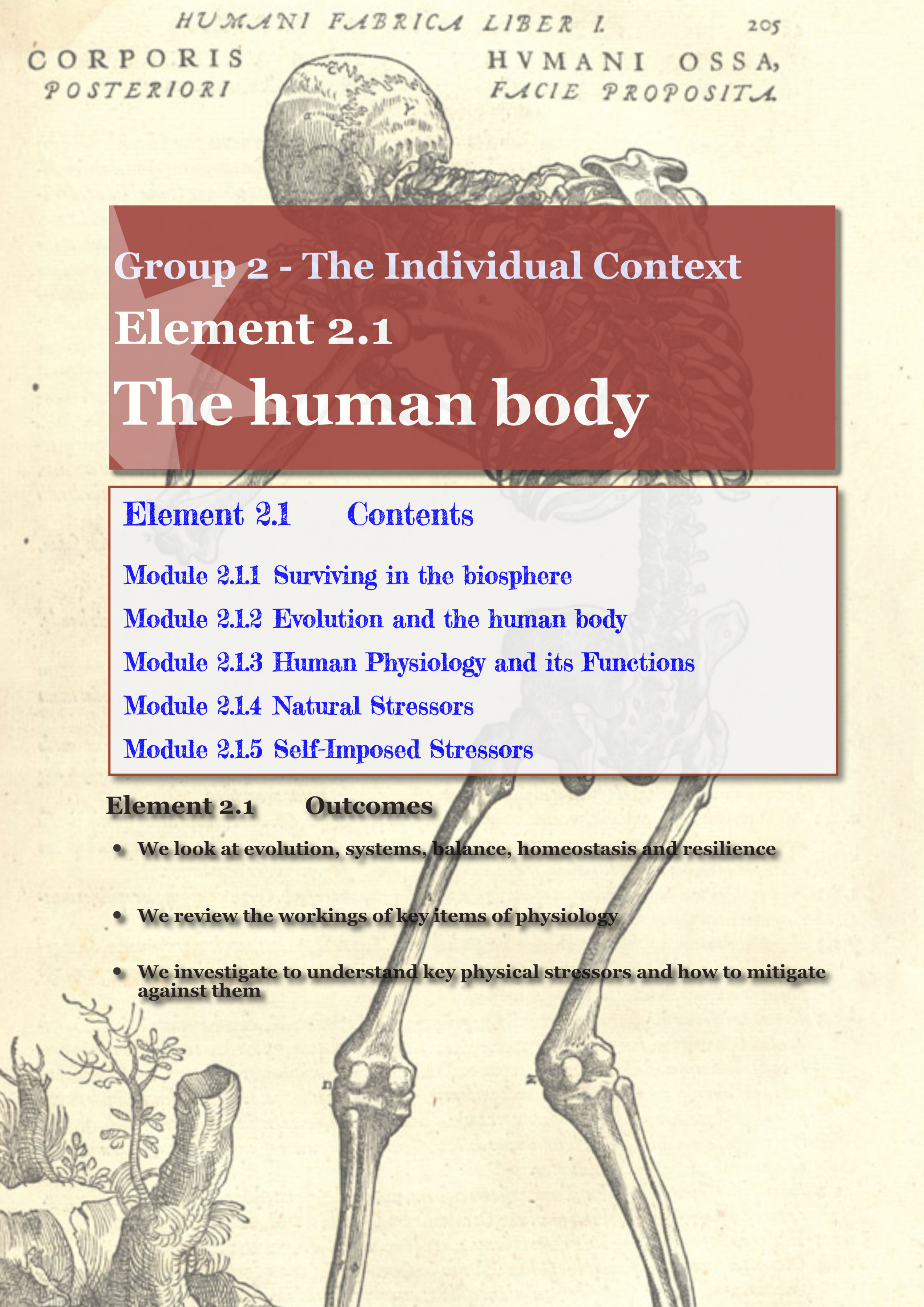


Group 2 - The Individual Context

Element 2.1

The human body

Element 2.1 Contents

Module 2.1.1 Surviving in the biosphere

Module 2.1.2 Evolution and the human body

Module 2.1.3 Human Physiology and its Functions

Module 2.1.4 Natural Stressors

Module 2.1.5 Self-Imposed Stressors

Element 2.1 Outcomes

- We look at evolution, systems, balance, homeostasis and resilience
- We review the workings of key items of physiology
- We investigate to understand key physical stressors and how to mitigate against them

