The Brain Under Construction [1]: a window into the developing brain

This briefing paper is **part of a series** produced by Mentor-ADEPIS to support the delivery of effective alcohol and drug education and prevention in schools and other settings.

About Mentor

Mentor promotes best practice around building young people's resilience to prevent alcohol and drug misuse.

About ADEPIS

The Alcohol and Drug Education and Prevention Information Service (ADEPIS) is a platform for sharing information and resources aimed at schools and other professionals working in drug and alcohol prevention. In 2017, ADEPIS was recognised by UNESCO, UNODC and WHO as a 'prime example' of best practice in alcohol and drug education.

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This briefing paper is part of a mini-series on 'The Brain Under Construction'. This paper looks at the structure and function of the brain and considers the uniqueness of the adolescent brain. Pictures of the brain in action show that adolescent's brains work differently than adults and scientific research is showing that the brain systems involved in decision-making, planning, social understanding and risk-taking are developing in adolescence. This research could have implications for education, rehabilitation and intervention.

This briefing paper is for:

- Teachers
- Practitioners
- Others who wish to understand more about a young person's developing brain

Introduction

"The human brain, then, is the most complicated organisation of matter that we know" – Isaac Asimov

Although we now know that the brain controls all the mental and physical functions of the body, it was not always held in high regard. The Greek philosopher Aristotle thought the heart, not the brain, was the location of intelligence. The ancient Egyptians also did not think much of the brain. In fact, when creating a mummy, the Egyptians scooped out the brain through the nostrils and threw it away. However, the heart and other internal organs were removed carefully and preserved.

While the brain is a remarkably complex, still poorly understood organ, over the past 25 years neuroscientists have discovered a great deal about its architecture and function. Their discoveries have led to huge strides in medicine, from pinpointing the timing at which children should be operated on for vision problems to shedding light on the mechanisms that cause such diseases as schizophrenia. Researchers have also found that in certain situations, the brain can repair and rebuild itself following trauma or brain damage from an injury.

A work in progress

Recent evidence argues that changes continue to occur in the brain over the whole life span.[1] Until recently, it was generally believed that most of the brain's development is finished by the age of 10. Learning languages becomes much harder after this age; however, with the advancement of Magnetic Resonance Imaging (MRI) and other techniques, researchers have found that during early pregnancy, brain cells develop at an amazing 250,000 per minute, and a newborn's brain will triple in size in the first year alone.

Although the brain is 90% of its adult size by the age of seven, there are drastic changes in the structure of the brain that appear until relatively late in child development and into early adulthood – different parts of the brain mature at different times.[2]

The moodiness, risk-taking, rule-breaking, and general turbulence of the adolescent years were long assumed to stem from the hormone changes of puberty. We now know that, although hormones certainly do contribute to the roller-coaster ride of adolescence, hormone changes are just part of the puzzle. It has become clear that, during the adolescent years, the organisation and functioning of the brain go through complex changes. Importantly, these changes seem to be unique to the adolescent years and not simply the

[1] Sowell ER, Peterson BS, Thompson PM, Welcome SE, Henkenius AL, Toga AW. (2003) Mapping cortical change across the human life span. National Neuroscience (3):309–315. [PubMed: 12548289]

[2] Giedd JN. (2004) Structural magnetic resonance imaging of the adolescent brain. Annual NY Academy of Science 1021:77–85. [PubMed: 15251877]

trailing remnants of childhood brain development.[3]

Adolescent brains are different

Until 15 years ago it was thought that brains were no different in adolescence as they were in adulthood. We now know that the young adolescent brain undergoes remarkable physical development. While brain size remains relatively unchanged, researchers report significant changes within the brain (Blakemore & Choudhury, 2006[4]; Casey, Giedd, & Thomas, 2000[5]; Dahl, 2004[6]). During early adolescence, 'synaptic pruning' (explained later) is actively restructuring the brain's neural circuitry (Giedd, 2004[7]; Mohr &Nagel, 2010)[8]. The prefrontal cortex—an area of the brain that handles executive functions such as planning, reasoning, anticipating consequences, sustaining attention, and making decisions—continues to develop. Additionally, gender-specific differences are evident in young adolescent brains (Caskey & Ruben, 2007[9]; Caskey & Anfara, 2014[10])

Pictures of the brain in action show that adolescents' brains work differently than adults' when they make decisions or solve problems. Their actions are guided more by the emotional and reactive amygdala and less by the thoughtful, logical frontal cortex. Research has also shown that exposure to drugs and alcohol during the teen years can change or delay these developments.

