UNIT 3: HOMEOSTASIS – Nerve Signals and Homeostasis

A. The Nervous System

- the nervous system, together with the endocrine system controls actions of the body
- endocrine effects take longer to occur, and last longer, whereas nervous system responses are faster and don't last very long
- the body is constantly adjusting to maintain the internal environment within safe limits
- responses take place either through the actions of electrochemical messengers relayed to or from the brain, or through a series of chemical messengers, called hormones, that are carried by the blood
- since the hormones are produced by glands, they require more time for response than nerves require
- the nervous system controls memory, learning, and language
- regeneration of nervous tissue is limited
- scientists continue to look for chemical factors that both stimulate and inhibit the growth of new nerve cells
- one such factor that prevents growth of axons in tissue fibres is MAG (myelin-associated glycoprotein) – if this were "turned off" the regeneration (mitosis) pathway of nerve cells could occur
- the use of stem cells has showed some promise – these are cells that have not yet specialized into tissue cells
- in October of 2000, scientists announced that they had reconnected severed nerves in the spinal cords of rats using spore-like cells from the nervous system of adult rats
- when spore-like cells were seeded into the spinal cords of injured rats, new cells began to grow in the area of the severed cord, which helped some of the rats stand on their hind legs

VERTEBATE NERVOUS SYSTEM

- there are two main divisions of the nervous system:

1. **central nervous system (CNS)**
   - consists of the nerves of the brain and spinal cord
   - acts as the processing or coordinating centre for incoming and outgoing information

2. **peripheral nervous system (PNS)**
   - consists of nerves that carry information between the organs of the body and the central nervous system

- further divided into

a. somatic nerves – control skeletal muscles (striated muscles), bones and skin

-- conscious or voluntary control

(i) sensory somatic nerves -- relay information about the environment to the central nervous system

(ii) motor somatic nerves – initiate an appropriate response

b. autonomic nerves – control internal organs of the body

-- subconscious or involuntary control

-- further divided into “on-off” switches:

(i) sympathetic nervous system – prepares the body for stress

(ii) parasympathetic nervous system – restores normal balance

- Figure 1, p. 412 illustrates the major divisions of the nervous system

1. Anatomy of Nerve Cells

- the nervous system has two types of nerve cells:

1. **glial cells** (also known as neuroglial cells)

    - non-conducting cells that have a structural support and metabolic function

2. and **neurons --** functional units of the nervous system

    -- organized into three groups:

    a. **sensory neurons** (also known as receptors) – see Figure 2, p. 413 for an illustration its structure

    - also known as afferent neurons
    - sense and relay information from the environment to the CNS for processing

- types include – thermoreceptors, chemoreceptors, mechanoreceptors
- located in clusters called **ganglia**

b. **interneurons** (also known as association neurons) – see Figure 2, p. 413 for its structure

- link neurons within the body
- found mostly throughout the brain and spinal cord
- integrate and interpret the sensory information and connect neurons to outgoing motor neurons

c. **motor neurons** (also known as efferent neurons) – see Figure 2, p. 413 for its structure

- relay information to the effectors – muscles, organs, glands

- all neurons contain:

1. **dendrites** – the part of a neuron that receives information, either from sensory receptors, as in the case of sensory neurons, or from other nerve cells, as in the case of motor neurons
   -- conduct nerve impulses toward the cell body

2. **cell body** -- the portion of the neuron that contains the nucleus and the majority of the cytoplasm

2. **axon** -- an extension of the cytoplasm
   -- projects nerve impulses from the cell body
   -- extremely thin -- approx. 100 axons can be placed inside the shaft of a single human hair (Figure 3, p. 414)
   -- carries the nerve impulse toward other neurons or to effectors
   -- covered with a white coat of fatty protein called **myelin sheath** – insulation for the neurons to prevent the loss of charged ions from the nerve cell
   -- the myelin sheath is formed by special glial cells called **Schwann cells**
   -- the areas between the sections of myelin sheath are known as the **nodes of Ranvier**
   -- nerve impulses jump from node to node, which speeds up the conduction process
   -- impulses move much faster along myelinated nerve fibres than they do along non-myelinated nerve fibres

-- the smaller the diameter of the axon, the faster the speed of the nerve impulse

- all nerve fibres within the PNS contain a thin membrane called **neurilemma** – which surrounds the axon
- nerves within the brain that contain myelinated fibres and a neurilemma are called white matter
- the neurilemma promotes the regeneration of damaged axons
- not all nerve cells contain neurilemma and a myelin sheath – nerve cells within the brain and spinal cord are examples of this
- these kinds of unmyelinated nerve cells are called grey matter – they don't regenerate after injury, therefore, damage to such cells is permanent

