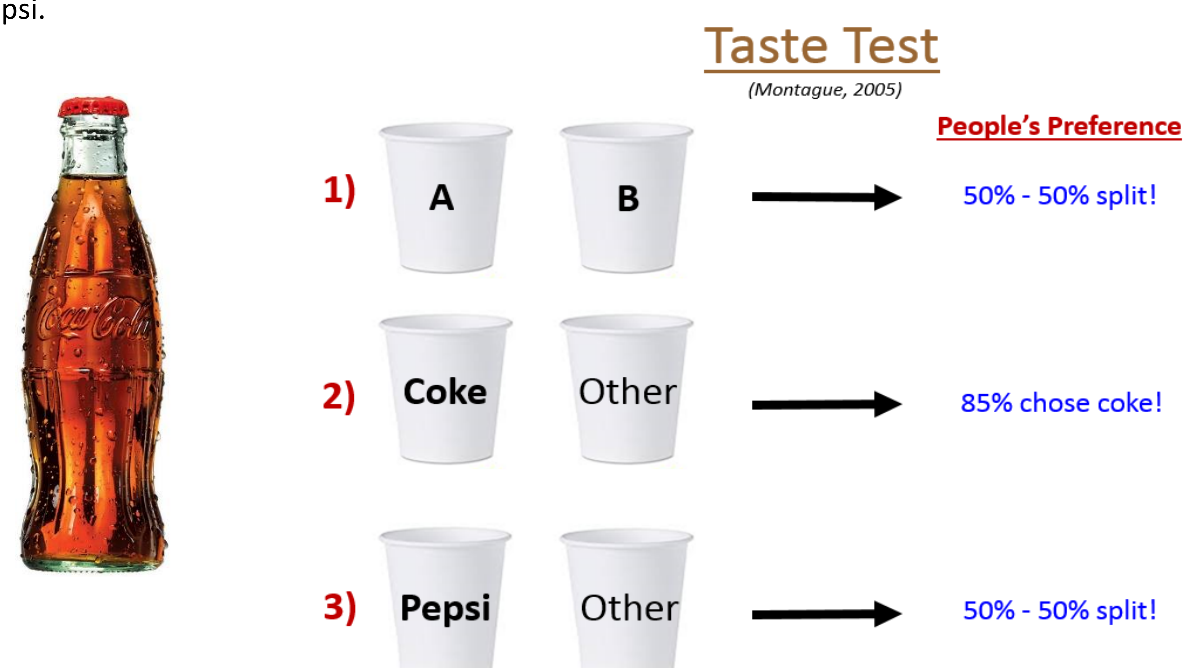



**Figure 9.9** In a study by Montague (2005), taste tests for Coke and Pepsi were performed. It was shown that if people did not know which soda they were drinking, as in trial **1)** with the cups only labeled with A and B, there was an approximate 50% who chose A (Coke) and 50% who chose B (Pepsi). In trial **2)**, when one of the cups was labeled "Coke" and the other cup labeled "Other" with both cups actually containing Coke, there was an 85% preference in the drink labeled "Coke". In the last trial, **3)** again both drinks are the same, this time it was Pepsi, with one of the cups was labeled "Pepsi" and the other cup labeled "Other" but also containing Pepsi. The result was a 50% split between "Pepsi" and "Other".

**Researcher's Comment from the Soda Taste Tests Experiments (2005)**:
*"There are visual images and marketing messages that have insinuated themselves into the nervous system of humans who consume the drink. It is possible that cultural messages perturb taste sensation."*

## 2. The Diencephalon (Epithalamus, Thalamus and Hypothalamus)

The diencephalon is composed of the regions: The **Epithalamus**, the **Thalamus** and the **Hypothalamus**. Note all three structures have the name thalamus in them! Thalamus, in Latin means 'inner chamber', 'den', 'vault', or 'sleeping room'. The prefixes epi- and hypo- accurately describe the relative positions of the two regions above and below the thalamus. The total size of the diencephalon is about **2.3 inches** in length (6 cm), which is actually a sizable sub-cerebral region.

The epithalamus is anatomically the most superior (see **Fig. 9.10** below) and also the smallest component of the diencephalon. The thalamus makes up the bulk of this region with its two distinctive rounded lobes. Finally, the lowest anatomical portion is the hypothalamus, which is the region that is directly most interactive with the rest of the body, by virtue of its central and exposed position within the brain, and due to its proximity and connection to the pituitary gland.

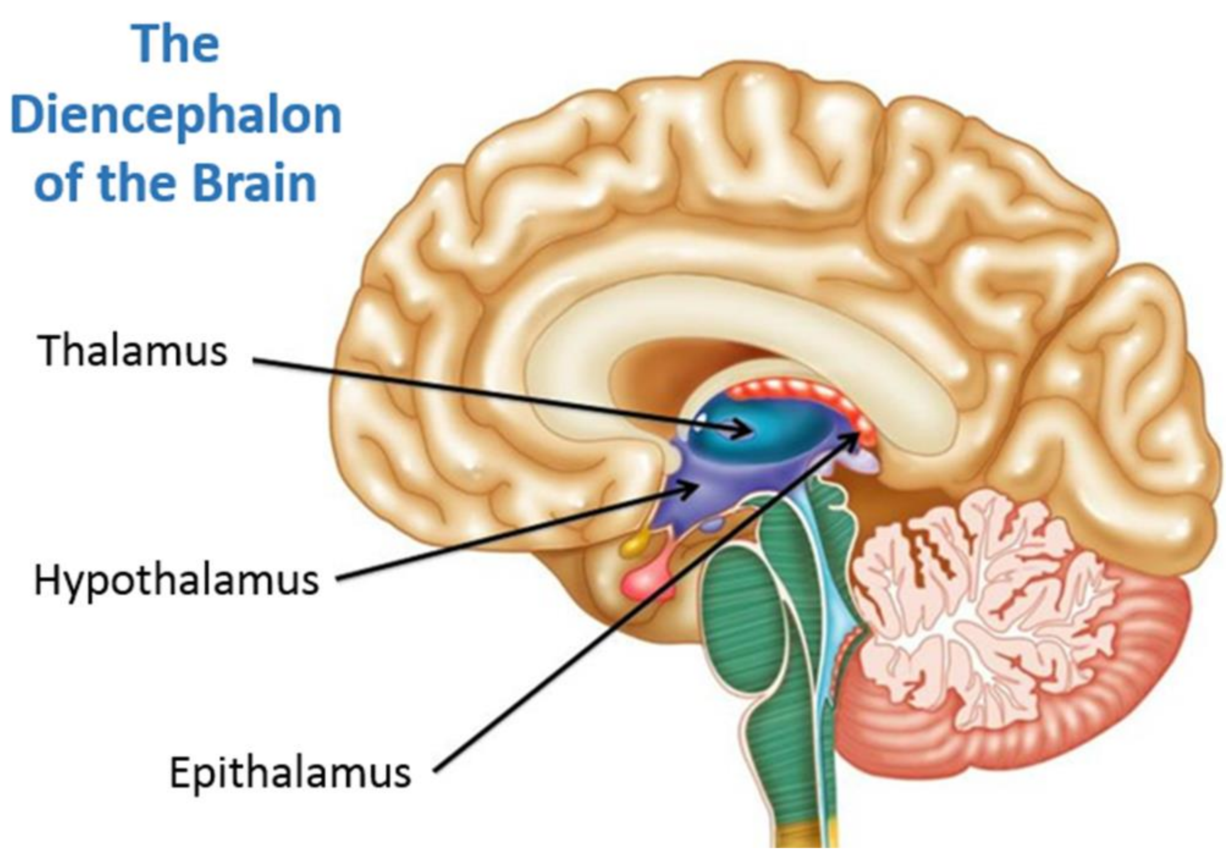



**Figure 9.10** This mid-sagittal section of the brain shows the three parts of the diencephalon of the brain. The epithalamus encompasses all of the orange-pink colored area, and at the end of it (at arrow) is the pine cone-shaped pineal gland. The thalamus as indicated is the largest portion, containing two bilateral lobes. The hypothalamus (colored purple here) sits directly under the thalamus and is also connected by a stock (the infundibulum) to both the anterior and posterior pituitary glands.

## The Epithalamus and the Pineal Gland

The **epithalamus** is the small upper segment of the diencephalon. The most significant structure it contains is the **pineal gland**, a hormone secreting endocrine structure. Under the influence of the hypothalamus, the pineal gland secretes the hormone **melatonin**, which prepares the body for the night-time stage of the sleep/wake cycle.

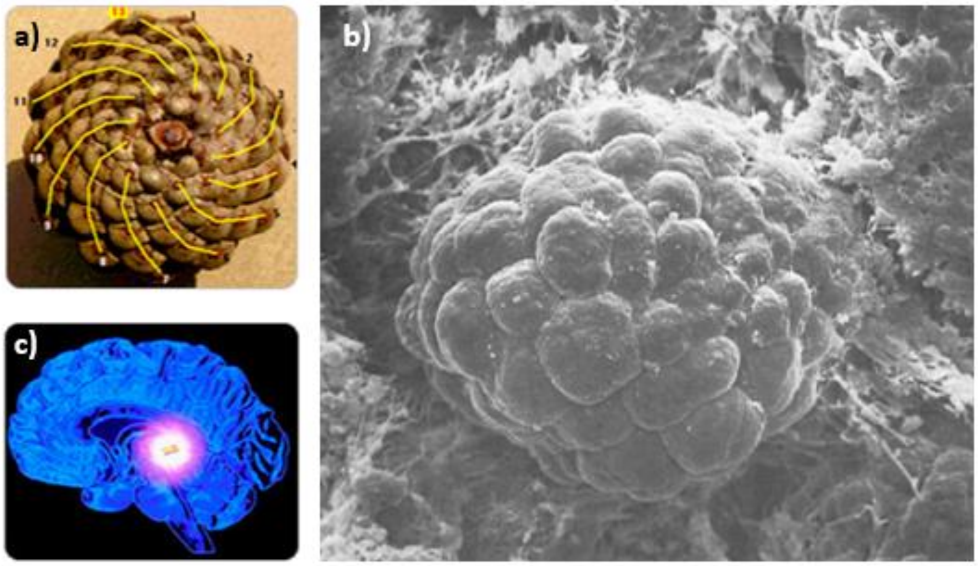



**Figure 9.11** The resemblance of the pineal gland to a pine cone in **a)** is where the glands gets its name. The Fibonacci sequence can be seen in the structure of the pine cone as it can be seen across all natural phenomena. In **b)** the pineal gland can be visualized in a scanning electron micrograph, and **c)** its location in the middle of the brain.