The neurobiology of puberty and adolescence has made important progress during the past decade through finely tuned studies on behaviour, Central Nervous System imaging, and molecular neurobiology.

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[3] White, A.A. *Understanding Adolescent Brain Development and Its Implications for the Clinician*. Journal of Adolescent Medicine 20: 73-90.

[4] Blakemore SJ, Choudhury S. Brain Development During Puberty: State of the Science. Developmental Science. 2006 Jan;9(1):11-4.

[5] Casey BJ, Giedd JN, Thomas KM (2000) Structural and functional brain development and its relation to cognitive development. Biological Psychology 54(1-3):241 -57

[6] Dahl, RE (2004) Adolescent brain development: a period of vulnerabilities and opportunities. Keynote address Annual NY Academy of Science1021:1-22.

[7] Giedd JN (2004) Structural magnetic resonance imaging of the adolescent brain. Annual NY Academy of Science 1021:77-85.

[8] Mohr PN, Nagel IE. (2010). Variability in brain activity as an individual difference measure in neuroscience? Journal of Neuroscience;30(23):7755-7.

[9] Ruben B, & Caskey MM. "Under Construction: The Young Adolescent Brain" Charlotte, NC. *The Young Adolescent and the Middle School* (2007). Available at: http://works.bepress.com/barbara_ruben/3/

[10] Caskey MM, & Anfara VA (2017) Developmental Characteristics of Young Adolescents. Available at https://www.amle.org/BrowsebyTopic/WhatsNew/WNDet/TabId/270/ArtMID/888/ArticleID/455/Developmental-Characteristics-of-Young-Adolescents.aspx

The structural and functional development of the brain is remarkably complex during infancy and childhood and continues a dynamic trajectory throughout adolescence.

By around age 14, an adolescent brain should reach the weight of an adult brain (due to the accumulation of myelin and dendrites). It is at this time that social conscience, insight, judgement, and reasoning are beginning to develop and show potential. The adolescent's frontal lobes are increasingly active in a way that allows them to consider and compare several things in the mind.

In adults, various parts of the brain work together to evaluate choices, make decisions and act accordingly in each situation. The teenage brain does not work like this and the prefrontal cortex may not fully develop until the late 20s.

The architecture of the brain

The physical structure of the body plays a critical role in the behaviour of an individual and the most important physical structure in relation to behaviour is, without doubt, the brain. It is a jellylike mass of fat and protein weighing about 3 pounds (1.4 kilograms).

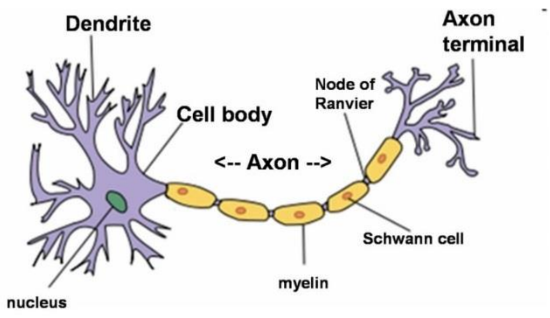
While the brain, with its unlimited storage capacity, only accounts for about 2% of body weight, it is one of the body's largest organs and requires a lot of energy and consumes about 20% of our total energy and oxygen intake. The brain is 73% water; studies have shown that it only takes 2% dehydration to affect memory, attention and cognitive skills. Further research has also found that 90 minutes of sweating can temporarily shrink the brain as much as one year of ageing.

There are three ways that the brain can repair itself:

- **Collateral Sprouting**, which is like a spider repairing a hole in a web
- **Substitution of Function**, where another part of the brain takes over the job of a damaged section
- **Neurogenesis**, which simply means that new neurons are forming

The brain is the hub of the Central Nervous System, a network of about 100 billion nerve cells that not only put together thoughts and highly coordinated physical actions but regulate our unconscious body processes, such as digestion and breathing.