2. Neural Circuits

- when you touch something hot, the immediate response is pulling away
- the response occurs before the brain gets the message
- this is called a reflex arc (Figure 6, p. 416)
- reflexes are involuntary – the sensory neuron passes the impulse on to an interneuron, which, in turn, relays the impulse to a motor neuron
- the motor neuron cause the muscles in the hand to contract and the hand pulls away
- the reason that the brain is not involved in the coordination or processing is because it would take too long for an effect to take place, that could result in worse damage

- the importance of the nervous system:

Structure	Function
neuron	• nerve cell that conducts nerve impulses
sensory neuron (afferent neuron)	• carries impulses to the central nervous system
interneuron	• carries impulses within the central nervous system

motor neuron (efferent neuron)	• carries impulses from the central nervous system to effectors
dendrite	• projection of cytoplasm that carries impulses toward the cell body
axon	• extension of cytoplasm that carries nerve impulses away from the cell body
myelin sheath	• insulated covering over the axon of a nerve cell • composed of Schwann cells
nodes of Ranvier	• regularly occurring gaps between sections of myelin sheath along the axon where nerve cells are transmitted
neurilemma	• delicate membrane that surrounds the axon of some nerve cells
reflex arc	• neural circuit that travels through the spinal cord • provides a framework for a reflex action

Homework: **1-6, p. 417**

B. The Impulse

- in the late 18th century, Galvani realized that the leg muscle of a frog could be stimulated to contract with an electric shock
- although his finding that it was that the muscle itself which produced "animal electricity" was incorrect, it sparked research in this area that ultimately lead to the understanding that nerve impulses were basically electric waves that traveled throughout the body

- this concept lead to the development of such technologies as the ECG (electrocardiogram), used to monitor heart contractions, and the EEG (electroencephalogram), used to monitor brain-wave activity
- there are differences between current in wire and those that travel through nerves:

1. current in a wire travels much faster
2. the cytoplasmic core of a nerve cell offers great resistance to the movement of electric current
3. electric currents diminish as they move through a conductor
4. nerve impulses remain as strong at the end of the transmission as they were at the beginning of the impulse
5. nerves use cellular energy to generate current, whereas the electric conductor relies on an external force to push the current through the conductor

- Figure 2, p. 418 shows how nerve impulses are electrochemical messages created by movement of ions through the nerve cell
- when a miniature electrode is placed inside the giant axon of a squid, a rapid change in the electrical potential difference across the membrane was detected every time the nerve became excited
- the resting membrane normally had a potential near – 70 mV and registered + 40 mV when the nerve became excited
- the voltage difference across a nerve cell membrane during the resting stage is called the **resting potential**
- the reversal of potential is described as an **action potential** – the voltage difference across a nerve cell membrane when the nerve is excited
- this action potential did not last very long – only a few milliseconds before the potential returned to - 70 mV
- the membranes become charged due to the movement of positive ions – not negative ions
- an unequal concentration of positive ions across the nerve cell membrane establishes the gradient
- potassium is high inside, and sodium is high outside – this creates a tendency for each to move down the gradient
- as potassium diffuses out, sodium diffuses in
- Figure 4, p. 420 illustrates the process of depolarization:

1. the relative rates of diffusion of each is unequal – the resting membrane is 50 times more permeable to potassium than it is to sodium -- this means that more potassium ions diffuse out of the nerve cell than sodium ions diffuse into the nerve cell (Figure 3, p. 419) -- the result is that the nerve cell loses a greater number of positive ions than it gains, making the exterior of the membrane positive relative to the interior
2. ion gates (protein channels) in the membrane of nerve cells control the movement ions across the cell membrane, where excess positive ions accumulate along the outside of the nerve membrane, while excess negative ions accumulate along the inside of the membrane -- the resting membrane is charged and is called a **polarized membrane**
3. the separation of an electrical charge has the potential to do work, which is measured in millivolts (mV) -- the potential of a resting neuron is – 70 mV, which indicates the difference between the number of positive charges found on the inside of the nerve membrane relative to the outside….. – 90 mV on the inside of the nerve membrane would indicate even fewer positive ions inside the membrane relative to the outside
4. when the nerve is excited because of a stimulus, the cell membrane becomes more permeable to sodium than potassium (see Figure 4, p. 420) – sodium gates open, while potassium gates close
5. sodium ions rush into the nerve cell because of the electrochemical gradient -- this rapid influx of sodium ions causes a charge reversal known as a **depolarization**
6. once the charge on the inside becomes positive, the sodium gates close, stopping the influx of sodium
7. a **sodium-potassium pump**, located in the cell membrane, restores the condition of the resting membrane by transporting sodium ions out of the neuron, while moving potassium ions inside the neuron, in a ratio of 3 Na^+ to 2 K^+ ions (see Figure 5, p. 420) – the energy comes from ATP, and the process of restoring the original polarity of the nerve membrane is called **repolarization**