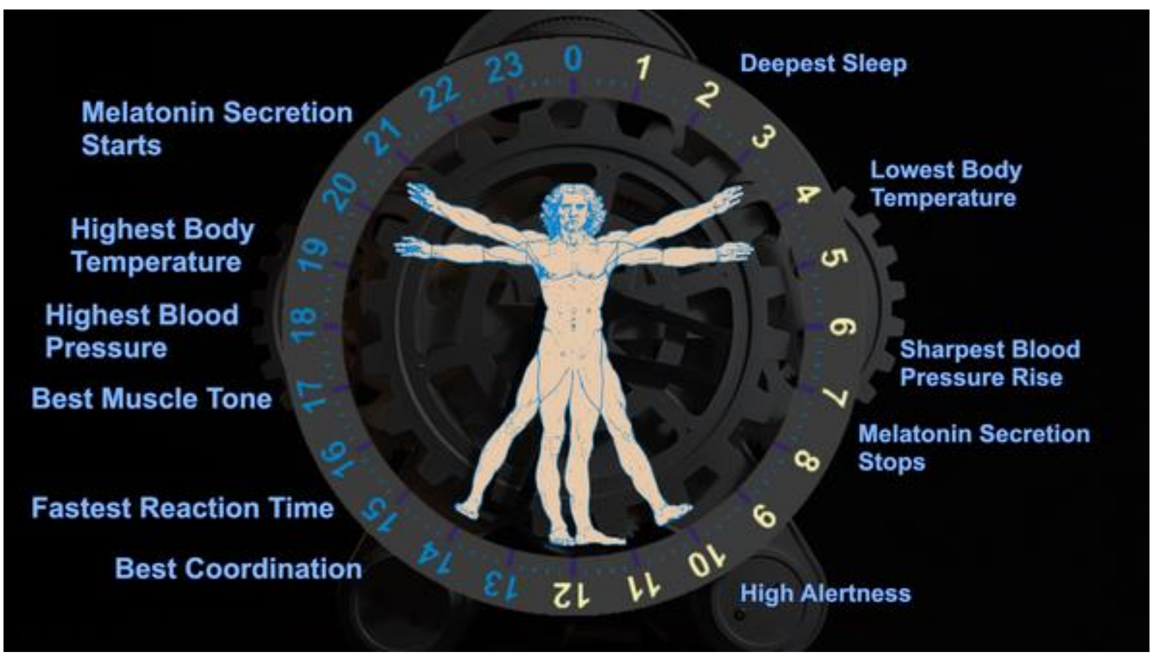



**Figure 9.12** The Vitruvian Man (drawn by Leonardo da Vinci circa 1490) gives a tour of the circadian rhythms of the body assisted by the cyclic release of melatonin from the pineal gland which is a structure within the epithalamus.

The pineal gland is very tiny (see **Fig 9.11**) for such a remarkable structure, in adults is about 0.3 inches long (approximately 0.8 cm). It weighs about 0.004 of an ounce (about 0.1 gram). So very tiny! Despite its small size, the pineal gland has a rich supply of adrenergic nerves, sensitive to the hormone **epinephrine**, that greatly influence its function. The endocrine section of this text goes into great detail regarding the stimulus and sequence of events for **melatonin** release, as well as the many physiological effects it has on the body. Although not a structure of the limbic system, the epithalamus has a role in connecting the limbic system to other parts of the brain.

## The Thalamus

The **thalamus** is the largest component of the diencephalon (**Fig. 9.13**), making up about **80%** of its mass. The thalamus is generally known as **the main relay center** for the various sensory and motor functions to and from the higher centers of the cerebrum.

The two hemispheres the thalamus are distinctive oblong bulb-shaped and create the sides of the 3rd ventricle in the brain. There are myelinated fibers within the thalamus that separate the different thalamic sub-parts that are defined by their distinct groups of neurons, which of course make up what are called **nuclei** in the CNS. See specifically **Fig. 9.13 c)** below for the many thalamic nuclei.

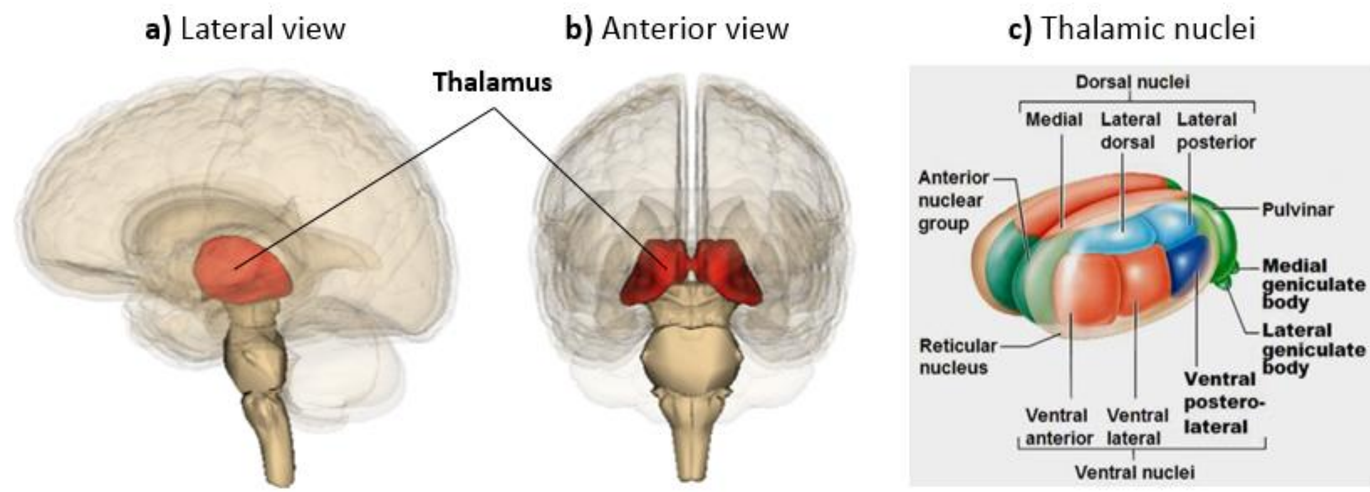



**Figure 9.13** The relative size and location of the thalamus within the brain is shown in **a)** the lateral view of the brain, where the thalamus is the bulk of the diencephalon, and in **b)** the two hemispheres of the thalamus can be seen, which are connected by the interthalamic adhesion (or the intermediate mass). Finally, **c)** shows a closer look at the many individual thalamic nuclei packed into this structure.

**Functions of the Thalamus**

A familiar phrase is that the thalamus acts as the **"gateway" to the cerebral cortex**. Recall the cerebral cortices (plural of cortex) are the outermost regions of the five lobes of the cerebrum where all the complex integration and thinking is going on. Therefore, a significant aspect of the function of the thalamus is to be the conduit for the flow of information up to the higher centers (from the peripheral body or from other regions of the brain), and also for the flow of information down, from the higher centers, out to other areas.

The thalamus also acts as a filter for incoming sensory information. It can **tone down** an incoming signal or can act to **amplify** an incoming signal.

For example, if a person were sitting reading a book in a busy café with lots of sounds and other distractions, this would be an example of the thalamic role in toning down all of the other signals present in the room allowing us to filter out the anticipated clanking and chatter in order to focus on another task, such as reading a great physiology chapter. In contrast, if while still in the same busy café a person is waiting for a phone call, it will be necessary to detect this sound amongst the many other competing noises. Consciously knowing this, the thalamus can facilitate the amplification of this specific incoming signal so that we can recognize it effectively as distinct amongst the variety of other stimuli. Thank you thalamus.

**The Relay Station**

All of the sensory information that is incoming form the periphery is relayed through the thalamus – that is an impressive amount of relaying! The **thalamic nuclei** relay and modulate information incoming from the periphery to the cerebral cortex. Basically, almost all **ascending** neural pathways first synapse within a thalamic nucleus, where the information is sorted, integrated, and analyzed by the thalami before they are sent further to the cerebral cortex.

In a chapter further ahead regarding sensations and perceptions, we will see that **visual** information detected in the eyes is relayed through the thalamus before it gets to the visual cortex of the occipital lobe. Same for hearing a **sound** that is processed through your ears, this information is relayed through the thalamus before it is delivered to the auditory cortex within the temporal lobe for processing and perception. Same for **taste**, **touch** and **balance**… but did you know that there is one sense that is the exception and does not go through the thalamus to get to the cerebral cortex? It is **olfaction**, or the sense of smell. This sensation bypasses the thalamus and instead is routed through the **hypothalamus**, in particular a structure called the **mammillary body**, which is a nucleus of the hypothalamus. The mammillary body is also a component of the **limbic system**, which is important as we have seen previously, in deriving the emotional content from sensory information. This routing of the sense of smell through the limbic system is why it is believed that olfaction is very closely tied to emotional memories.

As mentioned above, every sensory system (with the exception of the olfactory system) has a thalamic nucleus that receives sensory signals and sends them to the associated primary cortical area. Here are the systems and their thalamic nuclei:

- For the visual system, inputs from the retina are sent to the **lateral geniculate nucleus** of the thalamus, which in turn projects to the primary visual cortex in the occipital lobe.

- The **medial geniculate nucleus** acts as a key auditory relay between the **inferior colliculus** of the corpora quadrigemina of the midbrain and the primary auditory cortex.

- The **ventral posterior nucleus** is a key somatosensory relay, which sends **touch** and **proprioceptive** information to the primary **somatosensory cortex** of the parietal lobe.

- The regulation of sleep and wakefulness is an important role of the thalamus. It is involved with regulating **arousal**, and level of **awareness** and **activity**. Significant damage to specific regions of the thalamus can lead to permanent loss of consciousness, or the state of a coma.

- Thalamic nuclei have strong bi-directional or connections with the cerebral cortices, the **thalamo-cortico-thalamic** circuits are for reciprocal (back and forth) nature that is thought to be involved in conscious thinking.

## The Hypothalamus

Although relatively small in comparison to some other major brain regions, the hypothalamus plays a central role in many vital bodily functions, as displayed in **Fig. 9.14**. Not only does it relay and integrate sophisticated signals within both the central and peripheral the nervous systems, but it also provides a direct link between the **nervous system** and the **endocrine system** with its regulation of the **pituitary gland** and the **pineal gland**.

