International
Teaching
Seminars

The Evolution of the Brain

VIDEO SERIES

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OVERVIEW

The brain is responsible for every thought, feeling and behaviour we have and so there is potentially great benefit in understanding this complex organ. As a result, neuroscience, the study of the brain, is one of the most rapidly expanding areas of current research. And the resulting information is proving to be useful – not just to scientists. Since each and every one of us has a brain, and most of us interact daily with a range of other people with brains, this increased understanding impacts on every area of our life. So it would be great if more people knew more things about the way in which brains drive behaviour.

You have taken the first step on this journey. So, welcome, and thank you for allowing us the opportunity to share our excitement about this fascinating topic. We invite you to watch the video tutorials as a way to introduce some basic information. We know that people are likely to be at different stages on this journey. So take as much time as you need to feel comfortable with the content of these tutorials.

There are 4 tutorials:

Part 1 covers the evolution of the human brain and the function of different parts of the brain.

Part 2 looks at the smallest unit within the brain, the neuron, what it does and how it does this, and what happens when lots of these units come together in a system.

Part 3 discusses the chemical signalling in the brain and introduces the main neurotransmitters that communicate between neurons.

Part 4 considers the mechanisms in the brain that allow our brains to develop and learn throughout our lifespan.

Enjoy!

VIDEO TUTORIAL 1 – THE EVOLUTION OF THE BRAIN

PARTS OF THE BRAIN IN BRIEF

EVOLUTION OF THE BRAIN

As animals adapted to different environments, their brains evolved to fulfil a number of different functions. It is therefore possible to understand the function of the human brain by considering the demands placed on animals at different points in evolution. The human brain has benefited from this evolutionary process – in addition to the adaptations that occurred as human behaviour grew progressively more complex.

This functional approach to the brain provides a simple framework which we hope will make it easier to understand and remember the different parts of the brain and their functions. It is unlikely that you would ever have to remember each part of the brain (though you might want to commit to memory the ones that are most important in your own line of work). We have, therefore provided a handy look up table that describes the function of each part of the brain at the end of this section. You can consult this if you come across mention of a part of the brain and can't remember what it does.

THE CENTRAL NERVOUS SYSTEM

The central nervous system consists of the spinal cord and the brain.

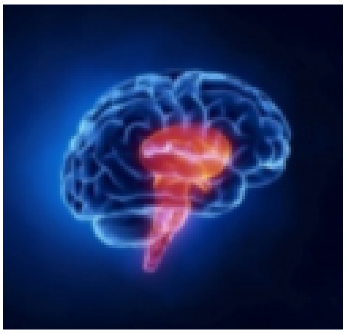
SPINAL CORD

The spinal cord communicates information from your body to your brain. It receives information from the both external (skin) and internal (muscles, internal organs, blood vessels) body and sends this to the brain. It then communicates information from the brain that allows your muscles to move creating action by sending these messages to your muscles.

Without the spinal cord, you would receive little information about the state of your internal organs, muscles and skin, and you could not send messages to your body asking it to move. Thus, the spinal cord plays an essential role in most behaviours. The function of the spinal cord can be checked through spinal reflexes. The most commonly known spinal reflex is the one that your doctor checks when she uses a small hammer to hit your leg just below the knee. If your spinal cord is working, this should cause your leg to kick.

THE BRAIN

The brain has evolved as three components: the hindbrain or brainstem, the mid brain and the forebrain.

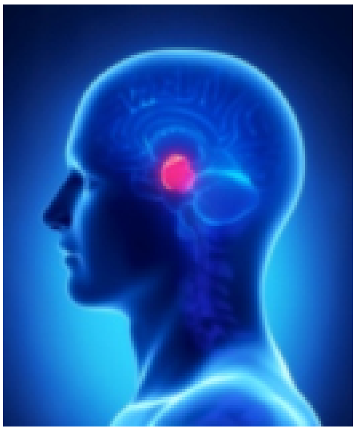


HINDBRAIN: THE BRAINSTEM

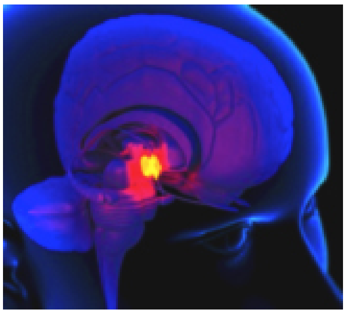
The brainstem sits above the spinal cord, and is made up from the pons, the cerebellum, reticular formation and the medulla. It is the most primitive part of the brain and therefore controls the most primitive functions that underlie survival, including:

- bodily activities essential to survival, such as changes in heartbeat and breathing (medulla)
- initiation of a set of reflexes such as swallowing, vomiting etc. (medulla)
- REM Sleep (pons)
- Motor learning (cerebellum)
- level of arousal (reticular formation)
- patterns of arousal including sleep and waking (reticular formation).

MIDBRAIN: THE TECTUM



The tectum is the major part of the midbrain, and is really important evolutionarily in the brains of birds. One thing that birds do very well is to navigate within their world and to keep track of where they are in relation to the outside world. This is the main function of the tectum – the inferior colliculus holds a map of auditory space locating sounds in relation to the head, and the superior colliculus does the same for the visual world providing information about the distance between, for instance our body and objects we can see in our visual environment. This helps us to navigate around our world without bumping into things and can be best demonstrated by considering how we manage to walk along busy streets without colliding with people.



FOREBRAIN

HYPOTHALAMUS AND PITUITARY

The hypothalamus and the pituitary gland are the control panel for the body's chemical factory. They coordinate our reaction to hunger, thirst and also our aggressive responses. The hypothalamus and pituitary release chemicals into our blood that are sensed by a range of organs including the kidneys (urinating), the thyroid (metabolism and growth), the testes and ovaries (reproduction) and the adrenal gland (stress).

Stress refers to the consequence of the failure of an organism to respond adequately to mental, emotional or physical demands, whether actual or imagined. This can trigger the fight or flight response. However, not all stress is bad. Where stress enhances function (physical or mental, such as through strength training or challenging work) it may be considered eustress. Persistent stress that is not resolved through coping or adaptation, deemed distress, may lead to anxiety or withdrawal (depression) behaviour. The difference between eustress or distress is determined by the disparity between an experience (real or imagined), personal expectations, and resources available to cope with the stress.