- until the condition of the resting membrane potential is restored, nerves cannot be activated again
- the nerve must repolarize before the next action potential can be conducted
- the time required for the nerve cell to become repolarized is called the **refractory period**, which usually lasts 1 to 10 ms

I. MOVEMENT OF THE ACTION POTENTIAL

- the movement of sodium ions into the nerve cell causes the depolarization of the membrane
- this signals an action potential in that area, but in order for this impulse to be conducted along the axon, it must move from the point of depolarization to adjacent regions (see Figure 6, p. 421)
- when the nerve gets excited, the difference across the membrane changes at that region causing an action potential
- in the region of the action potential two things happen: (see Figure 7, p. 421)

1. the positively charged sodium ions are attracted to the adjacent negative ions, which are aligned along the inside of the nerve membrane
2. the positively charged sodium ions of the resting membrane are attracted to the negative charge that has accumulated along the outside of the membrane in the area of the action potential

- the flow of positively charged ions from the area of the action potential toward the adjacent regions of the resting membrane causes a depolarization in the adjoining area
- this creates an electric disturbance, which causes adjacent sodium channels to open
- the result is a wave of action potential that moves along the cell membrane
- the wave of action potential and depolarization is followed by a wave of repolarization

II. THRESHOLD LEVELS AND THE ALL-OR-NONE RESPONSE

- nerve cells respond to changes in pH, changes in pressure, and to specific chemicals
- mild electric shock is most often used to stimulate nerve cells since it can be intensified and easily controlled
- Figure 8, p. 422 illustrates an experiment that Mr. Laudari did in university
- the experiment shows that the stimulus must be above a certain voltage in order to produce a response in the muscle
- the critical level is know as the **threshold level**
- the data shows that increasing the intensity of the stimuli above the critical threshold value will not produce an increased response – the intensity of the nerve impulse and speed of transmission are constant
- the results indicate an **all-or-none response** – neurons either fire maximally or not at all
- even though responses to stimuli are all or none, the brain is still able to recognize the differences between a two stimuli of different intensities
- the body has neurons of various threshold levels

- the more intense the stimulus, the greater the number of nerve cells stimulated, thus the frequency of impulses increases
- for example, a glass rod at 50°C causes more neurons to fire than a glass rod at 40°C
- Figure 9, p. 422 shows how the 50 °C rod stimulates more neurons than the 40°C rod
- the greater the number of impulses reaching the brain, the greater the intensity of the response

III. SYNAPTIC TRANSMISSION

- the small spaces between neurons, or between neurons and effectors, are known as **synapses**
- Figure 10 a, p. 423 shows how nerves can branch out to one another (in 3-D)
- at the end of the axon is an end plate – it is here that small vesicles containing chemicals called **neurotransmitters** are released (see Figure 10 b, p. 423)
- neurotransmitters are released from the **presynaptic neuron** and diffuse across the synaptic cleft, creating a depolarization of the dendrites of the **postsynaptic neuron**
- as nerve impulses travel from neuron to neuron, they slow down at the synaptic cleft – the more synapses, the slower the conduction
- this explains why reflex arcs are significantly faster than regular motor responses
- **acetylcholine** is a typical neurotransmitter found in the end plates of many nerve cells
- Figure 11, p. 424 shows how acetylcholine acts as an excitatory neurotransmitter on many postsynaptic neurons by opening the sodium ion channels, which in turn, causes depolarization in the postsynaptic neuron
- after depolarization has occurred, to make the neuron repolarize, and to stop it from being permeable to sodium ions, the enzyme **cholinesterase** is released from the postsynaptic membrane to destroy acetylcholine
- once acetylcholine is destroyed, the sodium channels are closed, and the neuron begins its recovery phase
- the reason why insecticides are very effective is because they block cholinesterase – the heart of an insect continues to contract and never relaxes
- some drugs that treat myasthenia gravis, a disease of progressive fatigue and muscle weakness caused by the impaired transmission of nerve impulses, prevent cholinesterase from working
- not all neurotransmitters are excitatory – some make the postsynaptic membrane more permeable to potassium
- this causes even more sodium to move out of the neuron, which increases the number of positive ions outside the cell relative to the number found inside the cell
- when this happens, the neurons are said to be **hyperpolarized** because their resting potential is even more negative than – 70 mV
- a hyperpolarized membrane means that more sodium channels than normal need to be opened in order for depolarization to be achieved
- such inhibitory neurotransmitters prevent postsynaptic neurons from becoming active
- sometimes, a postsynaptic neuron requires more than one presynaptic neurons to depolarize it
- Figure 12, p. 424 shows how the excitation of neuron D requires both neuron A and neuron B to send out neurotransmitters
- this way, a sufficient amount of neurotransmitter is released to cause depolarization of neuron D

