Module 4

Brain Anatomy, Development, and Function

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The Brain

The brain is the control centre of the nervous system. It receives sensory data, makes decisions, controls movement, and manages the body as a whole (Gibb, 2007). The brain is extremely complex, and no one completely understands its capabilities. In fact, the brain has been called "the most complex structure, natural or artificial, on earth" (Green, Heinemann & Gusella, 1998, p. 427). When fully developed, the adult brain weighs between 1 and 1.5 kg (about 3 pounds), and contains approximately 100 billion nerve cells (Encyclopaedia Britannica, 2008; Parent & Carpenter, 1996). Ongoing research and new technological advances in brain scanning equipment continue to provide new information that extends our understanding of brain function and human behaviour.

The Triune Brain (3 Functions of the Brain)

The brain is very complex. When describing the brain, it is helpful to use a relatively simple model that can explain our experiences and observations. The Triune Brain concept was introduced in the 1960s, and has become a popular way to understand how the brain functions. In this model, the brain is organized into three hierarchically distinct brain regions:

1. Reptilian or Primitive Brain
2. Emotional or Paleomammalian Brain
3. Rational or Neomammalian Brain

(Koch, n.d.; McGill University, n.d.; The Science of Psychotherapy (SOP), 2019)

> The brain is "the most complex structure, natural or artificial, on earth"
>
> (Green, Heinemann & Gusella, 1998, p. 427)

This model is a simplified explanation of brain activity and organization. Although some features of the original model are not completely accurate, according to more recent neuroscience evidence, the general concept is useful as it provides an easy understanding of brain functions.

Reptilian/Primitive Brain

This region of the brain has also been called the dinosaur brain (McKee & Miller, 2018). The dinosaur brain is made up of the brainstem and other parts that work together as a system. This system of the brain is responsible for the most basic survival functions, such as heart rate, breathing, body temperature, and awareness of your body in relation to your surroundings in space (The Science of Psychotherapy (SOP), 2019).

The functions of this part of the brain will take priority over other brain activity. For example, when we are in danger and must respond quickly, as an act of self-preservation, this part of the brain is aroused. This prepares us for action by initiating the release of chemicals throughout the body (Siegel, 2010; The Interaction Design Foundation, 2019).

Paleomammalian Brain

This is also known as the "emotional brain" or the monkey brain (McKee & Miller, 2018). The limbic system is the reactive part of the brain that starts the "fight or flight" response to danger (The Science of Psychotherapy (SOP), 2019). It is also involved in behaviours needed for feeding, reproduction, and caring for the young (Queensland Brain Institute, 2019). It includes the hypothalamus, hippocampus, and amygdala (Queensland Brain Institute, 2019; SOP, 2019). Together, these three parts form a very fast subconscious evaluation and response system designed to keep us safe. These structures are further explained in the next section.

Neomammalian/Rational Brain

This part is the "smart" brain. It is also known as the owl brain (McKee & Miller, 2018). It is the executive part of the system (Boss of the Brain) that is responsible for all higher-order functions such as:

- language
- abstract thought
- imagination
- creativity

(McGill University, n.d.; The Science of Psychotherapy (SOP), 2019).

It also stores memory, including biographical (e.g., remembering people and events) and automatic memories. Automatic memories include those needed for talking, writing, walking, playing the piano, and countless other familiar activities (The Science of Psychotherapy (SOP), 2019).

The three-part (triune) model is a relatively simplified way to understand the brain structure and functions. Another way is to look at the specific structures of the brain and their functions. Below is a list of some of the main structures of the brain and a general description of their functions.

Description and Functions of Important Brain Structures

1) **The Cerebral Cortex**

   The part of the brain that takes the longest time to develop is the cerebral cortex. It is the outer layer of the brain's most dominant part (the cerebrum) and can be easily identified by its bulging wrinkled surface (Carter et al., 2009).

   The neocortex is the outer layer of the cerebral cortex. The cerebral cortex is divided lengthways into two cerebral hemispheres (left and right) connected by the corpus callosum. Each of the hemispheres is divided into four lobes (parts) as listed below. (See **Table 4.1** for descriptions.)

   - Frontal lobe
   - Parietal lobe
   - Temporal lobe
   - Occipital lobe

   (Queensland Brain Institute, 2019)

The cerebral cortex looks after thinking, making plans, meeting goals, and controlling feelings. This area can turn short-term memories into long-term memories. It creates connections between the different parts of the brain. It is like the "Boss of the brain" or the CEO of a company, managing and running things. It is sometimes called the thinking brain or owl brain.

The cerebral cortex depends on the other parts of the brain to help it do its job. When the other parts have been harmed, it is more difficult to do thinking and reasoning.

