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ESSENTIALS OF
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FOR NURSING PRACTICE
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This section of the book focuses on control and coordination of body function through the nervous and endocrine systems. It builds on the introduction to the nervous and endocrine systems in Chapter 1 and consists of the following three chapters:

- **Chapter 5. The Nervous System: Control of Body Function**
  The nervous system is one of the two main control systems of the human body. It receives nervous impulses from the external surface of the body and the internal structures, integrates this information and sends nervous impulses to initiate activity of muscles and glands (both voluntary and involuntary). This system acts rapidly.

- **Chapter 6. Special and General Senses: Responding to the Environment**
  This chapter examines the range of different special sense organs (for vision, hearing and balance, taste and smell) and their function. It also considers the general senses – many located in the skin but some in the interior of the body. These include the senses of touch (pressure, vibration and proprioception), pain and heat.

- **Chapter 7. The Endocrine System: Control of Internal Functions**
  The endocrine system functions more slowly in the regulation of body function. In the classical model of endocrine function, hormones are secreted into the blood stream and carried round the body to the target organs where they link with receptors on the cell membrane (or in the cell nucleus) which alter cell function. More recently a number of different modes of function have been identified and are discussed. The endocrine system regulates a range of different bodily functions.
THE NERVOUS SYSTEM
CONTROL OF BODY FUNCTION

UNDERSTAND: KEY CONCEPTS

Before working through this chapter, you might find it helpful to watch the following video clips.
The URLs for these external videos can be accessed via the companion website https://edge.sagepub.com/essentialaandp. For eBook users, just click the play button.

LEARNING OUTCOMES

When you have finished studying this chapter you will be able to:

1. Describe the role of the nervous system in maintaining homeostasis
2. Describe the different kinds of nervous tissue and their roles
3. Explain how nerve cells communicate
4. Outline the structures and divisions of the nervous system, including the role of functional areas
5. Describe how the brain and spinal cord are protected and nourished
6. Discuss the interface between the nervous system, cognition and mental health
INTRODUCTION

This chapter will discuss the role and functions of the nervous system in contributing to the maintenance of homeostasis, including its relationship with and regulation of other systems in the body. You will learn about cells of the nervous system (neurons and neuroglia), how they communicate through transmission of nervous impulses and support each other, and how the nervous system is structurally and biochemically protected. This chapter will also return to the structural and functional divisions of the nervous system previously introduced in Chapter 1. Additionally, this chapter will enable readers to make links between body and mind through looking at the interface between the nervous system, cognition and mental health. This approach will help readers to place their knowledge and understanding within the perspective of the Person-Centred Practice Framework.

As the nervous system is a major control system in the body, this chapter contains a lot of information that you will need to learn. As a result, it is structured as follows:

1. Roles and functions of the nervous system in maintaining homeostasis.
2. Nerve cells.
3. Organisation of the nervous system:
   i. The Central Nervous System (CNS);
   ii. The Peripheral Nervous System (PNS).
4. Nutrition and protection of the nervous system.
5. Consciousness and sleep.
6. The nervous system and personhood.

The order of the content is set out in a way that will ensure you can understand information readily as you work through the chapter. For example, it is important to understand nerve cells before knowing how they communicate and are organised in the body.

Context

The nervous system is central to who we are as functioning, living, feeling people. It shapes who we are, how we experience life and how we function physically, socially and emotionally. As we go through the journey of life, the nervous system develops, and continues to develop, coordinating our development, influencing our life choices and cataloguing our experiences.

This is evident in all members of the Bodie family. Danielle is in the early stages of development – her nervous system is yet to mature. She is learning fast how to coordinate her movements, develop her speech and respond emotionally. Her experiences at this age will influence her mental health, her sense of security and how much she is exposed to learning and development experiences. The young adults of the family (Thomas (30), Derek (29), Michelle and Margaret (27), Kwame (28), Jack (28)), will largely have formed their own personalities and identities. Their development will have been influenced by environment and genetics, and will have guided them into their chosen careers, as it did the mature members of the family. For example, George developed fine motor skills for his job as an engineer. He also needed the ability to analyse and problem solve, all components largely undertaken by the frontal lobe.

Maud needed the ability to communicate well in order to be successful in working with her colleagues as a team when she was a dinner lady. She had to be able to multitask, have good psychomotor skills and to be skilled in calculating and observation. Both George and Maud will have very developed central nervous systems. Its optimal functioning is as relevant now as it was throughout their lives, enabling them to enjoy walking their dog, experience the joy of grandchildren and great-grandchildren,
experience their surroundings and remember key moments in their lives. Almost all of the members of the Bodie family have established meaningful relationships with someone, illustrating they have developed to some degree emotionally, a vital function of the nervous system that is central to quality of life. These are some aspects of the influence the nervous system has on personhood. As you work through this chapter, you will learn to apply this system more and consider influences on your practice as a person-centred nurse.

**ROLE AND FUNCTIONS OF THE NERVOUS SYSTEM IN MAINTAINING HOMEOSTASIS**

The major functions of the nervous system are to maintain homeostasis by:

- receiving information and transmitting it to the central nervous system for processing,
- integrating and analysing the different sources of information,
- making decisions,
- sending instructions to the muscles and glands of the body to:
  - carry out voluntary movement,
  - influence endocrine function (Chapter 7),
  - regulate unconscious activities through the autonomic nervous system.

So how does the nervous system contribute to homeostasis? Largely, the nervous system responds to the internal and external environment. It does this by being one of the major coordinating systems of the body, with the brain acting as the coordinating centre (Figure 5.1). The brain receives information from both outside and inside the body, integrates the information received and coordinates the response which is carried out through the actions of muscles and glands. Information to and from the brain is carried by nerve fibres that transmit impulses very quickly and result in an extremely rapid response.

**Figure 5.1  The nervous system as a control system**

The nervous system does not work alone in coordinating activities within the body: it is integrated very closely with the endocrine system whereby the hypothalamus acts as the control centre while also being part of the nervous system. This is discussed further in Chapter 7.
NERVE CELLS

In order to understand how the nervous system operates as a control system, it is necessary to understand how the different cells within the brain are structured and how they work. The nervous system is composed of two major types of nerve cells, neurons and neuroglia (Table 5.1).

Table 5.1  Types of cells in the nervous system

<table>
<thead>
<tr>
<th>Nervous system cell</th>
<th>Location</th>
<th>Subtype</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurons</td>
<td>Central and peripheral nervous system</td>
<td>Unipolar, bipolar or multipolar</td>
<td>To generate action potentials for sending and receiving information</td>
</tr>
<tr>
<td>Neuroglia</td>
<td>Central nervous system</td>
<td>Astrocytes</td>
<td>Secure neurons to their blood supply. Regulate external chemical environment of neurons by removing excess ions (such as potassium) and promote re-uptake of neurotransmitters released during synaptic transmission. Form blood brain-barrier</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microglia</td>
<td>Specialised macrophages capable of phagocytosis. Thus, they protect neurons from pathogens</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ependymal cells</td>
<td>Thought to be stem cells in the nervous system. Create and secrete cerebrospinal fluid (CSF) and circulate it by cilia activity. A role in reabsorption of CSF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oligodendrocytes</td>
<td>Produce myelin to coat axons of neurons</td>
</tr>
<tr>
<td></td>
<td>Peripheral nervous system</td>
<td>Schwann cells</td>
<td>Produce myelin to coat axons of neurons. Protective role - phagocytotic and remove debris to allow growth and regrowth of neurons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satellite cells</td>
<td>Regulate external chemical environment of neurons, particularly calcium ions. Thought to play role in chronic pain as they are sensitive to injury and inflammation</td>
</tr>
</tbody>
</table>

Neurons are invaluable cells within the nervous system. They are often referred to as nerve cells and their function is to rapidly transmit information to, from and within the brain and spinal cord. The number of neurons in the central nervous system is estimated as being 100 billion, supported by one trillion neuroglial cells (Woolsey et al., 2008). When neurons connect together, they form neural networks.

Neurons use the most energy in the brain, particularly for synaptic transmissions whereby one neuron triggers another (Harris et al., 2012). Glucose is the primary source of energy alongside lactate oxidation (Wyss et al., 2011) with 93% of ATP generated by neuronal mitochondria and the rest from glycolysis (Harris et al., 2012).

Neuroglia cells are very different to neurons in both structure and function. They are smaller than neurons and almost ten times more numerous. Their role is largely a supportive one. They provide oxygen and nutrients to neurons, create a barrier between one neuron and another, provide structural support to neurons and protect neurons by destroying pathogens. They also remove dead neurons. Additionally, they are now known to support the process of a neuron’s nervous impulse (action potential), regulating the uptake of neurotransmitters back into the neuron from the synaptic cleft (gap between
two communicating neurons), and also playing an important role in the growth and repair of neurons. A neurotransmitter is a chemical released by a neuron to transmit an impulse across the synaptic cleft (gap between two communicating neurons) to another neuron.