### The Hypothalamic Nuclei

Essentially the hypothalamus is a compact is a collection of **nuclei** – defined as a group of nerve cell bodies (gray matter) in the CNS that have a specific function and a discrete boundary (location). The hypothalamic nuclei can be described by their zones and their detailed anatomical location, but we will focus on the **physiological** aspects of what each of these distinct regions does.

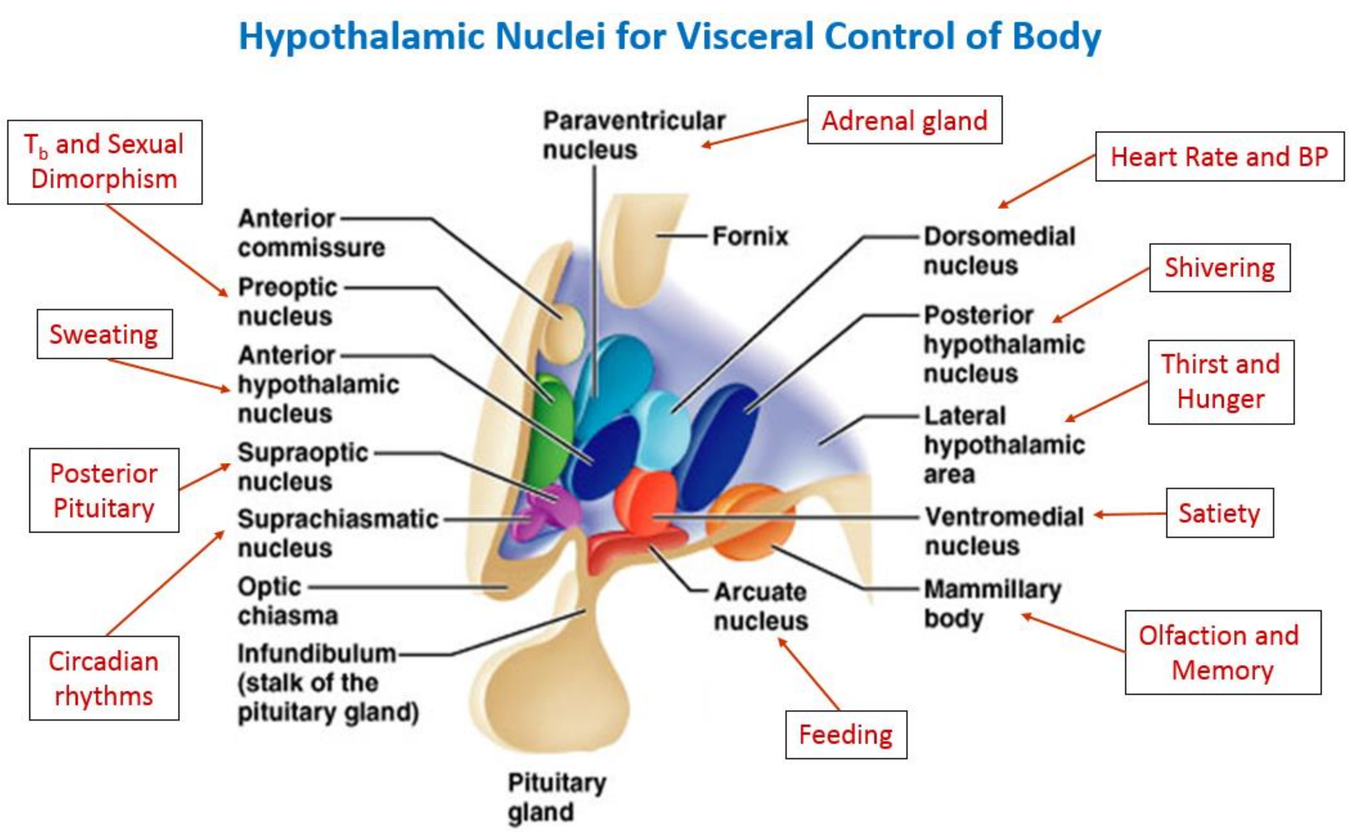



**Figure 9.14** This image shows the dozen or so nuclei that are located within the hypothalamus, arranged in a very compact yet strategic way. For each of the functional nuclei, the boxes indicated the major (but not the complete) function of each of these hypothalamic nuclei that the arrows are pointing at.

### The Functions of the Hypothalamic Nuclei

Each hypothalamic nuclei has specific **functions**. Together, they allow the very small hypothalamus to be the regulator of a wide variety of critical body functions seen in **Figure 9.14** above.

- **Medial Preoptic Nucleus:** This region is responsible for **thermoregulation** of the entire body, it's like a thermostat. It receives sensory input from various thermoreceptors in the skin, mucous membranes, and from within hypothalamus itself. In the example of a negative feedback loop in the introductory chapter of this text, the integration center for regulation of body temperature

($T_b$) was the hypothalamus. Now we know that the very specific region is the Medial Preoptic Nucleus (MPN) of the hypothalamus.

- This region also contains the **sexually dimorphic nucleus,** and modulates the secretion of gonadotropin releasing hormone (**GnRH**), necessary for **sexual maturity** and **reproduction**. It sends GnRH to the adenohypophysis (or anterior pituitary gland) which responds by releasing **follicular stimulating hormone** (**FSH**) and **luteinizing hormone** (**LH**) which promotes the development of the gametes and sex hormones in both sexes. Importantly, differential development between sexes is based upon in utero testosterone levels that are influences by the sexually dimorphic nucleus.

- **Paraventricular:** This region contains neurosecretory, with axons extending into the posterior pituitary, and other neurosecretory cells signal to the anterior pituitary. Since in influences the pituitary gland it plays an essential role in metabolism, growth, controlling responses to stress, immune responses and reproduction.

- **Supraoptic nuclei:** This contains about 3,000 neurons and regulates osmolality of blood and body fluids via the production of **antidiuretic hormone** (ADH), and aids in parturition (birthing) by the action of **oxytocin** on the uterus.

- **Anterior hypothalamic nucleus:** This is involved with **thermoregulation** by the stimulation of the **parasympathetic** nervous system, involved with the **heat loss-cooling** of the body. This involves panting and sweating to reduce body temperate when too high. Damage or destruction of this nucleus causes hyperthermia, an abnormally high body temperature caused by a failure of the heat-regulating mechanisms of the body to deal with the heat coming from the environment. It also has a role in the release of **thyrotropin inhibition hormone** which inhibits release of thyroid stimulating hormone.

- **Suprachiasmatic nucleus**: It is the central pacemaker of the circadian timing system and regulates most **circadian rhythms** in the body. The regulation of circadian activity is modulated by **serotonergic** input arising from the median raphe nucleus (of the superior cerebellar peduncles). These effects are mediated by several serotonin receptor subtypes that modify the suprachiasmatic nucleus (SCN) response to light and/or the phase of the SCN oscillation.

- **Dorsomedial nuclei:** It is involved in **feeding**, **drinking**, **body-weight regulation** and **circadian** activity. It is a necessary component for the expression of a number of behavioral and physiological circadian rhythms. Put succinctly it regulates the urge to eat.

- **Ventromedial nuclei:** It regulates female sexual behavior, feeding, energy balance, and cardiovascular function. Succinctly put it regulates the sense of fullness, and is associated with **satiety**. Studies show imbalances or damage here causes over-eating and obesity in rats, with an overproduction of the hormone **leptin**, which they cannot respond to causing them to over eat, leading to obesity.

- **Lateral nucleus:** is also important in regulation of feeding. This region responds to internal or external signals regarding **feelings of hunger**. Its absence or destruction has been implicated in extremes of **starvation** such as anorexia nervosa. Once you've eaten, the ventromedial hypothalamus sends signals telling you when you're feeling full and have had enough food. It regulates metabolism and food intake.

- **Arcuate nucleus:** Responsible for producing **growth hormone-releasing hormone** (GHRH), involved in the regulation of feeding and metabolism. **Dopamine** of this region inhibits lactation by inhibiting the release of **prolactin** (PRL).

- **Mammillary Body**: An important area for recollective memory, thought to be integrated with olfaction. Damage can to spatial memory deficit.

- **Posterior nuclei:** The posterior nucleus, like its anterior counterpart, is involved in **thermoregulation**, but operates via the sympathetic nervous system, for **heat conservation**, retaining the heat of the body. Damage or destruction of this nucleus causes hypothermia (lower than normal body temperature). Also associated with **increase blood pressure** and **pupillary dilation**, in conjunction with sympathetic stimulation, as well as **shivering** and **vasopressin** release.

In Summary: The **Hypothalamus** controls and regulates many important functions of the body, including:

**1) Control of the Autonomic Nervous System** - adjusts, coordinates, and integrates the A.N.S. centers in the brain that regulate heart rate, blood pressure, bronchiole diameter, sweat glands, G.I. tract activity, etc. It does this via the Parasympathetic and Sympathetic divisions of the A.N.S.

**2) Control of Emotional Responses** - in association with the limbic system, it forms part of the emotional brain. Regions involved in fear, pleasure, rage and sex drive are located in the hypothalamus.

**3) Regulation of Body Temperature** - the body's thermostat and set point is located in the hypothalamus. There are also two (2) centers in the hypothalamus that respond to changes in the set point for body temperature.

1. Heat-losing Center: activation of this center causes sweating and cutaneous vasodilation.
2. Heat-promoting Center: activation of this center causes shivering and cutaneous vasoconstriction.

**4) Regulation of Hunger and Thirst Sensations** - hypothalamus contains centers that regulate eating and drinking behavior the feeding and thirst centers.

Feeding Center: this center is always active and stimulates hunger which is 'fed' by eating.
Satiety Center: stimulated when satisfied, this inhibits the always hungry feeding center.
Thirst Center: Osmoreceptors detect changes in osmotic pressure of blood, ECF, and when tonicity of bloody fluids go above 310 mOsM, this in part stimulates the thirst response.

**5) Control of the Endocrine System** – the hypothalamus controls the release of pituitary hormones. It controls the anterior pituitary gland, when the hypothalamus releases hormones, it can stimulate or inhibit the release of other hormones from the pituitary (7 hormones). Also, it makes the 2 hormones (oxytocin and antidiuretic hormone (ADH)) that are stored in the posterior pituitary and released when signaled. All of these hormones regulate many other organs in the body.