THALAMUS

The thalamus is responsible for the following functions:

- Motor control
- Receives auditory somatosensory and visual sensory signals
- Relays sensory signals to the cerebral cortex

The thalamus is considered the relay station for the brain, shuttling information between sensory neurons and the cerebral cortex. It thus seems especially well-suited to responding dynamically to our environment. We can choose to pay attention to goals e.g. sources of food or water. However, in addition, certain salient features will grab our attention, such as a tiger emerging from a field of tall grass. Both focussing on goals, and examining salient objects are automatic.

The thalamus can switch between these two forms of attention. Attention to goals in the environment (food when we are hungry or water when we are thirsty etc) is controlled by input to the thalamus from the frontal cortex. Attention to life threatening objects in the environment to which we must pay close attention, in contrast, is controlled by connections from the reticular activating system in the brainstem to the thalamus. In this way, the thalamus has control of how much attention we pay and what we pay attention to.

BASAL GANGLIA

The basal ganglia are a collection of neural cell bodies that lie around the thalamus. These have a variety of functions including action selection, habit formation, reward reinforcement and emotion.

Action Selection: Substantia Nigra and Pars Reticularis

Action selection takes place in the substantia nigra and pars reticularis. This can be seen in diseases of the basal ganglia including Parkinson's disease where it becomes difficult to start new actions, and Huntingdon's disease in which inappropriate actions cannot be prevented.

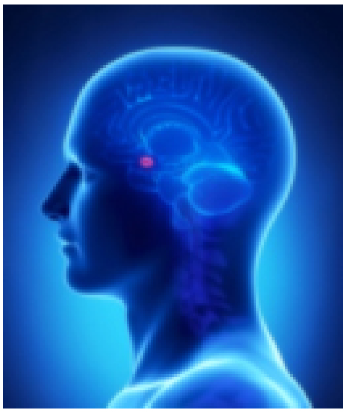
Habit Formation: Substantia Nigra and Pars Reticularis

The substantia nigra and pars reticularis of the basal ganglia also associate particular stimuli with sets of actions to form habits. For instance, if you see a ball coming quickly towards you, the instinct might be to duck. However, if you are a goal keeper, the instinct must change so that you dive towards the ball and catch it. Thus the basal ganglia have selected a new habitual response for this context.

Reward Reinforcement: Ventral Tegmental Area and Nucleus Accumbens

One reason the basal ganglia might associate a new response with a particular situation is if it is rewarding (team celebration when you save a goal). So the second function of the basal ganglia is to signal reward. This happens in the ventral tegmental area and the nucleus accumbens. The neurotransmitters in these areas are endorphins and dopamine – the reward chemicals so these areas make up our reward centres.

Emotion: Amygdala



The basal ganglia also contain the amygdalae (singular: amygdala). This part of the brain has a primary role in both processing of, and memory for, emotional reactions, and is considered part of the limbic system.

In humans, the amygdalae perform primary roles in the formation and storage of memories associated with emotional events. These emotional memories can trigger fear responses, including freezing (immobility), tachycardia (rapid heartbeat), increased respiration, and stress-hormone release. However, they can also trigger great joy, excitement, melancholy, compassion – indeed the full range of human emotional experience.

The amygdalae also are involved in memory consolidation. Following any learning event, the long-term memory for the event is not instantaneously formed. Rather, information regarding the event is slowly assimilated into long-term storage over time until it reaches a relatively permanent state, a process referred to as memory consolidation. It has been shown that emotional arousal following the learning event influences the strength of the subsequent memory for that event. Greater emotional arousal (positive or negative) following a learning event enhances a person's retention of that event.

HIPPOCAMPUS

The hippocampus (Latin for seahorse) is one of the oldest parts of the cerebral cortex, and is responsible for long term memory. People with damage to their hippocampus can remember things from their past (anything that happened before they lost their hippocampus) but they cannot hold anything new in memory for more than 2-3 seconds and so have lost the ability to make new long term memories. This tells us that the hippocampus is not the part of the brain in which we store memories (or nothing would be remembered after injury to this). Instead it has the function of moving memories from short to long term store – or memory consolidation. If you would like to see the effect that the loss of the ability to store long term memories has on the brain, go to YouTube and find clips about Clive Wearing. What do you notice about the things that he can do, and what he can no longer do?

Another important theory suggests that the hippocampus is important in remembering where we are. In 1971, O'Keefe and his student Dostrovsky discovered neurons in the rat hippocampus that appeared to show activity related to the rat's location within its environment. As with the memory theory, there is now almost universal agreement that the hippocampus plays an important role in spatial coding. Evidence for this comes from studies of London taxi drivers who have to develop "The Knowledge". Brain imaging has demonstrated that their hippocampi are larger than controls, and the longer they have been driving, the larger their hippocampi.

OCCIPITAL CORTEX

The occipital cortex lies at the back of the brain (as far from your eyes as possible) and is the part of the cerebral hemispheres that processes visual information. Vision is probably the most important sense that we have as humans. At least 50% of your brain has a visual function.

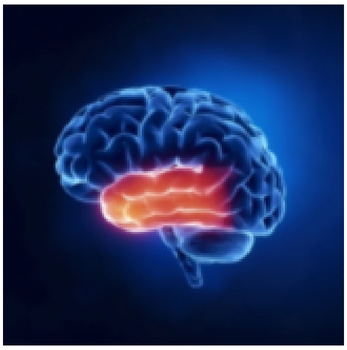
The brain processes patterns of light from the eyes by passing this signal sequentially through a number of areas each of which extract a different aspect of vision. Thus, different parts of the visual system perform a number of different functions including: detecting the edges of objects and using this information to work out the size and shape of an object, detecting the colour of objects, and detecting motion, and using this to determine if and when an object will collide with you. It is only when all of these individual elements of vision are perceived that you are able to identify the large, red bus that is moving towards you, and to determine whether you can get to the bus stop before it does.