Neurons communicate by sending nervous impulses, known as action potentials, through the cell. This passes from one cell to another by either an electrical or chemical transmission across the gap between two neurons enabled by the structure of the neuron.

**Structure of the neuron**

The neurons’ structure allows them to communicate efficiently and effectively throughout the body. Figure 5.2 shows a typical neuron in the peripheral nervous system. The nucleus is large and directs the metabolic activities of the cell, including protein synthesis. The nucleus is located in the cell body, which has projections from it known as dendrites which receive information from the connecting neurons. The cell body also contains neurofibrils (neurofilaments), exclusively found in neurons, which contribute to the transport of cellular material and facilitate axon movement and growth. The axon distinguishes the neuron and is a long projection which carries action potentials. It is surrounded by Schwann cells (peripheral nervous system) or oligodendrocytes (central nervous system) forming the myelin sheath insulating the axon and preventing passive movement of ions across the cell membrane. The Nodes of Ranvier are gaps between areas of myelination on the axon where ions can easily flow into the extracellular fluid (ECF). The end of the axon (axon terminal) contains synaptic vesicles holding neurotransmitters.

How is information transmitted?

**Action potential**

Nervous impulses are transmitted by action potentials along the axon. At rest all cells have a potential difference, i.e. a differing electrical charge, across the cell membrane due to the distribution of the electrolytes in the Intracellular Fluid (ICF) and ECF with the ICF at a lower charge than the ECF (indicated by the negative charge). Neurons have a potential difference of ~70 mV (millivolts). Neurons are specialised to be able to change this electrical charge difference, enabling them to produce an action potential, and then return it to its original state (Figure 5.3). This is action on the potential difference and explains why a nervous impulse is called an action potential.

An action potential has three stages:

1. **Depolarisation.** A stimulus makes the cell membrane more permeable to sodium which, attracted by the negative charge in the cell, allows a small amount of sodium into the cell. If depolarisation is large enough, the sodium channels open, allowing considerably more sodium to pass down the concentration gradient through the cell membrane into the neuron. The potential difference moves towards a positive value: the maximum positive value that can be reached is the action potential and for most neurons is +40 mV. Depolarisation triggers adjacent sodium channels to open, and then the action potential progresses along the axon. When the potential difference reaches +30 mV, sodium channels are inactivated, stopping more sodium moving into the neuron.

2. **Repolarisation.** As a result of inactivation, sodium channels close. Potassium channels open, causing a rush of potassium out of the neuron to restore the potential difference to negative (~70 mV).

3. **Refractory period.** After repolarisation, the potential difference falls to below ~70 mV and the neuron will not respond to another stimulus for a brief period, the Refractory Period. The sodium–potassium pump moves sodium out of and potassium into the neuron to restore the original resting potential and ionic concentrations.
Figure 5.2 Structure of a neuron
Action potentials pass between the Nodes of Ranvier by saltatory conduction, when electrical activity jumps between the gaps and thus moves more rapidly than along unmyelinated nerve fibres. Synaptic transmission is by neurotransmitters released from one neuron, passing across the synaptic cleft and attaching to receptors on the next neuron. It is important to note that an action potential is an ‘all-or-nothing’ phenomenon in which the change in potential difference must reach a certain level/threshold for the action potential to occur. A stimulus below the threshold will not result in any action potential, and a stimulus above the threshold will produce a full action potential.

Synaptic transmission

Once the action potential reaches axon terminals, it crosses the synaptic cleft for the signal to continue in another (the post-synaptic) neuron. Synaptic transmission starts in the synaptic knob and ends in the dendrite of the receiving neuron. There are two types of synaptic transmission, electrical and chemical.

**Electrical:** In electrical synaptic transmission, the gap between the axon terminal/synaptic knob and the dendrite is much smaller than in a chemical synaptic transmission. This is known as a gap junction, which contains gap junction channels which cross the membranes of both neurons (sending and receiving) (Figure 5.4). These permit ions and small molecules to flow from one neuron to the other, enabling depolarisation.
Chemical: Chemical synaptic transmission is the more usual form of transmission. It is slower and more complex (Figure 5.5):

1. Depolarisation triggers synaptic vesicles filled with neurotransmitters to merge with the pre-synaptic membrane.
2. Calcium channels open in the pre-synaptic membrane, calcium moves into the synaptic cleft and triggers the synaptic vesicles to release the neurotransmitter into the synaptic cleft.
3. Neurotransmitters diffuse across the synaptic cleft and interact with receptors in the post-synaptic membrane, the stimulus for triggering an action potential in the receiving neuron.
4. Neurotransmitters are either broken down in the synaptic cleft or reabsorbed from the ECF by astrocytes, which return them to the neuron for reuse, or are reabsorbed directly back into the synaptic knob.

**Neurotransmitters**

Neurotransmitters are the chemical messengers in the nervous system. There are four main types (see Table 5.2), and each neurotransmitter has a specific action.

**ORGANISATION OF THE NERVOUS SYSTEM**

Neurons and neuroglia make up the nervous system. Neuronal cell bodies are organised in identified groups (ganglia) or layers as in the cerebral cortex. The axons form pathways between the different parts...
of the nervous system (nerve tracts) or between the nervous system and other parts of the body (nerves). The nervous system is divided into the CNS and PNS (Figure 5.6).

### Table 5.2 Neurotransmitters

<table>
<thead>
<tr>
<th>Class of neurotransmitter</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acetylcholine</strong></td>
<td>Normally an excitatory function (sympathetic nervous system) Parasympathetic effect on some organs (e.g. reduces heart rate) Sometimes classed as a monoamine</td>
</tr>
<tr>
<td><strong>Monoamines (biogenic amines)</strong></td>
<td>Synthesised from amino acids Include catecholamines such as adrenaline (epinephrine) and noradrenaline (norepinephrine) Thought to mediate emotion, arousal and cognition</td>
</tr>
<tr>
<td><strong>Amino acids</strong></td>
<td>Inhibitory Amino Acids (IAA) or Excitatory Amino Acids (EAA) Glycine and glutamate are two amino acids neurotransmitters Glycine is inhibitory in the spinal cord, brainstem and retina Glutamate is excitatory and involved in learning and memory</td>
</tr>
<tr>
<td><strong>Neuropeptides</strong></td>
<td>Neuropeptides work at lower concentrations and are not recycled Effects last longer than other neurotransmitters Associated with analgesia, metabolism, reproduction, social behaviours, learning and memory</td>
</tr>
</tbody>
</table>

Nerve fibres are grouped in tracts or pathways. Two major tracts are:

- the corpus callosum which joins the two sides of the brain
- the internal capsule which consists of both sensory and motor fibres that carry information to and from the cerebral cortex.

### Grey matter

The grey matter (nerve cell bodies) is distributed mainly around the outside of the brain with a convoluted surface to increase the number of brain cells which can fit within the surface area of the brain. This part of the brain is concerned with higher functions and specific parts have different functions. There are also clumps of grey matter deep within the brain with specific functions, mainly those not under conscious control. In evolutionary terms, these are the older parts of the brain.

### White matter

The white matter (nerve cell axons) connects different parts of the brain, carrying entering information to the appropriate parts of the brain, and carrying instructions out of the brain. Much of the white matter runs in clearly defined tracts.

The spinal cord connects to the base of the brain and runs down within the spinal column. The distribution of grey and white matter is different from within the brain. Grey matter is within the centre of the spinal cord with nerve axons running in tracts around the outside.
THE NERVOUS SYSTEM

Central Nervous System

Brain and Spinal Cord

Peripheral Nervous System

Sensory

Carries information from sensory receptors and special sense organs to the CNS

Motor

Somatic Nervous System

Innervates skeletal muscles under voluntary control

Autonomic Nervous System

Involuntary regulation of muscles and glands

Sympathetic Division

Tends to be excitatory, speeding processes up, with some exceptions

Parasympathetic Division

Tends to be active in relaxation, slowing processes down. Exceptions exist

Figure 5.6 Organisation of the nervous system
THE CENTRAL NERVOUS SYSTEM

The structure of the brain

In the textbooks, the structure of the brain is described in two main ways (Figure 5.7). In this book, we are using Structure 1. Figure 5.8 shows the parts of the brain.

Structure 1

<table>
<thead>
<tr>
<th>Forebrain</th>
<th>Diencephalon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thalamus</td>
</tr>
<tr>
<td></td>
<td>Epithalamus</td>
</tr>
<tr>
<td></td>
<td>Hypothalamus (+ pituitary)</td>
</tr>
<tr>
<td>Cerebrum</td>
<td>Cerebral cortex (in lobes)</td>
</tr>
<tr>
<td></td>
<td>Basal nuclei</td>
</tr>
<tr>
<td></td>
<td>Limbic system</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Midbrain</th>
<th>Tracts of nerve fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nuclei of cranial nerves</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hindbrain</th>
<th>Pons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medulla Oblongata</td>
</tr>
<tr>
<td></td>
<td>Cerebellum</td>
</tr>
</tbody>
</table>

Structure 2

<table>
<thead>
<tr>
<th>Diencephalon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thalamus</td>
</tr>
<tr>
<td>Hypothalamus</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cerebrum (in lobes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midbrain</td>
</tr>
<tr>
<td>Pons</td>
</tr>
<tr>
<td>Medulla</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Brainstem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pons</td>
</tr>
<tr>
<td>Medulla</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hindbrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diencephalon</td>
</tr>
</tbody>
</table>

Figure 5.7 Structure of the brain

Figure 5.8 Parts of the brain
The forebrain

The forebrain is the largest section of the brain (Figure 5.9). It is associated with control of body temperature, reproduction, eating, sleeping, cognition and emotional responses. It consists of the diencephalon and the cerebrum.