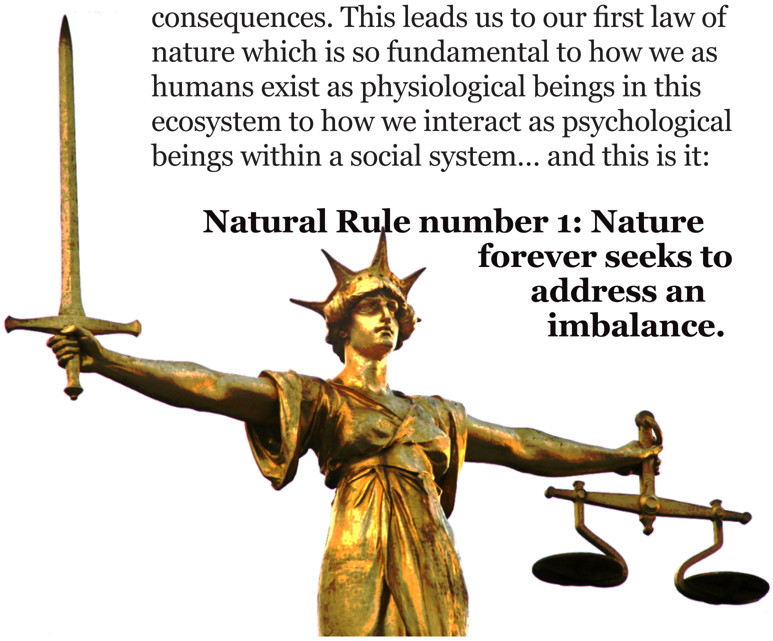
Element 2.1

The Human Body

Module 2.1.1 Surviving in the biosphere

2.1.1.1 Fate in the balance. Our whole existence is about balance. It is about what is given and what is taken in order to restore it to its natural equilibrium. Everything from the smallest atom to whole universes seek to maintain balance. And if it is not maintained disharmony ensues, often with tragic consequences. This leads us to our first law of nature which is so fundamental to how we as humans exist as physiological beings in this ecosystem to how we interact as psychological beings within a social system… and this is it:

Natural Rule number 1: Nature forever seeks to address an imbalance.



Attributed to Aristotle is the phrase: ‘ Nature abhors a vaccuum.’ His logic was that no vaccuum could exist because everything else would be more dense and would naturally flow into the void. What is easier to understand is the concept that **nature will try and equalise itself to avoid an imbalance**, and **this rule holds true in the physical and psychological world** in various forms. Over time it was expanded upon by other philosophers, scientists and pundits. Newton’s fundamental laws of physics are laws of balance, and systems theory holds similar observations, both of which we shall explore later in this module.

It is very important that this concept be understood for it is at the heart of everything in the universe. Another way of explaining it is that if there is a an inbalance, then it is rule of nature that balance will try to be resumed by some means. Natural systems such as the human body or an ecosystem or some other naturally-occurring collection of interdependent items that go to make a whole will have process that will try and find that balance. The same can be said for man-made systems that are designed, like nature, to exist in optimal conditions. The symbol of justice is Lady Justice who weighs the balance of evidence, comes to a decision and wields a sword of retribution. A system that is out of balance may result in a similar fate.

2.1.1.2 The Goldilocks zone. For life to be sustained on a planet such as Earth it needs to be in the Circumstellar Habitable Zone (CHZ), the zone around a star which is not too hot and not too cold such that water neither boils nor freezes but where the temperature range is ‘juuuust right’. As such, this zone has been nicknamed ‘the Goldilocks Zone’ after the character in the children’s story. Finding just the right balanced environment for life to exist is occupying the time of NASA in its Exoplanet Program. Prior to its decommissioning, the Kepler Space Telescope was searching for planets that are similar to Earth, and even long after the orbiting telescope ceased to operate, scientists are still finding valuable data and potential life-sustaining planets from the millions of data elements it has gathered. Two in particular are similar to Earth in size and distance from its star: Kepler-186f and Kepler 452b. (1) But of the planets discovered that are located within a star’s CHZ, no water—so critical for the sustainment of life—has yet been found. So until we find an althernative, this planet-the third from the Sun-will remain our home.

The Earth is estimated to be approximately 4.6 billion years old taking about 100 million years to accrete. In fact, the oldest material yet discovered and dated is from Western Australia consisting of zircon grains up to 4.4 billion years old. The source of water on Earth is still under debate, with theories suggesting that asteroids and comets, themselves made up of ice, were the source of water’s constituent parts, possibly as water vapour or ice. It is thought that solar ultraviolet radiation provided the mechanism to break up

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water molecules into hydrogen and oxygen.

A key requirement of life is a source of energy and the ability to synthesise that energy to create new organic material. This is conducted through chemical reactions that can be found occuring in all living matter and which is called metabolism. The chemical processes found at cellular level are common between all life forms with only minor variations. Various amino acids, consisting of carbon and attached hydrogen and oxygen create proteins which perform numerous functions, but one of which is particularly important, and that is metabolisation. The basic elements of a proteins are nitrogen, hydrogen, oxygen and carbon. Plants are able to synthesise photon energy from light (photosynthesis) to convert water's H_2O and carbon dioxide CO_2 into carbohydrates ($C_n[H_2O]_n$) such as sugar $C_6H_{12}O_6$ and and the waste product oxygen O_2. This process also creates a compound called adenosine triphosphate, or ATP as a by-product, which is extremely important to all life on earth for it can release energy when combined with water, something that will be re-visited when we discuss biological processes and metabolism.