PARIETAL CORTEX

The parietal cortex lies at the top of the head in front of and above the occipital cortex. It integrates information from different senses, and is particularly involved in determining spatial sense and navigation. For example, it contains both the somatosensory cortex (part of the brain that responds to touch and position of muscles) and the part of the visual system responsible for detecting where objects are in space in order to act on them. This enables regions of the parietal cortex to map objects perceived visually into body coordinate positions. This is what allows you to pick up a very full glass of beer without spilling it.

The parietal lobe is also the part of our brain that is involved in our understanding of numbers and their relations (mathematical relations). Processing in the parietal cortex allows us to look at a small number of objects (up to 4 or 5) and immediately know how many objects there are without counting them. It is also important for integrating information across senses. You can tell that the visual and auditory parts of a movie are out of synch because of the parietal cortex. It also helps us to communicate better in noisy environments since the added information you gain from lip reading when you are listening to someone talking in a noisy room allows you to understand what they are saying even when you can't hear every word.

TEMPORAL CORTEX



The temporal cortex lies just above the ears. It is important in hearing: not only in low-level perception of sounds but also in comprehension, naming, verbal memory and other language functions. Thus, it is very important in the development of language ability in humans.

The medial temporal lobes are involved in episodic/declarative memory. Deep inside the medial temporal lobes lie the hippocampi, which are essential for memory function - particularly the transference from short to long term memory and control of spatial memory and behaviour. This function is controlled by both the hippocampi and the temporal lobes. Damage to this area typically results in an inability to remember new events.

The temporal lobes also play a role in high-level visual processing of complex stimuli such as faces and scenes and in other visual processing including object perception and recognition. Thus, when this part of the brain is damaged, people can describe objects, but cannot say what they are. One patient with damage to his temporal lobe described a rose as: "About six inches in length... A convoluted form with a linear green attachment... It lacks the symmetry of the Platonic solids, although it may have a higher symmetry of its own". However, though he could provide a very detailed description of the object, he could not name it.

FRONTAL CORTEX

The frontal cortex is responsible for a wide range of functions including controlling motor responses, working memory, planning, inhibition and decision making. This part of the brain shows the greatest expansion in evolution and controls many of the behaviours that we consider our most human. Since it is one of the most important areas of the human brain, we will describe the function of more than one area.

At the back of the frontal cortex is the primary motor area which controls the co-ordinated movements of our muscles. This is also where we find a part of the brain that responds both when we produce a movement and when we watch someone else produce the same movement (mirror neurones). It is thought that this part of the frontal cortex is important in our ability to imitate others – a major mechanism for learning in primates and humans.

Dorsolateral Prefrontal Cortex

The dorsolateral prefrontal cortex (dlPFC) is involved in long term memory. To give an example, when you need to learn that two events are associated with each other, individuals might compare or contrast these items. This process enhances the capacity of individuals to remember the association between these items. The right dlPFC is especially likely to be involved in the memory of information that is personally meaningful. When this area is anaesthetized, for example, individuals cannot readily identify a picture of their own face.

The dlPFC is involved in inhibiting previously rewarded responses. When we are solving crossword puzzles, or trying to create something new, the dlPFC is required to inhibit old solutions that are no longer useful. We use this ability when thinking about risky and moral decisions: will we or won't we take the risk and therefore do we need to inhibit an action or not. This region is especially active when the costs and benefits, rather than emotional reactions, of alternatives are considered suggesting that the dlPFC primarily underpins cognitive rather than emotional processes.

Ventromedial Prefrontal Cortex

Another important part of the frontal cortex is the Ventromedial Prefrontal Cortex (vmPFC). While the dorsolateral prefrontal cortex is responsible for rational decision making, the vmPFC is more involved in emotional decision making. Part of the vmPFC is highly active during guessing tasks. In one study, when people had their brain imaged while performing a task, an increase in uncertainty in their decisions was associated with increased activity in vmPFC.

The vmPFC on the right of the brain is associated with the production of empathic responses, and is activated when people feel unfairly treated. Hedonic (pleasure) responses also activate vmPFC. Thus this area has been associated with preference judgement, and plays a key role in constructing one's self identity.

One particularly notable theory of vmPFC function is the somatic marker hypothesis. This suggests that this area of the brain has a central role in coding associations between events and visceral (bodily) feedback - for use in natural decision making. Thus, the vmPFC is where our gut feelings that we are right or wrong about a decision are constructed.

Divisions	Major Division	Major Components	Major Sub-Divisions	Function
Forebrain	Cortical	Cerebral Cortex	Occipital Lobe	Vision
			Parietal Lobe	Spatial Awareness
			Temporal Lobe	Hearing and Memory
			Frontal Lobe	Executive Functions
		Hippocampus	Associated with Temporal Lobe	Long-Term memory
	Sub-Cortical	Basal Ganglia	SubstantiaNigra and Pars Reticulata	Initiation and control of Movement
			Striatum, Amygdala	Perception and Regulation of Emotion
			Ventral Tegmental Area and Nucleus Accumbens	Motivation and Reward
		Thalamus	Lateral Geniculate Nucleus	Vision
			Medial Geniculate Nucleus	Hearing
			Ventral Posterior Nucleus	Movement
		Hypothalamus and Pituitary		Hormone Control and Production
Midbrain		Tectum	Superior Colliculus	Visual map of the world
			Inferior Colliculus	Auditory map of the world
Hindbrain		Pons		Sleep Body Functions Sensation and Posture
		Cerebellum		Movement Control Motor Learning
		Medulla		Breathing Heart Rate Blood Pressure
Spinal Cord			Dorsal Horn	Sensation (touch, pain, pressure etc)
			Ventral Horn	Movement