- this principle is called **summation**
- Figure 12 shows that when neuron C fires, neuron D becomes hyperpolarized
- other neurotransmitters, other than acetylcholine, are present
- serotonin, dopamine, gamma-aminobutyric acid (GABA), and glutamic acid are all neurotransmitters
- norepinephrine is excitatory in the peripheral nervous system, but is both inhibitory and excitatory in the central nervous system
- the interaction of excitatory and inhibitory neurotransmitters is what allows you to perform various physical acts involving your tricep and bicep muscles – when the bicep contracts, the tricep relaxes, because the bicep receives excitatory neurotransmitters, and the tricep receives inhibitory neurotransmitters
- inhibitory impulses of the CNS are just as important as excitatory impulses, because they help you prioritize information
- for example, you don't respond to every single stimulus in the room, instead, you focus your attention onto those things that are necessary for that particular moment
- Parkinson's disease is associated with involuntary muscle contractions and tremors – it is caused by inadequate production of dopamine
- Alzheimer's disease is associated with the deterioration of memory and mental capacity – it has been related to the decreased production of acetylcholine

Homework: **1-13, p. 426**

C. The Central Nervous System

- includes the brain and the spinal cord
- the brain is a concentration of nervous tissue that acts as the coordinating centre of the nervous system
- the brain is covered by a three-layer protective membrane knows as **meninges**
- the outer membrane is called the **dura mater**, the middle layer is called **arachnoid matter**, and the inner layer is called **pia matter**
- these three membrane layers form the blood-brain barrier, which determines what chemicals will reach the brain
- between the innermost and middle meninges of the brain and through the central canal of the spinal cord, is a fluid called **cerebrospinal fluid** – it functions as both a shock absorber and a transport medium
- the c.s.f. carries nutrients to the brain cells while it relays wastes from the cells to the blood
- in a procedure called a spinal tap, the fluid is extracted to diagnose bacterial or viral infections such as poliomyelitis and meningitis

A. The Spinal Cord

- ✓ carries sensory nerve messages from receptors to the brain
- ✓ relays motor nerve messages from the brain to muscles, organs, and glands

- ✓ Figure 1, p. 427 illustrates the anatomy of the spinal cord and its association with vertebrae
- ✓ a cross-section shows that the spinal cord consists of two types of nerve tissue – white matter and grey matter
- ✓ the core of the cord consists of unmyelinated interneurons, and the periphery, consisting of both sensory and motor neurons is myelinated
- ✓ the interneurons consist of nerve tracts that connect the spinal cord with the brain
- ✓ dorsal nerve tracts bring sensory information into the spinal cord, and ventral nerve tracts carry motor information from the spinal cord to the peripheral muscles, organs, and glands

B. The Brain

- ✓ the human brain is what makes us unique
- ✓ our hearing, vision, and sense of smell are relatively elaborate when compared to other species
- ✓ our ability to conceptualize and reason is extremely unique
- ✓ despite our uniqueness, the human brain shares developmental links with other chordates (see Figure 2, p. 428)
- ✓ the human brain is made of three distinct regions: the forebrain, the midbrain, and the hindbrain

- ➢ **The Forebrain:**

  - contains **olfactory lobes** – sense smell
  - contains **cerebrum** – coordinating centre where speech, reasoning, memory, and personality reside
  - the surface of the cerebrum is called the **cerebral cortex** – made of grey matter of many folds and fissures
  - the right side of the forebrain has been associated with visual patterns or spatial awareness
  - the left side of the brain is linked to verbal skills
  - research indicates that your ability to learn is heavily dependent on the dominance of on of the hemispheres
  - a bundle of nerves called the **corpus callosum** allows both hemispheres to communicate
  - each hemisphere can be further subdivided into 4 lobes: **frontal**, **temporal**, **occipital**, and **parietal**
  - Figure 3, p. 429 illustrates the location of these lobes, and the following table lists the functions of each:

Lobe	**Function**
frontal lobe	• motor areas control movement of voluntary muscles (walking/speech) • association areas are linked to intellectual activities and personality
temporal lobe	• sensory areas are associated with vision and hearing

	• association areas are linked to memory and interpretation of sensory information
parietal lobe	• sensory areas are associated with touch and temperature awareness • association areas have been linked to emotions and interpreting speech
occipital lobe	• sensory areas are associated with vision • association areas interpret visual information

- Figure 4, p. 429 shows parts of the human body drawn in proportion to the number of motor nerves that control them

- Below the cerebrum is the **thalamus**, and immediately below the thalamus is the **hypothalamus** – the direct connection between the nervous system and the endocrine system