About 2 billion years ago the oceans, produced by condensation of water vapour in the atmosphere as the earth cooled, achieved their more or less current form and have remained consistent chemical systems since then. (2) The origin of the first traces of organisms that would eventually develop into all living things on Earth are still being debated, with theorists postulating that early forms of life may have originated from space-borne molecules; or that amino acids formed through the chemical reaction of heat and methane, ammonia, hydrogen and water vapour; or that there is some other origin. In any case, life in the form of soft-bodied metazoans existed approximately 650 million years ago in the late-Proterozoic era. From these humble beginnings saw fish develop 100 million years later with continued evolution and sudden diversification of life forms—including air-

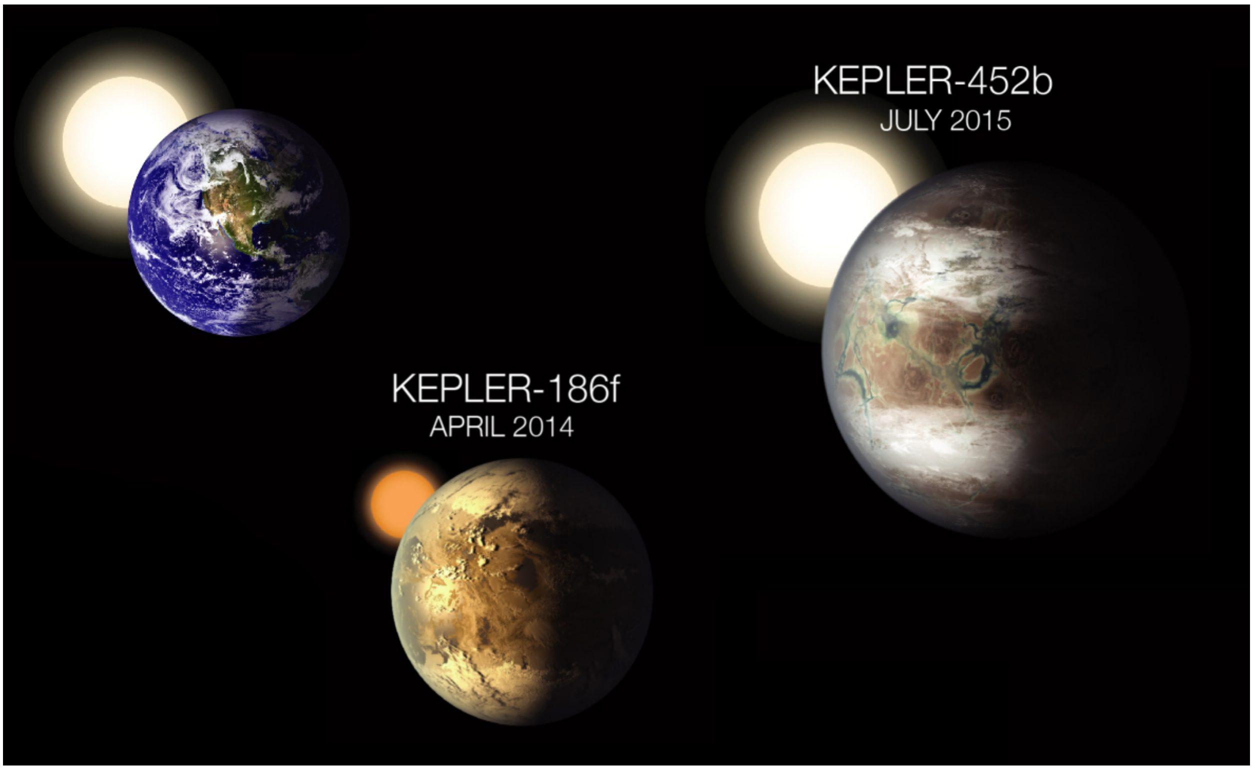

Figure 2.1. Kepler-186f is a 1.7 times the size of earth orbiting an 'M-type' star which is much cooler and dimmer than our sun. Its year is 129 days . Kepler-452b is about 1.6 times the size of Earth but its sun is similar to our own and has a year of 384 days but it is 1,799 light years away whereas Kepler 186f is a mere 500 light years away. (Image derived from NASA image.)

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laws of physics that use space and time as dimensions.

Systems can be influenced by human intervention to make them more or less stable or to bring them to a desired state. In some cases a system may be in a state that is not ideal and requires intervention by humans. An example is a central bank adjusting interest rates to encourage or dampen economic activity. Another example is the culling of an introduced pest species that is having a negative effect on a local ecosystem.

A negative feedback loop is a way that a system can find balance. It is called a negative feedback loop because it is an ongoing process that commits an action, then checks it, then corrects any errors by commiting an action, and so on and so on in a continuous loop. **If an inbalance occurs, then the difference between the desired optimal balanced state and the unbalanced state—what's called the 'delta'—is detected and an opposite feedback that negates (ie subtracts) the delta is fed back into the system to bring it into balance.** An example is cruise control in a car. If the speed is set for 100 km/hr and the car detects that it is only travelling at 90 km/hr, then the delta is - 10 km/hr. The system sees the inbalance and then takes steps to negate it by feeding into the system a means to increase speed to bring it back to the optimum end state. This means increasing the fuel supply to the engine to accelerate the motor and increase the car's speed. Once the error, or delta, is detected to be zero, ie the car is at the target speed of 100 km/hr, then the extra fuel supply is removed and the steady-state fuel supply to keep it at the desired speed is maintained.

In many cases a system will learn to adapt to external stimuli and constantly find its equilibrium depending on environmental conditions. Again, these systems could be man made or naturally occurring. **A system that is able to learn and adapt to an environment is called a Complex Adaptive System (CAS).** An example is the stock market that is influenced by buyer and seller behaviours, as well as regulatory intervention, and will adjust to external influences such as international tensions or changes to supply and demand.

Systemic maintenance of an optimal equilibrium can be found in chemistry, economics, biology, astronomy, engineering, mathematics, political science, anthropology, climate sciences and so on. This natural tendency for stability can be described using various laws such as Le Chatelier's principle in chemistry, Keynsian theories in economics and a host of others that involve systems. Newton's laws of physics as applied to systems are the most useful in explaining their behaviour.