The diencephalon

The diencephalon is composed of the thalamus, hypothalamus and epithalamus:

- **The thalamus**: is a relay centre for nervous impulses moving to and from the cerebrum. It is a large mass of grey matter that is positioned deep within the brain on either side. Except for olfaction, all sensory pathways go via the thalamus to be processed and relayed to the appropriate area of the cerebral cortex. It also has a role in processing painful stimuli, temperature and attention in collaboration with the reticular activating system.

- **The hypothalamus**: lies below the thalamus and includes several nuclei (groups of neuronal cell bodies) and tracts of axons. There are three groups of hypothalamic functions:
  - Control of the autonomic nervous system;
  - Control of the neuro-endocrine system;
  - Control of the limbic system.

- **The pituitary gland** is a small pea-sized extension below the hypothalamus. It is considered to be part of the endocrine system and is the key link between the nervous and endocrine systems (Chapter 7).

- **The epithalamus**: is composed primarily of the pineal gland and the habenula. The habenula is a relay from the limbic system, and deals with sleep, stress, pain and reinforcement processing (Lawson et al., 2013). The pineal gland secretes serotonin during the day and melatonin at night, in regulating the sleep–wake cycle. The large pineal gland in childhood is thought to inhibit the onset of puberty by secreting melatonin in high amounts before shrinking to a small size in adulthood.

Figure 5.9  The forebrain
Thalamic nuclei

Some nuclei in the thalamus have particular roles (Table 5.3).

**Table 5.3 Thalamic nuclei and their roles**

<table>
<thead>
<tr>
<th>Thalamic nuclei</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial geniculate</td>
<td>Relays auditory information from the midbrain to the primary auditory cortex</td>
</tr>
<tr>
<td>Lateral geniculate</td>
<td>Relays visual information from the retina to the visual cortex</td>
</tr>
<tr>
<td>Lateral dorsal</td>
<td>Works with the limbic system to form memories</td>
</tr>
<tr>
<td>Mediodorsal</td>
<td>Works with the limbic system and pre-frontal cortex to manage cognitive processes such as reasoning, thoughts and mood</td>
</tr>
<tr>
<td>Ventrolateral</td>
<td>Relays signals from the cerebellum to the primary motor cortex in coordinating movement</td>
</tr>
</tbody>
</table>

Hypothalamic nuclei

The hypothalamus is a major control system in the body occurring through 11 groups of nuclei regulating numerous homeostatic functions (Table 5.4).

**Table 5.4 Hypothalamic nuclei and their functions**

<table>
<thead>
<tr>
<th>Hypothalamic nuclei</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraventricular</td>
<td>Fluid regulation, anterior pituitary control, production of oxytocin</td>
</tr>
<tr>
<td>Preoptic</td>
<td>Thermoregulation, sexual arousal</td>
</tr>
<tr>
<td>Anterior</td>
<td>Thermoregulation, sexual arousal</td>
</tr>
<tr>
<td>Suprachiasmatic</td>
<td>Circadian rhythms such as the sleep/wake cycle</td>
</tr>
<tr>
<td>Supraoptic</td>
<td>Fluid regulation, anterior pituitary gland control, production of oxytocin</td>
</tr>
<tr>
<td>Dorsomedial</td>
<td>Emotional expression</td>
</tr>
<tr>
<td>Ventromedial</td>
<td>Appetite/hunger, satiety, fear and aggression</td>
</tr>
<tr>
<td>Arcuate</td>
<td>Growth, dopamine release</td>
</tr>
<tr>
<td>Posterior</td>
<td>Thermoregulation</td>
</tr>
<tr>
<td>Mamillary</td>
<td>Emotion (via the limbic system) and recognition memory</td>
</tr>
<tr>
<td>Lateral</td>
<td>Hunger</td>
</tr>
</tbody>
</table>

The cerebrum

The cerebrum consists of the cerebral cortex (grey matter) and underlying white matter, the basal nuclei and the limbic system. The cerebral cortex and some of the underlying white matter are folded in gyri to maximise surface area. A deep fissure divides the cerebrum into two halves, the cerebral hemispheres. It is further divided by folds (sulci) into five functional lobes (Figures 5.10a and 5.10b).
Cerebral cortex

1. **The frontal lobe.** This regulates voluntary control of movement, including learned complex movement. Planning and sequencing of movement occurs in the pre-motor cortex. The primary motor cortex enables muscles to work in synergy for coordinated movement. The neuronal axons from the primary motor cortex extend to the spinal cord and down to connect with the spinal nerves. Brocca’s area, associated with motor actions of speech such as word formation including articulation, pronunciation and expression, is also in the frontal lobe. The pre-frontal cortex is primarily involved with higher cognitive functions (reasoning, understanding, foresight and thinking). It has extensive connections with the other lobes of the cerebral cortex, and is thus associated with personality.

![Figure 5.10a  Lobes of the brain](image1)

![Figure 5.10b  Divisions of the brain](image2)
2. **The parietal lobe.** This area processes sensory information. The primary somatosensory cortex processes sensations of touch, vibration and proprioception (awareness of position) and is conveniently located beside the primary motor cortex. This enables the brain to respond rapidly. The somatosensory association area processes stereognosis – the recognition of an object by feeling shape, texture and temperature. Spatial perception, that is interpreting the nature of objects in the environment, including recognition of images and shapes, is processed in the parieto-occipital association areas, largely in the right parietal lobe. The left parietal lobe contributes to calculations, writing and reading. Finally, the optic nerve pathways pass through the parietal lobe.

3. **The occipital lobe.** This deals with visual stimuli, recognising, interpreting and finally memorising objects.

4. **The temporal lobe.** This focuses on processing the special senses, particularly taste (gustation), smell (olfaction) and hearing (audition). Additionally, it has roles in learning, memory, visual recognition and emotional actions. The primary auditory cortex interprets volume and tone of sound, and links with Wernicke's area to interpret spoken language. Wernicke's area is also associated with the production of spoken language. The medial areas of the temporal lobe integrate into the limbic system in relation to learning, memory and emotion.

5. **Insular lobe.** This is often referred to as the fifth lobe. It is a small area of dense tissue positioned under the temporal, frontal and parietal lobes and located under arteries and veins, making it difficult to isolate and access. Its limited accessibility has resulted in little understanding of its functions. They are thought to include (Stephani et al., 2011):
   - Thermosensation (perception of temperature),
   - Nociception (perception of pain),
   - Somatosensation (sensations originating mainly in the skin including proprioception, touch and temperature),
   - Viscerosensation (sensations originating in internal organs including pain, palpitations and spasms),
   - Gustation (taste).
   It is also thought to have a role in human emotions and associated behaviours.

**Basal nuclei**

The basal nuclei (or basal ganglia) refer to nuclei of grey matter buried within the white matter. These include the corpus striatum (caudate nucleus, putamen and globus pallidus), the substantia nigra and the subthalamic nucleus. The basal ganglia have an important role in motor and thought control and generally inhibit muscle tone.

**The limbic system**

This borders the brainstem and focuses on emotional state, instinct and motivation/drive. It has links into the olfactory system, the hypothalamus, the midbrain and the reticular formation. The structures of the limbic system include:

1. **The amygdala.** This contributes to storage of emotional experiences as memories and regulates emotional learning. It is associated with responding to stimuli that are potentially harmful/threatening, processing distress, and recognising and evaluating other emotive stimuli such as facial expressions (Sergerie et al., 2008).

2. **The hippocampus.** The hippocampus is primarily associated with formation of memory, including short-term (working) and long-term memory. Short-term memory works on quick recall over seconds and minutes, whereas long-term memory involves memory consolidation. Long-term memory can be subdivided into declarative memory (recalling personal experiences and language) and procedural memory (related to learning and recalling how to complete a task). The hippocampus facilitates
declarative memory, whereas the basal nuclei facilitate procedural memory. The hippocampus also organises sensory and cognitive experiences for storage in the frontal and temporal lobes of the cerebral cortex.

3. The **septum pellucidum**. Situated between the lateral ventricles at the midline of the brain, this contains no grey matter but comprises myelinated axons connecting parts of the limbic system (Raybaud, 2010). Its role is therefore unclear but when it is damaged or malformed people experience disorders relating to rage, pleasure and mood as it links parts of the limbic system that control these.

