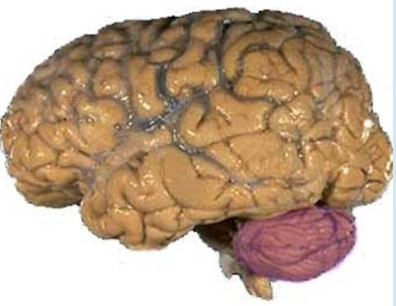


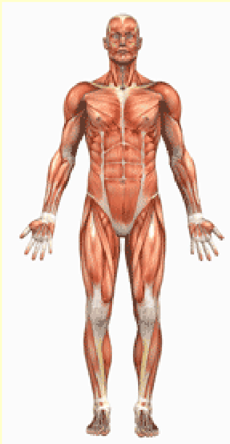
The Brain and Body Movement: Level I

- Rex M Heyworth PhD

In investigating how the brain is involved in memory and learning, I came upon material on the brain and body movement so decided to investigate this further. I soon discovered just how difficult it is to understand and explain body movements. I also realised that 'experts' in the area do not always agree, with different material and different authors often giving conflicting views, especially in the details of how the brain operates. Further, while a lot is now known about how specific parts of the brain affect body movements, I was unable to find any good websites that could integrate all this information to give a unified explanation of what is going on. Of course, a lot is still unknown about the brain and movement, which helps to explain this.

As a result, I decided to split the project into two parts: Level I, which is simpler but which attempts to give an* overall *picture of how the brain functions during body movements, and Level II, which is a more in-depth but fragmented treatment, in line with much of the material available online.

Movement – a complex task



The human body contains about 700 muscles that move a skeleton of over 200 bones. Human voluntary body movements turn out to be extremely complicated, involving the use of most parts of the brain for them to be carried out. Even the simplest voluntary movements are governed by extremely complex processes in the brain.

Many people have commented that the human brain is perhaps the most complicated thing in the *universe*, and that it is probably easier to explain how a space shuttle is built and operates than to explain how astronauts make the movements needed to climb into it!

Scientists are only beginning to understand the interactions that take place in the brain during movements, with a lot of the findings coming from careful experiments on *animals* and on people with *damage to the brain*.

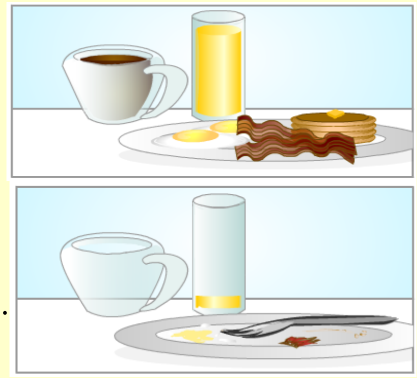
It turns out that body movements are very complex. Even a supposedly simple event, such as walking or picking up a cup of tea from the table are very complex tasks. Take the example of picking up a cup/glass from the table. A seemingly simple, everyday task! But in fact, it is very complicated.

Why are body movements so complicated?

Here are some of the kinds of things that are involved when reaching out and picking up a cup/glass, which we return to in greater depth later.

- We first have to decide what we will do, for example, "I want to pick up the cup of tea from the table" (not so difficult to do).
- The brain has to form an image of the scene that includes looking at the cup, the table and any other important objects, as well as the position of the person who is to carry out the action.
- The brain has to choose the appropriate movements to accomplish this task, and to carry them out in the correct order (sequence) and with perfect timing to give a smooth fluid non-jerky action.
- The movement of the arm and hand when reaching must be a 'goldilocks' action – just right, not too high or too low, not too fast or too slow, the arm must reach just the right distance and the hand must grip a glass cup with the correct pressure – too much and the glass breaks, too little and it slips from the grasp.
- To pick up the cup, the brain also has to figure out which muscles in the arms and fingers to contract and in which order to steer the hand to the glass then pick it up.
- There has to be continual *feedback* to the brain during the action to ensure everything is going as planned – for this, continuous sensory information is important, for example, *vision* to see how the action in proceeding, *touch* to ensure the correct pressure on the glass. And if it is not going correctly, the brain must make changes and instruct the muscles accordingly.
- As we will see, sensory information is needed from the start to the finish of a movement. Imagine what might happen if you were to close your eyes or are *not looking at the cup* (i.e. no vision) as in the picture above, or it is dark, or if you were blind. For example, your hand might hit the cup, might reach too far, might not bring the cup accurately to the mouth. To do this accurately also involves a special sense, called *proprioception*, which we will look at later.
- If an action is unfamiliar or new, we actually have to *learn* how to do it.
- For example, consider a child reaching for the cup of drink (disaster!), Or consider yourself learning a new skill in a sport such as swimming; your movements will be clumsy at first, with poor coordination, but later you don't even think about it. The same with picking up a cup. (If you have very young children, ask them to pick up a cup – an empty one!! – from the table and watch their progress over a year or so; they will soon learn to do this proficiently.

- When you reach the arm forward, when you hold a cup of tea (or any other heavy object), the change in weight in front of body will cause you to lose balance and fall over. The body needs to continually adjust its posture so this does not happen. In the picture (right), note the child's left hand on table; this is maintaining his balance so he doesn't topple over.
- Picking up all glasses/cups is not the same. The brain must adjust to the *context*. For example, when



picking up a cup with the bare hand or when wearing a glove, the brain will not behave exactly the same. Or being at an important gathering (where we need to be be very polite) will probably differ from how we pick up a cup/glass at home. Also, if the cup/glass is full and surrounded by plates full of food or is empty and surrounded by dirty dishes, we may think that the movements to pick up the cup are the same. Not so! This difference in context affects how the brain functions. Other factors, such as *how much* tea is in the cup and what *material* the cup is made from, also influence the brain's calculations. Very complicated!!

The brain has to deal with all these situations – not easy!

Two kinds of body movements

Almost all human behaviour involves movements, from talking to gesturing to walking to the most complex action we can think of. Body movements can be classified into two broad kinds; **reflex** and **voluntary** movements.

Reflex movements/actions are ones we do *not* consciously control and do not involve the brain, a common one being the knee jerk reflex (pictured, right). Voluntary movements are those we consciously carry out, such as deciding to pick up a cup of tea on from the table and drink it; they involve the brain.

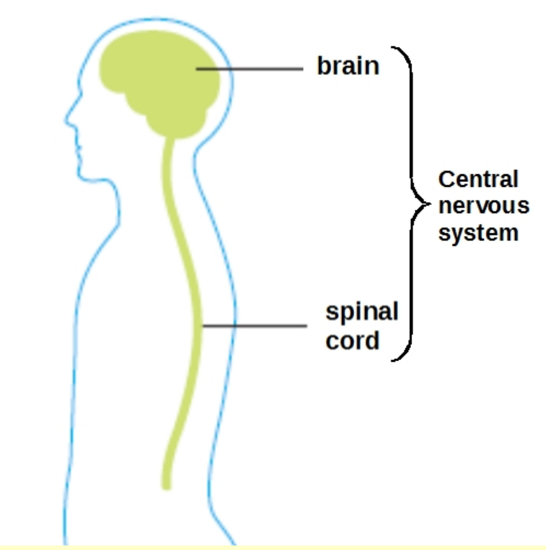
Some body movements have *both* a reflex component and a voluntary component. Examples are breathing, chewing, walking and running. Walking *resembles* a reflex activity because it usually happens without us thinking about it. But we *do* have to issue voluntary commands when we want to start or stop walking, pick up the pace to get across the street when the light turns amber, to make that little jump onto the curb, or a small sidestep to avoid a puddle, though we can do these without being aware of them.

Walking is an example of a voluntary action where nature has found the most effective compromise between the need to free our minds from repetitive movements and still retain some voluntary control to adjust to changes and obstacles in our environment. (Just imagine if this was not the case – we would have to consciously control and monitor every step we make, leaving no brain space for anything else!)

In this project both reflex actions and voluntary movements but the main focus is on *voluntary* movements.

The central nervous system (CNS)

The Central Nervous System (CNS) is the **brain** plus **spinal cord**. (Note that the spinal cord is *not* part of the brain.)



[Note: The orientation of the picture on the right and other diagrams involving the brain in books and in websites is frequently shown looking towards the left. I will try to follow this pattern in the pictures I use.]

The Central Nervous System controls most of the actions within the body. The spinal cord is the link between the brain and rest of body, including the muscles. Messages/signals from the brain to the muscles involved in a movement pass through the spinal cord. Sensory messages *from* the body to the brain, for example the sense of touch when we touch a cup, travel from sensory receptors in the fingers to the brain via the spinal cord. (But *not* the senses of vision, sound or smell. The eyes. ears and nose, which are conveniently placed on our heads around the brain, send sensory signals directly to the brain and not via the spinal cord.)

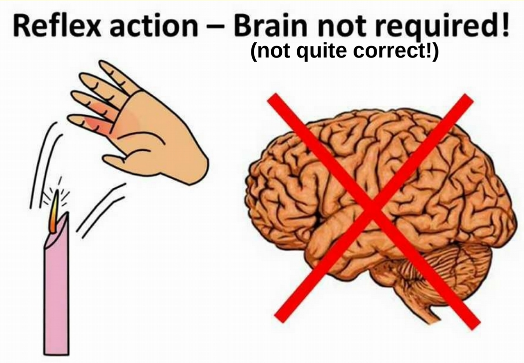
The spinal cord but *not* the brain is involved in **reflex** actions; the whole **CNS** is involved in **voluntary** movements.

Both reflex actions and voluntary movements involve sensory input and motor (i.e. movement) output. We will look at reflex actions first as they are simpler before moving onto voluntary movements

How a Reflex Movement/Action works

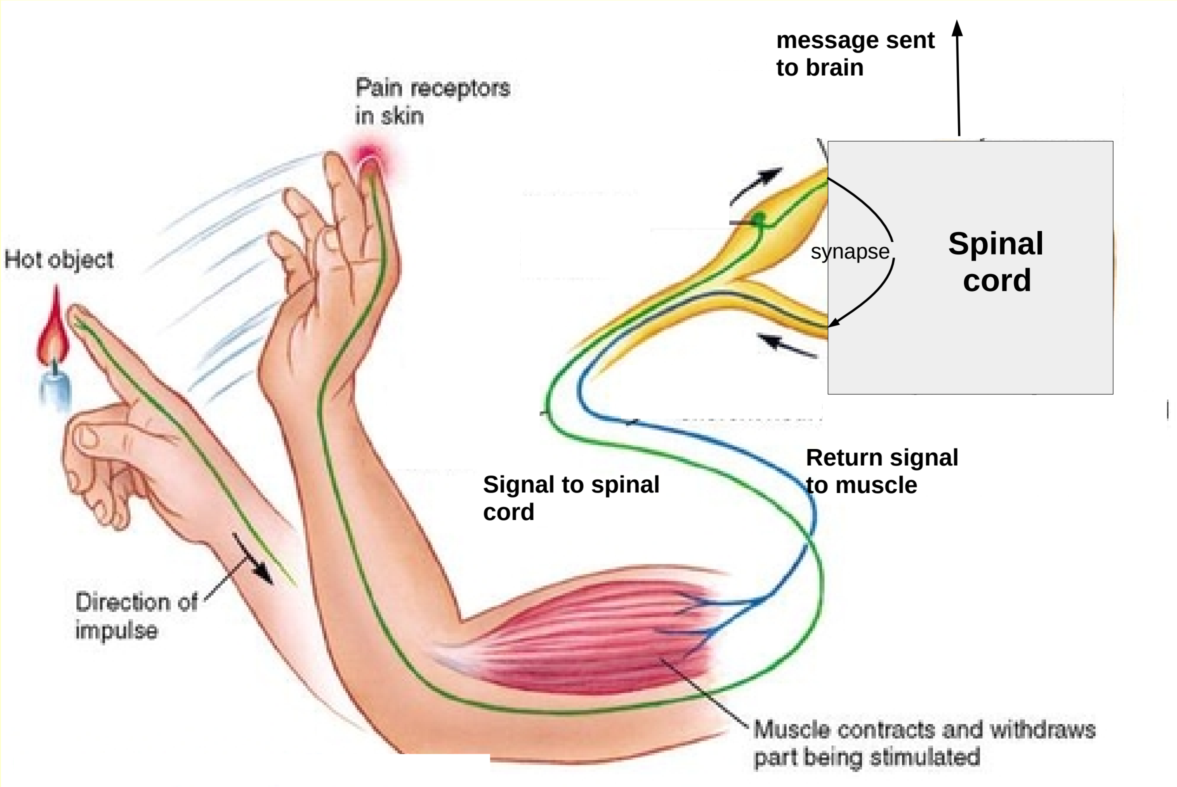
Reflex movements are called various names including a reflex *action* and a reflex *arc*.