VIDEO TUTORIAL 2 – SYSTEMS IN THE BRAIN

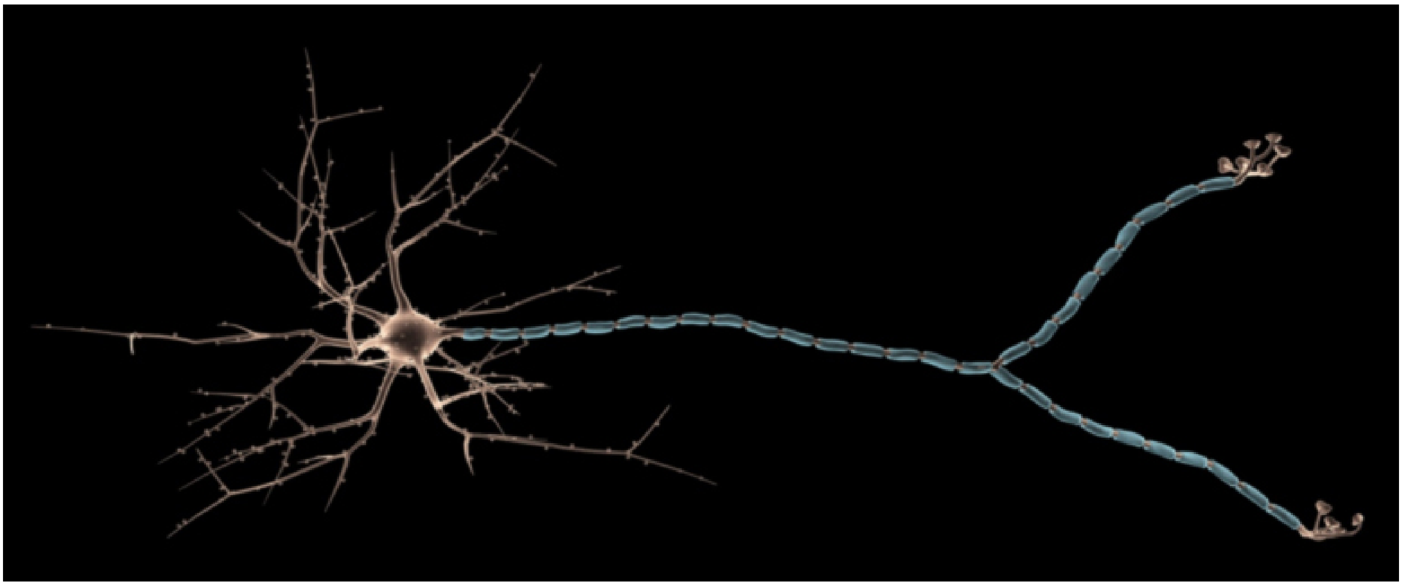
INTRODUCTION

In the first tutorial, we considered the parts of the brain, and their different functions from an evolutionary perspective. But our brain is much more than the sum of its parts, and so this tutorial considers how different parts of the brain act together to create complex behaviours.

We will approach this from two directions: First, we will examine the smallest unit of behaviour in the brain – the neurone. We will look both at the form and function of the neurone to understand why it is best suited to the role it plays within the brain.

We will then consider the brain as a system – how do the collections of neurones that form different brain areas connect up in a system. How does changing the activity within the system, or the parts of the brain that form the system, affect our behaviour?

By building up a picture of the brain from the simplest to the most complex component, we will find out how something that starts from simple components can create a sophisticated organ that is capable of multiple complex behaviours.

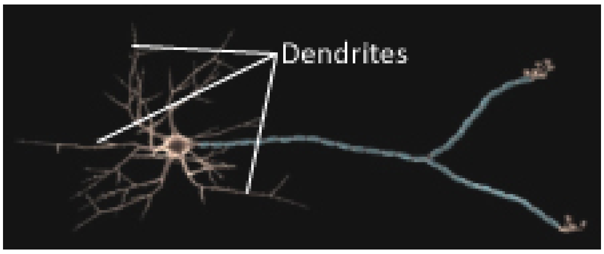


FUNCTION OF THE NEURON

The neurone is the basic building block of the brain so it is useful to know what it does and how it does this. The simple function of a neurone is to take a signal from one point and to communicate it to another point. In the process, it is able to integrate lots of different signals and to interpret their patterns in both space and time. By interpreting the pattern of activity, the brain can determine behaviours that are suited to a particular place, time and context. This decision making will incorporate both information in real time (what is happening in the moment), our past experiences of similar situations and our predictions about what might happen in the future.

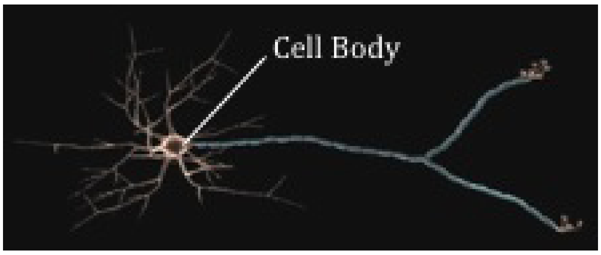
So how does a neurone work? Neurones communicate information in a single direction.

DENDRITES:



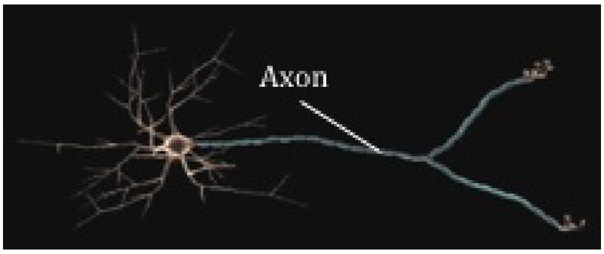
At the input end of the neurone, information comes in from sensory receptors (vision, hearing, touch, smell, taste etc.) or from other neurones (past experiences, future predictions). The parts of the neurone that take in information are called dendrites – these form a tree like structure at one end of the neurone. Information from different sources can be integrated within the dendrites since this structure can connect with neurones from a large number of places in the brain (or a single place depending on the type of neurone). When a neighbouring neurone is active, there is a small change in the electrical charge within the receiving neurone. One such small change in the electrical charge of a neurone is not sufficient to activate the neurone – many hundreds of these changes need to happen together (i.e. one neurone firing many times in quick succession or many neighbouring neurones firing together once or twice). When this occurs, the receiving neurone sums up all of the electrical changes, and this results in the firing of an action potential. The action potential is the basic form of electrical communication within a neurone – it creates an electrical signal that starts at one end of the neurone and travels down to the other end. Thus, the dendrites integrate information from different sources and create small changes in electrical activity within the neurone which come together to create sufficient electrical activity for an action potential to fire.