The brain's nerve cells are known as neurons, and make up the brain's "grey matter." The neurons transmit and gather electrochemical signals that are communicated via a network of millions of nerve fibers called dendrites and axons. These are the brain's "white matter." Each neuron is connected to around 10,000 others. The total number of connections in the brain is about 1000 trillion.



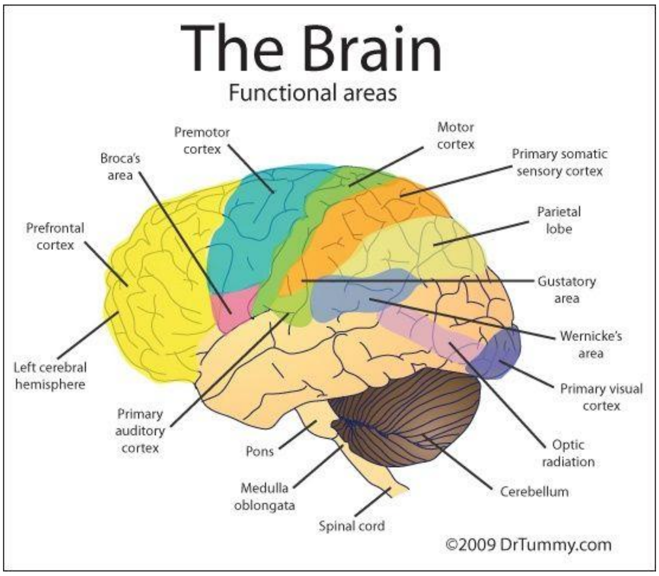
The cerebrum is the largest part of the brain, accounting for 85% of the organ's weight. The distinctive, deeply wrinkled outer surface is the cerebral cortex, which consists of grey matter. Beneath this lies the white matter. It's the cerebrum that makes the human brain—and therefore humans—so formidable. Whereas animals such as elephants, dolphins, and whales have larger brains, humans have the most developed cerebrum. It's packed to capacity inside our skulls, enveloping the rest of the brain, with the deep folds cleverly maximising the cortex area.

The cerebrum has two halves, or hemispheres. It is further divided into four regions, or lobes, in each hemisphere. The frontal lobes, located behind the forehead, are involved with speech, thought, learning, emotion, and movement. Behind them are the parietal lobes, which process sensory information such as touch, temperature, and pain. At the rear of the brain are the occipital lobes, dealing with vision. Lastly, there are the temporal lobes, near the temples, which are involved with hearing and memory.

The second largest part of the brain is the cerebellum, which sits beneath the back of the cerebrum. It is responsible for coordinating muscle movement and controlling our balance. Consisting of both grey and white matter, the cerebellum transmits information to the spinal cord and other parts of the brain.

The diencephalon is located in the core of the brain. A complex of structures roughly the size of an apricot, the two major sections are the thalamus and hypothalamus. The thalamus acts as a relay station for incoming nerve impulses from around the body that are then forwarded to the appropriate brain region for processing.

The hypothalamus controls hormone secretions from the nearby pituitary gland. These hormones govern growth and instinctual behavior such as eating, drinking, sex, anger, and reproduction. The hypothalamus, for instance, controls when a new mother starts to lactate.



The brainstem, at the organ's base, controls reflexes and crucial, basic life functions such as heart rate, breathing, and blood pressure. It also regulates when you feel sleepy or awake.

The brain is extremely sensitive and delicate, and so requires maximum protection. This is provided by the surrounding skull and three tough membranes called meninges. The spaces between these membranes are filled with fluid that cushions the brain and keeps it from being damaged by contact with the inside of the skull.

What's the matter?