Reflex actions are *automatic involuntary* actions. They are often present to keep us from harming ourselves. For example, if we were to touch something very hot with our hand, a reflex action would swiftly move the hand away from the source of danger. Note that the diagram says that the brain is not required but that this is not quite correct. We will come to this.



The diagram at the top of the next page is a representation of how the **reflex arc** for touching something hot works.

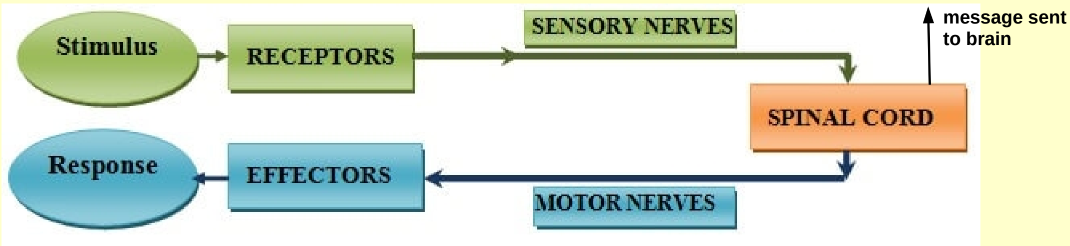
This reflex action begins in the skin. The skin has touch receptors for pressure, temperature and pain (see box, below. The pain receptors in the finger sense the pain from the heat and stimulate a nerve called a *sensory nerve* (or sensory neuron) (the **green** line in the diagram) and sends an electrical impulse/signal along its length to the spinal cord.

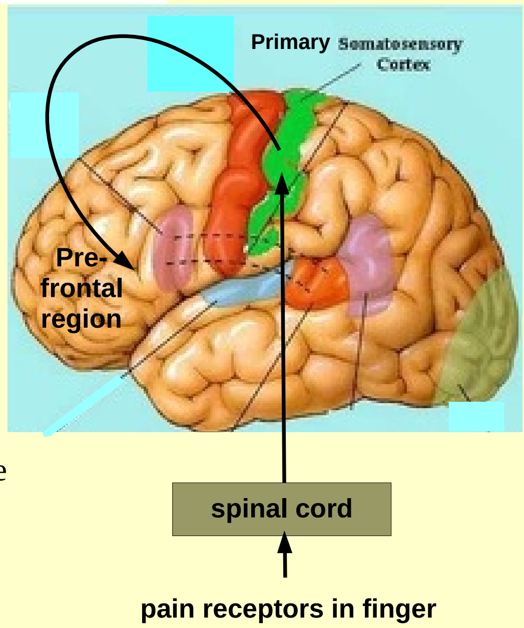


In the spinal cord, the sensory neuron is connected to a *motor neuron* (**blue** line in diagram) across a space called a *synapse*. If the impulse from the sensory neuron is big enough, the motor neuron is triggered and an electrical signal along the motor neuron. This stimulates the *effector organ*, in this case the biceps *muscle*, which contracts and moves the hand away from danger.

The relationship between the *sensory input* and the *motor output* in a reflex arc is *simple* and *direct*:

pain receptor in finger (sensory input) → spinal cord → muscles in hand/arm (motor output)





The brain is involved *indirectly* though not as part of the actual reflex movement. The spinal cord sends a message to the brain to tell the brain that the finger is being burnt, which we then *consciously* feel as pain.

The diagram on the right shows what happens. **Note**: *You will probably not understand this diagram fully right now. Later, when you have studied the parts of the brain, come back and read this section again.*

The nerve impulse produced in the spinal cord is transmitted to the *(primary) somatosensory cortex* area in the brain which registers the sense of pain. A signal is then sent to the *pre-frontal region* of the brain, which involves consciousness and we become aware of the pain.

Note that the reflex action has usually been completed *before* the brain knows that the finger was in danger. This is because reflex actions are *quick* and need *no conscious control*. Reflex actions are also hard-wired into the body, that is, the same stimulus (e.g. a burn) always gives the same response (withdrawal from the source of heat). This speeds up the action. Further, reflex actions do *not* have to be learnt. so memory has no effect on the response to the stimulus.

Note that we can over-ride a reflex action if the need arises. This then becomes a voluntary action. For example, if a baby is going to touch a very hot object, a parent could consciously grab the object and over-ride the reflex action that would normally cause the hot object to be dropped.

Nociception
(from Latin *nocere* 'to harm' + reception)

Touch receptors in the skin are nerve cells of three main kinds:

(1) receptors that sense *pressure* (as well as texture – how rough/smooth a surface feels to the touch),
(2) receptors that sense *temperature* (heat and cold) and
(3) receptors that sense *pain* (called **nociceptors**).

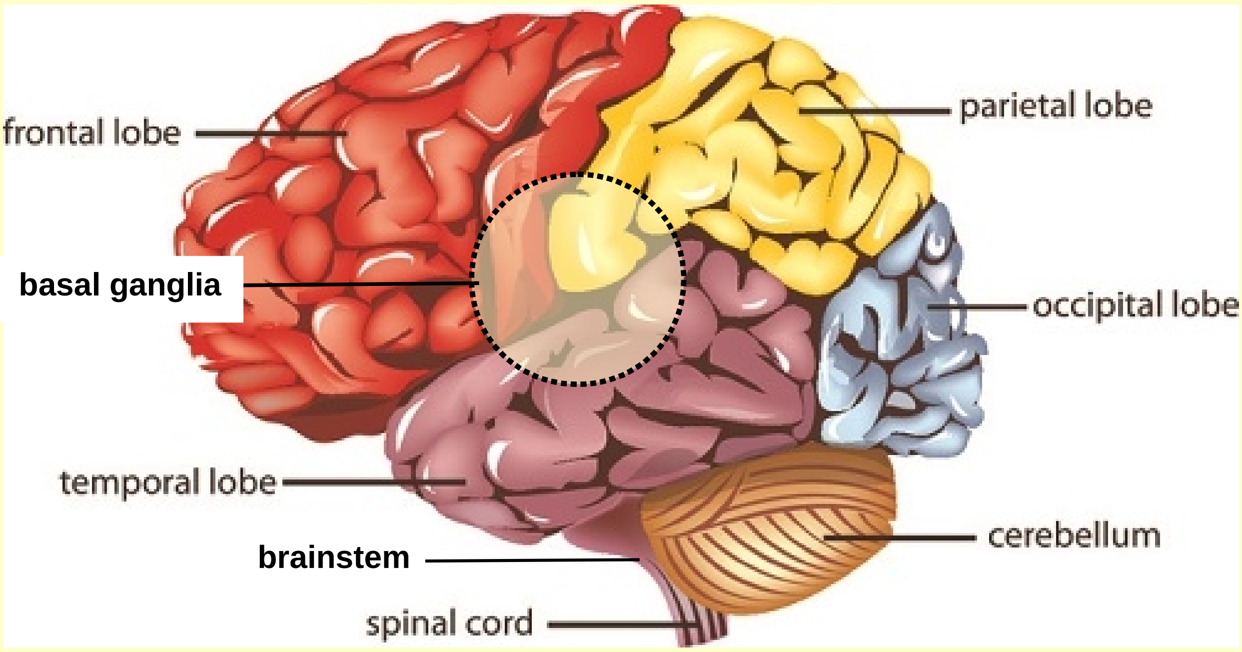
There are nociceptors for pressure and temperature. In normal situations, nociceptors are not used. But if there is a situation that can cause *damage* to tissue, for example, hitting a finger with a hammer (which involves excessive pressure) or burning yourself (excessive heat), or even a pain-causing illness, the corresponding nociceptors are activated. They transmit messages to the brain via the spinal cord, and we interpret these messages as pain. *Thermo*receptive nociceptors are stimulated by temperatures (heat or cold) that are potentially tissue damaging. *Mechano*receptive nociceptors respond to a pressure stimulus that may cause injury. Virtually every surface and internal organ of the body is wired with nociceptors.

However, by the time we (the brain) recognise the pain, it is too late to prevent what has just happened, though of course, we are likely to cease the action to prevent further damage.

Neuron or neurone? Sometimes you may come across the word **neurone** being used instead of neuron. In scientific sources the standard spelling is **neuron**. The spelling **neurone** is generally restricted to non-technical contexts, but note that it is usual in *motor neurone disease*. (Source: Oxford Dictionary)

We return to the action of a reflex arc in Level II.

Voluntary movements: Parts of the brain involved



A detailed discussion of the parts of the brain is included in the other neuroscience project on the brain, which deals with memory and learning. Here is just a review. Note that in the above diagram, the spinal cord is shown but remember that it is *not* part of the brain. All the parts shown in the diagram, except for the basal ganglia, are visible from the outside of the brain. The basal ganglia are located almost right in the centre of the brain.

Basic parts of the brain and their functions (i.e. what they do)

1. Cerebral cortex (the brain's outer layer), which has **four lobes**:

Frontal lobe: This is the area for the so-called 'higher' abilities, that is, those involved with consciousness, planning of movements, thinking and working memory. So as you read these notes, you are conscious of what you are doing and thinking because your frontal lobe is being used.

Parietal lobe: This lobe is associated with sensory skills and plays an extremely important role in voluntary movements (see below for the sub-division of this lobe).

Occipital lobe: This is the *visual* area of the brain where images of what we look at are first processed after receiving signals from the eyes. While vision is an important sense in carrying out movements successfully, this area of the brain itself won't feature much in our discussion.