✓ **The Midbrain:**

- less developed than the forebrain
- consists of four spheres of grey matter
- acts as a relay centre for some eye and ear reflexes

✓ **The Hindbrain:**

- joins with the spinal cord
- controls breathing movements, the diameter of blood vessels, and heart rate
- consists of the cerebellum, pons, and medulla oblongata
- the **cerebellum** controls limb movements, balance, and muscle tone
- the **pons**, which means "bridge" relays information between the two regions of the cerebellum and between the cerebellum and the medulla
- the **medulla oblongata** is the connection between the peripheral and the central nervous system that controls involuntary muscle action, and acts as the coordinating centre for the autonomic nervous system

C. Brain Mapping

✓ the brain is the most valued organs of the body

✓ table 2, p. 431 compares brain sizes to body mass – humans have the lowest ratio of all other organisms

D. Research in Canada

- ✓ three speech areas have been located in the brain
- ✓ they mostly occur on the left side
- ✓ the brain itself does not contain any sensory receptors, which is why surgeons conduct surgical procedures of the brain with conscious patients
- ✓ stimulation of various areas of the brain actually cause patients to recall past events
- ✓ in some cases, with stimulation of various parts of the brain, exact sounds, voices, and images can be recalled

E. Neuroimaging: Viewing the Living Brain

- ✓ these techniques are non-invasive, but cost a lot of money!

1. Positron-Emission Tomography (PET)

    - widely used scans today
    - they reveal physiological and biochemical processes in the body
    - a radioactive substance is sent to active areas of the brain
    - the radiation is detected by a PET camera connected to a computer

2. Magnetic Resonance Imaging (MRI) and Functional Magnetic Resonance Imaging (fMRI)

    - computer-aided imaging technique that can produce 2-D or 3-D pictures of the brain
    - MRIs are used to gain information on the structure of the brain whereas fMRIs are used to gain information on brain function and operation
    - the principle behind magnetic resonance is the behaviour of hydrogen atoms in water
    - a strong magnetic field forces the nuclei of hydrogen atoms within soft living tissue to align, which emit faint radio signals
    - the signals are picked up by a scanner and translated into a computer image
    - since soft living tissues contain mostly water, they will appear more opaque than dense tissues, such as bone

3. Computerized Tomography (CT)

- these are thin X-ray sections through the body
- the patient is slowly moved through a CT machine, and X-ray source circles around the body, illuminating successive sections from various angles
- a computer then produces high-resolution video images of the sections, which can be studied individually or combined into various 3-D views
- used to detect ruptured blood vessels in the brain

The Central Nervous System

Structure	Function
meninges	• protective membranes that surround the brain and spinal cord
cerebrospinal fluid	• circulates between the innermost and middle membranes of the brain and spinal cord • acts as a transport medium and shock absorber (cushion)
interneuron	• carries impulses within the central nervous system
olfactory lobes	• areas of the brain that detect smell
cerebrum	• the largest and most highly developed part of the human brain • stores sensory information and initiates voluntary motor activities
cerebral cortex	• the outer lining of the cerebral hemispheres
corpus callosum	• a nerve tract that joins the two cerebral hemispheres
cerebellum	• the region of the brain that coordinates muscle movement

Pons	• the region of the brain that acts as a relay station by sending nerve messages between the cerebellum and the medulla
medulla oblongata	• the region of the hindbrain that joins the spinal cord to the cerebellum • the site of autonomic nerve control

Homework: **1-6, p. 434**

D. Homeostasis and the Autonomic Nervous System

- autonomic system is part of the peripheral nervous system that regulates organs of the body without conscious control
- works together with the endocrine system in adjusting the body to changes that take place in the external and internal environment
- breathing movements, blood CO_2 and O_2 levels, diversion of blood to various parts of the body, responses to temperature stresses, responses to shock, dilation of pupils, etc are all controlled by the motor neurons of the autonomic nervous system
- made up of two distinct, opposing, units:

Sympathetic Nervous System	***Parasympathetic Nervous System***
• prepares the body for stress • have short preganglionic nerves and longer postganglionic nerves • preganglionic nerves release acetylcholine and the postganglionic nerves release norepinephrine • nerves originate from the thoracic vertebrae (ribs) and lumbar vertebrae (small of back) • increase heart rate, decrease peristalsis, increase the release of glucose, dilates pupils, relaxes bladder sphincter, increases blood flow to the skin, causes adrenal gland to release of epinephrine	• restores normal balance • have long preganglionic nerves and shorter postganglionic nerves • both the preganglionic and postganglionic nerves release acetylcholine • nerves exit directly from the brain or from either the cervical (the neck area) or caudal (tailbone) sections of the spinal cord • such examples are the cranial nerves • decreases heart rate, increases peristalsis, decreases the release of glucose, constricts pupils, contracts bladder sphincter, decreases blood flow to the skin, has no effect on the adrenal gland