The Central Nervous System has two kinds of tissue, each with distinct functions: *white matter* and *grey matter.* White matter, which makes up about 60% of the brain, is comprised of axons and dendrites, which create the network by which neurons send their signals. The remaining 40% of the brain is grey matter, where the neurons gather and transmit signals from. In simple terms, grey matter is the vehicle and white matter is the road or pathway.[11]

White matter

White matter in the brain is made up of collections of axons that are myelinated, that is, insulated by a fatty substance that appears white. It is thought that the myelination enhances transmission of signals across the brain.[12]

The brain's white matter enables nerve signals to flow freely between different parts of the brain. In teenagers, the part that governs judgment is the last to be fully connected. As such, the prefrontal cortex is a little immature in teenagers compared to adults. MRI studies indicate that white matter volume increases into the third decade of life.

Corpus Callosum

Corpus Callosum translates from the Latin for "tough body". It is also known as the Callosal Commissure. In a study of growth patterns of the developing brain, researchers found waves of growth in this section of the brain. The Corpus Callosum can best be described as a flat bundle of neuro-fibres that connects, and relays information, between the right and left cerebral hemispheres of the brain. It is the largest white matter structure in the brain. Researchers hypothesise that this part of the brain is largely controlled by genes. Of interest to educators and parents is their finding that the fibre systems influencing language learning and associative thinking grow more rapidly than surrounding regions before and during puberty but fall off shortly after.

Cerebellum

Studies have now shown that the cerebellum, at the back of the head just above the neck, is not genetically controlled and so is susceptible to the environment. It is a part of the brain that changes well into adolescence. Scientists think the cerebellum helps in physical coordination – but, looking at functional imaging studies of the brain, researchers also see activity in the cerebellum when the brain is processing mental tasks.

Giedd (2004) explains that the cerebellum works like "a maths co-processor. It's not essential for any activity, but it makes any activity better. Anything we can think of as higher thought, mathematics, music, philosophy, decision-making, social skill, draws upon the cerebellum. To navigate the complicated social life of the teen and to get through these things instead of lurching seems to be a function of the cerebellum."

Grey matter

The grey matter serves to process information in the brain. Structures within the grey matter process signals generated in the sensory organs or other areas of the grey matter. This tissue directs sensory (motor) stimuli to nerve cells in the central nervous system where synapses induce a response to the stimuli. These signals reach the grey matter through myelinated axons that make up the bulk of the white

[11] Blakemore SJ & Choudhury S. (2006) Development of the adolescent brain: implications for executive function and social cognition. Journal of child psychology and psychiatry.

[12] Spear LP (2013) Adolescent Neurodevelopment Journal of Adolescent Health (52) s7-s13.

matter in the cerebrum, cerebellum and spine.

Also found in the grey matter are the glial cells and capillaries. The glial cells transport nutrients and energy to the neurons and may even influence how well the neurons function and communicate. Because axons in the grey matter are mainly unmyelinated, the greyish colour of the neurons and glial cells combine with the red of the capillaries to give this tissue its greyish-pink color (after which it is named).

Pruning

The structural and functional development of the brain is remarkably complex during infancy and childhood and continues a dynamic trajectory throughout adolescence. In a baby, there is an increase in grey matter as the brain over-produces brain cells (neurons) and connections between brain cells (synapses) and then starts pruning them back around the age of three. Even though it may seem that having a lot of synapses is a particularly good thing, the brain consolidates learning by pruning away synapses and wrapping white matter (myelin) around other connections to stabilise and strengthen them. The process is much like the pruning of a tree. By cutting back weak branches, others grow stronger and flourish.

Adolescence represents an important period of neuronal maturation, during which the early part of the brain's neural circuitry is still actively restructuring (Giedd, 2004; Mohr, 2010). With the help of Magnetic Resonance Imaging (MRI) Giedd found a second wave of synapse formation which showed a spurt of growth in the frontal cortex just before puberty (age 11 in girls, 12 in boys) and then a pruning back during adolescence. This does not interrupt the synapse formation which continues to increase from experiences that occur during adolescence.

Pruning during adolescence is highly specific and can be pronounced, resulting in a loss of approximately 50% of the synaptic connections in some regions, but with little decline in others. Giedd (2004) hypothesises that the growth in grey matter followed by the pruning of connections is a particularly important stage for brain development as is the period of growth. For instance, even though the brain of a teenager between 13 and 18 is maturing, they are losing 1% of their grey matter every year. Giedd explains:

"If a teen is doing music or sports or academics, those are the cells and connections that will be hardwired. If they're lying on the couch or playing video games or MTV, those are the cells and connections that are going to survive."