Here are Newton's three laws:

Now we shall integrate some general observations on systems. Compare the observations of systems to Newton's laws and you will see definite similarities:

Understanding the nature of the systems helps in understanding human factors, especially where it pertains to the system of the human body, and the sociological systems within which humans interact such as teams.

Stability in a system makes it predictable, especially when an external effect or influence changes that stability. **Resilience is the ability for a system to return to its normal state after experiencing a disturbance**. (4) A system that is not resilient or has low resilience will either fail or take an inordinate amount of time to return to its pre-disturbance state or identity. The air transportation system is one such system that is highly susceptible to

> WHAT'S IN A NAME?
>
> A system is a group of elements forming a complex whole. It may be man-made or natural and each element is considered in relation to the others within the group even though they may not be dependent on each other. Systems have a tendency to find a state of equilibrium. If the equilibrium is disturbed or placed under stress, the system may try and return to its natural state of equilibrium. This tendency is called homeostasis and the speed at which it occurs and the effectivness of returning to its prior state (or adapting to a new equilibrium) is called resilience.

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disturbing variables that place stress upon it. One only has to see the effect that bad weather, say fog for example, at one airport has on the entire system. The same applies to humans. A stressor is something that causes stress and it may be physical, such as fatiguing work, or physiological, such as an illness, or psychological, such as emotional trauma. The ability of the human system to return to a normal state of equilibrium after the effects of stress, and the time that return to normalcy takes, is a measure of that person's resilience. Knowledge, training and experience greatly assist with increasing a person's resilience.

Homeostasis is the natural tendency for a biological system to return to its normal state. The term is most often applied to a living organisms but is sometimes used to describe technological functions that return systems to normal via a negative feedback loop, such as a thermostat on a heater or an autopilot. A more correct term would be a cybernetic process where cybernetics is the study of 'control and communications in animals and machines'. (5)

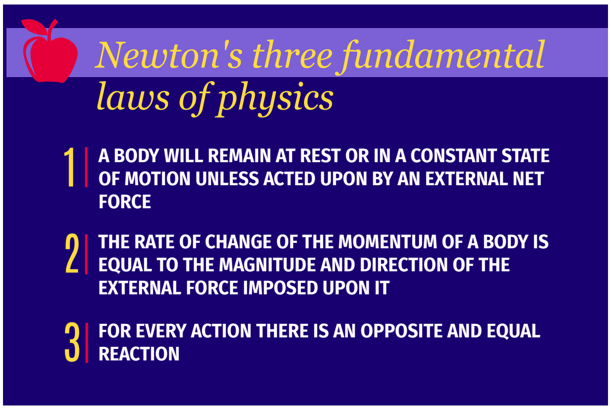

Table 2.1. Newtons three fundamental laws of physics.

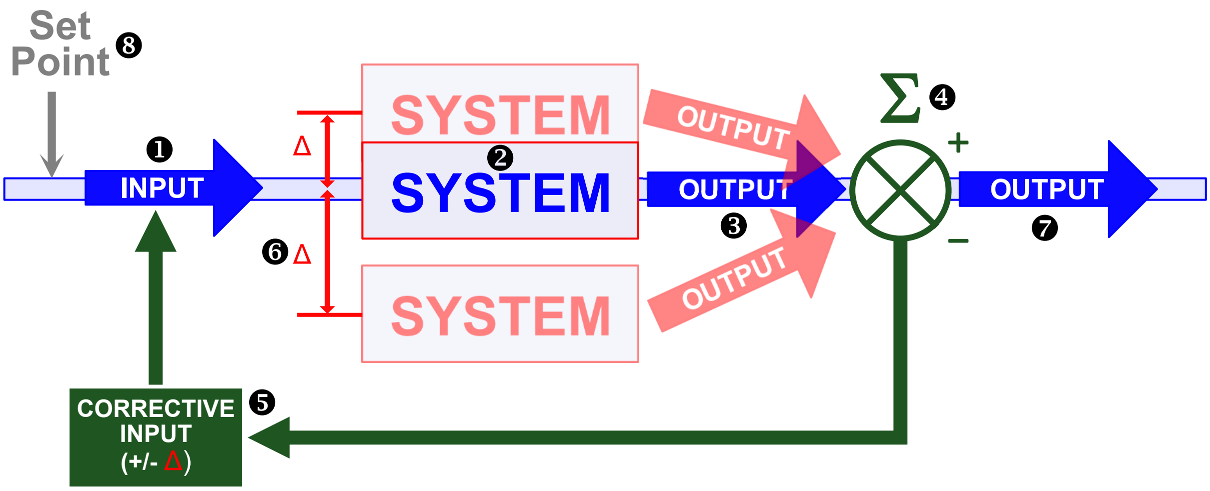

Figure 2.tk. A negative feedback loop where the input (1) to the system (2) results in an output (3) the sum of which is assessed at the summing point (4) which compares it to its reference state and if there is a difference (6) between the reference state and the actual state (ie the delta) then a corrective input to 'negate' the difference is provided into the input (5) which should result in a corrected output (7). The reference state is programmed as the 'set point' (8) and the system should maintain the set point.