Temporal lobe: This area stores different kinds of memories. This includes memory of the *general* steps involved in movements, that is, the steps you might list if asked how an action is carried out. (But *not* the knowledge of how to *perform* the actions, which is stored in the cerebellum and which we cannot describe as it is hidden from consciousness.)

2. Sub-cortical structures (sub = *under*; cortical = *cortex*) which include:

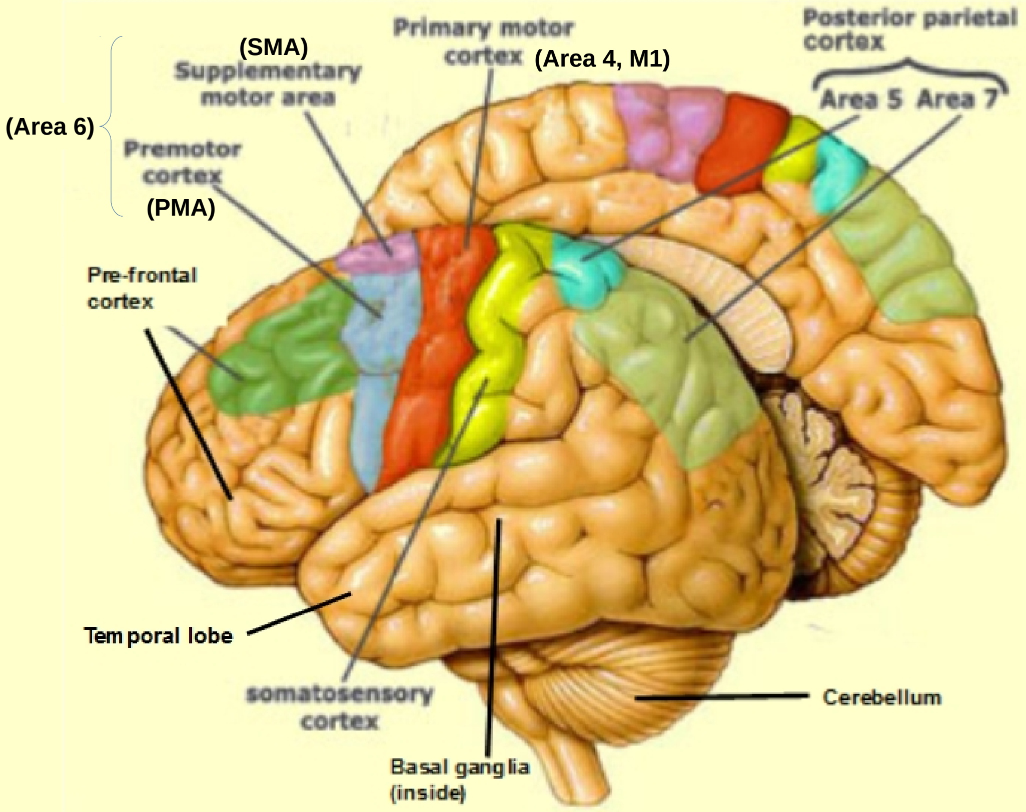
Brain stem: This is linked to the brain, the spinal cord and the cerebellum, and is involved in the transfer of information/signals from the cerebral cortex to the spinal cord and to the cerebellum.

Cerebellum: It has three basic roles. (1) To control *coordination* (i.e. working together) of movements and also for the accurate *timing* of movements so that they occur s*moothly and correctly*. Without this control, the arm of a person reaching for a cup may, for example, move too fast (or too slow), move in the wrong direction, the hand may try to grip at the wrong time. (2) To make corrections if things do go wrong. (3) It is involved in the *learning* of motor skills, such as walking, speaking, playing a sport or musical instrument. Many neuroscientists think (but cannot agree!) that the knowledge of the skills learnt in these activities is *stored* within the cerebellum.
Note: The cerebellum has a very high density of neurons – so high that while the cerebellum occupies only about 10% of the brain's total volume, it has over 50% of its neurons!

Basal ganglia: The basal ganglia are clusters of tightly interconnected nerve cells (neurons). They receive information from different regions of the cerebral cortex, for example, the frontal lobe and parietal lobe. The functions of the basal ganglia in motor (i.e. movement) control are not understood in detail. Current theories suggest they are primarily involved in allowing *appropriate* movements for an action to occur, and the inhibition of inappropriate movements, so that voluntary movements are able to be performed smoothly. For example, to reach for a cup, moving the arm forwards is appropriate while shaking of the hand is not.
Notes: (1) The basal *ganglia* technically should be called the basal *nuclei*, but they were named prior to the terms being defined and the name has stuck. (You can look up the Internet if you want to know the difference between a nucleus and a ganglion [plural: ganglia]). (2) Once the basal ganglia have processed information, they return it primarily to the **SMA** and **PMA** (see next section).

Further division of the cerebral cortex and functions of the parts

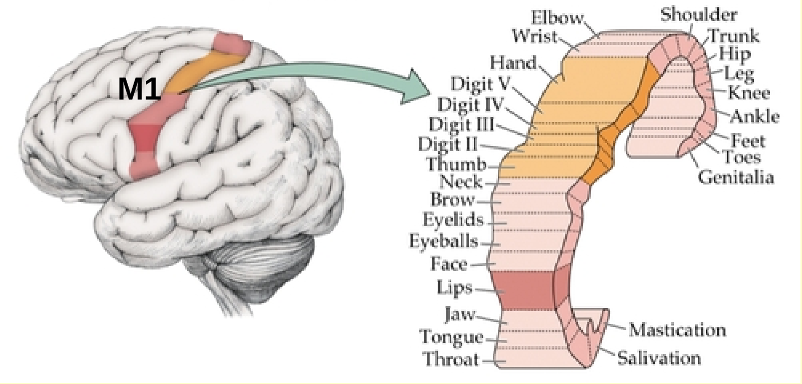
A further division of *some* of the lobes of the cerebral cortex is needed in order to understand how voluntary movements occur. Refer to the diagram and text below.



Frontal lobe

The frontal lobe is divided into several regions: The primary motor cortex, the secondary motor cortex and the pre-frontal cortex (see diagram above).

- **Primary motor cortex** (also called **Area 4** or **M1**) is the area that sends signals to move the muscles involved in a voluntary movement, instructing them to contract in order to carry out the movement. These signals in **M1** follow a set order (called a 'map') going from the head area down to the toes (see diagram, right).



  The primary motor cortex does not generally control *individual* muscles, but rather appears to control individual *movements* or *sequences of movements* that require the activity of *multiple* muscle groups. (Few movements are actually restricted to the activation of just a single muscle.)

- **Secondary motor cortex** (also called **Area 6)**. This area is further divided into two sub-areas:

  An upper part, called the **supplementary motor area (SMA)**, and
  A lower part, called the **pre-motor cortex/area (PMA)**.

  The **SMA** receives information from other areas of the brain (e.g. frontal cortex, basal ganglia, temporal lobe) which it uses to *plan* and *coordinate* the *general* movements for a voluntary action.

  The **PMA** selects the appropriate muscles for the *precise* movements that will be made. It gets specific input from the cerebellum about the *details* of the *skills* involved in a movement, which it coordinates to reach the goal of the action. It does *not* execute these; this is the role of the primary motor cortex.

  So, the **PMA** and **SMA** (Area 6) specify the precise sequence of contractions of the various muscles that will be required to carry out the selected motor action, in the case of reaching for a glass, moving stretching out the arm and curving the fingers around the glass.

  However, having said all this, the precise functions of the **SMA** and **PMA** do not seem to be fully understood.

  The primary motor cortex plus the secondary motor cortex is called the **motor cortex**. That is, **Area 4 + Area 6**.

  <u>Note on terminology</u>: Quite often, you may see the supplementary area called the supplementary *cortex* and the pre-motor area called the pre-motor *cortex* (as the latter is in the above diagram). This terminology is not correct though it is sometimes used (including my me!).

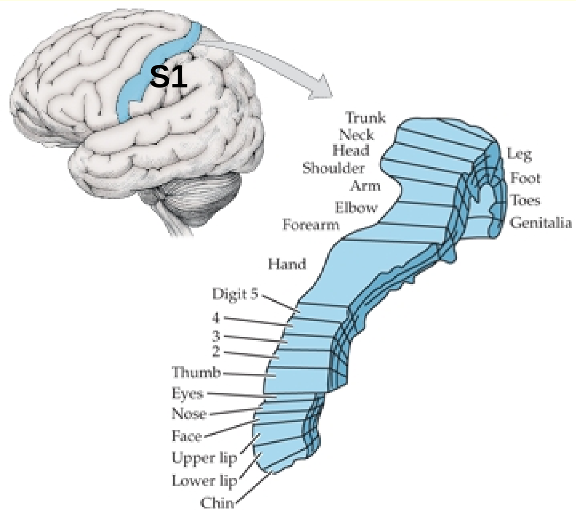
- **Pre-frontal cortex**: This is the *rest* of the frontal lobe and is where conscious awareness takes place.

  For example, when we decide to reach for a cup or when we are conscious of looking at what we are doing, our awareness of these occurs in this part of the brain. (In the above diagram, the pre-frontal cortex shows two areas – just ignore this for now and consider it as one whole area.)

Parietal lobe

(In the above diagram, ignore the terms 'Areas 5 & 7' – you will not need to know what they are; I could not find a suitable diagram on the Internet!). The parietal lobe is comprised of two main parts:

- **Somatosensory cortex** (or **primary somatosensory cortex** or **S1**). This is located at the anterior (front) end of the parietal lobe, adjacent to the primary motor cortex. It receives the senses of touch and pressure (on skin), temperature, pain and proprioception from around the body. (Note: The senses of sight, hearing and smell are received in other parts of the brain, not here). **S1** also has a 'map' of where senses from parts of the body are received; this 'map' is almost the same as the 'map' for **M1**.

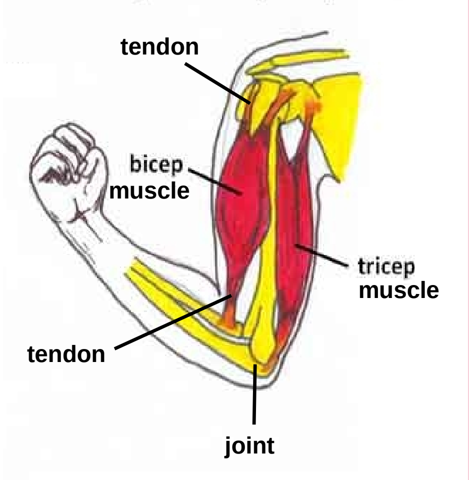


  Proprioception is a very important sense received in **S1.** This is described in greater detail below.

- **Posterior parietal cortex**. The parietal lobe is associated with *sensory skills*. It receives input from all the sensory areas of the brain (for example, the visual area in the occipital lobe and also the sensory input received by the primary somatosensory cortex). It then *integrates* the different types of sensory information received to create a 'model' (or 'mental model' or 'internal model') of what the brain is looking/sensing in the environment, including the position of body, for example, a cup on a table and the location of the person who is to pick up the cup. As we shall see, these models are *critical* in carrying out *voluntary* movements.