## 3. Midbrain

The **midbrain** (also called the **mesencephalon**), is part of the **brainstem** (= midbrain, pons and medulla oblongata). It connects the hindbrain and the forebrain. A major function of the midbrain is to aid in motor (body) movement, especially movements of the eye, as well as **visual** and **auditory** processing. Damage to certain areas of the midbrain have been linked to the development of Parkinson's disease (see below).

Portions of the midbrain receive visual and auditory input from the medulla oblongata in relation to protective **cranial reflexes.** The **corpora quadrigemina** of the midbrain is composed of for bodies, and contains the **superior colliculi** (the top two bodies) which are involved in **vision** processing and reflexes. The **inferior colliculi** (the lower two bodies) are involved in **auditory** processing and reflexes (see **Fig. 9.15** below). Examples of these types are reflexes are common, for instance if you are walking along the street and hear tires dramatically screeching, you'll **automatically** and **rapidly** turn toward the origin of the sound, often with a defensive or protective posture. Or if your sister throws a wadded up piece of paper at your face when you were not expecting it, automatically your eyes will close, and your arms and hands will attempts to block the belligerent object coming your way

<u>Functions of the midbrain include</u>:

- Controlling Responses to sight
- Hearing and visual reflexes
- Eye Movement
- Pupil Dilation
- Regulating Skeletal Muscle (Body) Movement

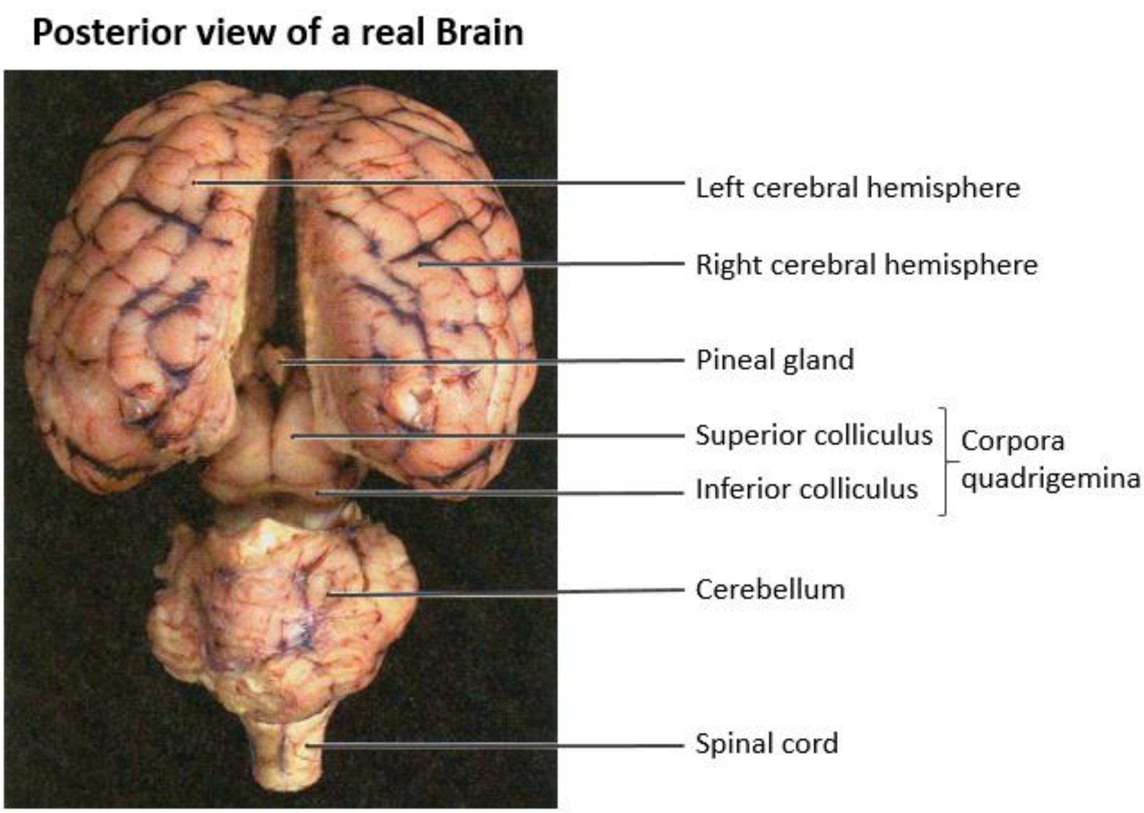
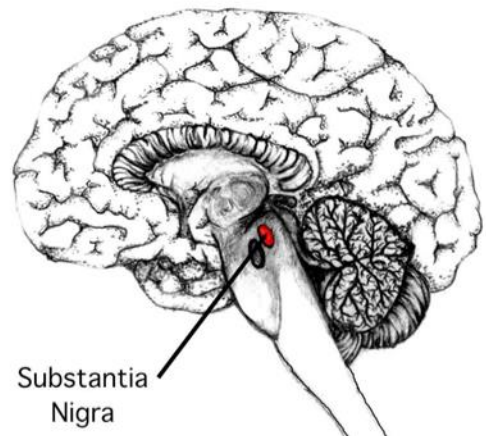



**Figure 9.15** This posterior (rear) view of a real brain shows the cerebral hemispheres partially separated to reveal the pineal gland that is deep in the brain. The superior (top) and inferior (bottom) colliculi that create the corpora quadrigemina of the midbrain are also seen, along with the cerebellum and the spinal cord.

A number of structures are located in the midbrain including the **substantia nigra** (meaning black substance), the **corpora quadrigemina** (meaning 2 sets of twin bodies), and origins for the oculomotor (eye muscle) and trochlear (pulley) cranial nerves, which control the movements of the eyeball.

- The **substantia nigra** has fibers that connect with the frontal lobe and other areas of the brain to coordination and control body movement. Many neurons in the substantia nigra coordinating muscle movement are **dopaminergic** (release dopamine). Neurodegeneration of these nerve cells results in a decrease of dopamine production and release. If high levels (60-80%) of dopaminergic cells degenerate, this may result in **Parkinson's disease**. Parkinson's disease is a nervous system disorder that results in the loss of motor control and coordination. It is characterized by slow jerky movements; tremors of the face and hands; muscle rigidity; and great difficulty initiating voluntary movements. In Parkinson's disease, an overactive region acts like a stuck brake, continuously inhibiting the motor cortex.



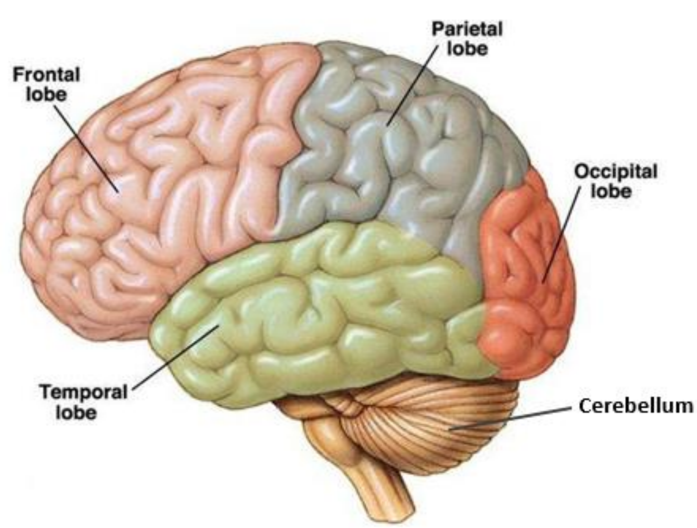

- Another disorder is called **Huntington's disease**, this involves an over stimulation of motor activities, such that limbs jerk uncontrollably. It is caused by the gradual degeneration of neurons of the **basal ganglia** located at the base of the cerebrum, specifically the caudate nucleus and putamen.

- The **corpora quadrigemina** ('4 bodies') are located in the midbrain. The top two bodies are called the **superior colliculi** and these are involved in **vision** processing and reflexes. The other pair of bodies are called the **inferior colliculi** and these are involved in **auditory** processing and reflexes.

## 4. Cerebellum

The cerebellum is located in the lower posterior of the brain, and the word means 'little brain'.

The cerebellum ("little brain") is a structure that is located at the back of the brain, underlying the occipital and temporal lobes of the cerebral cortex. The cerebellum accounts for about 10% of the total brain's volume, yet contains over 50% of the total number of neurons in the brain.




The outer portion of the cerebellum contains neurons, and the inner has tracts myelinated axons called the arbor vitae (meaning 'tree of life') because of its resemblance to branching tree. These communicates with the cerebral cortex. In basic terms the primary functions of the cerebellum are the control of motor skills such as **balance**, **coordination**, and **postural reflexes**. See **Figure 9.16** below.

The **cerebral peduncles** (which means little feet) are key in receiving and relaying information to other areas very quickly that are required for refining body movements, learning new skilled routines, and receiving information from the proprioceptors all over the body and converting into a dynamic spatial map of body part locations to maintenance balance and posture.

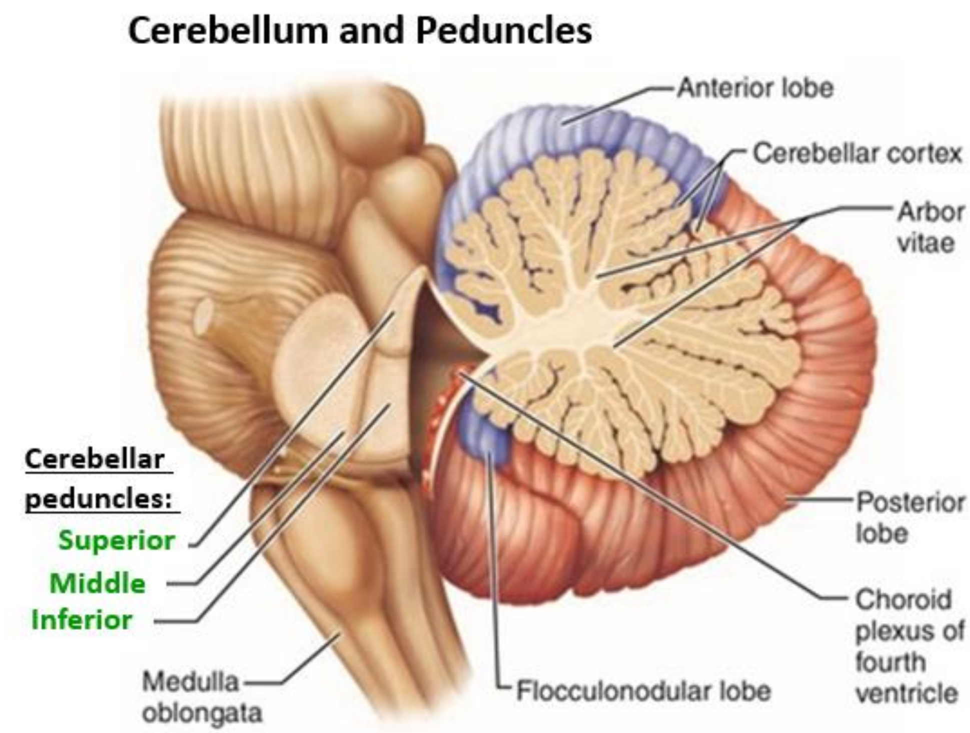



**Figure 9.16** The cerebellum seen in mid sagittal section, with the three cerebral peduncles, superior, middle, and inferior seen cut to show relative positions to each other. The peduncles are tracts that allow the cerebellum to receive and relay information rapidly to many areas needed for refining body movements, balance and posture.