4. The **cingulate gyrus**. The cingulate gyrus is thought to integrate emotion and sensory experiences, for example the sensation of pain and the emotional response (e.g. distress, anger).

5. The **insula**. The insula (or insular lobe) is discussed previously under the lobes of the brain.

6. The **parahippocampal gyrus**. This structure of the limbic system works with the hippocampus in processing declarative memory.

7. **Mamillary bodies**. Although not fully understood, the mamillary bodies (sometimes spelt mammillary) are thought to be a relay centre with a distinct role in memory operations (Tagliamonte et al., 2015).

**Midbrain**

The midbrain joins the part of the brain containing the thalamus and hypothalamus with the pons which links to the lowest part of the brain, the medulla oblongata (Figure 5.11). These parts of the brain contain the nuclei for the cranial nerves described later. The midbrain consists of:

- Tracts of nerve fibres
- A number of nuclei of cranial nerves.

![Figure 5.11  The midbrain](image)

An important component is the substantia nigra, which works with the basal nuclei to regulate movement through inhibiting the neurotransmitter/hormone dopamine produced in the substantia nigra. The cranial nerves responsible for eye movement originate in the midbrain, as do nuclei for the response to auditory and visual stimuli, such as turning your head to respond to a sound or visual stimulus. Corticospinal tracts pass through the midbrain on their way to the medulla, and reticulospinal tracts associated with the experience of pain are present.
The hindbrain

The hindbrain (Figure 5.12) is composed of:

- the pons,
- the medulla oblongata (or medulla),
- the cerebellum.

![The hindbrain](image)

**Figure 5.12** The hindbrain

Pons

The pons is in front of the cerebellum, below the midbrain and above the medulla. It consists mainly of nerve fibres which connect the two hemispheres of the cerebellum and fibres passing between the higher levels of the brain and the spinal cord. There are nuclei within the pons which act as relay stations and some are associated with cranial nerves. The pons also has a role in regulating breathing through the pneumotaxic and apneustic centres (Chapter 12).

Medulla oblongata

The medulla links the brain with the spinal cord and fits just within the cranium. As with the spinal cord, the grey matter lies centrally with the white matter surrounding it. Some nuclei act as relay stations for sensory information coming from the spinal cord. An area in the medulla, known as the pyramids due to its shape, is where the corticospinal and some sensory pathways cross over from left to right and vice versa. This is termed decussation, and is why the right cerebral cortex regulates movement in the left-hand side of the body and vice versa.

Also within the medulla are a number of vital centres which are concerned with coordination of the autonomic nervous system. These are the:

- Cardiac centre, regulating heart rate and force of contraction,
- Respiratory centre, or rhythmicity centre, regulating the pattern of breathing,
- Vasomotor centre, regulating the diameter of blood vessels,
- Reflex centres of vomiting, coughing, sneezing and swallowing.
The medulla and monitoring health status

The medulla could be thought of as the nurses’ friend. Its role in maintaining homeostasis means that it can tell us when something is wrong in the body. For example, if a person is in pain, the cardiac centre may increase heart rate and the respiratory centre the rate of breathing. This could happen if the person is in physiological shock from bleeding, for example. Vomiting may be a sign of gastrointestinal infection. The body automatically tries to compensate for illness, and these compensations are vital sources of data for the nurse to identify and interpret.

Cerebellum

The cerebellum coordinates the muscles of the body and regulates muscle tone and posture. In effect, it contributes to the fine tuning of motor commands and sensorimotor adjustment needed for motor learning (Brooks and Cullen, 2013). It achieves this through information about muscle stretch, position of parts of the body and other coordinating information from the pons and cerebral cortex. It relays back to the thalamus and cerebral cortex to respond appropriately. A role in cognition has been confirmed, with the cerebellum now known to both send and receive information to non-motor regions of the cerebral cortex. This includes pre-frontal areas that regulate higher cognitive functions (Buckner, 2013).

ACTIVITY 5.3: APPLY

Neurological control and occupation

Think about George Bodie. Why would an effectively functioning cerebellum be important in his career and in his pursuit of leisure activities now?

Reticular activating system

The Reticular Activating System (RAS) is composed of a number of nuclei that connect throughout the forebrain, midbrain and hindbrain. It controls arousal mechanisms used in maintaining consciousness and awake states essential for selective attention and purposeful responses. Arousal regulation is not confined to the RAS; neural pathways descend to the spinal cord and ascend to the cerebral cortex, refered through the thalamus and the suprachiasmatic nuclei (pair of neuron clusters in the hypothalamus situated directly above the optic chiasma of the hypothalamus). Through these processes the sleep–wake cycle is regulated.

The RAS contains the reticular formation, a core of nerve cell bodies which extend from the spinal cord up through the medulla, pons and midbrain to the hypothalamus and thalamus and with connections to the cerebral cortex. Functions of the reticular formation include:

- Skeletal muscle tone,
- Autonomic control as it forms part of the cardiovascular and respiratory centres in the pons and medulla,
- Somatic and visceral sensations, such as pain.

---

1Point at the base of the brain where the optic nerves cross over each other.
2Sensations from the body surface (skin) or musculoskeletal tissues.
3Sensations from the internal organs.
THE SPINE AND SPINAL CORD

When we refer to the spine, we are referring to the spinal (or vertebral) column and the mechanical structures that it is composed of, such as the vertebrae and the ligaments and tendons that connect them together (Chapter 15). The spinal cord refers to the neural tissue encased within the spine which runs from the medulla, where it joins the brain at the level of the foramen magnum (the opening on the underside of the skull), to the level of the first or second lumbar vertebrae.

Spinal cord

The spinal cord runs down through the space in the spinal vertebrae within three groups of neurons:

- **Ascending (afferent) neurons** carrying information up the spinal cord to the brain for processing.
- **Descending (efferent) neurons** carrying instructions down the spinal cord from the brain to the muscles and glands of the body.
- **Interneurons (association neurons)** acting as connections between descending and ascending neurons.

The spinal cord is an extension of the brain from the medulla with two main enlargements. The cervical enlargement (through the brachial plexus) provides neurons for the arms, and the lumbar enlargement (through the lumbosacral plexus) provides neurons for the legs. Below this, the cord narrows into a conical shape, the conus medullaris. Nerves resembling a horse’s tail (called the cauda equina) extend further down to the sacrum.

Spinal grey matter

The grey matter of the spinal cord is set out in an H shape and is divided into ‘horns’ (Figure 5.13):

1. **Anterior (ventral) horn.** This contains cell bodies of the somatic motor nerves that stimulate skeletal muscle. These run the length of the spinal cord.
2. **Posterior (dorsal) horn.** This contains cell bodies of the somatic and autonomic sensory (afferent) neurons running the length of the spinal cord.
3. **Lateral horns.** This grey matter contains cell bodies of the autonomic motor nerves that stimulate smooth muscle, cardiac muscle and glands. They run from T2 to L1 and link with the thoracolumbar ganglia running alongside the spinal cord and supplying the sympathetic nervous system.

![Figure 5.13  Grey matter of the spinal cord (horns)](image-url)
Spinal white matter

White matter surrounds the grey matter and is structured into three columns: the anterior, posterior and lateral columns. They are then subdivided into tracts – distinct sets of fibres going to or from the same place. The name of the tract indicates its path; for example, the corticospinal tract carries information from the cortex to the spinal cord.

THE PERIPHERAL NERVOUS SYSTEM (PNS)

The PNS refers to the nerves and ganglia outside the CNS, largely the cranial and spinal nerves. The PNS carries information to and from the CNS where information is processed. Structurally, the PNS is divided into two divisions: the sensory division/system and the motor division/system.

Sensory division/system

This division of the PNS carries sensory information through afferent neurons to the CNS for processing. This includes information from viscera of the thoracic and abdominal cavities (visceral sensations) and the skin, muscles, bones and joints (somatic sensations). Sensory input about the external and internal environments is received in the CNS. Some sensory input is consciously perceived, although considerable information for maintaining homeostasis does not need this level of awareness. Some sensory input is carried directly to the brain by the cranial nerves. Other input enters via the spinal nerves and is carried to the brain in various ascending tracts.

Sensory receptors are organs which convert energy from one form (e.g. heat, light, pressure) into electrical energy which is transmitted through the sensory nerve fibres. The sensitivity to a particular modality (i.e. touch, temperature, etc.) varies with:

- The density of distribution of the specific receptors for that modality/sensation,
- The degree of overlap of receptor fields,
- The size of the receptor fields.

Receptors vary considerably in structure including free nerve endings, specialised cells or within specialist organs (such as in the eye) (Chapter 6).

Many receptors demonstrate decreasing sensitivity to a continued stimulus thus permitting adaptation to, for example, continued pressure. Some receptors respond rapidly, others much more slowly. Electrical activity carrying sensory information is transmitted via sensory neurons to the CNS with most eventually arriving in the brain. Most sensory information is relayed through the thalamus.