Table 4.1: The Four Cerebral Lobes (Queensland Brain Institute, 2019)

Lobe	Description
Frontal Lobe	• Located directly beneath the forehead • The largest of the lobes • Responsible for "higher" brain functions like attention, planning, critical thinking, problem-solving, self-control, language, and complex movement • Integrates information and governs what the rest of the brain does
Parietal Lobe	• Located behind the frontal lobe, at the top of the head • Processes information from the senses (e.g., touch, pressure, pain), allowing people to perceive and interpret the world around them
Occipital Lobe	• Located at the back of the brain • Processes visual images by interpreting signals sent by the eyes
Temporal Lobe	• Located along the side of each hemisphere • Processes sound and, in turn, language • Involved in memory formation and retention through connection to the hippocampus

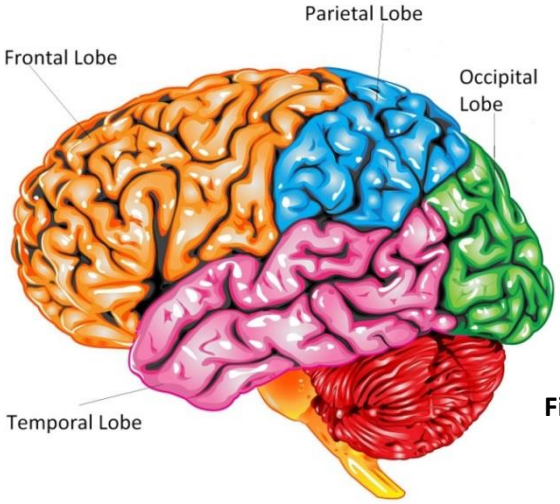


Figure 4.1: The Cerebral Lobes

2) **Corpus Callosum**

The corpus callosum is a thick, flat bundle of nerve fibres through which information flows from one side of the brain to the other (Gibb, 2007). The corpus callosum is necessary for the brain to function properly. It allows the two hemispheres to work together to analyze information and situations (Siegel, 2010).

3) **The Limbic System**

The limbic system is a set of brain structures that are centrally located in the brain. The limbic system is underneath the cerebral cortex and above the brainstem. Two of the major structures are the **hippocampus** and the **amygdala.** They are necessary for the brain's processing of emotion and motivation (Gibb, 2007).

The **hippocampus** comes as a pair (one in each hemisphere of the brain) and resembles the shape of a curvy seahorse (Queensland Brain Institute, 2019). It is involved in recognizing new experiences, learning, and memory (Parker, 2007). The hippocampus is particularly involved in the creation of short-term memories and associating memories with various senses (e.g., the association of Christmas with the smell of gingerbread) (Queensland Brain Institute, 2019). The **amygdala,** on the other hand, is located right next to the hippocampus and plays a central role in emotional responses, including feelings like pleasure, fear, anxiety, and anger (Queensland Brain Institute, 2019).

The limbic system is sometimes called the "feeling brain" or "monkey brain". It influences subconscious, instinctive behaviours (this is called the flight (run), fight, or freeze response) (Carter et al., 2009; Parker, 2007; Siegel, 1999). For example, when something happens to you, your brain tells you whether you are safe or not. The thalamus, hypothalamus, and basal ganglia are also involved in the actions of the limbic system (Queensland Brain Institute, 2019) and are described in **Table 4.2**.

Pineal Gland: The pineal gland is a small structure tucked between the two lobes of the thalamus. It is shaped like a tiny pinecone, and its main job is to produce the hormone melatonin, which regulates our sleep-wake cycles.

Table 4.2: Parts of the Limbic System

Structure	Description
Thalamus	• Located close to the centre of the brain; egg-shaped • "Relay station of the brain": receives input from all of the senses, except smell (olfaction); performs preliminary analyses; and directs messages to various parts of the brain • Processes information from the cerebellum and other brain areas involved in movement
Hypothalamus	• Located below the thalamus; connected to almost every other part of the brain • Regulates hormone release, which in turn controls sex drive, pleasure, pain, hunger, thirst, blood pressure, body temperature, and other functions • Essential to motivation, including the seeking out of activities that people find rewarding (e.g., sex, music, drugs) • Manages the body's daily cycles (**circadian rhythms**)
Basal Ganglia	The basal ganglia are structures lying deep within the brain and are involved in actions of the limbic system. They are involved in a wide range of processes such as: • emotion • reward processing • habit formation (learning or creating behaviours) • movement • learning (Queensland Brain Institute, 2019) They are particularly involved in co-ordinating the order of motor activity, such as when playing a musical instrument, dancing, or playing basketball. The basal ganglia are the regions most affected by Parkinson's Disease, which is characterized by tremors and uncontrolled movements (Queensland Brain Institute, 2019).