**The Cerebellar Peduncles**:
Superior cerebellar peduncle are tracts (white matter) connecting to **cerebellum** to the **midbrain**.

Middle cerebellar peduncle are tracts connecting the **cerebellum** to the **pons**. It receives most of its input from the pons from the **pontine nuclei**. The input to the pons is from the **cerebral cortex**, which is relayed from the pontine nuclei via transverse pontine fibers to the **cerebellum**.

Inferior cerebellar peduncle are tracts integrating sensory input from **proprioceptors** with motor **vestibular** (balance) input for maintenance of **balance** and **posture**.

**Two very important functions of the cerebellum are:**
**1)** Controls postural reflexes of muscles in body.
That is, it coordinates rapid, automatic adjustments to body parts in order to maintain equilibrium. The coordination of the cerebellum what is responsible for quickly regaining your balance if you trip and start to fall. The reason you may flail your arms out perhaps rather ignominiously in those times, is that the

cerebellum is constantly aware of where the body's limbs are in space and can very quickly calculate where they need to go to re-establish balance, and puts that plan in action without your conscious input.

**2)** Produces skilled movements.

The cerebellum is heavily involved in implementing routines for fine-tuned movements. What this means is that it takes an activity that initially is controlled or instigated at the conscious level, and after **much repetition** of this activity, it can be refined into a learned **skilled routine**., meaning done now (after all the practice) with little to no conscious thought involved in the activity. Examples are commonplace in everyday life, for example tying shoe laces. At one point this was a complex task that required conscious attention, but mostly we have that task automated as we develop. Other examples include driving, or being in the unenviable position of teaching your younger sister how to drive a stick shift in an old French car. Playing an instrument. Studying for an exam? The action, whatever it is, is practiced repeatedly until it becomes routine (subconscious). This then reduces the need for conscious attention to the task.

The cerebellum gets incoming information from **proprioceptors**, a type of sensory receptor found in movable joints, tendons, ligaments and muscle tissue. Using the information from proprioceptors in the body, the cerebellum can determine the relative position of various body parts and compares motor commands and intended movements with the actual position of the body part (legs, arms). In this way, it can perform any adjustments needed to change the direction or make the movement (action) in a smooth and coordinated way to meet the task.

## 5. Pons

The pons (which means bridge) plays a role in the regulation of the respiratory system. Contains two 'pontine' respiratory centers: **1)** the pneumotaxic center and **2)** the apneustic center. These two centers will be discussed in much greater detail in the respiratory system section.

The pons is not responsible for the rhythm of breathing (the medulla oblongata is) but it controls the changes in depth of breathing and the fine tuning of the rhythm of breathing that is set by the medulla oblongata. The pons also prevents over inflation of the lungs, and is therefore protective. The pons is also thought to be an active component to rapid eye movement (REM) sleep.

**Pons and Cranial Nerves**

The pons has four cranial nerves that are associated with its function, covering a range of roles, such as hearing, balance and equilibrium, gustation or taste, as well as touch and pain and facial sensations all form incoming sensory fibers. They also send motor fibers out to participate in eye movement, facial expressions, chewing, swallowing, urination, and the secretion of saliva and tears.

There are four cranial nerves that originate from the pons anatomically (as seen in **Fig. 9.17** below)

- The Trigeminal nerve, Cranial Neve V
- The Abducens nerve, Cranial Neve VI
- The Facial nerve, Cranial Neve VII
- The Vestibulocochlear nerve, Cranial Neve VIII

To be specific, the only cranial nerve that is directly associated ‘functionally with the pons is the **trigeminal nerve** (cranial nerve V). This is the largest of the 12 pairs of cranial nerves and functions both to innervate motor and receive sensory information from three branches that cover the face. There are also three other cranial nerves are located at the ponto-medullary junction, where the pons and medulla meet (see **Fig 9.17**). They are the **abducens nerve** (cranial nerve VI), this controls the lateral rectus extrinsic eye muscle and ‘abducts’ the eyeball to look laterally (outward). The **facial nerve** (cranial nerve VII) which innervates muscles of facial expression and is also responsible for taste sensation on the first one third of the tongue. Finally, the **vestibulocochlear nerve** (cranial nerve VIII) which is almost exclusively a sensory nerve bringing in information from the inner ear, via two branches: The vestibular branch for balance and equilibrium; and the cochlear branch for sound sensations in the cochlea.

**The Cranial Nerves of the Pons**

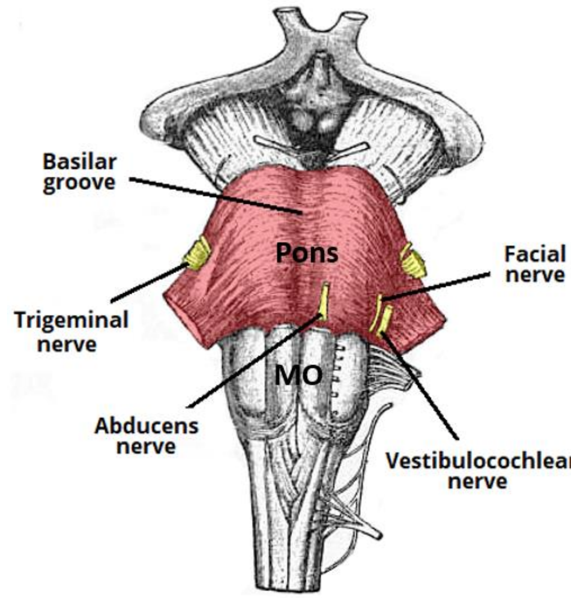



**Figure 9.17** Shows a frontal view of the pons (colored in red) and how four of the 12 cranial nerves originate from the pons.

## 6. Medulla Oblongata

The **medulla oblongata** (MO, or often just called the **medulla**), is the lowest anatomical part of the brain, the lowest portion of the brainstem, and is the last division of the brain before it becomes the **spinal cord**.

- **Parasympathetic system**: Relays the responses of this division of the ANS that usually promote relaxation or inhibition of various body functions.
- **Sympathetic system**: Relays the responses of this division of the ANS that usually stimulate emergency reactions and trigger the body’s fight-or-flight response.
- **Cerebellar peduncle**: The structure that connects the medulla to the **cerebellum**.
- **Tuberculum cinereum**: This is a raised area on the lateral aspect of the medulla oblongata produced by the spinal trigeminal tract and its nucleus. These are nerve fibers travelling from the hypothalamus to the **pituitary gland**. And as we have seen, many neurosecretory elements are fibers that release substances into the posterior pituitary, and so it’s not just signaling the gland.
- **Olivary body**: Are a pair of prominent oval structures containing the **olivary nuclei**. These nuclei receive input from the motor and sensory cortices, and have important outgoing (efferent) connections with the cerebellum, which are critical in the control of body movement. The superior olive nuclei are actually in the pons and involved in the aiding of the perception of sound.
- **Pyramids**: These are paired elongated masses of white matter on the central anterior aspect, flanked by the olives. These carry motor fibers from the corticospinal and corticobulbar tracts, meaning they connect the medulla to the spinal cord, pons, and cerebral cortex.

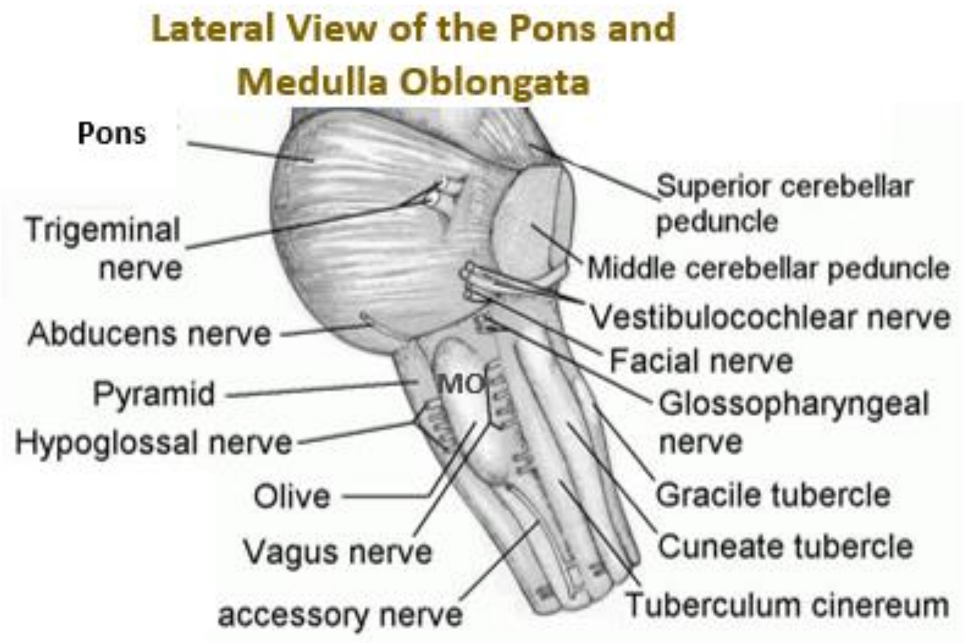



**Figure 9.18** Shows a lateral view and the close arrangement of the pons and the medulla oblongata (MO). Seen emanating from the MO are the last four of the cranial nerves, the glossopharyngeal, the vagus, the accessory and the hypoglossal.