ACTIVITY 5.4: APPLY

Sensory fatigue

Decreasing sensitivity in sensory receptors can be easily demonstrated. Have you ever been in a shop that sells scented candles? You can smell the first few very easily but after smelling a lot, you stop being able to differentiate the smells. Test this out the next time you are in a candle shop, or try with common smells at home, like lemons, coffee, etc.
Figure 5.14 Sensory order neurons

1. Stimulus
2. Receptors
3. Afferent neuron
4. Spinal cord or brainstem
5. Second-order neuron
6. Thalamus
7. Third-order neuron
8. Cortex
Receptors are classified in a number of different ways depending on the stimulus detected or the environment monitored. They may be classified as:

- **Enteroreceptors**: the internal environment.
- **Exteroreceptors**: the external environment located in the skin.
- **Proprioceptors**: relative position of parts of the body.

Sensory information is normally carried to the brain through three sets of neurons: first-, second- and third-order neurons (Figure 5.14).

**Sensory pathways**

Sensory pathways are ascending and organised in three distinct groups:

1. **Anterolateral pathways**. Temperature, pain and coarse touch sensations to the brain.
2. **Medial lemniscal pathways**. Discriminative touch, vibration and proprioception sensations to the brain.
3. **Spinocerebellar tracts** (anterior and posterior). Sensations for muscles and tendons (stretch) to the cerebellum to coordinate skeletal muscle movement.

The distribution of cells within the primary somatosensory cortex receive information from the different parts of the body as represented pictorially by the sensory homunculus. Those very sensitive body areas with many sensory receptors (e.g. lips, tongue) appear very large in the homunculus.

### ACTIVITY 5.5: UNDERSTAND

Using a web-based search engine, look up an image of a sensory homunculus. This will show you how parts of the body that are very sensitive have a greater representation in the brain.

**Posture and movement**

For the brain to send the correct instructions to the skeletal muscles, it needs first to receive information about tension and stretch from the various receptors. Sensory information from muscles, tendons and joints passes to the sensory cortex and the cerebellum which provide feedback about the effects of motor activity.

**Motor division/system**

The motor division/system refers to nervous impulses sent from the CNS to cells/organs/muscles to initiate responses. It is subdivided into two subdivisions – somatic (motor) and visceral (autonomic nervous system).

**The somatic nervous system (motor)**

The somatic nervous system is responsible for voluntary (conscious) control of body movements through stimulating contraction of skeletal muscles. The motor cortex controls movement of the opposite side
of the body and gives instructions to move different parts of the body. Efferent neurons carry impulses to the muscles of the skeleton to stimulate muscle contraction and regulate movement. The area of the cortex concerned with movements of different parts of the body for a particular activity is related to the importance of that function. A motor homunculus represents the parts of the body in proportion to the complexity of the movements controlled.

Movement is controlled at two levels through three motor pathways. The parallel direct and indirect pathways are designated as upper motor neurons. Both pathways end on the same motor neuron cell body in the spinal cord and travel to the muscle through the same nerve axon, the lower motor neuron.

1. **Direct (formerly pyramidal) pathway** (Figure 5.15). These upper motor neurons from the cerebral cortex pass down to the spinal cord through the direct pathway, i.e. without any synapses. These impulses travel directly from the brain to the level of the spinal cord where they synapse with the lower motor neuron. They are therefore called corticospinal tracts and carry impulses needed for fast or skilled movement.

2. **Indirect (formerly extrapyramidal) pathway** (Figure 5.16). The indirect pathway consists of all the other nervous input to motor function and also involves upper motor neurons. It is much more complex than the direct pathway. Information travelling through the indirect pathway passes through a series of synapses between some of the basal nuclei, the cerebellum and the motor cortex. It is, thus, slower in carrying information to the lower motor neuron.
   The basal nuclei and cerebellum are concerned with regulation and coordination of movement through moderating the activity of the motor areas of the cerebral cortex and brainstem. The basal nuclei carry out subconscious patterns of previously learnt movement. The cerebellum regulates fine movements through receiving information from receptors concerned with position and movement of the body (eyes, ears – balance, joint and muscle receptors). It also receives information from the motor cortex and compares intended with actual movement and makes adjustments to ensure smooth movement. Limb movement is largely determined through the reticulospinal tracts and balance and posture through the vestibulospinal tracts.

3. **The spinal cord (lower motor neuron)** (Figure 5.17). The spinal cord plays an important part in control of movement. Since both upper pathways (i.e. direct and indirect pathways) end on the same neuron, the motor part of the spinal nerve or lower motor neuron is also known as the final common pathway. The cell body of the lower motor neuron receives and integrates impulses from:
   - The direct and indirect pathways,
   - The sensory nerves carrying information from the tissues at that spinal level,
   - Association neurons carrying information from higher and lower segments of the spinal cord.

Motor instructions are then sent to the muscles supplied by the lower motor neuron.
Figure 5.15  Direct motor pathways

Figure 5.16  Indirect motor pathways
Reflexes

The spinal reflexes are important in coordination of movement at a subconscious level. More complex reflexes involve spinal segments and the associated nerves higher and lower in the spinal cord and/or on the opposite side of the spinal cord ensure correct coordination. The spinal cord also contains neural circuits that create walking movements.

A reflex arc exemplifies integration and coordination at the level of the spinal cord. It enables a very rapid response to noxious stimuli (Figure 5.18). More complex reflexes involve spinal segments and associated nerves higher and lower in the spinal cord and/or on the opposite side of the spinal cord. This ensures that actions are coordinated correctly. For example, if you stand on a drawing pin, the simple
reflex will withdraw your foot very rapidly and would result in you falling over. The complex reflexes associated with this simple reflex ensure that your other leg and body adjust their position so that you keep your balance and do not fall over.

The autonomic (visceral motor) nervous system

The autonomic nervous system is a subconscious control system for visceral organs including those of the circulatory, digestive and respiratory systems. Most of the pathways in the autonomic nervous system are motor pathways, but include some sensory pathways, indicating that the autonomic nervous system works in synergy with the sensory system in places. While technically part of the peripheral nervous system, the autonomic nervous system has elements in the CNS. Cranial and spinal nerves innervate the visceral organs, but the hypothalamus and medulla represent the control centres for the autonomic nervous system.

The autonomic nervous system has two divisions, the sympathetic and the parasympathetic nervous systems. Although anatomically and functionally different, both divisions normally stimulate the same organs. The sympathetic and parasympathetic nervous system work in harmony to maintain homeostasis. For example, when you are exercising, the sympathetic nervous system raises your heart rate. Following exercise, it is slowed by the parasympathetic nervous system. Of course, both are working in synergy to ensure the heart rate continues to meet the body’s needs and is neither too fast nor too slow.

**ACTIVITY 5.7: UNDERSTAND**

In order to further your understanding of the autonomic nervous system, watch this online video clip.

This video can be accessed via the companion website https://edge.sagepub.com/essentialaandp. For eBook users, just click the play button.

Parasympathetic nervous system

The parasympathetic nervous system mainly slows activities (the ‘rest and digest’ system) including:

- Slowing and pacing the heart rate,
- Constricting coronary arteries,
- Constricting bronchioles in the respiratory system,
- Reducing respiratory rate,
- Increasing motility of the digestive system and release of enzymes for digestion,
- Promoting conversion of glucose to glycogen to create an energy store,
- Relaxing gastrointestinal sphincter muscles to facilitate movement of gastrointestinal contents,
- Relaxing the internal urethral sphincter muscle and contraction of the bladder to permit urination/micturition,
- Constricting pupils and bulging the lens of the eye to permit close vision.

The vagus nerve plays a particularly important role in the parasympathetic system.
**Sympathetic nervous system (SNS)**

The sympathetic nervous system speeds activities through the fright, flight or fight response. Noradrenaline (norepinephrine) is the principal neurotransmitter in the SNS. Some activities include:

- Increasing rate and force of myocardial contraction,
- Vasodilating the coronary arteries,
- Dilating the respiratory bronchioles,
- Increasing respiratory rate,
- Reducing the motility of the digestive system and release of digestive enzymes,
- Constricting gastrointestinal sphincter muscles to reduce gastrointestinal activity,
- Promoting conversion of glycogen to glucose for energy for increased activity,
- Constricting the internal urethral sphincter muscle and relaxing the bladder to reduce urination,
- Producing renin for raising blood pressure (Chapter 12),
- Dilating pupils to increase light entering the eye for visual accuracy,

**Structure of the autonomic nervous system**

Through the sympathetic ganglion chain running either side of the spinal cord, the sympathetic nervous system innervates organs through thoracic and lumbar spinal nerves, whereas the parasympathetic nervous system uses cranial nerves and sacral spinal nerves (Figure 5.19).

---

**APPLY**

**Autonomic imbalance**

The structure of the autonomic nervous system is important when someone has a spinal cord injury. The level of the injury can mean that some organs may have parasympathetic stimulation but not sympathetic. For example in a cervical cord injury, the parasympathetic stimulus for the heart from the cranial nerves (the vagus nerve) may lead to a slow heart rate and low blood pressure. The sympathetic stimulus from thoracic spinal nerves, below the level of injury, cannot counteract this.