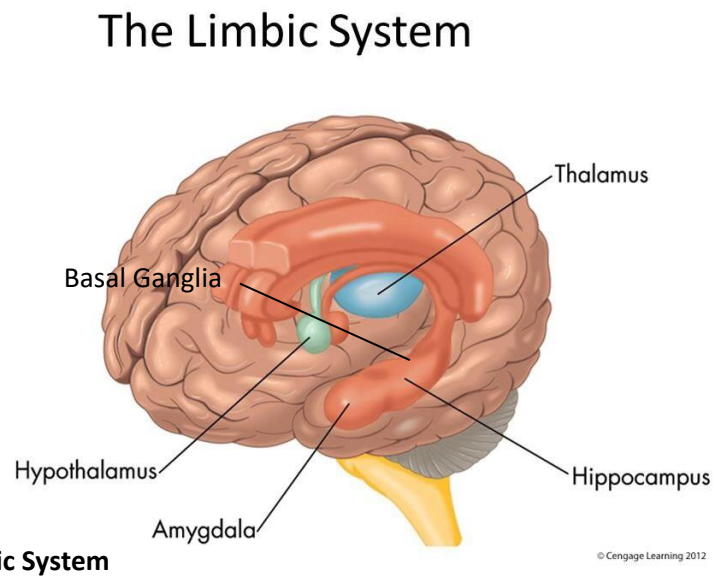


Figure 4.2: The Limbic System

4) **The Cerebellum**

The cerebellum (see **Figure 4.3**) is connected to the brain stem and, like the cerebrum, is divided into two hemispheres. The cerebellum is sometimes called the "little brain" (Carter et al., 2009; Queensland Brain Institute, 2019). Although it only accounts for one-tenth of the brain's volume, the cerebellum contains approximately one-half of the brain's total number of neurons (Parker, 2007). The cerebellum's primary functions are balance, posture, and coordination of voluntary movement (Encyclopaedia Britannica, 2008; Carter et al., 2009; Queensland Brain Institute, 2019).

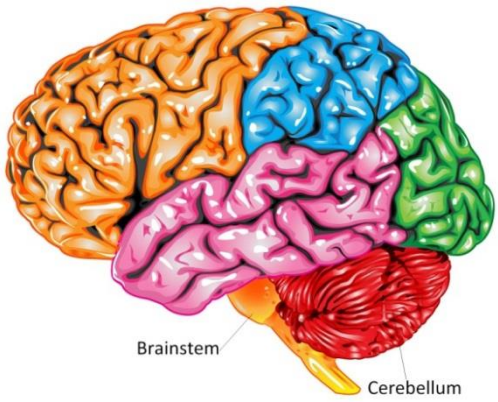


Figure 4.3: The Cerebellum

5) **The Brainstem**

The brainstem is located at the base of the brain and at the top of the spinal cord. Some people nickname it the primitive brain or dinosaur brain. The brainstem is responsible for regulating many vital bodily functions including breathing (respiratory), maintaining a heart rate (circulatory), feeling

hungry or full (digestion), and getting rid of waste (Carter et al., 2009; Gibb, 2007; Siegel, 2010). The brainstem consists of three parts:

- the **medulla oblongata**
- the **pons**
- the **midbrain**

Together, the medulla oblongata and the pons contain the **reticular activating system**, which plays a key role in sleep and alertness (Encyclopaedia Britannica, 2008).The three parts of the brainstem are discussed further in **Table 4.3**.

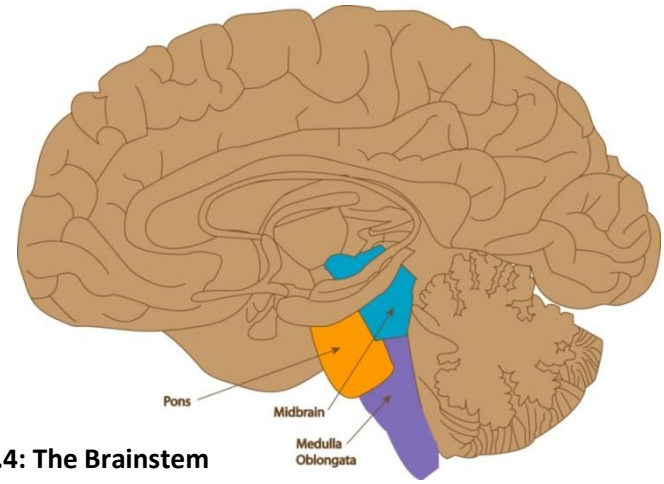


Figure 4.4: The Brainstem

Table 4.3: Parts of the Brainstem

Structure	Description
Medulla Oblongata	• Located at the bottom of the brainstem and connected to the spinal cord • Responsible for the automatic functions that keep the body alive (e.g., heartbeat, breathing, digestion, blood pressure)
Pons	• Located above the medulla oblongata • Works with the medulla oblongata to regulate some automatic functions (e.g., arousal and breathing) • Directs movement-related information between the cerebellum and the cortex
Midbrain	• Located at the top of the brainstem • Contains an extension of the reticular activating system, which plays a key role in sleep and arousal • Responsible for controlling and coordinating many of the body's sensory and motor functions (e.g., eye movements)

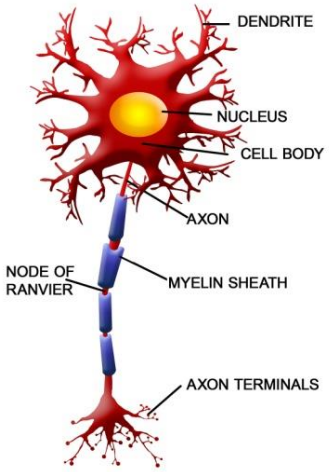


Figure 4.5

How the Brain Communicates (Neurotransmission)

The brain has many structures. Each is responsible for a variety of functions. For the brain and body to function properly, the parts of the brain need to be able to communicate with each other and with the rest of the body.