### The Medulla Oblongata and Cranial Nerves

The last four of the cranial nerves are significantly intertwined in the functions of the medulla, as seen in **Figure 9.18** above. The **glossopharyngeal nerve** (IX) delivers taste sensation from posterior one-third of tongue to the Medulla, and sensation from the pharynx, it senses blood pressure and $O_2$ and $CO_2$ content from the carotid artery. Parasympathetic fibers activate parotid salivary gland. It sends nerve fibers to elevate the pharynx when swallowing. The **vagus nerve** (X) motor fibers from the medulla descend to the neck for swallowing, controlling muscle of larynx; parasympathetic fibers regulate cardiac, pulmonary, and part of gastrointestinal activities. It brings sensation from the gastrointestinal tract back to the medulla as well as information for blood pressure (carotid sinus) and chemistry (carotid and aortic bodies). The **accessory nerve** (XI) comes from a union of cranial and spinal roots and emerges from the medulla to innervate the sternocleidomastoid and the trapezius to contribute to elevation of shoulders (shrugging). Also supplies motor fibers to the larynx, pharynx and soft palate. And finally, the **hypoglossal nerve** (XII) is a motor nerve from the medulla with fibers going to the intrinsic and extrinsic muscles of the tongue. It's concerned with food mixing and manipulation and also for movements of the tongue involved in speech and swallowing.

### The Vital Center of the MO

The medulla oblongata plays a critical role in transmitting signals between the spinal cord and the higher parts of the brain and in controlling autonomic activities, such as heartbeat and respiration. It houses some very important visceral centers that are also called **vital centers**, names because they regulate function that are vital to survival. The three vital centers are:

**1) <u>The Cardiac Center</u>** – Is the center which provides modulation and fine tuning of the heart rate and the strength (or force) of myocardial contractility. These two elements of cardiac activity generate **cardiac output**. This center adjusts the force and rate of the heartbeat when needed to meet metabolic needs of the body. This is mostly carried out by the **autonomic nervous system** (ANS), where the **parasympathetic** division slows the heart rate and the **sympathetic** division increases both the heart rate and the force of contraction.

**2) The Vasomotor Center** – This center regulates the **diameter** of peripheral **blood vessels** and therefore exerts an enormous influence on **systemic blood pressure** and **blood flow**. When blood vessels are constricted, this decreases blood flow but increases blood pressure. When blood vessels are dilated this increases blood flow but decreases blood pressure. For the most part, sympathetic division of ANS controls blood vessel diameter, and most vasculature of the body. The greater the sympathetic stimulation, the more the vasoconstriction (if alpha receptors present).

**3) The Respiratory Center** – This center is for the maintenance and control steady rhythm breathing as regular rates during times of eupnea, which is quiet breathing at rest. This is primarily done through the control of the diaphragm muscle, that large dome-shaped skeletal muscle immediately below the lungs. The diaphragm is controlled by the **phrenic nerve** that innervated this muscle to contract for inspiration.

Sensory receptors located inside blood vessels that measure blood pressure (**baroreceptors**) and blood chemistry (**carotid and aortic bodies**) relay this information to the medulla oblongata (integrations center) so that it can monitor and adjust heart activity and the blood flow to individual parts of the body . It also regulates respiration rate based on incoming information and in this capacity monitors blood acidity. The medulla oblongata has several additional centers that regulate **sneezing**, **coughing**, **hiccupping**, **swallowing** and **vomiting**. For the most part, all of these response are protective.

## The Central Nervous System: Spinal Cord

The basic structure of the spinal cord is that it is the downward continuation of medulla oblongata starting at the foramen magnum. It descends to about the level of the second lumbar vertebra, tapering to a structure called the conus medullaris.

The spinal cord projects 31 pairs of spinal nerves on either side along its length. There are 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal spinal nerves that radiate to and from the periphery. All spinal nerves are 'mixed' nerves meaning they all contain axons of both sensory (incoming) and motor (outgoing) neurons, thus information is going in both directions.

A cross section of the spinal cord exhibits the butterfly-shaped gray matter in the middle, surrounded by white matter. As in the cerebrum, the gray matter is composed of nerve cell bodies. The white matter consists of various ascending and descending tracts of myelinated axon fibers with specific functions.

The spinal cord serves as a passageway for the ascending (going up) and descending (going down) fiber tracts that connect the peripheral and spinal nerves with the brain. Each of the 31 spinal segments is associated with a pair of dorsal root ganglia. These contain sensory nerve cell bodies. The axons from these sensory neurons enter the posterior aspect of the spinal cord via the dorsal root. The axons from somatic and visceral motor neurons leave the anterior aspect of the spinal cord via the ventral roots. Distal to each dorsal root ganglion the sensory and motor fibers combine to form a spinal nerve - these nerves are classified as mixed nerves because they contain both afferent (sensory) and efferent (motor) fibers.

## Cerebrospinal Fluid

Cerebrospinal fluid (**CSF**) is a clear, colorless fluid (**Fig. 9.19**) that is found in the brain and spinal cord. The Central Nervous System (CNS) gets its oxygen and nutrients from CSF and not directly from blood. The CSF is a ***filtrate of blood***; this means it is actually filtered from the blood in your cerebral blood vessels. Everything starts in the **Heart**. The heart delivers blood to all the tissues of the body via blood vessels. Blood goes through the **choroid plexuses** in the brain, which are bundles of blood vessels that are located in the **ventricles of the brain** (described below). The fluid portion of blood is called **plasma** and as blood passes through these choroid plexuses only the plasma portion filters into the ventricles to create this special fluid that bathes and protects the delicate nervous tissue. Cerebrospinal fluid does not normally contain cells, such as red blood cells, or proteins, hence it is colorless.

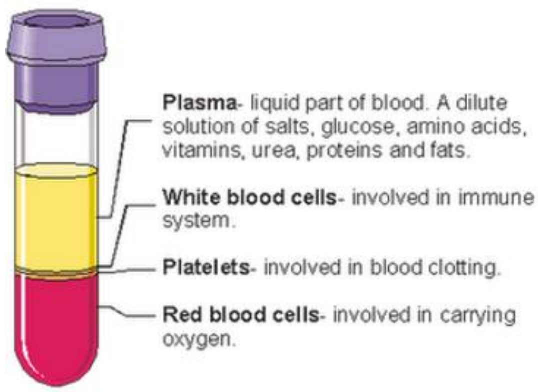



**Figure 9.19** When blood is spun at high speed in a test tube (image at left), it separates into its fluid component of plasma that sits on top of the heavier cellular components, called the formed elements. Cerebrospinal fluid (CSF) is a filtrate of blood (image at right) and is colorless. The sample of CSF shown is from a lumbar puncture procedure.

### The Roles of CSF in the CNS

**1. Cushions and insulates delicate nervous tissue**.

Cerebrospinal fluid acts as a cushion to insulate or buffer the brain, much like how an air bag operates in a car. It protects the delicate brain and spinal cord tissue from traumatic injury when jolted or hit.

**2. Gives Buoyancy to the brain ("floats" in CSF).**

The mass of the adult human brain is approximately 1,400 grams (less than 3 lbs). This is heavy when sitting on top of the cranial bones. Since CSF is very salty it allows the brain to be suspended in the CSF, such that the weight of brain becomes equivalent to a mass of about 25 grams!!! If not for this buoyancy provided by CSF, the brain's own weight would cut off blood supply and kill neurons in the lower sections.

**3. Exchange of gases ($O_2$ and $CO_2$), nutrients and wastes.**

The flow of CSF in the central nervous system (CNS) acts like the blood circulation does for other parts of the body, that is, it acts to exchange vital nutrients (glucose, fatty acids, amino acids, minerals), gases ($O_2$ in and $CO_2$ out) and metabolic wastes. CSF thereby regulates the exchange and metabolism of the CNS.

### The Creation and Flow of Cerebrospinal Fluid (CSF)

**Ventricles** of the brain are fluid filled chambers inside the brain. Cerebrospinal fluid (CSF) is created as a filtrate of the blood from the **choroid plexuses** which are present at every **ventricle** of the brain. The word choroid loosely means 'vascular' and plexuses means 'network', so the choroid plexuses are a network of blood vessels in the brain that are surrounded by ependymal cells which help to produce most of the CSF.

There are four ventricles of the brain: The lateral ventricles (1 and 2); the 3rd ventricle; and the 4th ventricle, (see **Figure 9.20** Below).

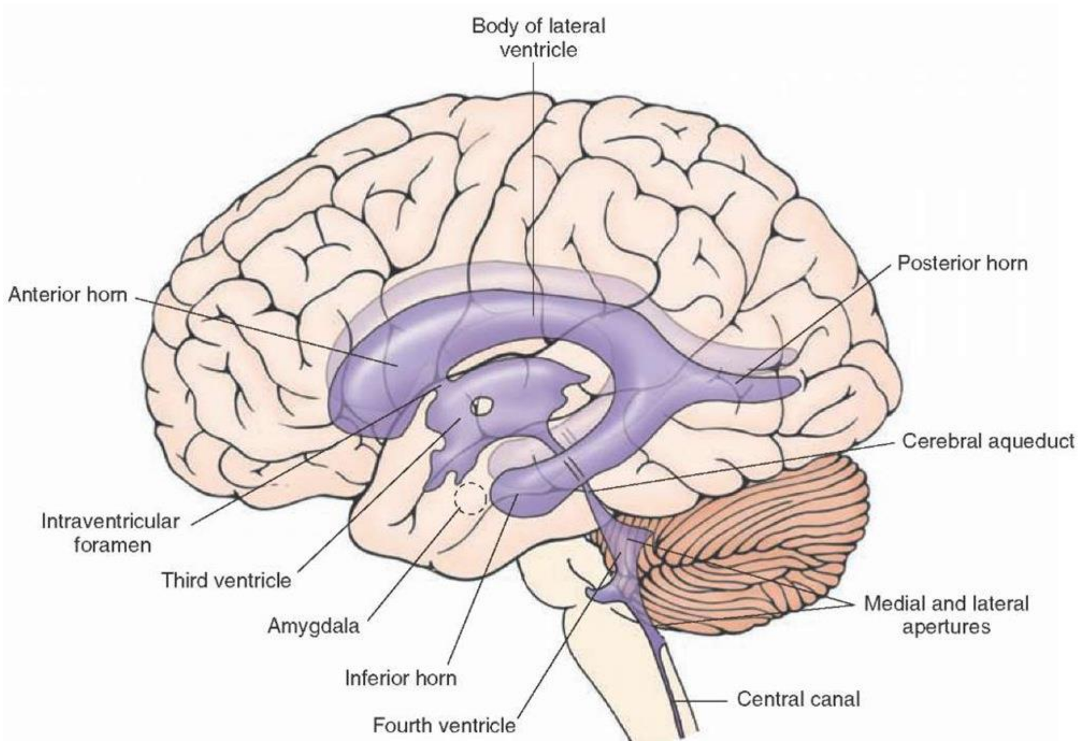



**Figure 9.20** Lateral aspect of the brain showing the cerebrospinal fluid (CSF) filled ventricles within the brain and the central canal of the spinal cord. There is a small but constant circulation of CSF throughout the CNS.