Proprioception

Proprioception means 'sense of self' and is the sense of the *position* of the body and where the limbs (arms and legs) are when at rest and during movement. In the limbs, there are proprioceptors, which are sensors located in the muscles and tendons that provide information about joint *angle*, muscle *length*, and muscle *tension* (i.e. force applied to them), which provides the necessary information to determine the position of the limbs in space. A normal person with eyes closed or blindfolded, or a blind person, is still able to know through proprioception if, for example, an arm is above the head or hanging down in front, by the side, or behind.



Origin: Forces on the muscles, tendons and joints maintain limb position against the force of gravity and indicate the *position* of a limb. The movement of a limb occurs because of changes in the length and forces applied to muscles and the forces on the tendons and joints. Note: A tendon joins a muscle to a bone; a joint is the point at which bones connect (see the diagram above, right).

Field sobriety test

Proprioception is tested by American police officers using the field sobriety test to check for alcohol intoxication. The subject is required to touch his or her nose *with eyes closed*; people with normal proprioception may make an error of no more than 20 millimetres, while people suffering from impaired proprioception (a symptom of moderate to severe alcohol intoxication) fail this test due to difficulty locating their limbs in space relative to their noses. Close your eyes and try it yourself now.

Maintaining posture and balance

The maintenance of posture and balance involves three senses – *vision*, *vestibular proprioceptive* cues (from the inner ear) and *proprioceptive* cues. These are *combined* to control balance when there are changes in body or head position. A test (called the **Romberg** test) requires a person to maintain balance while standing with feet *together* and *eyes closed* (pictured, right). It tests whether the proprioceptive components are working properly when the visual cues are missing and proprioceptive cues are the only major source of information. A loss of balance is interpreted as a problem with proprioception.

Proprioception is also what allows someone to learn to *walk in complete darkness without losing balance*.

<u>Test yourself</u> using two different tests:

1. Do the above test.
2. Stand with feet about 20 cm apart and eyes closed. Get another person to push you gently on the chest. If proprioception is intact, balance will be maintained.

Learning new skills: Examples

During the learning of any new skill, sport, or art/drawing, it is usually necessary to be familiar with some proprioceptive tasks specific to that activity. Here are some examples:

1. Without the appropriate proprioceptive input, an artist would *not* be able to brush paint onto a canvas without looking at the hand as it moved the brush over the canvas.
2. It would be *impossible to drive a car* because a motorist would not be able to steer or use the pedals while looking at the road ahead.
3. A person could not *touch type* without looking at the keyboard.
4. People could not perform *ballet* or even be able to *walk* without watching where they put their feet.

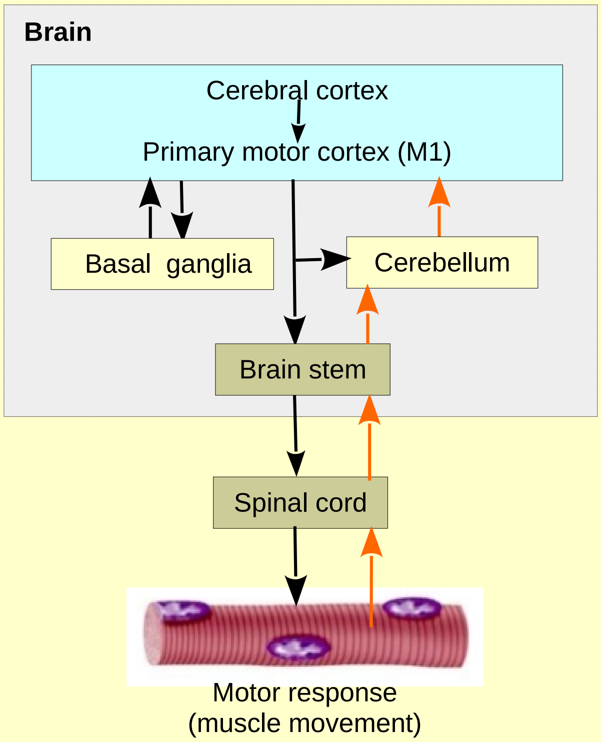
The Brain and Voluntary Movements

Definition: A voluntary movement is described as an *intentional* effort undertaken jointly by the motor cortex and numerous other neural systems acting in a 'consulting capacity'.

All the parts of the body that are involved in producing movements make up what is known as the **motor system**. (A system = parts working together.)

Voluntary movements are under our *conscious* control and so are *not* reflex actions. They are more complex than reflex actions, are slower and involve many parts of the brain. Memory can also play a part, which also causes voluntary actions to be much slower than reflex movements. We will take the example of picking up a cup/glass from a table to illustrate how this happens.

The diagram below shows the organisation of the motor system for a voluntary movement. (This diagram is simplified and not 100% accurate but is adequate for our purposes at the moment.)



Movements are *initiated* in the cerebral cortex (with the help of the basal ganglia). Signals are sent to **M1**, which then sends signals to the muscles, via the brain stem and spinal cord (**black** arrows), to move the appropriate muscles for the desired movement. **M1** also sends a copy to the cerebellum (**black** arrow ↳). The cerebellum gets *feedback* messages from the muscles and joints (**orange** arrows ⟶), compares this feedback with the intended movements and sends any necessary corrections to **M1** which then sends modifications to the muscles to ensure the movements occur smoothly, accurately *and* correctly.

Prerequisites needed to effect a voluntary motion

1. Sensory input

Our whole existence depends on our senses, whether or not we are moving. Without senses, we could not live. Think how difficult it would be to do things if we could not see, hear, feel, or did not have proprioception.

Sensory information is needed for movements both for carrying out the movements and for feedback to correct any errors in the movement. For movements in normal-sighted people, the senses involved are mainly *vision*, *touch* and *proprioception*. For blind people, sound will also be important. For blind *and* deaf people, the sense of *touch* is critically important, for example, using a walking stick to feel the way, bumps/raised dots on paths to guide the blind which are detected by touch in the feet and by the hand holding a walking stick.

Helen Keller (1880 – 1968, pictured left) was blind and deaf for most of her life. Yet she was able to live independently, relying entirely on the sense of touch (for example, reading using Braille and touching people's voice boxes to detect speech vibrations which she learnt to 'hear') and, as the picture shows, the sense of smell. She was the first deaf-blind person to earn a bachelor of arts degree.

2. Mental model of the environment

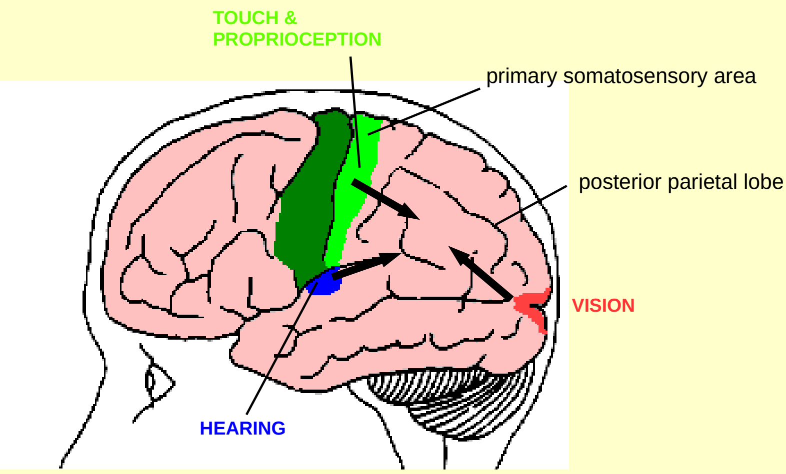
In order to make a desired movement, such as reaching for a cup/glass, it is essential for the motor system to know the starting position of the body and arm. To do this, as mentioned earlier, the human brain uses sensory information to create a mental model of the surrounding world. Note that when we see or hear something, this is *not* actually reality but merely a *model* of reality that the brain creates. So, two people looking at the same thing, only see the models their brains have created, which is why, when things are pointed out to us, we might – correctly – say “Oh, I didn't see that!” On something being pointed out, we then include that in a modified model and so see the world slightly differently.

What is reality?
People often ask this question, but it has never been answered by science and may never be answered. Typing this question into my Google Search turned up 750 000 000 hits! There are also many videos on the question. Here is a link to one from a BBC Horizon programme. But don't expect it to answer the question!

http://www.dailymotion.com/video/xkvoa0_bbc-horizon-2011-what-is-reality-hdtv_tech
Maybe the answer is in the quotation, attributed to Albert Einstein, but which he did *not* actually say: "*Reality is merely an illusion, albeit a very persistent one.*"

All the sensory information we detect is transferred to the posterior parietal cortex in the brain: visual, (from the visual areas in the occipital lobe) sound (from the auditory/hearing area in the temporal lobe), touch and proprioception (from the primary somatosensory area) – see picture at the top of the next page.

The post parietal cortex *combines* all the sensory information to create a **mental model** of the scene. (Note: This model is not like an image/ picture but you might like to think of it in this way; but for a blind person, an image/picture is not possible though a model is still created in the brain of the blind person.)



To become *aware* of a movement (or anything else), this model passes to the pre-frontal cortex. For some movements, we may *not* be aware of what if happening; in such cases, the model is *not* passed to the pre-frontal area of the brain.

A blind person also creates an image but it is not as detailed as one using vision – imagine an action such as walking with your eyes closed The models created in the mind of Helen Keller would be even simpler.

Mental models and movement: For example, a person reaching for a glass/cup on a table, with the person sitting at/next to the table (cf. picture). The brain of the person reaching for the cup/glass creates a model/mental 'picture' of this scene.

To create this model, the brain needs sensory input; without the senses, a movement is impossible. For our discussion, the three important senses used will be vision, touch and proprioception. In order to make any desired movement, such as reaching for a cup/glass, it is essential for the motor system to *know the starting position* of the arms and hands. The *proprioceptors* provide information about the lengths of the muscles, the forces being applied to the muscles and the tension in muscle tendons. The brain uses this information to calculate joint position and other variables necessary to make the appropriate movement. and incorporates all this into its mental model.

In the posterior parietal cortex, all the information from the senses is combined to form a model of the scene in which the movement is to occur. During a movement, this model is continually updated as the movement changes based on new sensory input and feedback.

For many voluntary actions, such as when we reach for a glass/cup, we are aware of what is happening because the model in the post parietal cortex passes to the pre-frontal (awareness) area of the brain.

We are *not* consciously aware of *all* voluntary movements, for example walking, as the mental model is *not* passed to the pre-frontal cortex/area. But it can be. When walking, we *can* be aware of putting one foot in front of the other. This can happen if something unexpected happens, such as a hole in the pavement we must avoid, a pause we must make because of a vehicle approaching us, or an obstacle/person in our path that we must move around to avoid.

3. Knowledge of a movement

To reach for a glass/cup, the brain must *know* the *steps* in the procedure. When we learn a new procedure, whether as a child or as an adult, the memories of the *general* steps of the movement are stored in the **temporal lobe**. For example, the general steps for reaching for a cup might be: stretch out one arm, lower the forearm, open the hand when it is near the cup, enclose the hand around the cup, squeeze to hold the cup, lift the cup, etc.