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Module 2.1.2 Evolution and the human body

2.1.2.1 Homonids and bipedalism. Hominids, the collective term applied to the ancestors of modern apes, orangutans, chimps and humans, are thought to have originated in Africa or Eurasia around 11 million years ago. Of the four genera, Homo—man—is the branch that includes

Three general observations of systems

1. CHANGING ONE PART OF A SYSTEM MAY HAVE AN EFFECT ON THE WHOLE SYSTEM UNTIL EQUILIBRIUM IS RESTORED OR A NEW EQUILIBRIUM IS ATTAINED
2. THE RATE AND AMOUNT OF ADAPTATION OF A COMPLEX ADAPTIVE SYSTEM TO AN EXTERNAL STIMULUS WILL BE DEPENDENT ON THE INTERACTION OF THE SYSTEM WITH ITS ENVIRONMENT
3. AN ACTION IMPOSED ON A SYSTEM WILL RESULT IN A REACTION AND, DEPENDING ON THE COMPLEXITY OF THE SYSTEM, MAY BE PREDICTABLE

Table 2.2. General observations of systems.

modern *homo sapiens* and emerged roughly 2 million years ago from which also evolved other species of primates such as *homo erectus, homo heidelbergensis, homo neanderthalensis* and finally, *homo sapiens*. Large molar teeth with thick enamel suggests they foraged for food that included tough vegetation, seeds, fruits and tubers. The cyclical changes in climate that occur approximately every 100,000 years would see global temperatures rise and fall bringing with them advancing and retreating glaciation and changes in vegetation and sea levels. These changes meant widespread variations in wildlife patterns and food sources and encouraged migration. It also included a change in their locomotion going from an arborial to terrestrial domain and **bipedalism, that is to say, walking on two feet**. This, in turn, commenced a change in their stature and physique. **The skeletal structure, particularly the spinal column, adjusted to shift the body's centre of gravity**.

Several theories exist as to why homonids began to walk erect: it takes less energy; it may allow for wading in water to avoid some predators or to prey on aquatic animals; or standing in tall grass searching for danger or for food. Another advantage is that it presents less surface area to the sun keeping the body cooler. Along with changes to stature, the increased use of tools and the discovery of the benefits of cooking food and the increase in meat in the diet saw changes in the hands, brain size and jaw shape and teeth size. The increase in brain size did not equate to a corresponding cognitive ability. Indeed, *neanderthals* had larger brains than *homo sapiens,* but were more backward in their use of tools as figure 2.2 attests.

2.1.2.2 Human cells and the remarkable neuron. While it may seem unusual to now discuss human cells while we have been discussing planets and evolution, but understanding cells, and one type of cell in particular, is critical in understanding the development of humans and the control of virtually all aspects of our existence, and especially when we consider the ability for hominids to evolve and to learn. Of course, we are speaking of the neuron and we shall explore this remarkable feature of biology in later sections of this text. But first we need to understand cells. **A cell is the basic building block of life**. 10,000 human cells could cover the head of a pin and there are about 30 trillion cells in the human body. **Cells perform chemical reactions, take in nutrients, give off heat and communicate with other cells**. Various functions can be carried out by specific cells making them sensitive to particular stimuli causing them to react in a particular way. (Smith) **A cell is enclosed in a membrane** which helps to keep out toxic substances but also allow specific molecules to enter via openings in the membrane called receptors. The membrane is a double layer of lipids consisting of phospholipid, cholesterol, and glycolipid molecules. These lipid chains that form **the membrane will allow**

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certain molecules to pass through while repelling others. Embedded within the membrane are proteins that acts like gates or carriers. They may allow the free flow of ions or molecules through the membrane, or receive ions or molecules on one side of the membrane and carry them through to the other side. (Editors) These proteins are called transmembrane receptors. Other receptors may be found inside the cell and are called intra-cellular receptors.

The transmembrane receptors are of particular interest to us and include ligand-gated ion channels, G-protein coupled receptors and hormone receptors. Each one of these receptors reacts in a different way to a different signal. **A receptor will receive and transduce signals from an external signalling agent. The type of signal is usually a ligand but other stimuli can cause an affect also.** A ligand is a signal molecule that could be a hormone, an ion, a protein or another element or compound and will have a certain property that will make it bind to or repel from a receptor. Depending on the type it may be able to pass through a cell membrane unaided. (Bartee et al). **The ligands can cause a reaction in the receptor to various degrees or cause an opposite or blocking effect or can alter the effect of the signal.** For example, a ligand signal will cause a receptor to, in the case of an ion channel, open it to allow ions to flow into or out of a cell. Because an ion is a charged molecule, this has the effect of changing the electrical potential of the cell either making it more charged or less charged. The ions are usually metals such as calcium, potassium, chlorine or sodium atoms that have electrons exchanging between atoms.

A neuron is a nerve cell and the basic cell of the nervous system of vertebrates. A neuron consists of a cell body called a soma to which are attached dendrites. Emanating from the cell body is a long tail called an axon, at the end of which are axon terminals. The axon terminals send signals to the dendrites of other neurons through a small gap called a synapse cleft. **The signal from one neuron to another may be in the form of a chemical or a change in electrical potential. This is called a neuro-transmitter**. The neurons may receive a stimulus from a receptor cell which will cause them to initiate a signal to the brain. These receptor cells could be such things as photo-sensitive cells in the eyes, or chemoreceptors in the nose. The receptor cells send signals to the neurons through their dendrites. **The neurons are critical in providing the brain with information about the body or about the environment in which it is. They also provide signals from the brain to the organs and limbs to perform actions, either voluntary or involuntary.** Neuron links are strengthened with experiences and practice, enabling an organism to perform functions in response to stimuli. In advanced species this equates to learning. In the most advanced species this enables cognitive reasoning and advanced communication. Neural networks are therefore critical to human cognitive functions.