Pruning has been speculated to help with the "rewiring" of brain connections into adult typical patterns. It has been proposed that this decline in grey matter volume partly reflects an important neurodevelopmental process: the loss of connections between brain cells (synapses) during development. This process partly depends on the environment in that connections that are used are strengthened; connections that aren't used are lost – they are pruned away. Synaptic pruning fine tunes brain tissue according partly to the environment. This is happening throughout adolescence in several cortical regions, including the prefrontal cortex

As childhood ends and adolescence begins, the brain switches from overproduction mode to selection mode.

Early in the second decade of life, the brain stops overproducing synapses in the frontal lobes and puts the synapses that exist on the chopping block. Hundreds of billions of points of communication will be sacrificed through the teenage years. Only those that form meaningful, useful points of contact will be kept. Guided by a teenager's experiences, the frontal lobes are shaped and moulded into a configuration that will carry the individual, for better or worse, through the adult years (White, 2009).

These changes include not only 'pruning' the grey matter but developing more white matter. The increase in white matter volume may be associated with continued myelination of white matter tracts or increases in the calibre of axons.[13]This might explain some of the erratic, illogical and emotional behaviour thought to be characteristic of teenagers. It might also explain why schizophrenia often does not show up until young adulthood (Sowell & Peterson, 1985).

Prefrontal Cortex

The prefrontal cortex sits just behind the forehead. It is particularly interesting to scientists because it acts as the CEO of the brain, controlling planning, working memory, organisation, and modulating mood. It is associated with the human's unique ability to be aware of their own ability to think (metacognition) which distinguishes us from most of the rest of the animal kingdom. The pre-frontal cortex communicates with the other sections of the brain through connections called synapses.

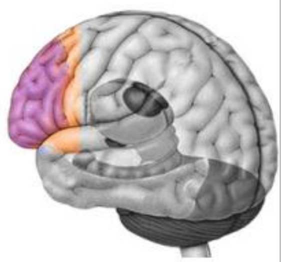
As the prefrontal cortex matures, teenagers can reason better, develop more control over impulses and make judgments better. In fact, this part of the brain has been dubbed "the area of sober second thought."

This brain region has been implicated in planning complex cognitive behaviour, personality expression, decision-making, and moderating social behaviour. Functional connectivity between the prefrontal cortex (PFC) and striatum (STR) is thought critical for cognition and has been linked to conditions like autism and schizophrenia. The prefrontal cortex, which handles reasoning and judgement, grows during the pre-teen years, is pruned back during adolescence, increasing impulsivity, risk-taking behaviour and susceptibility to addiction.

Many studies have shown that brain activity associated with tasks such as decision-making, planning, inhibiting a response and reasoning, changes across adolescence. Considerable research is currently focussed on the social brain – that is the network of brain regions that is used to understand other people.

What does the prefrontal cortex (the "Executive Center") control?

- Sound decision making
- Empathy
- Considering consequences
- Regulating emotions
- Self-awareness
- Morality



[13] Paus, T., Keshavan, M., & Giedd, J. N. (2008). Why do many psychiatric disorders emerge during adolescence? Nature Reviews Neuroscience, 9(12), 947-957.

The research shows consistently higher levels of activity in a social brain region called the medial prefrontal cortex in adolescents when they carry out social tasks that require understanding irony, thinking about social emotions such as guilt or embarrassment, or thinking about someone else's intentions, for example.

The different levels of activity within regions of the social brain might be because adolescents and adults use a different cognitive strategy (mental approach) to make social decisions.

The relationship between the prefrontal cortex and the limbic system – the area that supports emotion and many behavioural tendencies, as well as long-term memory – has received increasing attention. The limbic system develops on a steeper curve than the prefrontal cortex, so that the disparity between these two regions is greatest during adolescence. The result may be an imbalance that may favour behaviours driven by emotion and response to incentives over rational decision making. It is this imbalance – not just the protracted development of cognitive control alone – that contributes to the prevalence of risk-taking in adolescents.[14]

The plastic brain

When we learn more, the brain adapts and strengthens neural pathways, which is something known as 'Plasticity'.