- nerves that originate from the brain are called **cranial nerves**

- one very important cranial nerve is the **vagus nerve**
- the vagus nerve branches regulate the heart, bronchi of the lungs, liver, pancreas, and the digestive tract

A. Natural Painkillers

✓ Endorphins and Enkephalins

- manufactured by the brain when injury occurs
- they attach to pain receptor sites on specialized pain interpretation cells called **substantia gelatinosa (SG)** – a band of gelatinous grey matter in the dorsal part of the spinal cord that release pain neurotransmitters
- when the pain neurotransmitters attach to the injured organ, pain is felt
- the greater the number of pain neurotransmitter attachments, the greater the sensation of pain
- pain neurotransmitters are not produced when endorphins and enkephalins are attached to the SG cells

B. Artificial Painkillers

✓ Opiates (a.k.a sedative narcotics)

- heroin, codeine, and morphine
- since they have a similar structure to endorphins, opiates occupy they same receptor sites, thus work in the same manner as endorphins and enkephalins
- heroin and opium reduce pain and create a feeling of tranquility
- when artificial painkillers are used, it causes the body to produce less natural painkillers
- this creates a dependency on the drug
- once the use of the drug stops, SG receptors become vacant, and pain transmitters are produced in abundance
- depressants such as valium and Librium enhance the action of inhibitory synapses by releasing inhibitory neurotransmitters like **gamma-amino-butyric acid (GABA)**
- alcohol (ethanol) does not act directly on the synapse, but on the plasma membrane to increase pain threshold levels
- other drugs in the category of barbiturates, and benzodiazepines are among the most widely abused

Homework: **1-5, p. 437**

E. Sense and Perception

- all sensory responses convert one source of energy into another
- taste and smell – chemical stimuli are converted to nerve action potentials
- touch – mechanical stimuli are converted to nerve action potentials
- vision – light stimuli are converted to nerve action potentials
- balance – mechanical energy and gravitational energy converted to nerve action potentials
- highly modified ends of sensory neurons are called **sensory receptors**
- specialized sensory organs like the eye, ears, nose, etc function to group together specific sensory receptors and amplify the energy of the stimulus to ensure that it reaches a specific threshold level
- Table 1, p. 438 lists different types of sensory receptors found within the body
- despite having a lot of sensory receptors to detect environmental stimuli, much of the environment remains undetected
- what we detect is what is relevant to our survival
- for example, the wavelengths human eyes can detect from the electromagnetic spectrum are those between 350 nm and 800 nm, and any sound below a frequency of 20 Hz or above a frequency of 20 000 Hz is not detected by the human ear
- the manner in which the sensory receptors are stimulated also affects the response
- for example, a hot tub is tolerated only if you slowly give your thermoreceptors in your skin time to adjust to the stimulus
- once the receptors become accustomed to the stimulus, they have undergone **sensory adaptation** – the neuron ceases to fire even though the stimulus is still present
- this is why the touch receptors in your skin aren't constantly responding to your clothes that you are wearing

F. The Human Eye – Structure and Function

- made of three separate layers – the **sclera**, the **choroid**, and the **retina**
- sclera is the outermost layer – protective, and maintains eye shape
- the front of the sclera is clear and bulges forward, forming the **cornea** – the "eye window" that bends light toward the pupil
- the cornea requires oxygen and nutrients, but cannot get these from blood since capillaries would prevent it from being transparent
- therefore it receives O_2 in a dissolved form from tears, and nutrients from the **aqueous humor** – a transparent fluid held in a chamber behind the cornea
- the choroid layer has pigmented granules within it to prevent any light that has entered the eye from scattering
- the front of the choroid contains the **iris** – a thing circular muscle that acts as a diaphragm, controlling the size of the pupil, thus the amount of light that enters the eye
- the iris is what give people their eye colour

- immediately behind the iris is a bulbous structure called the **lens** – its shape is altered by **ciliary muscles** and **suspensory ligaments** that are attached to it
- a large chamber behind the lens, contains a jelly-like **vitreous humor** which maintains the shape of the eyeball
- the retinal layer is made of three layers of cells – light-sensitive cells, bipolar cells, and cells from the optic nerve
- there are two different types of light-sensitive cells – **rod cells** and **cone cells** (see Figure 2, p. 440)
- rod cells respond to low intensity light and the cone cells require high-intensity light and respond to colour
- once excited, the message is passed from the rods and cones to the bipolar cells, which, in turn, relay the message to optic nerve
- Figure 3, p. 440 shows how the nerve carries the impulse to the central nervous system (occipital lobe)
- a tiny depression in the centre of the retina, called the **fovea centralis,** is the most sensitive receptor area of the eye
- the fovea centralis contains many closely packed cone cells and receives most of the light that enters the eye
- surrounding the fovea are rod cells – this explains why when you identify an object from the periphery of your visual field, you don't associate any colour to it
- where the optic nerve comes in contact with the retina, there are no rod cells or cone cells -- this area is referred to as your blind spot
- Table 2, p. 441 summarizes the structure and function of various parts of the human eye