The brain must *also* know the *precise details* of how the muscles and joints must move to carry out the movements, and the *precise timing* of the movements. This is called '**procedural knowledge**' and is also learnt and probably stored (not known for certain) in the **cerebellum**. But we are *never* aware of this knowledge is; it is always hidden from our consciousness, which is why we cannot only demonstrate a skill and not explain it (though people sometimes try to!).

Children's movements are often extremely clumsy, often disastrously so! Ask a child to reach for a glass of milk on the table. or pour milk. Disaster! Arms all other the place, timing all wrong, spilt milk everywhere and perhaps broken glass all over the floor. But the child gradually learns – especially the *fine details and the timing* – and soon is (almost) as capable as an adult at picking up and drinking a glass of milk.

"Keep playing like that and you'll strike oil!"

But adults can be just as incompetent initially when learning a new skill, for example, learning to hit a golf ball. This is a skill I myself never mastered and led me to give up trying to play golf! So, while I knew the general steps needed to hit the golf ball correctly, and which were stored in my temporal lobe, my unconscious procedural knowledge of the fine skills and timing needed stored in my cerebellum was sorely lacking!

The temporal lobe sends the general steps of a movement to the secondary motor cortex (Area 6), which using it to plan the necessary movements. The cerebellum sends information about the *details* of skills – how muscles must move, the required direction, the force to be exerted, in what order and for how long. (Notice that I say the *secondary* cortex. This consists of the **SMA** and **PMA**, but I am not sure which information is sent to which of these two areas.)

Question: How does the cerebellum learn from experience?
The cerebellum learns through trial-and-error, When (1) learning a new skill (as above), and (2) from feedback. such as from visual and proprioceptive senses. If an action is wrong, (e.g. moving an arm in the wrong direction when trying to pour milk), the feedback indicates this to the cerebellum and learning occurs for the new conditions so that next time the same conditions are met – hopefully – the arm will move in the correct direction. If it still fails, more learning occurs. The cerebellum builds up a 'memory' of many different situations it has faced. So perhaps that is why the movements of a child are often full of errors; not enough learning has taken place yet for perfect actions. The same thing occurs with older people when learning any new skill, for example, kicking a ball, making a basketball shot or hitting a golf ball.

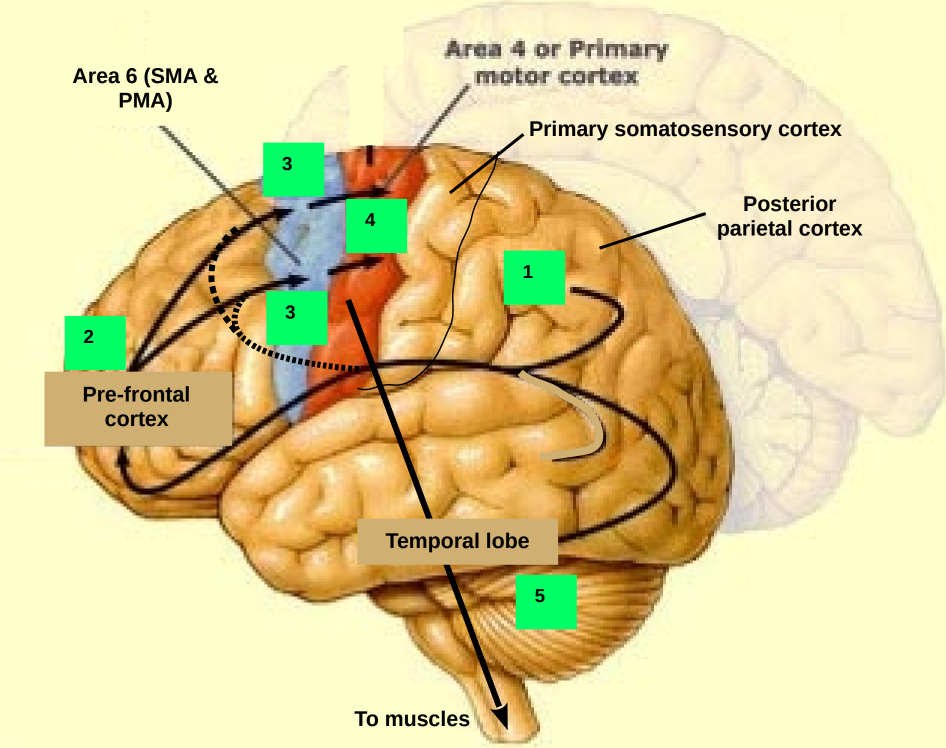
How the brain carries out **voluntary** movements

While reading the steps below, also refer to the diagram below. The explanation is based on my my current understanding on how this happens. The explanation again takes as an example of a movement the reaching for a cup/glass of drink on a table after a person decides to have a drink.

Note: In this example, we are *assuming* the cup/glass is *already* on the table. and the person then decides to have a drink. If not, and the person *first* decides he wants a drink, the situation will be is slightly different from the one described and modifications would need to be made. So, for the purposes of this explanation, we are assuming that the person decides to have a drink *after* seeing the cup/glass of drink on the table.

Further note: *You may sense that in the explanation below, there is repetition of what has been said before. This is deliberate as understanding improves when something is repeated in a slightly different way.*

NB: The numbers in the diagram correspond to the steps in the text



Step 1: **Preparation of a mental model** (*in the posterior parietal cortex/lobe*)

1. A person is seated at a table or perhaps is lying on a sofa. Whether or not the person decides to have a drink, he *sees* the cup/glass (vision) on a table.
2. Sensory information related to the scene passes into the posterior parietal cortex. This would include vision (from the occipital lobe) and proprioceptive sense of body and limb position (e.g. if the person is on a sofa or seated at a table) which is received first in the primary somatosensory cortex and then passed to the posterior parietal lobe.
3. The posterior parietal cortex integrates all this sensory information to create a model of the scene. This scene will include the location of the table and the cup on the table and the person himself.

Step 2: **Deciding the goal and an appropriate strategy** (*in the pre-frontal region*)

1. The model in the posterior parietal cortex is passed to the pre-frontal cortex (where the working

memory is) and the person becomes conscious of the scene. That is, the person sees the scene in from of him.

2. From what he sees, the person makes a conscious decision in his working memory on what he wants to do, in this case to reach for the cup on the table (this is often refereed to as the *goal*).

3. The person needs a strategy/plan – a sequence of actions – to attain the goal. That is, the person needs have a list the sequence of steps necessary for this. For a familiar action, such as reaching for a cup, this knowledge is already stored in the *temporal lobe* based on what has been learnt in the past. If asked to state these steps, the person could easily do this, which is why in the diagram, there is an arrow from the temporal lobe to the pre-frontal cortex. But if the person does not consciously list the steps (which is what would normally happen – how often do we have to list the steps?), this information goes straight to Area 6 (and so the diagram will have to be modified, which is what the dotted black lines indicate).

Step 3: **Selecting the muscles and the muscle sequence needed** (*in the secondary motor cortex*)

From now on, everything happens *unconsciously.* The action moves to the secondary motor cortex (Area 6) – the supplementary area (**SMA**) and pre-motor area (**PMA**).

1. Based on the goal set in the pre-frontal cortex, the general sequence of steps for the movement are transferred to the **SMA** (either from the temporal lobe directly – dotted black line – or via the pre-frontal cortex – full black line). The **SMA** transforms these general steps into a *sequence of contractions of the various muscles* that will be required to perform the desired movements, in this case, stretching out the arm and grasping the cup/glass with the hand.

2. The basal ganglia loop also sends information to the **SMA** to select the *appropriate* movements for the planned movement(s) and to block any movements that are unsuited to the situation. (It seems that there are may be more movements than necessary in Area 6 and the basal ganglia are used to decide which movements ones are appropriate and which are not in order to achieve the desired goal.)

3. The cerebellum sends to the **PMA** (I think!) *precise details* of how the muscles are to contract and the exact timing (based on memories of the skills learnt from past experiences).This information is integrated with that the more general information of the sequence in the **SMA**.

Step 4: **Carrying out the movement** (*in the primary motor cortex*)

1. Once **Area 6** has decided how the movements are to be executed, the final instructions are passed to the primary motor cortex (**M1**/Area 4).

2. The primary motor cortex determines how much force each muscle group must exert and sends this information along the nerves via the brain stem and spinal cord to the muscles to generate the movements. The spinal cord is the main pathway for execution of voluntary movement in humans.

Step 5: **Monitoring the progress of the movement** (*in the cerebellum*)

The motor system needs *feedback* to check that the desired movements are proceeding as planned and to ensure that the posture and balance of the body during the action is maintained. If things are not right, changes are made. The cerebellum is involved in this with what is called a **cerebellar loop**. Here is how the loop works:

1. As we have already commented, when the motor cortex (**M1**) sends commands/signals to the muscles telling them how to move, it also sends a copy to the cerebellum, informing the cerebellum of what the *intended motion* is. A copy of the model is also transferred from the posterior parietal cortex.

2. In addition, the cerebellum receives sensory input, especially visual (from looking) touch (from the skin, e.g. when grasping the cup/glass), informing the cerebellum of what the *actual* motion is. It also receives proprioceptive input (from the muscles and joints) giving feedback on the position of the body, arms and fingers. and also on balance: reaching the arm forwards for a cup/glass would cause the body to fall, as the body's centre of mass shifts to a location in front of the body axis.

3. Using the copy of the model and the intended motion, the cerebellum determines *what adjustments need to be made to correct any errors* (differences between the intended and actual movement and any changes in balance). For example if, when reaching for a glass, the arm is not close enough to the glass and needs to move further or if there is insufficient finger pressure to hold the glass. Also, the ability to *adjust* when picking up a cup/glass that is empty (and so lighter) or full (and so is heavier) depends on this feedback loop.

4. The cerebellum sends corrective signals for the movement and posture back to the motor cortex to modify the original commands, which then signals the muscles to alter their activity.

<u>Extra notes on the cerebellar loop</u> (perhaps repeating things already mentioned): (1) The cerebellum acts like an internal 'clock' that precisely regulates and fine-tunes the *sequence* and duration of movements, for example, the timing of the steps in moving the arm towards the cup/glass, fingers grasping the glass, lifting the glass. (2) Because the cerebellum controls the fine details, it results in movements that are so fluid (smooth) and harmonious (all working together) that we are not even aware of them.

Feedback or feedforward?
Does the cerebellum provide feedback alone (or only) or is 'feedforward' also involved. The idea of feedforward is to ensure some action goes correctly *before* it actually happens, instead of after (as with feedback). This is an issue in neuroscience and will be discussed in Level II. Some scientists think that feed<u>back</u> is suitable for slow movements (e.g. change in posture), whereas feed<u>forward</u> is necessary for fast movements (that is, most voluntary movements).

Ascending and descending tracts of the spinal cord

As we have mentioned, signals/messages/information are sent *downwards* from the cerebral cortex to the spinal cord and muscles, and also from the cerebral cortex to the cerebellum. These pathways are called **descending pathways** or **descending tracts**.

In contrast, nerve pathways that go *upwards* from the spinal cord carry *sensory* information from the body to the brain or to the cerebellum. These are called **ascending pathways** or **ascending tracts**. So:

Ascending tracts: Sensory – deliver sensory information from the body to the brain and cerebellum
Descending tracts: Motor – deliver information to the muscles or to the cerebellum.