---

**CRANIAL AND SPINAL NERVES**

**Cranial nerves**

Cranial nerves emerge directly from the brain and brainstem whereas spinal nerves emerge from the spinal cord. There are 12 cranial nerves: some all motor, some all sensory, some mixed. The nuclei for the cranial nerves are within different parts of the brain. The nuclei for the first (olfactory) and second (optic) cranial nerves connect with parts of the forebrain concerned with smell and vision. The other cranial nerve nuclei are in the brainstem. However, information entering the brain is sent to various parts of it. The cranial nerves mainly supply muscles and sensory receptors of the face, head and neck. Table 5.5 identifies the function of each cranial nerve, although some work together to control particular actions and interpret different sensations.

The following mnemonic may help you in remembering these nerves: On Old Olympus’ Towering Tops A Finn And German Viewed Some Hops.
Figure 5.19 The autonomic nervous system
<table>
<thead>
<tr>
<th>Cranial nerve</th>
<th>Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Olfactory</td>
<td>(O)</td>
<td>Sensory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Olfaction (smell): originates in olfactory mucosa in nasal cavity, terminates in olfactory bulb beneath the frontal lobe</td>
</tr>
<tr>
<td>II Optic</td>
<td>(O)</td>
<td>Sensory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vision: originates in retina, terminates in thalamus from where information is relayed to the visual cortex</td>
</tr>
<tr>
<td>III Oculomotor</td>
<td>(O)</td>
<td>Motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eye movement: opening eyelids, constricting pupil, focusing sight, proprioception. Originates in midbrain, terminates in muscles moving eye, iris and lens (ciliary muscles)</td>
</tr>
<tr>
<td>IV Trochlear</td>
<td>(T)</td>
<td>Motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eye movement and proprioception. Originates in midbrain, terminates in oblique muscles of the eye</td>
</tr>
<tr>
<td>V Trigeminal</td>
<td>(T)</td>
<td>Motor and sensory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Three divisions, originate in face and terminate in pons:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ophthalmic division: Main sensory nerve of upper face for touch, temperature and pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maxillary division: Main sensory nerve of middle face for touch, temperature and pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mandibular division: Main sensory nerve of lower face for touch, temperature and pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motor function: stimulates the muscles for chewing (mastication)</td>
</tr>
<tr>
<td>VI Abducens</td>
<td>(A)</td>
<td>Motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eye movement. Originates in pons, terminates in lateral rectus muscles of the eye</td>
</tr>
<tr>
<td>VII Facial</td>
<td>(F)</td>
<td>Sensory and motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motor for muscles of facial expression, control of tear, nasal, palatine, and salivary glands, originates in pons, terminates in facial muscles and glands, and muscles of middle ear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensory for taste on anterior two thirds of tongue, originates in taste buds, terminates in thalamus</td>
</tr>
<tr>
<td>VIII Vestibulocochlear (Auditory)</td>
<td>(A)</td>
<td>Sensory, but some motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hearing and balance (equilibrium). Sensory originates in inner ear, terminates in pons and medulla. Motor fibres originate in pons, terminate in outer hair cells in cochlea</td>
</tr>
<tr>
<td>IX Glossopharyngeal</td>
<td>(G)</td>
<td>Motor and sensory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensory: tongue and pharyngeal sensations (touch, pressure, taste and pain), outer ear sensations (touch, pain and temperature)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swallowing, production of saliva, gagging, regulation of blood pressure and breathing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motor fibres originate in medulla and terminate in parotid salivary gland, glands of posterior tongue and stylopharyngeal muscle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensory fibres originate in pharynx, middle and outer ear, posterior of tongue and internal carotid arteries</td>
</tr>
<tr>
<td>X Vagus</td>
<td>(V)</td>
<td>Motor and sensory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swallowing, taste, speech, respiratory, cardiovascular and gastrointestinal regulation, hunger, satiety and intestinal discomfort</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motor fibres originate in medulla and terminate in tongue, palate, pharynx, larynx, thorax and abdomen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensory fibres originate in thorax, abdomen, root of the tongue, epiglottis, pharynx, larynx, outer ear and dura mater, terminate in medulla</td>
</tr>
<tr>
<td>XI Spinal accessory</td>
<td>(S)</td>
<td>Motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swallowing, head neck and shoulder movement. Originates in medulla and C1 to C5 or C6 of spinal cord, terminates in palate, pharynx and muscles of shoulders, head and neck</td>
</tr>
<tr>
<td>XII Hypoglossal</td>
<td>(H)</td>
<td>Motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Movements of the tongue for speech, moving food and swallowing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Originates in medulla, terminates in muscles of the tongue</td>
</tr>
</tbody>
</table>
Spinal nerves

There are 31 pairs of spinal nerves emanating from the spinal cord, each distributed to a specific part of the body. During foetal development, the nerve fibres get stretched out as the body develops, resulting in a distribution of dermatomes over the body, showing the area supplied by each spinal nerve. Dermatomes are therefore areas of skin normally supplied by a single spinal nerve.

Some of these nerve fibres arise from the spinal cord (T2 to T12) while the others originate from the four plexuses or nerve networks:

- cervical,
- brachial,
- lumbar,
- sacral.

Each plexus originates from nerve fibres from several segments of the spinal cord and forms several major nerves. Trauma to a nerve plexus can cause major loss of function to the part supplied.

NUTRITION AND PROTECTION OF THE NERVOUS SYSTEM

As the nervous system is home to the major control systems in the body, its nourishment and protection are vital for survival.

Nutrition

Cells of the nervous system must receive adequate nutrition and oxygen and this occurs through the cerebral and spinal circulation which distributes blood to the various parts of the central nervous system. Cerebrospinal Fluid (CSF) also provides nutrition to parts of the central nervous system (discussed later).

Cerebral circulation

The main arteries supplying the brain are the two internal carotid arteries and the basilar artery (arising from the two vertebral arteries) (Figure 5.20). The Circle of Willis is a circle of blood vessels that supplies blood to the different parts of the brain. It is formed from the main arteries supplying the brain joined by the connecting
arteries. It enables regulation of blood flow and blood pressure within the brain and facilitates collateral circulation if arteries in the brain are narrowed or blocked. The blood from the brain drains into sinuses (wide vessels with no muscle in the walls) which return it to the main circulation at the internal jugular vein in the neck.

**Figure 5.20** Cerebral circulation

**Activity 5.10: Apply**

**Presentation of neurological impairment**

Earlier in this chapter you learned about the different parts of the brain and their functions. If circulation was interrupted or occluded (blocked) to the following parts of the brain, what signs and symptoms could a person have?

1. The temporal lobe.
2. The frontal lobe.
3. The occipital lobe.

**Spinal circulation**

The spinal cord is nourished by three main arteries and an arterial network although the CSF supplies the nutrients and oxygen to the tissues of the brain and spinal cord.
**GO DEEPER**

**Spinal circulation**

The anterior spinal arteries supply the anterior two thirds of the spinal cord and the posterior spinal arteries supply the posterior surface. Additionally, the posterior spinal arteries give rise to the vasocorona, which supplies blood to the superficial layer of the anterolateral surface of the spinal cord. Posterior spinal veins and anterior spinal veins drain into the radicular veins to return venous blood to the vertebral venous plexus. This drains blood into the larger veins in the neck, thorax and abdomen.

**Protection**

The brain and spinal cord are protected by:

- The bone surrounding them (cranium and spinal column),
- The meninges,
- Cerebrospinal fluid,
- The Blood–Brain Barrier (BBB).

**Cranium and spinal column**

These bony structures all provide a structural defence for the brain and spinal cord and are explored in Chapter 15.

**The meninges**

The meninges are the three layers of connective tissue that surround the brain and spinal cord (Figure 5.21):
The **dura mater**: This is the outermost layer of the brain and spinal cord composed of the outer periosteal layer (absent from the spinal cord) and inner meningeal layer. These are largely closely joined except where they separate in the cranium to form venous sinuses that assist in returning blood to the heart. The dura is tough to prevent friction against the skull, and is a lining that retains CSF within the CNS. It also suspends the brain in the cranial cavity.

The **arachnoid mater**: The arachnoid mater is next, separated from the dura mater by the dural space and from the pia mater below by the subarachnoid space. Web-like extensions connect the arachnoid and pia mater and the subarachnoid space is filled with CSF. The arachnoid mater contains large blood vessels and the arachnoid villi from these reabsorb CSF as it circulates through the CNS.

The **pia mater**: The pia mater is a thin, impermeable fibrous membrane adjacent to the brain and spinal cord ensuring that CSF remains within the subarachnoid space. Blood vessels pass through the pia mater to the brain and spinal cord.