This communication (called **neurotransmission)** takes place through the nerves and **neurons** found in the brain and body (Encyclopaedia Britannica, 2008). There are over 100 billion neurons in the brain. There are about ten times as many **glial cells** which support and protect these neurons (Encyclopaedia Britannica, 2008). **Figure 4.5** shows the structure of a typical neuron.

Gibb (2007) uses the metaphor of a tree to describe neuronal function. Neurons pass information from the leafy top section (**dendrites**) down the trunk (**axons)** to the roots (**synapses**). **Table 4.4** below provides further information about neurons and their parts.

Table 4.4: Neurons and Parts of Neurons

Structure	Description
Neuron	• Made up of a cell body (control centre of the neuron) with a nucleus, branch-like structures called dendrites, and nerve fibres called axons • Specialized for the task of receiving and processing information signals
Axons	• Carry signals away from the cell body to the dendrites of other neurons
Myelin Sheath	• Serves as insulation for the axons, reducing the risk of short-circuits caused by other nearby axons • Helps to speed up the signals
Nodes of Ranvier	• Small gaps in the myelin sheath • Contains many proteins, allowing the signals to recharge and continue onward
Dendrites	• Receive signals from neighbouring neurons and transmit them to the cell body of the neuron in which they are embedded
Synapse	• Small gap between two neurons through which one can send signals to another (communication through neurotransmission)
Glial Cells	• Surround, support, protect, and feed the neurons • Help to form the “blood-brain barrier,” a structure that prevents unnatural substances from reaching the brain • Include Schwann cells
Schwann Cells	• Any of the cells that surround the axons of the outer nerves, forming the myelin sheath of myelinated nerve fibers • Provide support for non-myelinated nerve fibres.

Grey Matter	• The tissue found in the brain and spinal cord. • It consists of neuron cell bodies and their dendrites, glial cells, and capillaries. • This tissue is actually more pink-coloured than grey because of its rich blood supply
White Matter	• The tissue found in areas of the brain and spinal cord which serves as host to axons (long cords that extend from neurons) • In the brain, white matter is buried beneath the grey surface, carrying signals across different parts of the brain • In the spinal cord, it is the external layer surrounding the grey core

Neurotransmission is how neurons communicate with each other. This communication is a chemical process, where the brain receives, analyzes, and transmits all of the information necessary to carry out its functions (Encyclopaedia Britannica, 2008; National Institutes of Health & National Institute on Drug Abuse [NIH & NIDA], 2010). Neurotransmission is an *all-or-nothing* impulse. Neurons will not transmit information unless they receive enough stimulation (i.e., stimulation must reach a certain threshold).

The following are the three basic steps involved in neurotransmission:

1) Information (carried by an electrical impulse) travels through the cell body of a neuron and down the axon. The axons of neurons contain **neurotransmitters** (chemical messengers). These neurotransmitters are held until the neuron is stimulated.
2) A message or signal sent from the neuron, called an **action potential**, stimulates the release of neurotransmitters across the synapse (gap between neurons).
3) The neurotransmitters bind (attach) themselves to the appropriate **receptor sites** on the dendrites of the next neuron. This binding process passes on the neurotransmitter's message. The relationship between receptors and neurotransmitters is often compared to a lock and key. Just as a key fits only in a specific lock, a neurotransmitter binds only to a specific receptor.

(Baron, Earhard, & Ozier, 1999; NIH & NIDA, 2010; Encyclopaedia Britannica, 2008; Siegel, 1999)

There are about a dozen different neurotransmitters. Each has its own role and effect (Encyclopaedia Britannica, 2008). Some of the more common neurotransmitters include (NIH & NIDA, 2010):

- **Acetylcholine:** Taken from the diet and plays an important role in learning and memory (WHO, 2004)
- **Dopamine:** Involved in the reward and pleasure centre of the brain and also needed for voluntary movement, attention, decision-making, and other cognitive processes (Nicholas, 2003)
- **GABA (gamma-aminobutyric acid):** Thought to regulate arousal or general level of energy and alertness and to play an essential role in normal brain function (Pastorino & Portillo, 2006)
- **Norepinephrine:** A neurotransmitter which impacts mood, memory, arousal, and is involved in controlling anxiety and stress (Thomas-Cottingham, 2004)
- **Serotonin:** Involved in many different behaviours including sleep, arousal, mood, eating, and pain perception (Pastorino & Portillo, 2006)

Abnormal levels of neurotransmitters can have serious effects. For example, dopamine is involved in movement, attention, and learning. Low levels of dopamine are associated with Parkinson's disease, while high levels of dopamine have been associated with schizophrenia (Encyclopaedia Britannica, 2008). Because other neurotransmitters have different specific roles, other potential effects of neurotransmitter imbalances include difficulties with sleep, mood, eating, and controlling pain.