CELL BODY:



The second part of the neurone is the cell body and it has two functions. The first is to add up all of the small changes in electrical activity within each of the dendrites that surround it and to fire off an action potential if there is sufficient change in electrical response. The second is as a store house and energy creation factory for the neurone. The nucleus of the cell body contains tiny pieces of machinery that create the energy and neurochemicals that are required by the neurone.

AXON:



Neurones send information from one place to another through a wire like process called the axon. Axons can be of any length depending on the function that the neurone fulfils – a neurone that takes information from the foot to the spinal cord will be long, while a neurone that communicates from one part of the brain to another can be millimetres in length. Thus the shape of the neurone is related to its function.

The signal that is communicated along the axon is the action potential. Since this is an electrical signal, communication is more efficient if the axon is insulated – just as electrical signals pass more efficiently down insulated cables. Insulation for axons comes from a fatty coating called the myelin sheath. The myelin sheath wraps around the axon in sections with spaces in between.

The spaces between the myelin sheath are called the nodes of Ranvier and it is these that allow action potentials to be transmitted more efficiently and more quickly. The action potential can jump from node to node between the myelin sheaths very efficiently. When the brain is first formed and during childhood, many of the neurones in the brain do not have a myelin sheath. These develop over time as the brain develops. Increased myelination increases the efficiency of neurones and so part of the increase in skill and ability that we see across development is the result of increasing myelination. Myelin is also lost in some diseases. People with Multiple Sclerosis have a loss of myelin which decreases the efficiency of their brains, and is partly responsible for the degeneration found in this disease.

SYNAPSES:

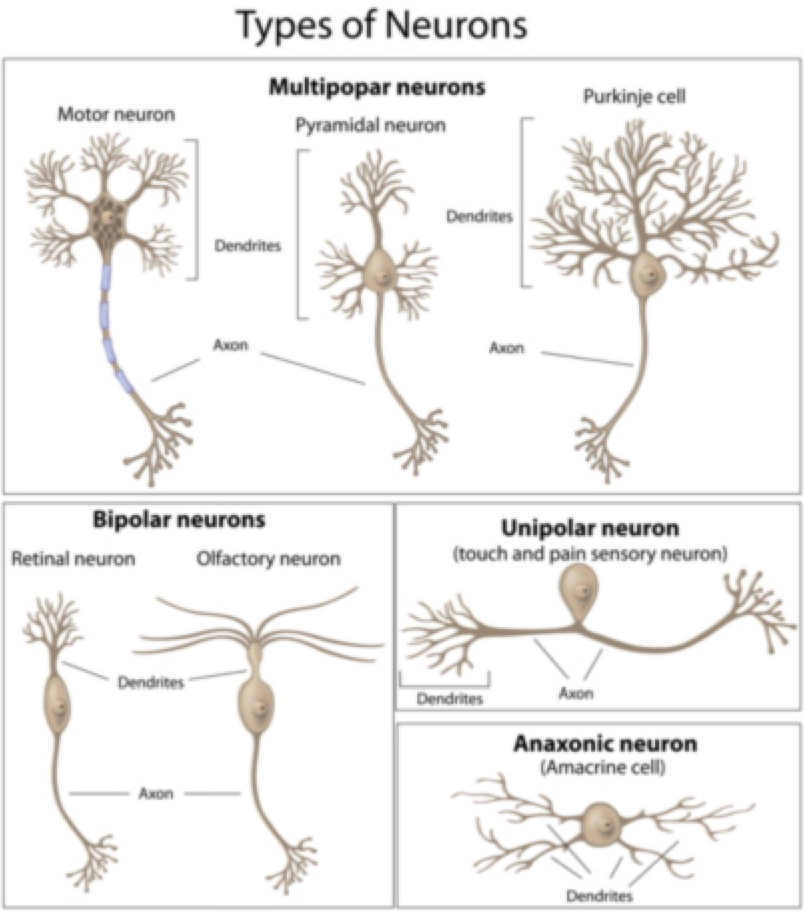
At the far end of the axon are another set of branches which contain the synaptic terminals. Neurochemicals – the chemical messengers of the neurone – are released from these, and are taken up by the next neurone in the chain, creating the small changes in electrical activity that start off the electrical communication in the next neurone in the complex chain. The gap between the synaptic terminals on one neurone and the dendrites on the next neurone is called the synapse or the synaptic gap. This is where chemical signals pass between neurones.

ELECTRICAL AND CHEMICAL SIGNALLING IN THE BRAIN

The benefit of the electrical connection is that we can communicate information very quickly and efficiently. Chemical transmission slows communication within the nervous system. But the real benefit of the chemical transmission is that it can change the level of activity in the next neurone in the chain – thus it can either increase the number of action potentials in the next neurone, or it can decrease the number of action potentials. This provides a means of either filtering out information that is unimportant – imagine if you actually felt every touch of your clothes on your skin. It also provides the brain with a means to increase the weight of more important information – your brain will be more highly active in threatening situations. Thus, while electrical activity in the form of an action potential is either on or off, the chemical communication system in the brain converts this into a graded signal which can be turned up or down.

The other feature of the chemical transmission between the neurones is that the number of connections can be changed as required. This allows us flexibility in the patterns of connection between neurones in the brain. Thus, infants might have a very strong connection between visual neurones representing mother and neurones representing sources of food. Later in life, these connections are less important, and so can be changed to be more appropriate for your lifestyle. This ability to change the connections between neurones in the brain forms the basis for learning and memory making these incredibly important for the function of the brain. We will discuss this in more detail in Tutorial 3 where we consider the neurotransmitters and in Tutorial 4 when we consider how the brain changes.

Neurones come in many shapes and sizes – and this is because the shape of the neurone suits its function. So the axon of a neurone can range from metres to millimetres long. There are a whole range of shapes and sizes of neurone some of which are illustrated here. They can have very dense dendritic branching or only one dendritic branch, they can have many synapses or only one, and they can have long or short axons. But, the shape of each neurone fits its function.



Within the central nervous system, groups of neurones in different parts of the brain have been shown to have different functions. The brain can therefore be seen as a collection of groups of neurones or modules with all of their cell bodies in one place – the gray matter of the brain. Axons from different modules connect up to allow communication between these – and since axons are covered in white fatty myelin sheaths, this forms the white matter of the brain.