Synapses are selected based on whether they're used or not, so behaviours that shape the brain are more likely to be maintained if started at this age. The brain is acting a bit like a sponge; it can soak up new information and change to make room for it.

When engaging in an activity repeatedly and learning it as second nature, neural pathways in the brain shape themselves according to that activity or memory. Those pathways will fade if the activity is no longer practiced, because the brain recognises that it doesn't require as many resources for that function.

Adolescence is a time when the brain is more 'plastic' than it will ever be again, capable of remarkable adaptability considering the many social, physical, sexual, and intellectual challenges this developmental phase brings.[15]

What does this mean for those who work with young people?

Adolescents have specific developmental vulnerabilities and describing them as how we see them 'in the simplest terms' does not do justice to the complexities and challenges of this period. It is important to remember the unique challenges that this period brings and that each one of them is a brain in progress, ultimately taking on different identities that will be realised in adulthood. The brain is only one of many changes happening during adolescence and it is essential we look at ways of

[14] Casey, B. J., Getz, S., & Galvan, A. (2008). The adolescent brain. Developmental Review, 28(1), 62-77.

[15] Casey, B.J., Glatt, C.E., Lee, F.S., (2015) Treating the Developing versus Developed Brain: Translating Preclinical Mouse and Human Studies. *Neuron*, 86, 1358-1368.

providing support to young people to help them navigate the challenges they face.

Adolescence is a time of opportunity for learning new skills and forging adult identity. It represents a period of brain development during which environmental experiences, including teaching, can and do profoundly shape the developing brain. This is a major opportunity and sensitive period for teaching and introducing substance prevention programmes.

The research on brain development in adolescence adds new dimensions to our understanding of adolescence – a time of both heightened opportunity and risk – and could have implications for 'when to teach what' and could inform both substance prevention programme design and practice with the aim of ensuring that prevention activities exploit periods of neural plasticity that facilitate maximal learning.

As the Russian novelist Dostoyevsky once wrote "It is not the brain that matters most, but that which guides them – the character, the heart, generous qualities, and progressive ideas" – it is these things that substance prevention programmes should foster.

Further briefing papers in this series will consider:

- Adolescent Development and Vulnerabilities
- The Neurobiological Effects of Substance Use
- The Adolescent - Wired for Risk-Taking
- The Adolescent Social and Emotional Development
- Adolescent Cognitive Control
- Adolescent Mental Health

Glossary

amygdala - a part of the brain (and part of the limbic system) that is used in emotion.

axon - the long extension of a neuron that carries nerve impulses away from the body of the cell.

axodendritic synapse - a synapse formed by contact between a presynaptic axon and a postsynaptic dendrite.

brain - the organ in the body that is responsible for thought, memory, sensory interpretation, movement, and other vital functions.

brainstem or **brain stem** - the base of the brain. This part of the brain connects the brain's cerebrum to the spinal cord. The brain stem controls many automatic and motor functions. The brain stem is composed of the medulla oblongata, the pons, the midbrain, and the reticular formation.

central nervous system (CNS) - the brain and spinal cord

cerebellum - the part of the brain below the back of the cerebrum. It regulates balance, posture, movement, and muscle coordination.

cerebral cortex - the outer layer of the cerebrum, composed of six cell layers of deeply folded and ridged grey matter.

cerebral hemisphere - one side of the cerebrum, the left or right side of the cerebrum.

cerebrum - the largest and most complex portion of the brain. It controls thought, learning, and many other complex activities. It is divided into the left and right cerebral hemispheres that are joined by the corpus callosum, which communicates between the two hemispheres. The right side of the brain controls the left side of the body, and vice versa. Each cerebral hemisphere is divided into four lobes: the frontal lobe (responsible for reasoning, emotions, judgment, and voluntary movement); the temporal lobe (contains centres of hearing, smells, and memory); the parietal lobe (responsible for touch and spoken language ability), and the occipital lobe (responsible for centres of vision and reading ability).

corpus callosum- a large bundle of nerve fibres that connect the two cerebral hemispheres.

cortex - the outer layer of the cerebrum, composed of six cell layers of deeply folded and ridged grey matter.