The following websites provide information (video or interactive information) about the brain:

- The Centre on the Developing Child (Harvard University) https://developingchild.harvard.edu/
- Components of the Brain http://www.nlm.nih.gov/medlineplus/ency/anatomyvideos/000016.htm
- Discovery: How Neurons Work https://www.teachertube.com/videos/discovery-how-neurons-work-6483
- Public Broadcasting System: The Secret Life of the Brain https://www.youtube.com/watch?v=MS5HUDVNbGs
- Engaging all learners! Supporting Students with Fetal Alcohol Spectrum Disorders http://www.engagingalllearners.ca/il/supporting-students-with-fasd/#0

Prenatal Brain Development

Before examining the effects of prenatal alcohol exposure on the fetal brain, it is helpful to understand how the human brain develops in utero (before birth). See **Module 3: Fetal Development** for more information on fetal development.

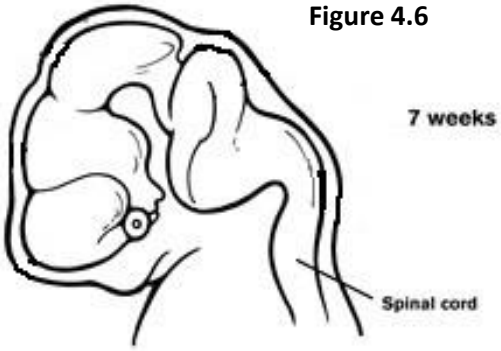
Most people do not realize how early the brain begins to develop in utero. The process starts between the second and third week of fetal development, and it continues well into adulthood (National Research Council, 2015; Tierney & Nelson, 2009). The fetus generally develops from the top to the bottom. The head and brain form first, followed by the torso and the limbs.

The brain, however, develops from the bottom up, with the brainstem maturing first (Siegel, 2010). The brain continues to develop throughout pregnancy and into adulthood (Zeanah, 2009). Regions necessary for higher cognitive activities (e.g., the forebrain) take longer to develop than other regions of the brain. **Figures 4.6 to 4.8** illustrate the development of the brain throughout the prenatal period.

Zero to Two Months

Three weeks after conception, the outermost layer of the embryo folds in on itself and forms an inner **neural tube** (Gibb, 2007; Joseph, 2000). This is where the **central nervous system**, which includes the brain and the spinal cord, starts to form. One end of the tube becomes the spinal cord and the other end forms a series of bulges that will become different distinct brain structures. The front

Figure 4.6



portion of the tube includes the cerebral hemispheres, thalamus, hypothalamus, and the basal ganglia, which are connected by a structure in the middle portion of the tube to the rear-most portion of the tube. The rear end of the tube is the brain stem. The remaining cells eventually form the spinal cord (Tierney & Nelson, 2009; Gibb, 2007). Neurons, which play a key role in the performance of brain functions, appear as early as week 5 and continue to be rapidly produced up to week 25 of pregnancy (National Research Council, 2015).

The role of new neurons is to move into new locations in the developing brain where they will serve special roles. These neurons are guided to their new location by following signals from nearby cells. Some seizure disorders and cognitive challenges have been linked to neurons not travelling to the correct location (National Research Council, 2015).

Two to Three Months

During the second and third months of fetal development, the growing brain begins to take shape. The brain stem matures to form the medulla oblongata, pons, and midbrain (Joseph, 2000). The medulla oblongata is responsible for arousal, breathing, heart rate, and gross motor movement of the body and head. Around the ninth gestational week, spontaneous fetal movements can already be seen (Joseph, 2000).

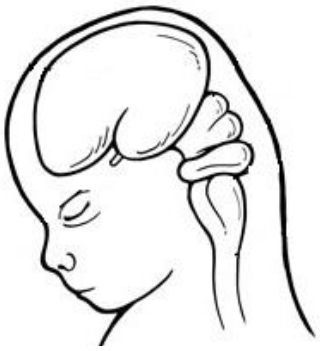


Figure 4.7

Three to Seven Months

The rapid creation of nerve cells (neurogenesis) typically reaches its highest point between the third and fourth months of pregnancy. As many as 250,000 nerve cells are being generated per minute from the neural stem cells (National Research Council, 2015; Zeanah, 2009). Developing neural cells (known as precursors) usually become either neurons or glia cells (National Research Council, 2015). Neurons play key roles in carrying messages and signals. Glia cells provide support to the neurons (**Table 4.5**). With a few exceptions (e.g., the olfactory bulb which is responsible for scent perception), babies are born with almost all of the estimated 100 billion neurons that all humans possess (Zeanah, 2009).