The cerebrospinal fluid **(CSF)** is found in the **ventricles** inside the brain, in the **subarachnoid space** of the cranial and spinal meninges, and in the **central canal** of the spinal cord. It is a filtrate of blood and contains no cells or proteins. In an adult there is usually about 140 to 170ml (average of 150ml) of CSF in circulation at any one time within in the Central Nervous System (**CNS**). For children it ranges from 20 to 60 ml. In adults, there is approximately 500ml of CSF made per day.

**The Choroid Plexus is where CSF Begins**
The basic circulation of CSF starts at the choroid plexuses of the two large **lateral ventricles** (located in the cerebrum). From here, the CSF passes through the **interventricular foramen** (these are not holes but connecting tubes) which deliver CSF to the **3rd ventricle**. The CSF then goes into the **cerebral aqueduct** on its way to the **4th ventricle**, which is located down by the cerebellum, pons and medulla oblongata (MO). The CSF then exits the 4th ventricle into the **subarachnoid space** or into the **central canal** through 3 apertures (openings) at the 4th ventricle - one **median aperture** and two **lateral apertures**. See **Figure 9.21** at right

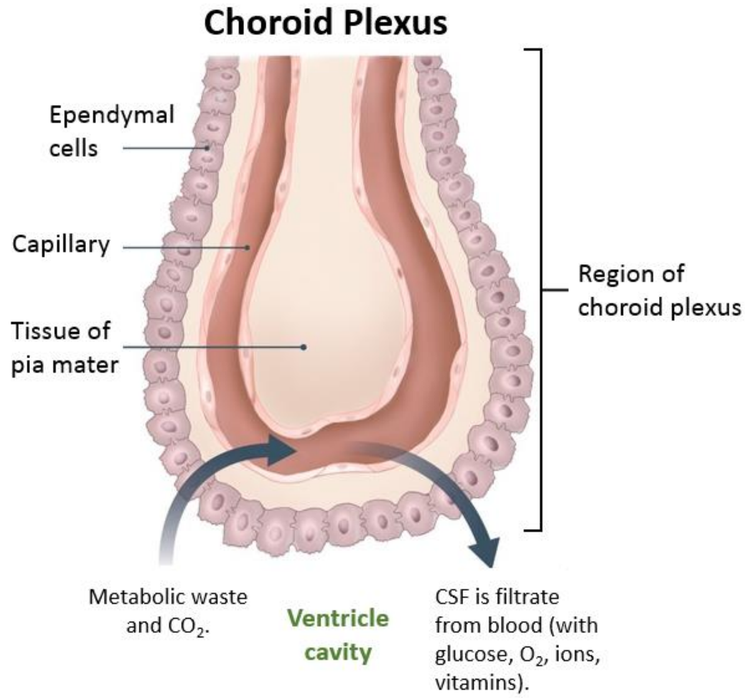



**Figure 9.21** The choroid plexus is a vascular structure that is located in all four ventricles of the brain. As shown in the diagram above, the blood from the capillary is filtered through the ependymal glial cells to become cerebrospinal fluid (CSF) as it moves into the ventricular cavity. Circulating vital elements such as glucose and oxygen ($O_2$).

**The Circulation of CSF**
Once the CSF is in the subarachnoid space, it can circulate all around the brain and spinal cord. Finally, the CSF needs to go back to where it came from – it started from blood and so needs to be returned to the blood supply. Since CSF is just a filtrate of blood, it can be re-mixed with the blood and taken back to the heart for the process to start all over again from the beginning (circulate means "makes a circle").

The CSF that is in the subarachnoid space returns to the vascular system via **arachnoid villi** (or granulations) – these are connections from the subarachnoid space into the **dural venous sinuses**. Remember a sinus in the cardiovascular system is a large blood vessel, usually a vein, and these veins are sandwiched in between the two layers of the cranial dura mater. Once the CSF enters the large dural sinuses (ab example is the *superior sagittal sinus*) it is reunited with blood in the venous circulation and it flows back to the heart. The process will repeat from the choroid plexuses. See the separate drawing of CSF circulation in **Figure 9.22** below for a visual depiction of the sequence of events.

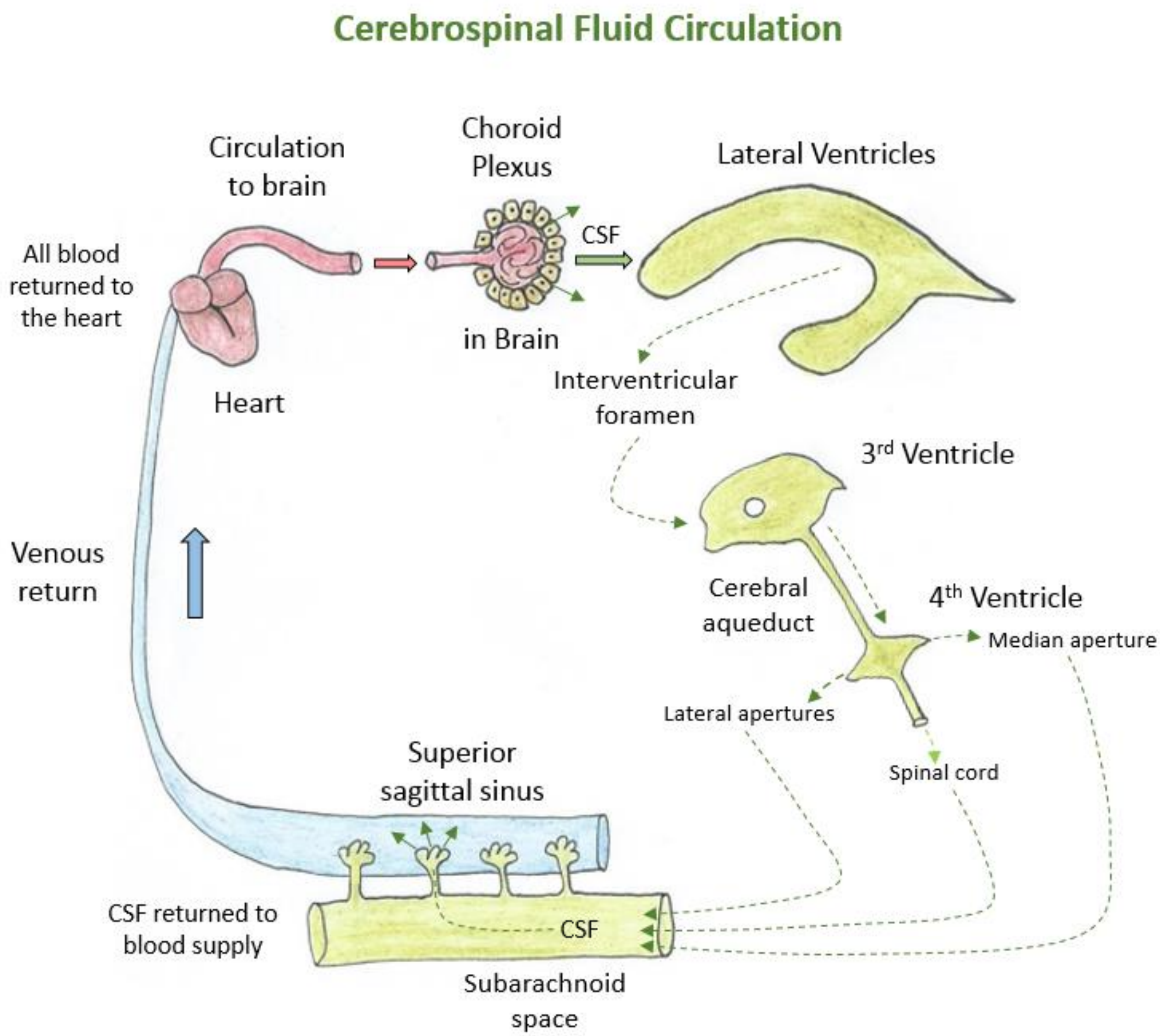



**Figure 9.22** This diagram illustrates the creation and circulation of cerebrospinal fluid (CSF), which is color coded in green in the diagram. It starts at the heart, which provides blood to the brain that is filtered at the choired plexus, the filtrate produced is CSF and it is pushed directly into the lateral (1st and 2nd) ventricles. There is a choroid plexus in every ventricle, which makes and moves more CSF forward.

**Hydrocephalus** ('water on the brain') is an abnormal accumulation of cerebrospinal fluid (CSF) in the ventricles or subarachnoid space of the brain, which may cause increased intracranial pressure (ICP) inside the skull (**Fig. 9.23** below). It can be caused by impaired CSF flow, impaired re-absorption, or excessive production of CSF. Hydrocephalus may lead to enlargement of the cranium if it occurs during development (when fontanels are still present). It can be fatal if ICP is excessively high and not quickly alleviated.

**Treatments for Hydrocephalus**

Surgical treatments commonly utilize various cerebral shunts that can act as a detour for the blocked fluid circulation. This involves inserting a catheter (tube) into the cerebral ventricles to bypass the obstruction or the malfunctioning arachnoid granulations (villi). This allows for the drainage of excess fluid into other body cavities, where it can be reabsorbed. Most shunts drain the fluid into the peritoneal cavity (**V**entriculo-**P**eritoneal shunt); alternative sites include the right atrium (**V**entriculo-**A**trial shunt).