2.1.2.4 Neurotransmitters and hormones as messengers. The importance of understanding the cocepts of neurons, neurotransmitters and hormones will become more and more evident as we progress. They are crucial in regulating our body, our mood, our learning and motivations and thus our behaviour. They are also critical in how we perceive the world around us and process information and, of course the processes of homeostasis.

There are two main types of communicators in the body that take the form of chemical compounds: neurotransmitters which are produced in neurons; and hormones which are produced in the endocrine system's various glands. Some compounds can assume the role of both a neurotransmitter and/or a hormone depending on where it was synthesised and stored and where it acts. For example, dopamine is a hormone that is created in the cells of the adrenal glands but is a neurotransmitter when it is formed in the neurons of the brain in the substantia nigra and the ventral tegmental area. Within the brain it works in the neurons and between them as a neurotransmitter attaching to dopamine receptors, but there are also dopamine receptors on other parts of the body such as the

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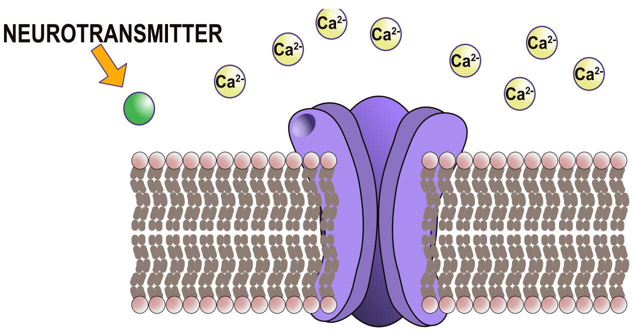
kidneys and pancreas. In the neural system, dopamine gives the brain a signal that is interpreted as pleasureable. Outside the neural system, dopamine encourages blood flow to the kidneys and increases the excretion of sodium into urine.

There are over 100 identified neurotransmitters and hormones and other substances involved in synaptic transmission and homeostasis (Hyman), but a few of them make a disproportionately large contribution to, and influence on, human life and endeavours.

Adrenaline (Epinephrine) $C_9H_{13}NO_3$ is well known for its rapid onset during times of sudden high stress causing the body to ready itself to flee, to fight or to freeze. It is a vital adaptive functional neurotransmitter and hormone. As a hormone it is a sympathomimetic compound (ie it stimulates the sympathetic nervous system). It is produced primarily in the adrenal medulla of the adrenal glands on the kidneys and causes vasoconstriction and gastrointestinal relaxation, stimulates the heart, and dilates bronchi and cerebral vessels. (Pubchem) Through various processes it increases blood glucose and fatty acids providing the body with an increase source of energy while at the same time reducing blood flow to the peripheral blood vessels (vasoconstriction). This serves to increase the amount of blood and blood pressure available to the central organs and larger muscles to aid in the transfer of oxygen and to enable an increase in their use. The receptors that are activated by adrenaline are called α– and β– adrenergic receptors. When adrenaline is found in the neurons of the brain, they bind to the same receptors as noradrenaline (norepinephrine) (Feher). Adrenaline and noradrenaline act in similar ways except adrenaline acts more readily as a hormone in the periphery and noradrenaline acts more like a neurotransmitter. Neurons will also re-uptake adrenaline from the synapse and enzymes can break them down or they can be stored for use again.(Kapalka). An epinephrine autoinjector, also known as an EpiPen, is used to inject epinephrine for severe allergic reactions. The relaxing of the bronchi and stimulation of the heart help to overcome the life-threatening effects of an allergic reaction when inflammation threatens to close airways and interrupt heart function.

Noradrenaline (Norepinephrine) $C_8H_{11}NO_3$ is produced in the adrenal glands like adrenaline and performs many of the same functions, but is more akin to a neurotransmitter and is found in greater concentrations in neurons of the sympathetic nervous system than adrenaline. (Rogers) Both respond to stress by stimulating α– and β– adrenergic receptors that cause vasoconstriction of the muscle of the iris, arteries, veins, bladder and gastrointestinal tract as well as causing the heart to beat faster and with more pressure and opening up the airways. (Pubchem) Noradrenaline has been implicated in the strengthening of synaptic bonds resulting in heightened memory. This has both positive and negateive effects. If the synaptic bond is related to a positive experience, then the memory is more likely to be positive or neutral. But if the bond is related to a negative experience, then 'memory triggers' may evoke negative physiological responses such as the release of noradrenaline resulting in fear and increased heart rate. This



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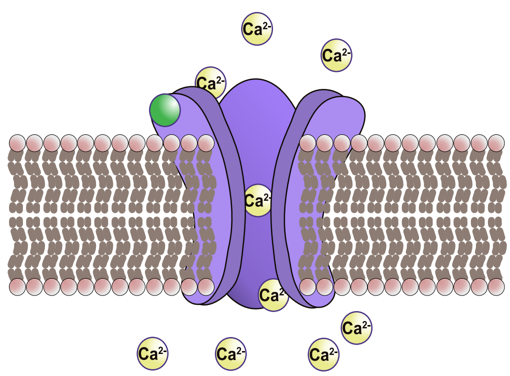

LIGAND-GATED ION CHANNEL - OPEN

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is heightened when the event was emotionally charged. While an emotionally-charged memory may be stronger, it is not necessarily more accurate. Indeed, subjectivity may actually increase in these instances with memories being skewed, while remaining strong. (Tully) This will be examined more closely in the section on memory. Like adrenaline, noradrenaline either degrades or is taken back up by the neuron (reuptake).