Technical terms:

Some of the pathways have special names.

- The descending pathway from **M1** to the spinal cord and then on to the muscles is called the **corticospinal** tract.
- The descending pathway from the cerebral cortex to the cerebellum. is called the **corticopontine** (or **cortico-ponto-cerebellar**) tract.
- The ascending pathway from the spinal cord to the brain is called the **spinothalamic** tract.
- The ascending pathway from the spinal cord to the cerebellum is called the **spinocerebellar** tract.

These names are derived from the parts that are linked. The first part of the name gives the starting point of the flow of the information and the last part to where the information is delivered. Thus 'corticospinal' comes from 'cortico-' (= cerebral cortex) and '-spino' (= spinal cord). 'Corticopontine' comes from 'cortico-' and 'pontine-' (i.e. pons, part of the brain stem). 'Cerebellar' of course refers to the cerebellum. 'Spinothalamic' refers to 'spino'- (=spinal cord) and '-thalamic' (i.e. the thalamus, through which the information passes on its way to the cerebral cortex). (I suppose it could be call the 'spinothalamiccortico pathway but it isn't!) Finally, 'spinocerebellar' refers to the spinal cord and the cerebellum.

<u>Note</u>: There is no special name for pathway from the cerebral cortex to the basal ganglia/nuclei.

A deeper discussion about these and other pathways can be found in Level II including the thalamus, which is mentioned above.

How the brain carries out movements involved in **reaching for an object**

We will now focus out attention on movements involved in reaching for a cup/glass, first the overall movement and then two simpler sub-movements. More complex movements involve more parts of the cerebral cortex. Simpler movements involve fewer parts of the brain.

The discussion here overlaps a lot with what has already been discussed so again there is – deliberately – repetition.

Overall movement: Reaching for the cup/glass on a table

Reaching for and picking up a cup/glass is actually a *complex* action! Here, we will describe the *general* movement and not every detailed sub-movement. The diagram on page 16 can also be used here as it also refers to an overall movement.

1. The *initial* **sensory input** will (for most people) be *vision* (i.e. the sight of the table area with the glass/cup on it) and *proprioception* (position of the body of the person doing the reaching and the initial position his of arms and hands). Vision is received in the occipital lobe and proprioceptive information in the primary somatosensory cortex. All this sensory information is transferred to the posterior parietal cortex.

2. In the posterior parietal lobe, the sensory information is integrated to create a mental **model**. The posterior parietal lobe passes this model to the pre-frontal area which gives us a picture of the scene.

3. When we decide to pick up the cup/glass, the general steps for the movement are transferred from the temporal lobe to the **SMA**. (Of course, if we really wanted *state* the steps involved, this information would *also* go to the pre-frontal area, for example, a parent telling a child what to do, but usually we are not consciously aware of these steps so it does transferred to the pre-frontal cortex.) The **SMA** transforms these into a *sequence of contractions of the muscles* required to perform the desired movements.

4. The *fine details* of the forces needed to move the muscles, the correct sequence (e.g. muscles to stretch out arm come before muscles squeezing fingers to grasp glass) together with the and timing/speed of their movement is passed from the cerebellum to the **PMA**.

5. Information in the **SMA** and **PMA** is integrated to give an accurate and detailed plan of action. Information from the basal ganglia confirms the appropriate actions and blocks any inappropriate actions that might be lurking in these secondary motor areas.

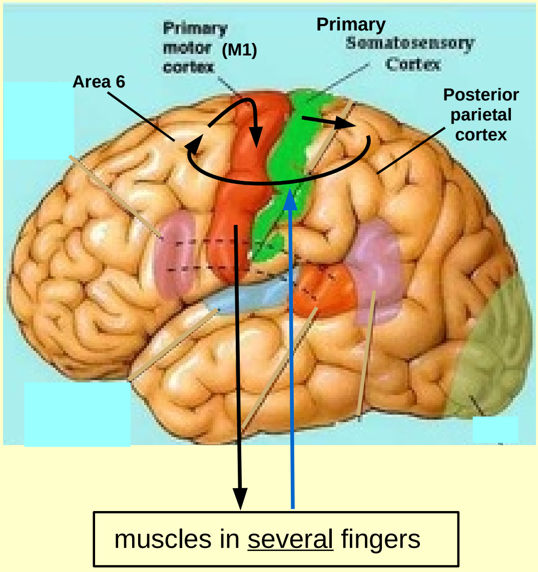
6. The final instructions are passed to **M1**, which sends signal down the spinal cord to the appropriate muscles to execute the movements. A copy of these instructions *and* a copy of the model from the posterior cortex are sent to the cerebellum.

7. During execution, proprioceptive feedback from the muscles and joints is sent to the cerebellum which compares the current situation with what it should be. Any necessary corrections are transmitted back to **M1**, which then sends instructions to the muscles to modify the action. **Note**: There may also be visual feedback, for example, we might *see* that the arm is nowhere near the cup. Necessary corrections probably come from the model of this situation, which is continually updated as the action proceeds. However, if we are reaching for the cup with our eyes closed or are not looking at the cup, the brain can only rely on proprioception, but, I guess, having both proprioceptive and visual feedback ensures a more successful outcome.

<u>Can a blind person reach for a cup</u>? Yes, but the person probably has to be *told* where the cup is (i.e. sense of sound) together with proprioception (same as for sighted person). Or, without sound (e.g. blind and deaf person), then by *touch* only, for example moving arm across the surface of the table (carefully!) to feel for the cup/glass with proprioceptive feedback. For a sighted person, the mental model will be very detailed as it includes information from several senses; for a blind and deaf person, the model will be very simple and so the chance of failure is greater.

Sub-movement 1: Grasping the cup

An example of a sub-movement is the selection of the fingers that must work together to grasp the cup/glass. The action will differ slightly depending on the size and shape of the cup/glass (e.g. for a tall narrow glass or a short curvy one).



For this sub-movement, the brain needs to focus on where the fingers of the hand are in space and to adjust these positions in order to gasp the cup/glass correctly. Differently shaped cups/glasses will require fingers in different positions around the cup/glass. All these subtle points will be incorporated into the model.

As we shall see, because this is a less complex movement, some of the steps can be eliminated or 'short-circuited' out of the procedure so as not to be unnecessarily repeating things already done.

The following is what I think happens for this sub-movement:

1. Visual signals from looking at the cup/glass are sent to the visual area (occipital lobe; not labelled in diagram). Proprioceptive signals from finger muscles and joints indicating the current position of the fingers are sent to the primary somatosensory cortex (**blue** arrow ↑). These will then be sent to the posterior parietal cortex where they will be integrated to modify the mental model.

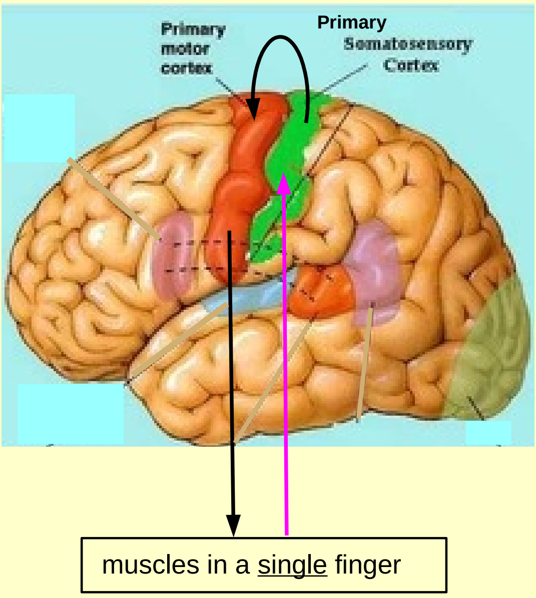
2. As the mental model is modified only slightly, it does not need to be sent to the pre-frontal region (at least, this is what I think!). Instead, a signal goes from it *directly* to **Area 6**, 'short-circuiting' out the pre-frontal lobe. As always, the **SMA** chooses the appropriate sequence of muscle movements, in this case, in the fingers. The **PMA** works on the details of how the finger muscles should move to grasp the cup/glass

3. Again as before, **Area 6** sends a message to the primary motor cortex (**M1**) to execute the action and grasp the cup/glass with the appropriate fingers at the appropriate angles. Also as before, a copy of the instructions is sent to the cerebellum.

4. Visual feedback (*if* you are looking at what is happening) and especially proprioceptive feedback (from the finger muscles and joints grasping the cup/glass) will be important here to ensure that the appropriate number of fingers and the angles of these fingers are suitable for the size and shape of the cup/glass. If the grip is not as planned, the cerebellum sends corrections to **M1**. This loop will probably occur several times (but very, very quickly) until the grip is correct.

If the cup/glass is of a shape and size *never met before*, some learning may also be required though this too will be fast, if the person is an adult, as he will have had grasped many very similar but not identical cups/glasses before. Thus, one more minor learning skill will be added to the repertoire in the cerebellum, which means that the next time an identical (or almost identical) cup/glass is to be lifted, the knowledge of the skill for the grip will be available.

Sub-movement 2: Regulating the pressure on the cup/glass



Once the fingers grasp the cup/glass, they need to exert the correct pressure. This action is likely a sub-movement of the above sub-movement and will take place the moment the fingers contact the cup/glass.

This sub-movement involves regulating the *finger force/pressure* on the cup/glass once the fingers are actually touching the it. The force to hold the cup/glass needs to be just right. Too little and the cup/glass cannot be gripped; too much and the cup/glass might might break. This is the first time in the overall movement that the sense of touch is involved (I think!).

1. Touch receptors in the skin detect the *pressure* of the fingers on the cup/glass and its *texture*. (Finger position is also at play of course, detected by proprioception in the finger muscles and joints but is not part of this sub-movement). So, when the cup/glass in touched, these receptors send *pressure and texture* signals to the primary somatosensory cortex (**magenta** arrow ↑).

2. Now, you might think that this sensory information will be transferred to the post parietal cortex (as in the above examples) to update the mental model. This is probably true, but it seems that *very* simple actions occur *directly* and can 'short-circuit' even more things out of the process. The primary somatosensory cortex detects the pressure and texture and sends a message *directly* to the primary motor cortex (**M1**) to exert the appropriate pressure. The primary motor cortex then signals the contraction of individual muscles in the fingers. That is:

touch receptors in fingers (for pressure and texture) → primary somatosensory cortex → primary motor cortex (**M1**) → muscles to exert appropriate pressure

Also, the action does *not* involve the **SMA** or **PMA**. I am not clear about this, but if correct, the movement will be much quicker as these steps are also omitted.

3. If the cup/glass in gripped with just the right pressure, it will be able to be lifted. If the pressure is too little or too much (i.e. not in accord with the pressure that has been learnt from carrying out the action in the past), the cerebellum sends corrective feedback signals to **M1**, which then sends a corrective signal to the muscles in the fingers.

If the *pressure* on the cup/glass is wrong, (e.g. the cup/glass slips from the grasp because it is full of drink and so heavier than usual), learning again occurs for the new conditions so that next time the same conditions are met – hopefully – just the right force is exerted to hold the cup/glass. If the action still fails, more learning takes place until cerebellum has a memory of the many different situations it has faced.