LIGHT AND VISION

- particles of light enter the eye as they are reflected or transmitted from objects
- as they enter through the pupil and into the eye, they are focused onto the retina, creating an image that is inverted both vertically and laterally, and is much smaller than the object
- the image is created on the retina much like it is on a film of a camera
- in fact, the eye is very much like a biological camcorder

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<u>Afterimages</u>

- images are retained for a number of seconds before the next one is realized are called afterimages
- there are two types of afterimages – positive and negative
- positive afterimages are when you close your eyes and can still see the image in the dark
- negative afterimages are when you look at bright objects for an extended amount of time and look away, yet still see the image

<u>Focusing the Image</u>

- light is first bent by the cornea toward the pupil as it enters the eye because it moves from air (less optically dense) into the cornea tissue (more optically dense)

- it is further bent by the lens to a focal point behind the lens because the lens is thickest at the middle than at the top and bottom
- the image created on the retina is real, inverted and much smaller than the object
- to control the shape of the lens, ciliary muscles contract and suspensory ligaments maintain a constant tension
- thickening and thinning out the lens causes the image to move in front, or behind the retina, respectively
- for near vision, the ciliary muscles contract, the tension of the ligaments is decreased, and the lens is thickened
- for distant objects, the ciliary muscles relax, the tension of the suspensory ligaments increases, and the lens is thinned out
- the adjustment of the lens for the focusing of near and far objects is called **accommodation**
- any object that is more than 6 m from the viewer requires no accommodation
- as you get older, layers of protein around the lens become thicker, making the lens less flexible
- this results in the inability to accommodate
- another adjustment that takes place during accommodation is the dilation of pupil
- for distant objects, the pupil dilates to let in as much light as possible
- for close objects, the pupil constricts, decreasing the amount of light that enters the eye, sharpening the image

Vision Defects

✓ **Glaucoma**

- every day, a small amount of aqueous humor builds up in the anterior chamber of the eye and the excess is drained by tiny ducts
- when blockage of these ducts occurs, and the aqueous humor build-up does not drain, the pressure of this excess fluid causes the blood vessels of the retina to collapse
- when this happens a condition called **glaucoma** develops – neurons die due to the lack of nutrients and oxygen

✓ **Cataracts**

- when the lens becomes opaque and prevents some of the light from passing through, **cataracts** may develop
- the correction for this is to remove the lens and fit the person with strong eyeglasses

✓ **Astigmatism**

- when the cornea shape and the lens shape are asymmetrical, a person is said to have an **astigmatism**
- this causes certain parts of an object to become blurry while other parts are in focus

- to correct this problem, the person is fit with glasses that have a special shaped lens

✓ **Nearsightedness (myopia) and Farsightedness (hyperopia)**

- when the eyeball is too long, and the lens cannot stretch enough to bring the image further back onto the retina in focus a person is said to be **nearsighted** – they can see objects that are close in sharply, but not distant objects
- myopia is corrected with a lens that is concave – thinnest at the geometric centre
- when the eyeball is too short, and the lens cannot be flattened enough to bring the image up to the retina in focus a person is said to be **farsighted** – they can see objects that are far sharply, but not close objects
- hyperopia is corrected with a lens that is convex – thickest at the geometric centre

CORNEAL SURGERY

- most of the focusing problems associated with the eye are cornea related
- instead of wearing eyeglasses, an alternative is to reshape the cornea to a desired shape that refracts light at the correct angle so as to sharpen and focus the image precisely on the retina
- a procedure known as **radial keratotomy** was developed in the 1970s where the cornea was actually cut with a special scalpel and appropriately reshaped to enhance vision
- with the development of lasers, a less invasive procedure known as **photorefractive keratotomy (PRK)** is now used
- a laser removes a layer of tissue off the cornea to resculpt it accordingly -- no incisions are made
- another procedure, known as **laser in-situ keratomieusis (LASIK)** is also done where a flap of cornea is cut, the layers underneath are flattened with a laser, and the flap is then resealed onto the cornea
- yet another procedure is the use of **corneal ring implants** to change the shape of the cornea, which can be removed, changed, or upgraded at any time
- finally, in extreme cases, **permanent implantable contact lenses** can be used to correct vision
- these are placed behind the cornea, but in front of the natural lens