Final Months

In the final months of pregnancy, the fetal brain begins to:

1) get rid of unnecessary cells and connections (a process known as **apoptosis)**
2) protect remaining neurons and connections through **myelination** (progressive insulation of the neuronal axons with myelin sheath)

(Joseph, 2000; National Research Council, 2015)

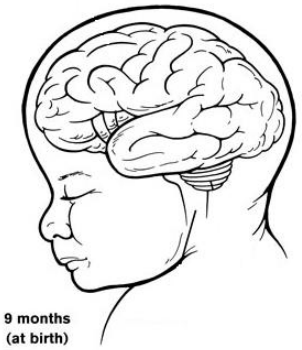


Figure 4.8

Apoptosis is necessary to produce balance because of the overproduction of cells and synapses. Myelination protects the remaining brain cells. This process is not complete until well after

birth (Joseph, 2000). From 37 to 40 weeks of pregnancy, the fetus is considered full-term. Although the fetal brain already contains billions of neurons, it will continue to develop and change, and will continue to build new connections between neurons throughout its lifespan.

Table 4.5: Simplified Overview of Fetal Brain Development

Gestational Month	Brain Development	Related Developments
One	• Neural tube forms, part of which becomes the spinal cord and part of which becomes the brain	• All major organs are forming, and the heart begins to beat
Two	• Major structures of the brain begin to form, including the cerebrum	• Foundations for all major organs are now in place
Three	• Brain continues to grow new neurons and make connections between them	• Fetus develops physical reflexes but cannot yet control movements
Four	• Parts of the brain begin to receive signals from the ears and eyes	• Fetus can detect bright lights and hear sounds, but cannot yet interpret them
Five	• Brain continues to make more connections	• Fetus begins to control its movements and begins to react to sounds
Six	• Cerebral cortex starts to separate into lobes	• Primitive type of memory and conscious behaviour emerge
Seven	• Brain begins to form grooves and indentations typical of a more mature brain • Fetal brain waves can be detected	• Eyelids open and the fetus begins to "see" in the womb • Fetus can suck its thumb and swallow
Eight	• Auditory (sound) and visual cortex begins to function	• Fetus has primitive ability to interpret sights and sounds and to distinguish language
Nine	• Brain continues to grow • Most of the neurons that will develop are already in place • Brain is ¼ the size and weight of an adult brain	• Lungs mature and the immune system continues to develop

Effects of Prenatal Alcohol Exposure on Fetal Brain Development

Throughout this module, it has been emphasized that the brain begins to develop very early in the womb and continues to develop throughout the lifespan. The brain has already begun to develop by the second month of pregnancy, when many women may not even know they are pregnant (Gibb, 2007; Joseph, 2000). No other organ in the human body takes as long to develop or goes through as many changes as the brain.

During the first trimester (0 to 3 months gestation), the growing fetal brain, body parts, and facial structures are most susceptible to harm. This period is referred to as the sensitive or **critical period** of development (Moore, Persaud, & Torchia, 2020; National Research Council, 2015). Fetal exposure to **teratogens,** like alcohol, during this critical period can result in particularly severe impacts (DeHart, Sroufe & Cooper, 2004; National Research Council, 2015). Teratogens are substances that interfere with the typical development of the fetus, usually by preventing or interfering with normal cell division and placement. (See **Module 3: Fetal Development** for more information on the effects of teratogens on fetal development.) The teratogenic effects of alcohol extend to all parts of the brain except the occipital lobe which remains relatively unaffected (Lebel et al., 2011).

Evidence of the impact of maternal alcohol use on the developing fetal brain has been established using a variety of methods (Guerri, Bazinet & Riley, 2009; Spadoni et al., 2007). These methods include:

- autopsies
- neuropsychological and behavioural studies
- neuroimaging studies (most recently)

Similar to autopsy studies, neuroimaging studies (using Magnetic Resonance Imaging) observe a smaller total brain volume in individuals with FASD (Lebel et al., 2011). Changes to specific brain structures are summarized in **Table 4.6**. based on research evidence (Fryer et al., 2009; Guerri et al., 2009; Moore et al., 2014; Noland et al., 2003; Riley & McGee, 2005; Spadoni et al., 2007).

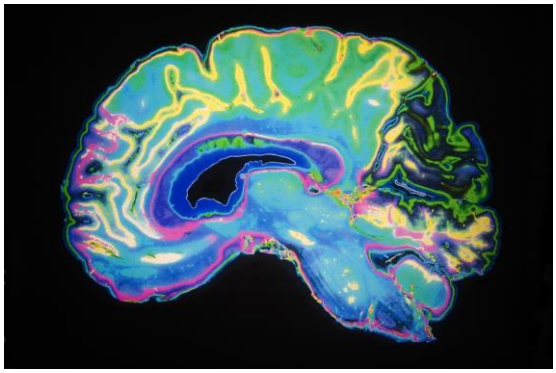


Figure 4.9: MRI of Adult Brain

Table 4.6 also shows the impacts caused by prenatal alcohol exposure result in lifelong deficits, which can affect multiple aspects of development. For example, Spadoni et al. (2007) suggest that the impact on the frontal and parietal regions is consistent with the functional and behavioural effects often associated with FASD. Common effects are challenges with executive functioning, which are associated with poor planning, rigid thinking, reduced behavioural inhibition, and problems with memory. For more information about the primary impacts associated with FASD, see **Module 8: FASD & Primary Disabilities**. This type of research highlights how important it is to remember that behaviours commonly associated with FASD are the result of impacts to corresponding areas of the brain.