Note: Here the learning, if needed, involves learning the correct pressure. For Sub-movement 1 above, the learning involved the shape/size of the cup/glass. Each is part of the skill involved in grasping a cup/glass. Skills are very detailed and need to include all the smallest things in order to perform an action correctly and smoothly.

This sub-movement action may *seem* to be like a reflex action. But it *cannot* be so, as reflex actions do not involve the brain. It is thus a voluntary action and not a reflex action but does happen without awareness as a signal goes directly to **M1**. Of course, we *can* consciously control and adjust the pressure ourselves as when we crush a paper cup before throwing it away. In this case, the parts of the brain needed for conscious awareness (pre-frontal lobe) will be involved, but then this action becomes more complex and more like the example given above for the overall movement.

Exercise

The discussion for the two sub-movements above has only got only as far as gripping the cup/glass. The next sub-movement in the sequence is lifting the cup/glass, which involves lifting the hand and forearm. This will be another complex movement and will probably involve most of the brain as was the case for the overall movement described above. Your task is to describe what happens in the brain for this sub-movement.

Mental imaging of body movements

So you want to learn to ski, play tennis, swim or become a ballet dancer? To learn new physical skills, you must repeat them many times in order to become proficient. In so doing, the details of the skills involved are store in your procedural memory. This repetition is what is commonly called **training** or **practising**.

But there seems to be another way of learning a skill or improving the performance of a movement besides repeating it over and over: simply *imagining* it, that is, visualising or picturing it in the mind!

This method is called **mental imaging** and it is being used more and more people, especially by athletes, to improve their performance. People who are better at generating mental images of movements make faster progress in learning or improving physical skills than do people who just practice a movement over and over again and don't imagine it mentally.

There seem to be two ways mental imaging can be done.

1. **Watching** *someone else* perform a skill
   This can be done either directly or from a video. It can be useful for someone who is not an expert or is learning a skill. For example, when a tennis fan – such as the little boy in the picture – closely watches the actions of a skilled player, the fan can actually be learning some of the skills even though he or she is not actually playing. The next time the fan goes to play tennis, he or she will find it easier to recall and replicate these movements.

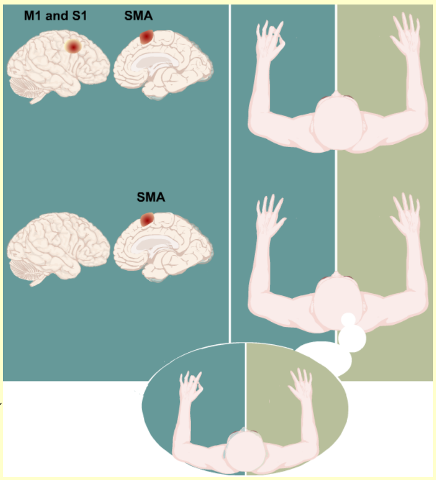
2. **Imagining/Rehearsing** it *yourself*
   This is particularly useful for an *expert* who already knows the movements involved. For example, high jumpers, divers and weightlifters try to imagine or rehearse in their minds all the physical movements involved before they actually perform the movement. Downhill skiers too mentally rehearse their entire path down the race course before they start their descent. They see every turn, feel their body pass over every bump, and mentally perform all the manoeuvres required to race their way down the hill. This has been shown to improve performances and reduce times.

Video: Cat tennis fans
Even kittens might learn to become tennis players by watching a tennis match.
Take a look at this video:
https://youtu.be/JgAgfC8Tqok

Why does it work?

As we have seen, carrying out voluntary movements activates many parts of the brain, especially the motor system. By using brain scanning techniques (in which a person watches a video of a movement while lying still in a scanner, such as an fMRI scanner), scentists have discovered that when people *imagine* themselves performing a movement, many of the same brain neurons 'fire' when they observe the same action performed by another. (The same is true for animals, such as monkeys, and maybe even kittens!) These neurons are called **mirror neurons** because they mirror or copy the behaviour of the neurons in the other person's brain, as though the observer himself were performing the action. They were discovered in experiments with monkeys by the Italian neurophysiologist Giacomo Rizzolattiin the mid-1990s.

Examples of experiments showing this mirroring action



1. In an experiment with a monkey, when it was breaking a peanut, some neurons in its **PMA** fired. The same neurons fired when it saw another monkey or a person breaking a peanut.
2. When a person performed a *complex* sequence of finger movements, the **SMA**, **M1** and primary somatosensory cortex (**S1**) were active (picture, top right). When the person remained still but mentally rehearsed the movement, the **SMA** was still active but **M1** and **S1** were silent (picture, lower right); **M1** must be silent as this is the area that sends instruction for muscles to move.
3. In a 2004 experiment with three groups of people, namely, a group of ballet dancers, a group of dancers of capoeira (a Brazilian dance/martial arts form, pictured right), and a group of non dancers watched short videos of dancers performing brief ballet and capoeira moves. The areas of the dancers' brains were *more* active when they were watching movements of the *same* kind that they were trained in than when they were watching the other kind. The non-dancers showed even less mirror-neuron activity than the ballet dancers watching capoeira or the capoeira dancers watching ballet.

Rehearsing a movement mentally enables people to perform movements more efficiently, the reason being that t*he brain does not seem to make any great distinction between actually performing a movement and simply visualising it in the mind's eye* (though, of course, the muscles make a distinction, as they do not actually move during the visualisation!)

Swimming

The picture on the right is of me swimming! Would mental imaging help me improve? Watching someone swimming is probably not useful as most of the movements occur under the water! A video *may* help; I do have an animated video which I have watched several times. As I am not an expert swimmer and have never been able to work out *exactly* how I should swim (never having had a coach), rehearsing would be a waste of time! (Stick to running; it is much simpler!!)

Brain damage and effects on movement

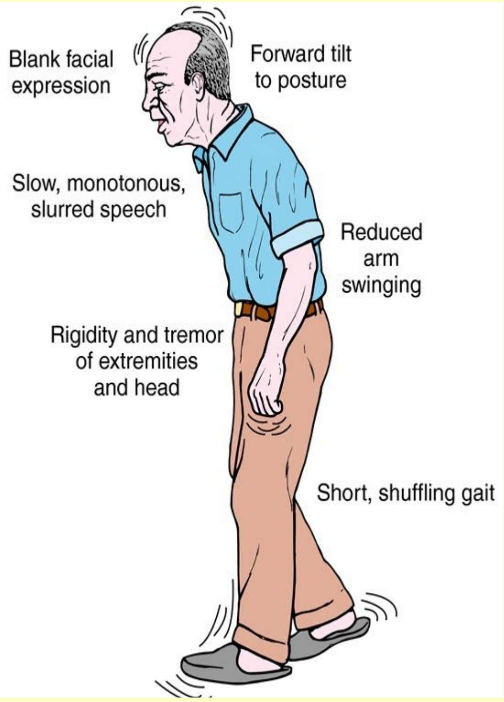
Knowledge of how the brain works is often gained from investigations with people who have movement disorders. We will discuss some of these disorders and the parts of the brain involved.

Three are discussed here: **Parkinson's disease**, **ataxia** and **apraxia**.

Damage to the basal ganglia: Parkinson's disease

In 1817, James Parkinson (1755 – 1824, pictured left) a British physician, reported on several patients with a condition now called Parkinson's disease.

Parkinson's patients display *trembling* when *not* actively moving, for example, just holding a cup of tea. But more serious is a difficulty in *starting* movements they have planned, *slowness* of movement (*bradykinesia*), as well as trembling and slowness once they do begin them (i.e. *coordination*). In addition, changes in speech occur.



The basal ganglia, which normally inhibit inappropriate movements, do not do so in Parkinson's patients, and so do not prevent these inappropriate motor commands from descending to the spinal cord and then to the muscles.

Symptoms of Parkinson's disease appear when 75-80% of neurons in one part of the basal ganglia (substantia nigra) are lost!

Note: Patients with Parkinson's disease can exhibit hand tremors. But be careful; there is another common affliction called 'Essential Tremor', the cause of which is not understood, but it my be due to abnormal electrical brain activity involving through the thalamus.

Video: Parkinson's disease
There are many videos on the Internet for Parkinson's disease. Here is one of them. But you can do a search to find others.
https://www.youtube.com/watch?v=IHDFQfmkKlg

Damage to the cerebellum: cerebellar ataxia

[From Greek: *a-* = no/not, *taksia* = order, hence 'lack of order / lack of *coordination*']

Ataxia is a non-specific term. It does not refer to a specific disease but to dysfunction of the parts of the nervous system that *coordinate* movement. Perhaps confusingly, some symptoms overlap with those for Parkinson's disease. Here we look at **cerebellar ataxia** (also called *cerebellar hypoplasia*) and then **sensory ataxia** (which is *not* due to damage to the cerebellum).

Unlike the basal ganglia, damage to the cerebellum does *not* result in *lack* of movement or poverty of movement. Instead, it is characterised by a lack *coordination* and *accuracy* of movement. It may affect walking, picking up objects, speech, eye movements, the ability to swallow and other voluntary movements.

How a patient is affected depends on which parts of the cerebellum are damaged (the parts are discussed further in Level II). Thus, although some of the examples below may seem to conflict, this is because of damage to different parts of the cerebellum. As well as injuries, *alcohol consumption* can also produce damage to the cerebellum.

Some symptoms of cerebellar ataxia

Note: As most of these symptoms involve movements, which are difficult to appreciate with still pictures, refer to the videos listed below. As you read the text, keep in mind the idea of coordination, that is, of muscles always working in the proper order, working at the proper speed/timing, and *not* working when they should be motionless

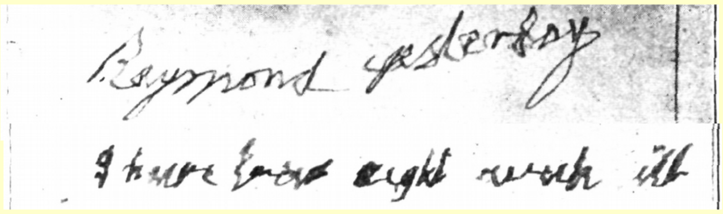
- Patients cannot perform *smooth, coordinated* movements: instead they are *jerky* and not in the correct sequence. For example, touching the nose with a finger requires coordination in movement of the shoulder, elbow and wrist joints. Patients with cerebellar apraxia will perform these as *separate steps* rather than as a single uniform motion.

- Difficulty in accurate *timing*. For example, when trying to *grasp a cup,* the hands may start moving *late*, advance *unsteadily*, and either stop before reaching their target, or accelerate past it. Stopping also will be too late, and inefficient, so that his *hand ends up missing the object and going past it*.

- An inability to perform rapid, *alternating movements* like rapidly turning the hands over so that the palm faces upwards then downwards, pictured right (and called *dysdiadochokinesia* if you are interested!).
- *Posture and balance*: A patient will typically stand with feet wide apart in order to gain better balance and avoid swaying backwards and forwards, even when standing still. *Unusual gait*, with unequal steps, sideways steps, and uncertain starts and stops (see picture right, below). These balance problems are similar to those found in people who are drunk.