Cerebrospinal fluid

CSF protects and nourishes the CNS. About 400–500 ml of CSF daily is formed by the choroid plexus in the sides and floor of the lateral ventricles and the roof of the third and fourth ventricles. Only about 150–180 ml of this is in circulation as it is readily absorbed by the arachnoid villi back into the blood. The flow of CSF is as follows (see Figure 5.22):

1. CSF is created in the choroid plexus.
2. It moves through the foramen of Monro to the third ventricle.
3. It passes through the cerebral aqueduct to the fourth ventricle.
4. It then passes through three apertures (two lateral and one median) to the cerebellomedullary cistern.
5. From here it circulates over the spinal cord and enters the subarachnoid space where it is reabsorbed.

CSF is normally clear and odourless containing glucose, protein and white cells (largely lymphocytes, monocytes and macrophages) but no red blood cells. As CSF flows in one direction it effectively washes...
out waste products and metabolites. With the meninges it provides protection by acting as a cushion for impact and lubricates the meninges for frictionless movement of the brain.

**Blood–brain barrier**

As a structural and chemical barrier the BBB strictly regulates substances passing from the circulatory system into the nervous system.

- **Structural:** A mechanical barrier occurs as capillary endothelial cells in the brain are packed very tightly together with no gaps (fenestrations) in the cell walls. The capillary lumen also has a reduced surface area.
- **Chemical:** Capillary endothelial cells in the brain have large numbers of mitochondria for high production of energy. Additionally, specific proteins inhibit lipid-soluble drugs crossing from the blood into the brain by actively transporting them into the blood stream. Should substances pass, these cells contain drug-metabolising enzymes to eliminate or deactivate them before reaching CNS tissues.

Routes for substances to cross the BBB are:

1. Transport mechanisms control movement of water-soluble substances through ion channels, transport proteins or, for larger items, transcytosis. Transcytosis moves large molecules by capturing them in vesicles, carrying them across the cell, and exporting them out the other side.
2. Fats move across by diffusion.

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**APPLY**

**BBB and drug administration**

The BBB is useful in preventing substances entering the brain. However, sometimes the brain can become infected by bacteria and viruses. In these circumstances, drugs are often required to treat the infection. When these drugs enter the body outside of the nervous system (i.e. orally, intravenously or by intramuscular injection), the therapeutic dose may not be achieved within the central nervous system as the BBB may impede the drugs from entering. In such situations, certain drug preparations can be given directly into the ventricles of the brain (intraventricular route) or the subarachnoid space (intrathecal route). This ensures that the therapeutic level of the drug can circulate and act within the central nervous system. Such drugs are given under strict conditions and with specialist education and training.

Caffeine and alcohol cross the BBB freely which is why they both can have a relatively acute effect on the nervous system.

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**GO DEEPER**

**Neurogenesis (growth of new neuronal tissue)**

The brain grows and develops from conception into maturity through stem cells in the walls of the ventricles. For many years it was thought that mature adult brain cells do not repair or regenerate. Over the past 20 years we have found this not to be true and that new nerve cells are constantly being produced in the brain to maintain homeostasis. For example, Spalding et al. (2013) determined that the hippocampus generates 700 new neurons daily, about 1.75% regeneration. Their study concluded that neurons are generated throughout adulthood, albeit with some decline as a result of ageing.

Neurogenesis, or the growth of new neuronal tissue, appears to be limited to the hippocampus and the olfactory bulb where there are active stem cells. Stem cells in other regions of the brain do not appear to be active in producing new nerve cells. When neurons are damaged in the CNS, they generally do not
repair well. In contrast, neurons of the PNS are much better at adapting to injury by growing new axons and making new synaptic connections (Purves et al., 2011). The difference is down to genetic programming - adult CNS neurons tend to no longer express the gene that causes axonal growth, whereas the same genes can be reactivated in adult PNS neurons. The reactivation occurs in the PNS as macrophages efficiently remove cell debris in damaged neurons, and Schwann cells provide the optimal conditions to promote regeneration. This is through enhancing cell adhesion molecules, the extracellular matrix, and a variety of growth factors called neurotrophins. That same efficiency is not present in the CNS and the debris from damaged neurons can remain, impeding repair.

Additionally, oligodendrocytes produce a substance called Nogo, which inhibits axons extending to form new connections (Purves et al., 2011). Astrocytes compound this by releasing more factors that also inhibit axons extending in the presence of injured cells. Even if CNS neurons do reactivate the gene for repair, the surrounding environment inhibits it. As a result, there is limited repair. However, some neurons in the CNS do manage to repair and reconnect, and so some level of recovery can occur. Research continues into how to promote this process for those with neuronal damage in the CNS.

While we are born with most central neurons created, it is through synaptogenesis (formation of synapses between neurons), pruning (removal of unnecessary neuronal connections and strengthening important ones) and apoptosis that we modify and refine neuronal function and efficiency over time and as we develop. This is why infants develop according to milestones, gaining skills sequentially, such as learning to control the head, sit and stand before walking.

CONSCIOUSNESS AND SLEEP

Consciousness

Consciousness is a state of explicit awareness dependent on both biological arousal in the brain, mainly by the reticular activating system (RAS) and the processing of experiences (perception). A person can process, interact and experience their surroundings, and is influenced by their state of mind. Consciousness is crucial not only to survival but also to a person’s experience of their reality, and therefore is an integral component of personhood. Only through consciousness can the brain process information, analyse it and make decisions that influence the present while planning for the future.

There is significant debate on how consciousness is achieved. However, there is a general consensus that both cerebral hemispheres are functioning simultaneously and both the central and peripheral nervous systems are involved. The reticular formation receives signals from various sources in the nervous system and directs them to the thalamus. The reticular formation contains the reticular activating system and has a role in regulating signals that go to the thalamus. The thalamus then directs signals out across the cerebral hemispheres to the cerebral cortex. The thalamus also communicates with the hypothalamus in this regard to regulate the sleep–wake cycle. Being awake is a vital component of consciousness. The pre-frontal cortex is stimulated by the thalamus and is central to regulating perception and experience of the environment to produce a response. The limbic system integrates this to provide an emotional element to that response.

Sleep

Sleep comprises two out of three states of human existence:

- Wakefulness,
- Non-Rapid Eye Movement (NREM) sleep,
- Rapid Eye Movement (REM) sleep.

The electrical activity present in the brain can tell us a lot about how alert or sleepy a person is. This activity can be viewed as brain waves. Figure 5.23 describes these briefly. We spend around one third of
our life asleep and sleep is considered central to homeostasis and health. More and more studies now highlight that our overall health is dependent on the duration and quality of sleep. Sleeping more or less than seven hours at night has been shown to increase mortality and morbidity (Ferrie et al., 2007; Cappuccio et al., 2011). However, we still do not fully understand all the components of sleep and its entire role in homeostasis. Figure 5.24 shows the structure and functions of sleep.

**Figure 5.23** Brain waves

**Figure 5.24** Structure of sleep

Sleep operates in cycles largely based around a 24–25 hour day. There are five stages within each cycle lasting about 90–100 minutes. Four stages are NREM stages and the fifth is REM. Figure 5.25 illustrates the structure of a cycle of sleep. A healthy night’s sleep normally consists of four to five cycles. However,
there are two natural periods of sleepiness during the day. The obvious one is at night, and the second is in the early afternoon, roughly between 3 pm and 5 pm. People have more periods of sleepiness in early life as they are growing and learning rapidly. Older adults also have more, usually shorter, periods of sleep over the 24 hours. These cycles are regulated by various biological and social factors (Table 5.6).

![Stages of sleep](image)

**Figure 5.25 Stages of sleep**

**Table 5.6 Factors regulating sleep**

<table>
<thead>
<tr>
<th>Biological factors</th>
<th>Social factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>The hypothalamus is the body’s biological clock, determining the circadian rhythm. It regulates sleep in the nervous system, influenced by social factors regarding timing; triggered by light and melatonin from the pineal gland</td>
<td>Exposure to light</td>
</tr>
<tr>
<td>The Ascending Reticular Activating System (ARAS) sends signals to the forebrain and hypothalamus to regulate sleep; signals to the thalamus are forwarded to the cerebral cortex – pathways similar to those of consciousness</td>
<td>Social activities such as:</td>
</tr>
<tr>
<td>The forebrain works with the RAS to regulate NREM sleep</td>
<td>o Regular meal times</td>
</tr>
<tr>
<td>The pons regulates REM sleep and reactivates the brain from sleep</td>
<td>o Regular times of going to bed and getting up</td>
</tr>
<tr>
<td>Three neurotransmitters/hormones from the pons are central to controlling sleep:</td>
<td>o Levels of stress</td>
</tr>
<tr>
<td>o Noradrenaline arouses the cerebral cortex to achieve wakefulness; low levels are present in sleep states</td>
<td>o Emotional state</td>
</tr>
<tr>
<td>o Acetylcholine achieves wakefulness and regulates REM sleep; low levels are present in sleep states</td>
<td>o Undertaking exercise</td>
</tr>
<tr>
<td>o Serotonin, involved in regulating REM and NREM sleep</td>
<td></td>
</tr>
</tbody>
</table>
Think of baby Danielle Zuma. She is two months old and will be growing and learning faster than at any other stage in her life. Danielle therefore needs plenty of sleep. This allows release of growth hormone in cycle 4 of sleep, helping to achieve the expected growth and development. As she grows through her first few years, REM sleep will be crucial in enabling her brain to learn and recall new information and develop her language skills. It will also allow her to process emotional experiences, and is therefore central to her emotional development. Having a pattern to the day, including settling her to rest in relation to feeding and emotional state, will be central to regulating her sleep.