Classically, when we consider the function of the brain, we think about different modules being active for particular functions. Thus, if we were to image the brain using, for instance, functional Magnetic Resonance Imaging (fMRI), we would be looking for the areas that are active during a particular behaviour, but not active for a different behaviour – for instance what areas of the brain allow us to communicate through speech. Here, we could determine the activity in the brain when we listen to speech compared to when we listen to other non-speech sounds. This would allow us to identify the areas of the brain that interpret a particular set of sounds as speech. We would not be interested in other areas of the brain that are active for both speech and non-speech sounds, for instance parts of the auditory system, since these contribute less to our ability to communicate with other human beings.

This kind of approach has led to the idea that each part of the brain has a different function, and in the first tutorial we looked at some of the known functions of each part of the brain. So, when we listen to someone speaking, and understand their meaning, we will have activity in Wernike's area on the left hand side of the brain at the junction between the temporal and parietal lobe since this area is responsible for understanding speech. In comparison, if we were to speak in reply to that person, we would find activity in Broca's area which is in the left frontal cortex since this part of the brain is responsible for expression of speech. Each of these is therefore a module within the brain with a known function and this kind of labelling of areas of the brain has led to what I think of as an advanced phrenology. The phrenologists in the Victorian era used the shape of the skull and where people had bumps or indents in their skulls to indicate areas of strength or weakness in their personalities – an idea which has been debunked by our more advanced imaging techniques. Despite this, our approach to the brain has been similar – though we are now making our measurements of areas of strength and weakness from the inside of the head rather than the outside. Still, we are considering the brain as a series of modules each with a different function. One of the biggest changes in recent neuroscience is a move away from thinking about the brain as purely modular, and to start thinking of the brain as a system.

SYSTEMS IN THE BRAIN

By treating the brain as a series of modules, our metaphor of connections in the brain can be compared to a telephone operator at an exchange connecting up two people who want to speak on the phone. This is rather out-dated, and a better and more modern analogy might be to think of the brain like a smart phone which has lots of applications (apps). Each app has a different function – it might be playing music, finding directions to a new location, or a game. And each will involve different instruction sets. However, the apps will also be dependent on some common functions of the phone – for instance the speaker system to play sounds, the screen to show images, or the GPS system to determine movement and location. Thus, the different functions of the phone depend on some common central resources that are enlisted as required. And this can also be used to describe the systems in your brain. There are some core activities such as moving your muscles, seeing, speaking, listening or knowing where you are in space. These functions are recruited in different patterns to create different behaviours. Thus, any complex behaviour will depend on activity in a number of different (core) modules to create that behaviour.

We can use an example to illustrate this: Imagine that you can see a fully grown, male lion rushing towards you. He is roaring loudly, so that you can see every sharp tooth in his head – and you can't help but notice that those teeth are very large and very sharp. Your heart starts pounding, you can feel the blood rush from your stomach to your muscles, and your brain is signalling for you to run away fast and far. Many parts of your brain will be highly activated by this event.

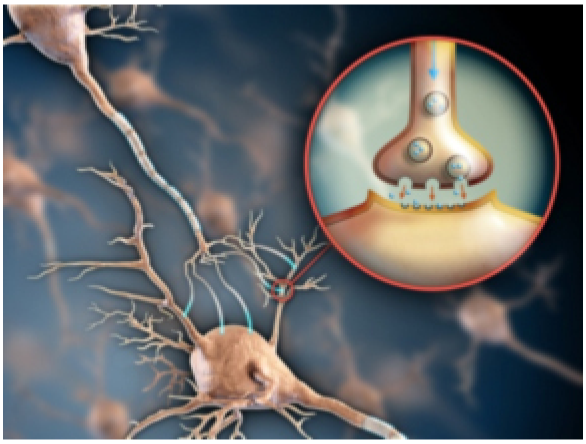
However, while some part of your brain is signalling that you should run, unconsciously, you are also aware of the large moat between you and the lion, and the wall that he would have to jump to get to you. So, another part of your brain is signalling that you are safe and that there is no need to run. The same parts of your brain are active, but your response might now be to turn to your friend with whom you are visiting the zoo and say 'That gave me such a fright – I really wanted to run away!' By recruiting additional modules in your brain into the active system, the response has changed. Even without being conscious of the process, we are constantly reviewing our response to events and assessing potential threat. This requires a combination of responses from the visual, action, emotional and decision making parts of the brain at both the subcortical and cortical level. And from this, we can see that we are always using a lot more than 10 or 20% of our brains.

We can also examine the myth that there are left brain people and right brain people. For any of the behaviours I have described, both sides of the brain will be active. So while you might activate parts of the brain located on one side for a particular behaviour – for instance the left hand side of your brain for speech, or the right hand side of the brain for processing faces – any behaviour will also activate parts of the brain on the other side too. Your brain is a complex system.

There is a major benefit to having a brain that is able to combine modules into different systems to accomplish different behaviours and that is that there is more than one way to achieve a particular behaviour. This means we can do things in different ways depending, for instance, on our level of expertise, our age, or even whether parts of our brain have been damaged.

VIDEO TUTORIAL 3 – CHEMICAL SIGNALLING IN THE BRAIN

Neurones use both electrical and chemical communication systems. They communicate electrically by sending action potentials from one end of the neurone to the other and chemically in a way that allows a single neurone to turn up or down the activity in the next neurones in the chain. We will now return to chemical transmission and talk more about how this happens, and the different chemicals or neurotransmitters involved.



Chemical transmission takes place at the synapse which is the name for the gap between two neurones. The neurone before the gap is called the pre-synaptic neurone and the neurone after the gap is called the post-synaptic neurone. Chemical transmission is activated when an action potential travels down the axon of the pre-synaptic neurone and reaches the synaptic branches at the end of the neurone. Neurotransmitters are stored within bubbles (vesicles) at the end of the synaptic branches and it is these neurotransmitters that will be used to activate neighbouring neurones. The vesicles release neurotransmitter into the gap between the two neurones (the synapse or synaptic gap) in response to a change in electrical activity. Neurones are often specified by the single kind of neurotransmitter they release – thus dopaminergic neurones release dopamine – the reward chemical, and adrenergic neurones release noradrenaline –a chemical associated with our response to stress. The effects of specific neurotransmitters will be covered in more detail later in this tutorial.