Dopamine $C_8H_{11}NO_2$ which is a contraction of 3,4 dihydroxyphenethylamine, is often called the 'pleasure' chemical, but a more accurate description is that it is the motivation chemical. It is synthesised in the neurons of the brain where it acts as a neurotransmitter, as well as the adrenal glands (like adrenaline and noradrenaline). In fact, dopamine is the pre-cursor to both those chemicals.

2.1.2.4 Human optimal habitable range. Human beings, whilst constantly evolving, have not evolved so significantly that they can withstand very harsh environments. Indeed, the evolution of *homo sapiens* at this stage of their development sees an optimal range of comfort parameters. They are:

Within those parameters humans can exist comfortably without tools. Early humans could rarely influence those parameters markedly, which brings us to the notion of affordances.

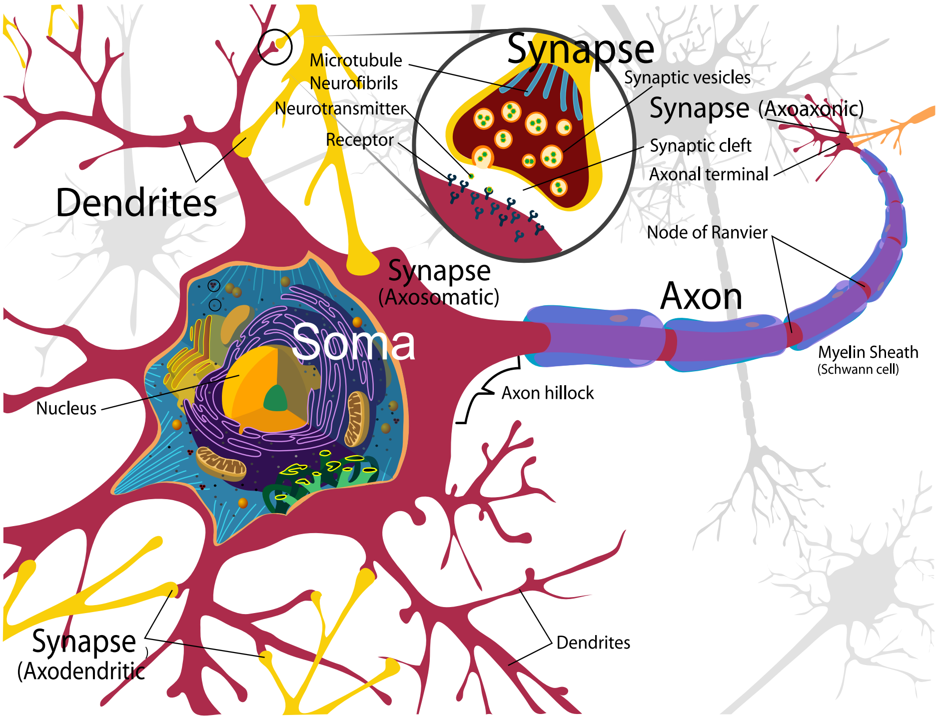

Figure 2.3 Neurons are nerve cells that permit the carriage of signals to or from the brain. Each cell can connect to another cell and will communicate by means of chemical or electrical reactions (through the flow of ions).

2.1.2.4 Affordances, learning and tools. The Earth contains four key domains: the atmosphere, lithosphere, hydrosphere and biosphere. The first three describe the air, land and water respectively as physical domains whereas the last, the biosphere, describes the nexus of the first three where life can be sustained. Each domain provides various environments where organisms can exist and, as we have seen, there is a narrow optimal habitable band where humans can live healthily and in comfort. But within the biosphere there are several environmental conditions in which humans inhabit. Each of these environments afford different resources of which humans have learnt to take advantage. **Affordance is what**

MODERN HOMOSAPIENS' OPTIMAL HABITABLE RANGE

		minimum	maximum
1	UV exposure unclothed, in shade, no exertion	400nm	280nm
2	Temperature Range unclothed, in shade, no exertion	24 deg C	28 deg C
3	Atmospheric Pressure for permanent habitation	Sea Level	18 000'
4	Atmospheric Humidity for optimal conditions	30%	50%
5	Acceleration for optimal conditions	9.8ms/s downwards	
6	Ambient Noise for optimal conditions	0 dBA	75dBA (cont.)
7	Hydration for optimal conditions	Sufficient for ambient conditions of exertion/heat/humidity	
8	Nutrition for optimal conditions	Sufficient to provide micro and macro nutrients	
9	Toxins for optimal conditions	Free from toxins/disease	
10	24hr Sleep/Wake Cycle for optimal conditions	Sufficient to satisfy fatigue levels	
11	Light Levels for optimal conditions	3 lux	108,000 lux