cranium - the top of the skull; it protects the brain. The cranium and the facial bones make up the skull.

dendrites - the branching structure of a neuron that receives messages.

diacephalon - along with the telencephalon (cerebrum) comprise the two major divisions of prosencephalon (forebrain). Main structures of the diencephalon include the hypothalamus, thalamus, epithalamus (including the pineal gland), and subthalamus. Also located within the diencephalon is the third ventricle, one of the four brain ventricles or cavities filled with cerebrospinal fluid.

frontal lobe - the top, front regions of each of the cerebral hemispheres. They are used for reasoning, emotions, judgment, and voluntary movement.

glial cells - nerve cells that form a supporting network for the neurons in the brain. The word "glia" comes from the Greek word for glue.

grey matter - central nervous tissue that is relatively dark in colour (in contrast to white matter) because of the relatively high proportion of nerve cell nuclei present

hormones - biochemical substances that are produced by specific cells, tissues, or glands in the body. Hormones regulate the growth and functions of cells and tissues in the body. An example of a hormone is insulin, which is secreted by the pancreas. Hormones were first discovered by the British scientists William Bayliss and Ernest Starling in 1902.

hypothalamus - a region in the upper part of the brainstem that acts as a relay to the pituitary gland - it controls body temperature, circadian cycles, sleep, moods, hormonal body processes, hunger, and thirst. The hypothalamus is part of the limbic system and works with the pituitary gland.

left hemisphere - the left half of the cerebrum - it is the centre for speech and language. In some left-handed people, however, the right hemisphere controls speech.

limbic system - the interconnected areas of the brain that are used in emotions and some other behaviours.

meninges - a series of three protective membranes (the dura matter, the arachnoid, and the pia) that cover the brain and the spinal cord.

motoneurons (multipolar neurons) - neurons responsible for movement - the cell bodies of these neurons are located within the brain or spinal cord and the axons are located in muscle fibres

myelin - a fatty substance that covers axons.

myelin sheath - a fatty substance that surrounds and protects some nerve fibres.

neuron - a nerve cell. Neurons have specialized projections (dendrites and axons) and communicate with each other via an electrochemical process.

neuroscience - the study of the brain and the nervous system.

neurotransmitters - chemicals that transmit nerve impulses between neurons. Some neurotransmitters include acetylcholine, dopamine, endorphin, epinephrine, serotonin, and histamine.

occipital lobe - the region at the back of each cerebral hemisphere that contains the centres of vision and reading ability.

parietal lobe - the middle lobe of each cerebral hemisphere between the frontal and occipital lobes; it contains important sensory centres.

peripheral nervous system - the part of the nervous system that includes the cranial nerves and the spinal nerves.

pituitary gland - a gland attached to the base of the brain that secretes hormones.

right hemisphere - the right half of the cerebrum - it processes visual information.

sensory cortex - any part of the brain that receives messages from a sense organ (like the eyes, nose, tongue, or ears) or messages of touch and temperature from anywhere in the body.

sensory neuron (bipolar neuron) - an afferent nerve cell that carries sensory information (like sound, touch, taste, smell, or sight) to the central nervous system.

skull - the bones that comprise the head.

spinal cord - a thick bundle of nerve fibres that runs from the base of the brain to the hip area, running through the spine (vertebrae).

Striatum - a subcortical part of the forebrain and a critical component of the reward system.

synapse - a structure where an impulse passes from one neuron to another across a gap.

temporal lobe - the region at the lower side of each cerebral hemisphere; contains centres of hearing and memory.

thalamus - a small structure at the top of the brainstem that serves as a relay centre for sensory information, pain, attention, and alertness.

white matter - heavily myelinated central nervous tissue that is light in colour (in contrast to grey matter) - it consists mostly of axons covered with the insulating lipid-protein sheath myelin.

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http://time.com/4292298/lsd-acid-trip-drugs-brain/

https://www.brainscape.com/blog/2012/03/facts-about-your-grey-matter/

http://slideplayer.com/slide/9694751/

https://biology.stackexchange.com/questions/25967/nerves-neurons-axons-and-dendrites-by-example