The way a neurotransmitter works can be compared to a key that opens a specific lock. Each neurotransmitter opens a specific set of gates on the post-synaptic dendrites with which it makes contact. Thus, pre-synaptic neurones that release dopamine will connect up with a set of post-synaptic neurones that contain a lock for which dopamine is the key. When these gates are opened, there is a small change in the electrical charge of the post-synaptic neurone and it is the ability of the post-synaptic neurone to integrate a number of these small changes in electrical charge that results in action potentials firing in the post-synaptic neurone. An excitatory neurotransmitter causes an increase in the number of action potentials in the post-synaptic neurone, while an inhibitory neurotransmitter will cause a decrease in the number of action potentials. A combination of excitatory and inhibitory synapses on a post-synaptic neurone can therefore both turn the neuronal activity level down or off (inhibition) or turn it up (excitation) in a graded manner.

Some medicinal and recreational drugs act by interfering with the lock and key mechanism at particular synapses. A drug that has the same effect as a particular neurotransmitter is an agonist for that neurotransmitter, whilst a drug that blocks the action of a neurotransmitter is called an antagonist. For example, drugs of addiction including heroin, opium and cocaine are agonists for opioid neurotransmitters present in the reward system. Addiction involves over-activation of the reward system often through stimulation of the system by drugs. If drug taking is repeated, it activates a homeostatic mechanism in the brain that turns down the effectiveness of the drug over time. This process is called down-regulation and it results in the need to take more drug to create the same effect.

In Tutorial 2, we talked about the brain as a system. Each of our complex behaviours results from co-ordinated activity in different combinations of modules within the brain. The ability of neurotransmitters to grade neuronal activity by combining inhibition and excitation adds to the complexity of the system. However, despite the vast number of behaviours of which we are capable, there are only six major neurotransmitters in the brain with each neurotransmitter used repeatedly across many different modules. For example, you may have heard of dopamine as the neurotransmitter related to reward associated with pleasurable experiences. However, this is also the neurotransmitter that is used in the frontal cortex for many of the executive functions of the brain including working memory, planning and decision making, and it is also an important neurotransmitter in the retina of the eye. Similarly, other of the major neurotransmitters will be active within many different parts of the brain and therefore involved in many different behaviours.

A particular behaviour can also be driven by more than one neurotransmitter. Sleep and wakefulness are controlled by a combination of serotonergic, acetylcholinergic and adrenergic neurones. The combination of these neurotransmitters regulates our level of wakefulness both subconsciously through the natural rhythms of day and night and more consciously when we have to stay awake even when we feel tired for instance when driving.

The following table provides information on each of the 6 major neurotransmitters:

NEUROTRANSMITTERS

Neurotransmitter	Function	Example of Disorder
Acetylcholine	The first neurotransmitter to be identified, it is an excitatory neurotransmitter that is widely distributed in the brain. Acetylcholine is found at the junction between neurones and muscles and so it causes muscles to contract. It also stimulates the excretion of certain hormones which makes it important in regulation of body functions including wakefulness, attentiveness, anger, aggression, sexuality, and thirst.	Alzheimer's disease is associated with a lack of acetylcholine in certain regions of the brain.
Dopamine	Dopamine is involved in controlling movement and posture, modulating mood and plays a central role in reward and addiction. Dopamine is an inhibitory neurotransmitter, thus it results in a decrease in the activity of the neurones with which it connects. The inhibition of one set of neurones however, can decrease the inhibitory effect that these neurones have had on the next neurones in the chain – so, two negatives – inhibition of an inhibition – make a positive and cause an increase in activity in the whole system. Dopamine is also a major neurotransmitter in the frontal cortex where it helps to control executive functions, and in the retina of the eye where it is involved in vision.	The loss of dopamine in certain parts of the brain causes the muscle rigidity typical of Parkinson's disease. Parkinson's patients also complain of loss of emotional range.
Serotonin (5 hydroxy-tryptamine or 5-HT)	This contributes to various functions, such as regulating body temperature, sleep, arousal, mood, appetite, and pain. The common drug for depression – Prozac –increases the level of serotonin in our system and thus decrease feelings of depression. Serotonin also affects our response to stress as adults during development. When mother rats groom their pups, serotonin is released. This would be the equivalent of mothers cuddling their babies. The release of serotonin in the infant brain decreases the activity in the system that responds to stress, and this decrease is retained across the lifespan. Thus, a lack of maternal warmth and therefore early release of serotonin, can lead to an increased response to stress throughout life.	Depression, suicide, impulsive behaviour, and aggressiveness all appear to involve certain imbalances in serotonin.

Neurotransmitter	Function	Example of Disorder
GABA (gamma-aminobutyric acid)	This is the most common inhibitory neurotransmitter in the brain thus it decreases activity in the neurones to which it connects. GABA contributes to motor control, vision, and many other cortical functions.	Some drugs that increase the level of GABA in the brain are used to treat epilepsy and to calm the trembling of people suffering from Huntington's disease.
Glutamate	This is the most important excitatory neurotransmitter and is released by half of the neurones in the brain. Glutamate release causes a large increase in the activity of the post-synaptic neurones. A well known maxim of neuroscience is that neurones that fire together wire together. Thus when two neurones are highly active at the same time, the connections between them are strengthened to make it easier for them to fire together in the future. This increase in strength is the result of glutamate release. It is also possible to decrease the strength of connections if neurones stop firing together which provides the flexibility to unlearn old behaviours that no longer serve us. Since our memories are stored as connections between neurones in the brain, loss of glutamate neurones is associated with Alzheimer's disease.	Glutamate is thought to be associated with Alzheimer's disease, whose first symptoms include memory malfunctions.
Noradrenline (or norepinephrine)	This neurotransmitter is involved in attentiveness, emotions, sleeping, dreaming, and learning. Noradrenaline is also released as a hormone into the blood, where it causes blood vessels to contract increasing blood pressure and causing heart rate to increase. We recognise these changes as symptoms of stress and so can feel anxious or threatened when this happens especially when we cannot identify the cause. For example, increases in heart rate while we are in the gym are not associated with stress, while increases in heart rate just before we have to take an exam do make us feel stress and can cause our performance to drop if we begin to feel too anxious.	Norepinephrine plays a role in mood disorders such as manic depression.