ACTIVITY 5.11: APPLY

As you will have learned (and probably experienced), you have two natural periods of sleepiness in the day. The obvious one is overnight, the other in the early afternoon.

- Does society enable this natural process to occur?
- Think about the care provided on hospital wards. What normally happens in the afternoon? How could this impact on the person who is recovering or dealing with illness? How could practice be more person-centred in this regard?
- How do hospital activities impact on the regulation of circadian rhythms?

THE NERVOUS SYSTEM AND PERSONHOOD

Personhood refers to the quality of being an individual person. While there are many components of personhood, which will not be debated here, the biological components are largely based within the nervous system. The reticular formation and limbic system are thought to play key roles in personhood; the reticular formation being key in regulating arousal and consciousness. Both are necessary for awareness. You have already learned how the limbic system regulates emotion, behaviour, motivation and long-term memory. Combined, a person’s ability to interact and respond emotionally is regulated biologically. Central to this will be a person’s life experiences, analysed and laid down in memory through the limbic system linking experiences with emotion.

The nervous system and mental health

As we learn to understand the nervous system better, we are discovering more and more how it is central to maintaining a person’s mental health. We know that there are areas of the brain involved in maintaining mental health and that some hormones are also important.

There are four key areas of the brain that contribute to a person’s mental health status: the amygdala, hippocampus, anterior cingulate cortex and pre-frontal cortex. Some of these we have already looked at earlier in this chapter, particularly as three are core areas of the limbic system. Figure 5.26
Amygdala
Regulates response to fear through fright, flight, fight response. Part of this is recalling previous experiences that caused fear and using those to regulate the response being experienced at that moment. The amygdala is one component involved with phobic experiences as it links fear with a previous unpleasant experience. However, that response can be relearnt if the person is exposed to the experience again and it is positive, part of the management of phobias and post-traumatic stress disorder.

Anterior Cingulate Cortex
Role in regulating emotional responses. Influences feelings of motivation, focus and realisation. For example, realising when we did something well, or need to improve something. As a result, when the anterior cingulate cortex operates ineffectively, people can experience depression, lack of motivation or drive. Dysfunction in this area of the brain is linked with behaviour disorders and schizophrenia.

The Hippocampus
This area of the limbic system is associated with creating memories and working with parts of the cerebral cortex to lay them down in long-term memory. Memories are very important to a person's health related quality of life, from being able to reminisce to being able to learn new skills to be independent and self-caring. It has a key role in regulating mood.

The Pre-frontal Cortex
Within this area of the cerebral cortex, the brain coordinates cognitive functioning. This includes executive functioning, the ability to take a problem, solve it and make decisions, all underpinned by making judgements. To achieve this, the pre-frontal cortex accesses short- and long-term memory and regulates the amygdala in times of heightened stress.

Figure 5.26  Functional areas in the brain regulating mental health

Table 5.7  Hormones regulating mental health

<table>
<thead>
<tr>
<th>Serotonin</th>
<th>Dopamine</th>
<th>Glutamate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role in regulating numerous functions within the body: regulating mood, regulating sleep; regulating the mood of a person</td>
<td>Dopamine commonly known for role in controlling movement</td>
<td>This very common neurotransmitter attributed to learning and memory, specifically in the hippocampus. It is very important in brain development and increases the excitability of neurons, promoting sending of nervous impulses</td>
</tr>
<tr>
<td>Depression is linked with low levels of serotonin</td>
<td>It is also involved in regulating reward-motivated behaviour</td>
<td></td>
</tr>
<tr>
<td>Some types of antidepressants promote the presence of serotonin within the synaptic cleft so that the receiving neuron works better in regulating mood. This is achieved by drugs that stop serotonin being recycled or reabsorbed back into the sending neuron</td>
<td>Rewards increase the level of dopamine and a lack of dopamine is linked with disorders such as schizophrenia and attention deficit hyperactivity disorder</td>
<td></td>
</tr>
</tbody>
</table>
ACTIVITY 5.12: APPLY

Perception and personhood

Think about the experiences people have during their lives and how these can vary from person to person so vastly. How can environment influence personhood and how is this facilitated by the central nervous system?

People’s past experiences will influence how they react to a number of things, whether it be psychological triggers that have resulted in a mental health problem, or how they learn to manage an aspect of their health. In order to be person-centred, we must try to empathise with people and understand what has influenced their view of the world. Your view of the world will influence your outlook, and so you may not fully appreciate the outlook of those in your care. How can you overcome this to be person-centred? Consider the Person-Centred Practice Framework in your reflection. Finally, think about your role as a nurse and how you respond to different personalities.

CONCLUSION

By now you should have a good understanding of how the nervous system works and plays a key role in regulating homeostasis. You should also appreciate how the nervous system plays an essential role in a person’s experiences of life, being the link between body and mind through regulating emotions and experiences, and linking these with memory. An understanding of the nervous system is therefore central to understanding mental health. Furthermore, we have seen that the adaptive responses by the nervous system to maintain homeostasis provide nurses with key information about what is going on in the body. This is a rich form of data that is vitally important in caring for people.

However, the nervous system cannot coordinate homeostasis alone. It integrates with the endocrine system to achieve this. You will learn more about this second control system in Chapter 7. Next, however, we will go into the nervous system a little further in Chapter 6 and look at the special senses.

Key points

- The nervous system is one of two control systems in the human body, regulating all biological activities in the body along with the endocrine system. Without the nervous system, we would not be able to respond to the internal or external environment.
- There are two types of nervous tissue – neurons which send electrochemical impulses in response to stimuli received and to effect an action as a result of stimuli, and neuroglia which support and protect neurons.
- Neurons communicate by sending electrochemical impulses (called an action potential) down the axon of the cell (called an action potential). These impulses move from neuron to neuron crossing gaps between neurons, called synapses, either chemically or electrically.
- Nervous tissue is organised into two main divisions of the nervous system – the CNS and the PNS. There are further subdivisions of both systems that have different roles in maintaining homeostasis.
- Different lobes of the brain have dedicated functions. However, they often interlink throughout the nervous system.
- Consciousness is controlled by the nervous system. Sleep is a state of consciousness and is fundamental to learning and development as well as for reparative processes in the body.
- A person’s life experiences are recorded and associated with emotion by the nervous system. These can be recalled from memory and influence how a person reacts to a variety of situations.
Revision of this chapter will require you to be structured. It is important you revise it in the order it is laid out. This means there are six key areas to revise:

1. Roles and functions of the nervous system in maintaining homeostasis.
2. Nerve cells.
3. Organisation of the nervous system:
   - The central nervous system;
   - The peripheral nervous system.
4. Protection and nutrition of the nervous system.
5. Sleep and consciousness.
6. The nervous system and personhood.

In order to help you revise, consider the following questions, answers for which can be found by visiting https://edge.sagepub.com/essentialaandp. For eBook users, just click on the tick icon to access the answers. Test yourself by revising the chapter first, and then answering these questions without looking at the book. Afterwards compare your answers with the text and with the notes you made. Did you miss anything in your notes? Here are the questions:

1. What are the major functions of the nervous system?
2. Describe the divisions of the nervous system and their functions. Support this with a diagram of the structural divisions of the nervous system.
3. Describe how nerve impulses are transmitted.
4. Describe in outline the major structural elements of the CNS and their functions.
5. How many cranial nerves are there? What is the 5th cranial nerve called and what are its characteristics? Which cranial nerve innervates the organs of the thorax and abdomen?
6. What happens to motor nerves as they pass through the medulla oblongata? Where does this happen for sensory nerves? What is the significance of this?
7. What is a reflex arc? Illustrate this in a diagram.
8. Briefly explain how information is transmitted to the central nervous system and represented in the cerebral cortex.
9. What activities is the autonomic nervous system concerned with? What are the effector organs for this system? How is the autonomic nervous system structured, and what are the functions of its divisions?

(Continued)
10. Where is CSF formed and reabsorbed in the brain? How many fluid-filled spaces are there filled with CSF? Why do we have CSF?
11. What are the functions of the meninges surrounding the central nervous system? Describe the three layers of the meninges.
12. Briefly describe how blood is supplied to the brain.

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- Revise key terms with interactive flashcards
- Test yourself with multiple-choice questions
- Access the glossary with audio to hear how complex terms are pronounced
- Print out or download the key points from the chapter for quick revision
- Explore recommended websites suitable for revision.

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REFERENCES