Table 4.6: Impact of Alcohol Exposure on the Fetus

Brain Area	Role	Potential Impact due to Alcohol	Negatively Impacts
Corpus Callosum	• Passes information between the two hemispheres	• Failure to grow (agenesis) • Shift in location (displacement) • Smaller size • Variability in shape	• Coordination of both sides of the body, attention, problem-solving, and verbal memory
Cerebellum	• Controls muscle coordination, movement, attention, and memory	• Smaller size • Displacement	• Balance, coordination of both sides of the body, attention, verbal learning, and memory
Basal Ganglia	• Controls fine motor movements • Important for perception	• Reduced volume	• Movement, procedural learning, executive functioning (working memory, planning, cognitive flexibility, verbal reasoning), attention, and response inhibition
Cerebral Cortex/Grey and White Matter	• Contains nerves that transfer information around the brain	• Reduction in the amount of white matter • Abnormalities in density and distribution • Significant reduction in grey matter structures	• Executive functioning • Visual-motor skills
Thalamus	• Relay station for incoming information (nerve impulses)	• Reduction in volume and density • Decreased blood flow through the brain • Decreased dopamine and serotonin neurotransmission	• Communication of sensory and motor information • Motor coordination • Control of emotion and inhibition

Magnetic Resonance Imaging (MRI) of living brains shows smaller overall brain size in people with FASD and uneven reductions in the size of certain brain structures such as the corpus callosum, basal ganglia, and cerebellum (Lebel et al., 2011; Nunez et al., 2011; Spadoni et al., 2007). Prenatal alcohol exposure is the major cause of impaired development of the corpus callosum and, in some instances, this structure is not there (National Institute on Alcohol Abuse and Alcoholism (NIAAA), 1996; Spadoni et al., 2007; Riley et al., 1995; Swayze et al., 1997). The corpus callosum is the major communication link between the right and left halves of the brain and any abnormalities in this structure can lead to deficits in

attention, intellectual functioning, reading, learning, verbal memory, as well as executive and psychosocial functioning as seen in FASD (Mattson et al., 2001). A smaller cerebellum affects balance, gait, coordination, and cognition (Mattson et al., 2001; Mattson et al., 1996).

Good News! Neuroplasticity

There is good news. Research has shown that the brain is continually changing in its structure and function as a result of experience and stimulation. This is known as neuroplasticity (National Research Council, 2015). Neuroplasticity takes place at multiple levels ranging from an increase in the size of a specific brain region to changes in the production and release of certain chemicals (National Research Council, 2015). For example, if a person learns or practices a skill, the part of the brain responsible for that task grows bigger and more efficient. This enables the person to perform the task even better. It is, therefore, important to enrich the experiences of a child in the early years, while preventing disturbances, to support healthy brain development.

Video: Neuroplasticity (Sentis Brain Animation Series) *https://www.youtube.com/watch?v=ELpfYCZa87g*

In summary, prenatal alcohol exposure can have serious effects on the developing fetal brain. These effects can result in lifelong impacts to function and behaviour challenges. Although the first trimester is a sensitive period for alcohol's teratogenic effects on the fetus, the brain continues to develop throughout the remaining trimesters and can be impacted by exposure to alcohol. It is recommended that women not use alcohol in pregnancy. Women who are unable to stop using alcohol may reduce impacts to the fetus by reducing alcohol use (harm reduction). Women are encouraged to talk with their healthcare providers about their alcohol use.

Prenatal Alcohol Exposure and its Impacts on the Brain

The impacts of prenatal alcohol use on the developing brain can be seen through the behaviour of the individual. There are ten domains of functioning that can be impaired (Cook et al, 2015). The ten domains are as follows, and individuals with suspected FASD are assessed in the following areas:

Table 4.7: Ten Brain Domains

Ten Brain Domains* Associated with FASD Diagnosis**	
Domain	**Example**
1. **Motor skills** – How the muscles move and act	Fine motor skills (small muscles), gross motor skills (large muscles), muscle tone, reflexes, balance, coordination
2. **Neuroanatomy/Neurophysiology** – How the brain and nervous system are built and work	Brain structure, head size, seizure activity

3. **Cognition** – How one learns, understands, and gains knowledge	Thinking, perception, and reasoning
4. **Language** – How one uses and understands language	Ability to hear and interpret language and communicate to others (verbal or nonverbal)
5. **Academic achievement** – How one progresses in school subjects	Includes measures of math, reading, and writing
6. **Memory** – How one stores information and remembers it when needed	Remembering what is heard (auditory) and what is seen (visual) Remembering information over time
7. **Attention** – How one focuses and stays on task, including with those tasks that are less enjoyable or more challenging.	Ability to focus and keep attention, including tasks that are less enjoyable or more challenging Ability to ignore or tune out distractions
8. **Executive function** (“Boss of the Brain’’) – How mental skills are used to get things done	Impulse control, planning, problem solving, organizing, controlling one’s thoughts, following instructions, understanding abstract concepts (e.g., time, value of money)
9. **Affect regulation** – How one controls emotions, reacts to stress, and reacts to different situations	Includes current or possible mental health diagnoses (e.g., depression or anxiety)
10. **Adaptive behaviour, social skills, social communication** – How one manages everyday life and social situations	Ability to take care of oneself (everyday life skills), and respond age-appropriately to others
*** **Sensory** – How one responds to different sensations like touch, movement, sound, smell, sight, and taste When someone is being assessed for a diagnosis of FASD, the person’s response to different sensations such as touch, movement, sound, smell, sight, and taste is not included in the assessment; however, the sensory response can impact all brain domains.	