VIDEO TUTORIAL 4 – OUR LEARNING BRAIN

Why does it matter that we have billions of neurones, and what determines the way that our brains connect?

Throughout evolutionary history, changes in the structure of the brain have resulted from mutations that have led to successful adaptations to new environments. Much of this change occurred in primates and as humans first evolved and so much of the structure of our brain was specifically adapted to life on the savannah. We will come across many examples of this throughout the Certificate programme. Beyond this, however, our brains have continued to evolve with many later adaptations resulting from the re-use of successful neural mechanisms. Many later adaptations to our brain provide the social skills that allow us to live societies and so, for example, we have become exquisitely good at using visual cues to recognise other members of our species as a result of adaptation to part of the brain in the temporal cortex called the fusiform face area. This visual ability was adapted in even more recent evolutionary history so that a part of the brain adjacent to the fusiform face area is used to recognise the words on a page – the visual word form area. Your ability to distinguish faces has evolved to allow you to tell the difference between words with similar spelling (e.g. trial and trail or brain and brian).

One of the most successful, and therefore highly conserved, processes in the brain is the structure of the synapse. This structure provides a framework for the most important aspects of our human existence – the ability to learn and to create new ideas. Consider that, in order to be able to learn new ideas quickly and efficiently, we need a mechanism of change in the brain that functions quickly. Every time you take in a new piece of information (even temporarily), something needs to change in your brain in order for that piece of information to be stored. And, the structure that provides the ability to change with the required speed and durability – is the synapse. We know that neurones in the brain connect with thousands of other neurones and it would be easy to believe that once a synapse is created it is stable – so long as the connection between the two neurones is used sufficiently. However, this is not quite the case. A better way to think about synapses is that they are like skin cells – they are constantly replaced over time. So the number and strength of a connection between two neurones remains relatively constant since the number of synapses remains constant, however, the actual synapses creating this connection will change regularly. Indeed, we create, and lose, new synapses constantly and it has been estimated that 20% of the synapses between two neurones can be replaced in a 24 hour period.

Creating and destroying synapses is an energy consuming process and so there must be some strong evolutionary advantage to this. This process provides a huge capacity for change – and thus it gives the brain its plasticity. If the brain made synapses but did not unmake them, then we would code information whether it was wrong or right, and we would have no means to undo learning which is no longer useful to us. By constantly changing the synapses, information that repeats or is marked as important is coded in memory while information that is no longer useful is deleted. This confers a fundamental evolutionary benefit since it provides us with a means of learning in new environments.

An example here might help. Imagine that, as a child (or an unsuspecting tourist) you were told that the haggis is an animal that roams the mountains of Scotland. You might even have been told that it has shorter legs on one side of the body than the other so that it is less likely to roll off the mountain. This information will have been coded in your memory. However, at some point in time, you will have realised that this is just not true – and so the information will need to be unlearned. You might still remember having been told this, but, crucially, you will also remember that it was a joke.

An analogy for the plasticity of the brain is that we create different kinds of pathways through our brain as we learn new behaviours. If something happens just once, and there is no reward for the behaviour, the connections in the brain will be like the track of a small animal through a forest. It is there, but hard to follow and it can be easily replaced with a new path. If the behaviour is repeated, or is more important, it might resemble a footpath laid with paving stones. Again, this is not a permanent structure, but it is harder to replace. The most important behaviours, however, will have connections that are like six-lane motorways.   These behaviours will be habitual and therefore the most difficult to change.

It used to be dogma that the only new elements that were created in the brain were synapses and that humans were born with all of the neurones that they would ever have. However, now it has been proven that new neurones are created in some parts of the human brain. One part of the brain that creates new neurones is the hippocampus – the area of the brain that codes the addresses of your long term memories. We also now know that there are contexts in which we make more neurones than average, and contexts in which we make fewer. We make fewer new neurones when we are depressed or anxious and we create more new neurones when we exercise. The level of plasticity also changes with age: Our brains create more new synapses and neurones when we are very young than when we are older. But, while memory and other functions related to plasticity can deteriorate with age, synapses that are continually used are constantly strengthened and so your memory is less likely to fade with age if you continually use the information stored within it.

It is important to have more plastic brains when we are younger since human infants come into the world with very few hard wired skills. Young mammals like foals or calves are immediately able to stand up and walk – if a little unsteadily to begin with. In comparison, human babies are pretty helpless. This is an advantage since it means that we can wire up our brains to best suit an individual environment. It also means that children that are well fed and cared for, and who are exposed to lots of new experiences, will develop brains with many more connections than children who have more impoverished environments. Our brains adapt to our circumstances in both positive and negative ways.

So why do we not retain all of this plasticity throughout our lives? We do retain some plasticity, since the ability to create new synapses and new neurones is lifelong. However, there are advantages in not doing this as well as when we were children. We keep much of the learning that we have created during our lives in synaptic connections and so, as our brain fills with more and more information, it becomes progressively more difficult to create completely new connections. However, as a result of the increase in information stored, older adults are much better than younger adults at integrating information from a range of sources and therefore are better able to see the bigger picture and to plan for events. Thus, while we lose a little of our memory – if we don't use it – we gain wisdom from the connections that we have made in our brains and an increasing flexibility in putting together information from a range of different sources. Plasticity and the information stored in our brains is the very basis of our very human ability to be creative and to change our environments in ways that protect us and provide us with new solutions to problems.

CONCLUSION

In these four tutorials I have covered the major parts of the brain from an evolutionary perspective which has allowed us to consider its function. I have described the basic building block of our brains – the neurone – and have shown why it is such a versatile and ideal form for its function. We have considered how the brain works as a system and how this provides greater flexibility in our behavioural repertoire. We have considered the synapse and the neurochemicals that allow us to communicate between neurones, and finally, we have considered why this particular structure allowed us to become one of the most innovative and creative species on the planet.

And that is your amazing brain...!

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