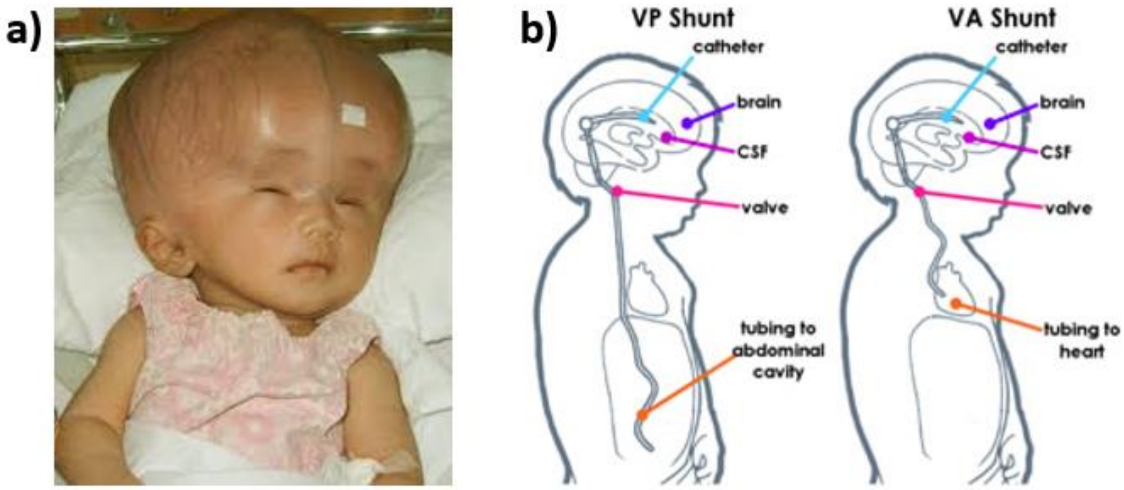



**Figure 9.23** Seen are **a)** an infant with hydrocephalus; notice how the fontanels allow for significant expansion of the cranium. Hydrocephalus is often categorized as either intraventricular (within the ventricles of the brain) or extraventricular (outside of the ventricles of the brain). While **b)** shows the two common shunts to drain excess CSF: The Ventriculo-Peritoneal (VP) shunt, and the right atrium Ventriculo-Atrial (VA) shunt.

## The Circumventricular Organs

The circumventricular organs (CVOs) are highly vascularized structures located around the third and fourth ventricles of the brain. Their distinct characteristic is the lack of a **blood brain barrier** (BBB) in that region.

Since the BBB is a restrictive barrier, there is a need for small discrete locations where vital chemical messengers from the brain can pass into the circulation. Such are structures are the ones that permit **hypothalamic hormones**, which are polypeptides, to exit the brain without disrupting the BBB, and maintain the ability to permit substances that do not cross the BBB to trigger changes in brain function.

These circumventricular organs (CVO) are specialized areas that are points of communication between the blood, the brain and the CSF. They permit many signal molecules to leave the brain without disrupting the blood brain barrier (BBB) and permit substances that do not cross the BBB to trigger changes in brain function.

Also critical is **sensory ability** of the brain, and part of the function of **CVOs** is as **sensory organs**. Specific regions are able to detect molecules in plasma and transmit that information into other regions of the brain, providing direct information to the ANS from the systemic circulation. The important CVO's are shown in **Figure 9.24** below.

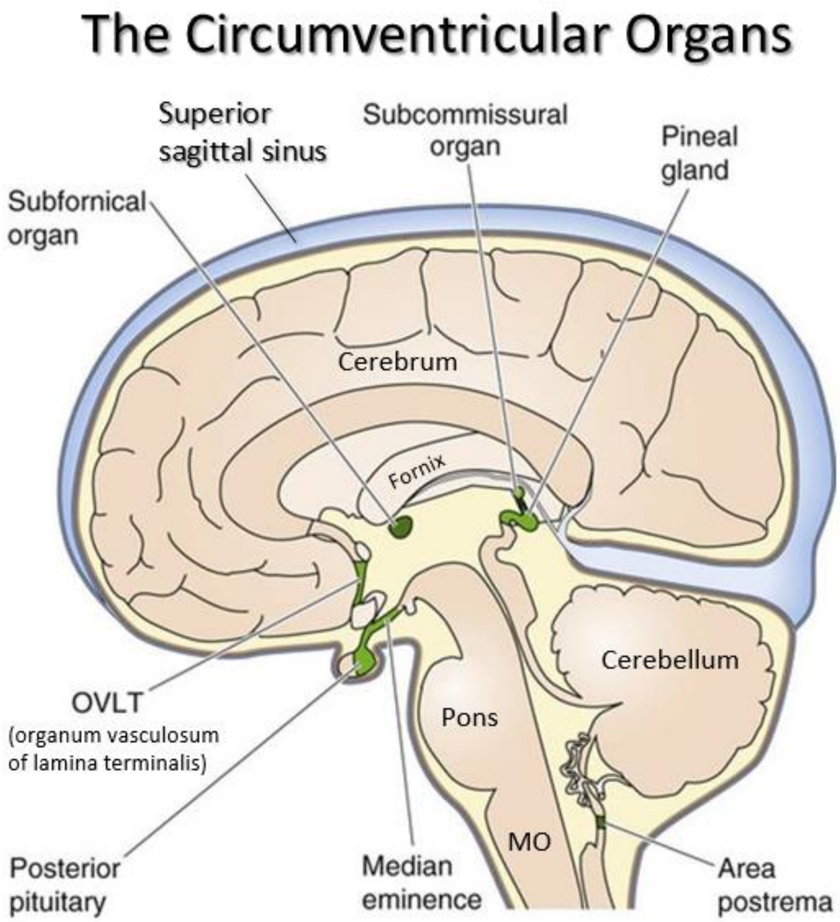



**Figure 9.24** The mid-sagittal section of the brain above shows the locations of the circumventricular organs (CVOs) at key sites. Some of these sites allow the passage of molecules that would usually be restricted by the blood brain barrier (BBB) to leave the brain. Other regions act as sensory organs for the brain, able to detect signals.

**The Specific CVOs and their Purpose**

<u>Sensory Circumventricular Organs</u>

There is a component of the CVO's that function as sensory organs, they are able to detect molecules circulating in the plasma and relay this information into various regions of the brain, providing a direct avenue of communication to the CNS and the systemic circulation. These organs include:

- The **organum vasculosum of the lamina terminalis** (**OVLT**) resides along the rostral wall of the third ventricle, lacks a complete blood–brain barrier. It is involved in **osmoregulation**, playing a pivotal role in body fluid homeostasis.,

- **Area postrema**: Site of the chemoreceptor trigger zone for **vomiting**, sends major and minor axons to the medulla oblongata regions of the brain involved in the autonomic control of cardiovascular and respiratory activities.

- **Subfornical organ**: Active in osmoregulation, cardiovascular regulation, and energy homeostasis.

Secretory Circumventricular Organs

The compliant of the CVOs that act as conduits or secretory organs produce hormones and glycoproteins and transfer them into the peripheral vascular system, utilizing feedback from the CNS and stimuli external to the CNS. These include:

- **Sub-commissural organ** (**SCO**): Responsible for the secretion of the **glycoprotein SCO-spondin**. This molecule contributes to commissural axon growth and the formation of Reissner's fiber that extent into the spinal cord.

- **Posterior pituitary**: Stores and releases **oxytocin** and **ADH** (also called vasopressin), both produced in the hypothalamus.

- **Pineal gland**: The main function is the secretion of melatonin.

- **Median eminence**: Allows for the transport of **neurohormones** between the CSF and the peripheral blood supply.

## Review Questions for Chapter 9: The Central Nervous System

**1.** The primary cortex of the parietal lobe is concerned with what type of information?
- **a)** Initiating fine motor movement.
- **b)** Somatic sensory perception.
- **c)** Regulating appetite.
- **d)** Auditory and olfactory perception.
- **e)** Perception of internal organs.

**2.** An important function of the cerebellum is:
- **a)** Language acquisition.
- **b)** Predictive ability.
- **c)** Respiration rate regulation.
- **d)** Autonomic reflexes.
- **e)** Producing skilled routines.

**3.** Which of these functions is not controlled by the medulla oblongata?
- **a)** hiccupping
- **b)** sneezing
- **c)** vomiting
- **d)** eye movement
- **e)** breathing

**4.** Regarding the subconscious mind, which of the following is not accurate?
- **a)** It can processes about 4 million bits of info per second.
- **b)** It is heavily influenced by visual imagery.
- **c)** It is not involved in habits of routines of the body.
- **d)** The subconscious mind decodes any text, no matter how it's written.
- **e)** This realm can multi-task thousands of events at a time.

**5.** The amygdala is specifically located in the ________; and it part of the ________. A central role of the amygdala is ________.

- **a)** Temporal lobe; limbic system. Detecting threatening stimuli.
- **b)** Occipital lobe; autonomic system. Detecting threatening stimuli.
- **c)** Temporal lobe; limbic system. Language perception.
- **d)** Cerebrum; limbic system. Detecting threatening stimuli.
- **e)** Frontal lobe; Reticular activating system. Fight or flight.

**6.** The following is an example of cerebral lateralization. The area of the brain for the mechanics of speech is the ________ area. If a person is left handed, it is found in the ________.

- **a)** Wernicke's: left hemisphere
- **b)** Broca's: left hemisphere
- **c)** Broca's: right hemisphere
- **d)** affective language: temporal lobe
- **e)** Wernicke's: right hemisphere

**7.** Which of these best describes the functions of the **posterior nuclei** of the Hypothalamus?

- **a)** Thermoregulation involving cooling the body down.
- **b)** Regulation of hunger and thirst.
- **c)** Thermoregulation involving heat conservation.
- **d)** It releases antidiuretic hormone and oxytocin.
- **e)** The sense of olfaction.

**8.** Of the vital centers in the <u>medulla oblongata</u>, which area controls systemic blood pressure?

- **a)** The blood pressure control center
- **b)** The vasomotor center
- **c)** The cardiac control center
- **d)** The respiratory control center
- **e)** The diametrical control center

**9.** The circumventricular organs (CVO's) functions to:

- **a)** Allow hypothalamic hormones to leave the brain without disrupting the BBB.
- **b)** Prevents any exchange between the brain and the blood stream.
- **c)** Help to regulate body temperature.
- **d)** Provide exits for hormones but are not sensory organs.

**10.** Which of the following are true of the <u>pineal gland</u>?

- **a)** It is located in the midbrain.
- **b)** It releases melatonin and ACh as light intensity decreases.
- **c)** It is found in the hypothalamus.
- **d)** It is located in the epithalamus and releases dopamine.
- **e)** It releases DMT.

*Answers in Appendix B*