Prenatal alcohol exposure can harm any of these domains. When developing supports for an individual and family, addressing each domain is key. If a problem occurs, it is important to remember it is a result of alcohol’s impact on the brain. Education and awareness about the impacted brain domains help to develop appropriate supports and strategies. Another key fact to remember is that each individual with FASD has strengths. A strength-based approach helps with self-esteem while addressing concerns or behaviours.

The Teenage Brain – A Time of Further Brain Development

Adolescent Brain Development and Alcohol

Although much of the brain's development takes place during fetal development and the first few years of life, adolescence is also an important period of brain development for specific parts of the brain. Adolescence is generally defined as the period between ages 10 to 20. It is a time when there are rapid increases in physical and mental capabilities, many of which occur during puberty (Chartier, Hesselbrock & Hesselbrock, 2010; Dahl, 2004). Research has also shown that the brain continues to mature up until mid-twenties (Lebel, 2008; Tamnes et al., 2017).

Alcohol use during adolescence cannot cause a teenager to develop FASD, as those impacts only occur during prenatal development. However, alcohol can have other effects on the brain, and it is important to educate young people on the possible risks of alcohol use. It is also a time to teach adolescents about the risks of alcohol use during pregnancy.

Many of the changes in the brain during adolescence are based on **grey matter** and **white matter** (Lebel et al., 2008; Tamnes et al., 2010). During adolescence, grey matter will continue to increase in certain parts of the brain while decreasing in others (Lebel et al., 2008; Pfefferbaum et al., 2013). White matter, on the other hand, continues to increase throughout adolescence and adulthood (Lebel et al., 2008; Tamnes et al., 2010).

Other brain structures continue to mature during adolescence. They include:

- **Amygdala**, which is involved in emotion, increases in size (Zehr et al., 2006; Giedd et al., 1996)
- **Hippocampus**, which is involved in short-term memory, increases in size (Suzuki et al., 2004; Giedd et al., 1996)
- **Basal ganglia**, which is involved in movement and higher cognitive functions, decreases in size (Mattson et al., 1996)
- **Corpus callosum**, which connects the two hemispheres of the brain, continues to develop (Giedd et al., 1999)
- **Cerebellum**, which is responsible for higher cognitive functioning, movement, language, and emotion, continues to develop throughout adolescence and adulthood (Diamond, 2000)

These brain changes are all part of the typical development of the adolescent brain. When alcohol is introduced during adolescence, it can cause this development to stop, or can cause abnormal development to occur (Patton & Viner, 2007; Bava & Tapert, 2010).

The Canadian Low-Risk Alcohol Drinking Guidelines (LRDG) provide recommendations on how individuals can lower their risk of chronic (long-lasting) effects if they decide to use alcohol. The LRDG suggests that young people should delay drinking as long as possible. Waiting until age 24 is best (Butt et al., 2011; Canadian Centre on Substance Use and Addiction (CCSA), 2018). This will reduce harm to a young person's brain and body. The guidelines also suggest that young people should never have more

than 1 to 2 drinks on one occasion, and never drink more than 1 to 2 times a week (Butt et al., 2011; CCSA, 2018).

The following brain changes have been found in adolescents who use alcohol:

- Neurotransmitter disruption (glutamate, NMDA receptors, GABA, dopamine, serotonin, etc.) (Crews et al., 2007), which can have multiple effects on the body, such as sleep disruption, increased possibility of alcohol dependence, and changes to the body's reward system
- Smaller prefrontal grey and white matter volumes (Crews et al., 2007), which can lead to poorer cognitive functioning (Brown & Tapert, 2004; Bava & Tapert, 2010) and poorer verbal learning
- Smaller hippocampus volumes which can affect memory and learning (Schweinsburg et al., 2010; Bava & Tapert, 2010)

For more information on alcohol use during adolescence, especially the behavioural effects and risks involved, see **Module 5: The Role and Impact of Alcohol in Canada**.

Conclusion

The brain is very complex. It works to coordinate thought, movement, and action through the use of neurotransmitters. During each trimester of pregnancy, there are specific changes that occur in the brain and body of the fetus. There are critical periods where alcohol has the potential to cause the most harm, which can lead to later effects in social, behavioural, and developmental functioning.

Although much of the brain's development takes place prenatally and in infancy, it continues to develop throughout adolescence and into the mid-twenties. Alcohol use can cause lasting lifelong impacts and changes to the brain. Awareness of the risks that alcohol has at any age and taking measures to reduce those risks are beneficial.

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