Homework: 1-6, p. 444

G. Hearing and Equilibrium

- the ear performs two separate functions – hearing and equilibrium
- the ear can be divided into three sections:

- the outer ear
  - contains the **pinna** – external flap that collects and funnels the sound waves from a large area to a canal
  - contains the **auditory canal** – carries sound to the eardrum (tympanic membrane) and makes earwax that traps, collects, and pushes out foreign invading particles
- the middle ear
  - begins with the **eardrum** or tympanic membrane – receives sound waves and resonates, causing the ear bones to move
  - three small bones, called ear **ossicles** are connected in series
  - they are the **malleus (hammer), incus (anvil),** and **stapes (stirrup)** – the malleus receives the vibrations from the eardrum, then moves the incus, which, in turn, moves the stapes
  - because the ear bones are small and dense, they amplify the vibrations and transfer the mechanical energy efficiently to the oval window
  - the **oval window** receives sound waves from the ear ossicles and transfers it to the fluid in the inner ear
  - the over all purpose of the middle ear is to amplify and concentrate the sound from the eardrum to the smaller oval window
- the inner ear
  - made up of three distinct areas – the **vestibule**, the **semi-lunar canals**, and the **cochlea**
  - the vestibule and semi-lunar canals are involved with balance, while the cochlea is related to hearing
  - the vestibule contains two small sacs – the **utricle** and the **saccule**, both establish head position and static equilibrium
  - there are three semi-circular canals, each arranged at different angles, each helping to maintain dynamic equilibrium
  - the cochlea is shaped like a snail's shell and contains two rows of specialized hair cells that run along the inside of the entire canal's length
  - the hair cells respond to different frequencies (short ones to high frequencies, and longer ones to low frequency sounds), and they convert the mechanical vibrations into nerve impulses
- eustachian tube
  - extends from the middle ear to the mouth and the chambers of the nose
  - 4.0 cm in length and 3 mm in diameter
  - it functions to equalize the air pressure on both sides of the eardrum

- this is the reason why throat infections often lead to ear infections, or vice versa

HEARING AND SOUND

- when particles vibrate back and forth at a specific frequency, they possess mechanical energy
- the periodic oscillations of particles is by definition a wave
- therefore, sound is an example of a wave
- all waves require a medium to travel through
- this means that sound cannot be transmitted in a vacuum
- when sound waves – which consist of compression and rarefractions of air particles – push against the eardrum, the vibrations are passed on to the three bones of the middle ear
- this “lever system” of bones transfer, amplify, and concentrate the mechanical wave to an oval window
- as the oval window pushes inward, the round window, located immediately below the oval window, moves outward, triggering waves of fluid within the inner ear
- the cochlea receives these movements, the hairs are stimulated, and the mechanical pulse is converted into an electrical signal
- the hearing apparatus within the cochlea is called the **organ of Corti –** a single inner row and three outer rows of specialized hair cells that are anchored in the basilar membrane (see Figure 3, p. 447)
- when the hairs move, the sensory nerves in the basilar membrane are stimulated
- the auditory signal is then sent to the temporal lobe of the cerebrum via auditory nerves, and the sound is banked
- when intense sound is heard, a safety mechanism kicks in to prevent the bones from vibrating wildly, which can damage them as well as the inner ear
- this safety mechanism is actually a reflex arc – it consists of two responses….first tiny muscles contracting, which restrict the movement of the malleus and reduce the intensity of movement, and then a second muscle contracts, pulling the stapes away from the oval window, thereby protecting the inner ear from powerful vibrations
- sometimes, if the sound is too sudden – like a bomb or fire cracker – the protective reflex doesn’t kick in fast enough
- this could lead to permanent hearing damage

EQUILIBRIUM

- there are two kinds of balance – static and dynamic
- static involves movement along one plane
- the position of the head is monitored by two fluid-filled sacs called the saccule and the utricle
- within the saccule and the utricle are tiny hair-like receptor cells, each containing cilia that are suspended in a gelatinous material that contains small calcium carbonate granules called **otoliths**
- as the head moves forward, the otoliths are pulled down by gravity
- when the otoliths move, they cause the hair receptor cells to bend (see Figure 5, p. 448)
- when the hair receptors bend, sensory nerves are stimulated and information about the head’s position is relayed to the brain for interpretation
- to maintain balance while you are moving, the three fluid-filled semicircular canals are used
- each canal is equipped with a pocket called an **ampulla**
- when the body moves, the fluid in the canals move
- the fluid moving causes the ampullae to move, which in turn, causes the cilia that are attached to the hair cells to move
- this initiates nerve impulses, which are then carried to the brain
- it is believed that motion sickness is the result of the fluid within the semicircular canals is moving continuously

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