- A delay in *initiating* voluntary movements. People take longer to initiate movements, often because they must actively plan sequences of movements that are performed effortlessly by normal individuals.
- *Intention tremor* [not the same as 'essential' tremor – cf. comment above]. A normal person can make a controlled movement to an object. In a patient with a damaged cerebellum, the movement towards the object starts smoothly but then moves back and forth until the hand slowly contacts the object – this is called an *intention tremor.* For example, when reaching for a cup or a book, the hand moves normally at first but then shakes as it makes contact with the cup or book. (Compare this with a *resting* tremor, where the hands shake even when someone doesn't mean to move them, which can occur in Parkinsons' patients)

- *Abnormal speech* (*ataxia dysarthria*): The muscles that produce speech are affected, resulting in speech that is slow and disjointed, breaking words up into individual syllables in speech that is otherwise linguistically normal.
- *Abnormal writing*: Muscles of the hand are affected. The examples in the picture (right) are specimens of the writing of two men with injuries received to the cerebellum in World War I. The upper is of the words, 'Raymond, yesterday'; the lower, 'I have been eight weeks ill.'



Finger-nose-finger test: This test is often used to detect a lack of coordination due to cerebellar ataxia. The patient is asked to alternately touch his nose and the examiner's finger as quickly as possible as shown in the picture (right).

Exercise

To help understand and be more familiar with the above symptoms, try acting them out by following the descriptions given in the text.

Videos for cerebellar ataxia

There are many videos on the Internet for cerebellar ataxia. Here are some of them. But you can do a search to find others.

Rapidly alternating movements:
https://www.youtube.com/watch?v=2EZqnmxWyAY

Cerebellar gait:
https://www.youtube.com/watch?v=eBvzFkcvScg

Intention tremor:
https://www.youtube.com/watch?v=mBr1ZZ1dr3E

Speech ataxia (*dysarthria*):
https://www.youtube.com/watch?v=W1xhYBNn5n8
https://www.youtube.com/watch?v=7BnGxeMAM_s

Finger-nose test + abnormal writing:
https://www.youtube.com/watch?v=ji-nPrbigxA

Damage to the spinal cord: Sensory ataxia

This is ataxia due to a loss of *proprioception*. Remember that proprioception is the sense where the parts of the body are located in relation to each other at rest and during a movement. (A blind person, or a normal person if blindfolded, knows through proprioception if an arm is above the head or hanging down in front of, by the side, or behind.) Note that sensory ataxia is caused by damage to the spinal cord and *not* the cerebellum.

Symptoms

A person typically has an unsteady *stomping* gait, with the heel striking hard as it touches the ground with each step (picture, right).

Postural instability is worse in *poorly lit* environments. Loss of balance can occur in the dark, when closing one's eyes or removing clothing over the head. If a doctor asks a patient to stand with eyes *closed* and feet together, his/her instability will clearly worsen. This is because a loss of proprioception makes the patient much more reliant on the sense of sight to maintain balance, that is, the patient needs to look to know where his limbs are in order to maintain balance.

Differentiating cerebellar ataxia and sensory ataxia

Romberg's test (described earlier) does not directly test for cerebellar ataxia. However, it helps to *differentiate* cerebellar ataxia from sensory ataxia. In cerebellar ataxia, the patient is likely to be unsteady on his feet even with the eyes open.

Ageing and sensory ataxia

Proprioception gets worse with ageing, especially due to changes in the tendons. This can affect balance. As with other things, exercise helps, specifically exercises that practice balance. Examples of such exercises (from left to right in the pictures):





- Standing on one foot for 10 seconds. Do 10 repetitions, then switch to the other foot. (In the beginning, you might want to have a wall or a chair to hold.)
- Heel-toe walk: Take 20 steps while looking straight ahead. This can also be used as a field sobriety test (see earlier in this article).
- Exercising on a half-ball ('BOSU' ball – **BO**th **S**ides **U**p), which is hard and flat on one side but rounded on the other.
- Seated Balance Exercise (on a chair or a ball) – improves proprioception, balance and strength. For added difficulty, close your eyes. Can progress from sitting to standing, especially on one leg.

Personal experience with loss of proprioception

I notice that nowadays I lose my balance more easily when standing in moving vehicles. Recently, I stepped into a local train just as it, unexpectedly, started to move. I lost my balance and fell over, taking a couple of people with me! So, I will have to get a bosu ball!!

Video: Bosu (half-ball) balance trainer
http://fitnessista.com/2012/07/focus-on-bosu-balance-trainer/

Exercise
Again, act out some of the above symptoms and do some of the exercises for proprioception. This will help you understand and be more familiar with them. I am sure you will have no difficulty with stomping!

Damage to the posterior parietal cortex: Apraxia

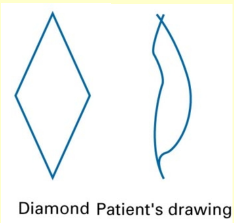
[From Greek: *apraxia* = inaction, from prefix *a-* (= not/no) + *praxis* = 'a doing, an action']

Apraxia is a poorly understood motor disorder caused by damage to the brain, especially the *posterior parietal cortex*, in which people have difficulty with or are unable to perform tasks or movements especially *when asked or when consciously wanting to do so*, even though their muscles are normal and they can often carry out the tasks or movements normally otherwise. Damage to the pre-motor areas and the frontal and temporal lobes may also result in apraxia. There are several different kinds of apraxia.

Note: Do not confuse apraxia with ataxia, the latter being a lack of *coordination* of movements that is *always* present.

Some examples
The pictures, from left to right relate to the five example described below.



- People can *explain* how to perform an action (so the temporal lobe, which stores the general procedure, must be OK), but are *unable* to act out or imagine a movement when *asked to do so* such as "pretend to brush your teeth" or "pick up the cup" (suggesting they may *not* be able to create a mental model of the action in the posterior parietal lobe). However, they *are* able to perform these actions without any problems in *normal* situations. (This is called *ideomotor apraxia*.)
- Impaired ability to complete multi-step actions. For example, a person may complete actions in an incorrect order, such as buttering bread before putting it in the toaster, putting on shoes before putting on socks, or lifting an (imaginary) cup to the mouth before reaching out to grasp it. (This is called *ideational/conceptual apraxia*)
- A loss of ability to plan and perform a previously learned task when given the necessary objects or tools (also *ideational/conceptual apraxia*). For instance, if given a screwdriver, the patient may try to write with it as if it were a pen, or try to comb his hair with a toothbrush – though I suspect that the girl in the picture above is doing this deliberately and not because she has apraxia.
- The inability to draw or drawing, copying or constructing diagrams of simple shapes or objects (*constructional apraxia*).

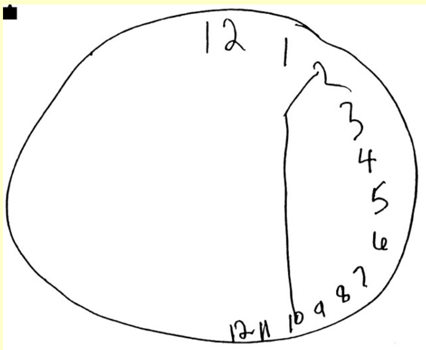
- Another kind of apraxia is *speech apraxia* in which people find it difficult or impossible to move their *mouth* and *tongue* to speak causing problems saying sounds, syllables, and words. This happens, even though the person has the desire to speak and the mouth and tongue muscles are physically able to form words. It is because the brain has problems *planning* the *movements* of the body parts needed for speech (e.g., lips, jaw, tongue).

Video

The picture (right) is of a clock face drawn by a person suffering from constructional apraxia. The links below are to videos showing a similar clock face drawn by two people, the first by a lady with apraxia caused by a stroke* in her parietal lobe:

https://www.youtube.com/watch?v=VdIC-x6UZg0

https://www.youtube.com/watch?v=CzrVWdlw6qM



*A **stroke** occurs when blood flow to an area of brain is cut off. When this happens, brain cells are deprived of oxygen and begin to die. When brain cells die during a stroke, abilities controlled by that area of the brain such as memory and muscle control are lost.

Exercises

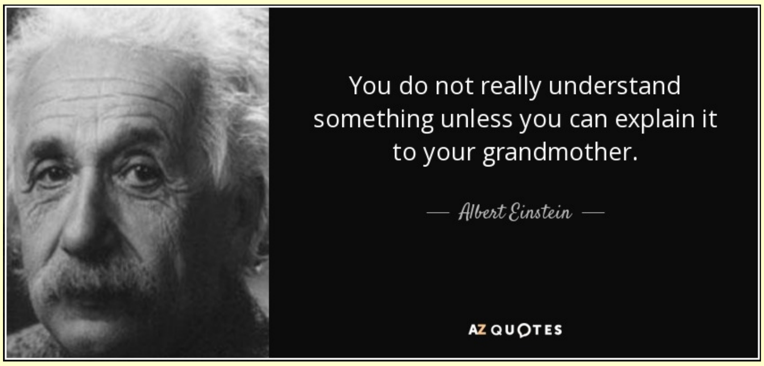
1. Again, do some of the above exercises. This will help you understand and be more familiar with them.
2. Try some of the tests with other people. Good examples would be (1) asking a person to demonstrate a movement such as “pretend to brush your teeth” (ideomotor apraxia), (2) draw shapes, such as those given above (constructional apraxia)

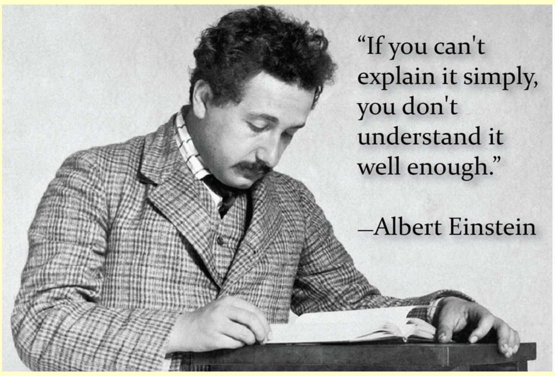
Damage to the motor cortex

If the motor cortex (any or all of **SMA**, **PMA**, **M1**) is damaged, for example, by a stroke (which can result in paralysis in this case), a person loses the ability to make precise movements, especially of the hands and fingers. However, the memory of motor sequences learned previously is largely spared (as these are stored in the temporal lobe and the cerebellum and not the motor cortex and these areas of the brain are unaffected), though these movements will be executed more clumsily. These observations provide further evidence that the *cerebellum rather than the motor cortex* plays a key role in learning and remembering of movements, also known (as we have noted earlier) as *procedural memory.*

Postscript

I often seem to involve Albert Einstein (1879 – 1955) in my projects. This project is no exception. I agree with the *sentiment* expressed in these quotes that are attributed to Einstein. As I have commented earlier, too many of the authors of the websites on the brain and movement that I looked up do not seem able to explain things very well. And being able to explain so that somebody else understands is the mark of a good teacher. However, in order to understand something yourself first often takes a lot of time, especially if the topic is one we are unfamiliar with, which is why it took me many *months* to write this project. I hope my efforts enhance *your* understanding.





References

No references are included here. Instead, they are given at the end of Level II as they apply to the material in both articles.