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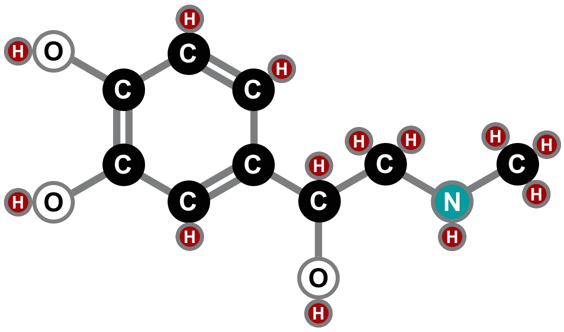
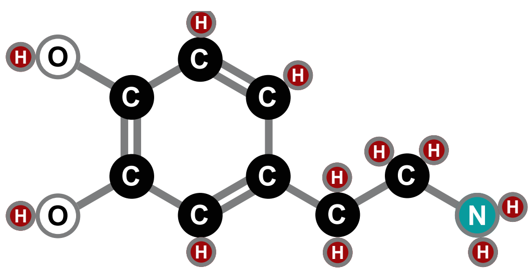
an environment offers an animal,



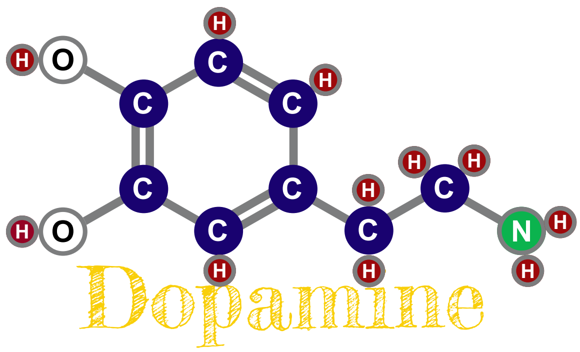
elements of which could be an advantage or a disadvantage. (Gibson, 2015) This adaptation to an environment is known as **affordance learning - it describes how an organism will learn to take advantage of what an environment has to offer.**

As the Earth's climate went through its cycles, hominids took advantage of the land bridges that emerged with the advent of cooler climates. This widespread cooling also resulted in massive droughts in many regions on the planet. Migrations of hominids occurred taking them away from the hotter and drier lower latitudes along the equatorial region, to higher latitudes or along coastlines in search of food and water. **Hominids demonstrated affordance learning by taking advantage of the new environments and adapting**. They also demonstrated cognitive reasoning by creating tools and ways to increase their range, particularly a means of carrying water and creating fire. This led to the preeminence of *Homo sapiens* amongst the hominids due, in part, to their ability to make more complex tools. The result was the other species such as *homo neanderthalensis* and *homo erectus* and *homo heidelbergensis* all dying out.

Later, other developments such as the domestication of dogs and hooved animals, and



technological advances such as a knowledge of irrigation, the planting of crops, the smelting and forming of iron and copper and other metals, and advances in transportation such as carts and boats, gave rise to less of a nomadic existence involving hunting and gathering food, to a more static and organised socially-based organisation with group interaction. This was facilitated by communication through a common language and a method of order within the group. This cooperative system, a by-product of the human urge to be with similar humans, has led to very complex interactions, both good and bad, at every level - from two people to billions of people. This context will be explored more deeply in *Group 3 - The Interactive Context*.



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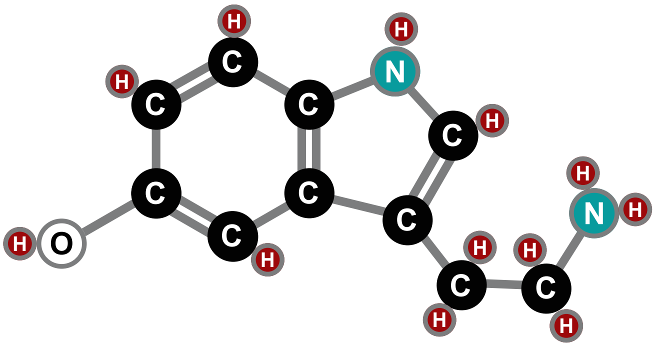

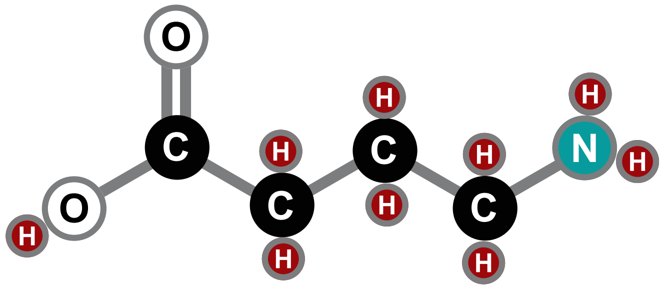

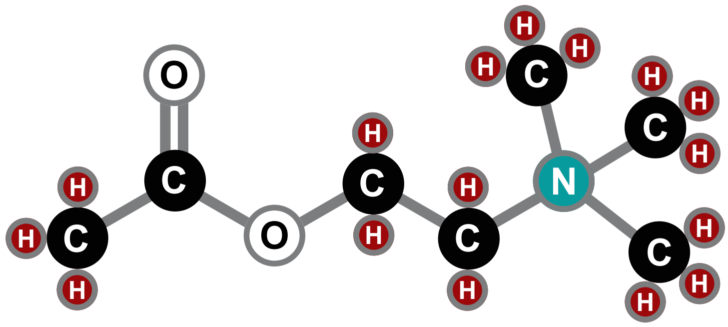

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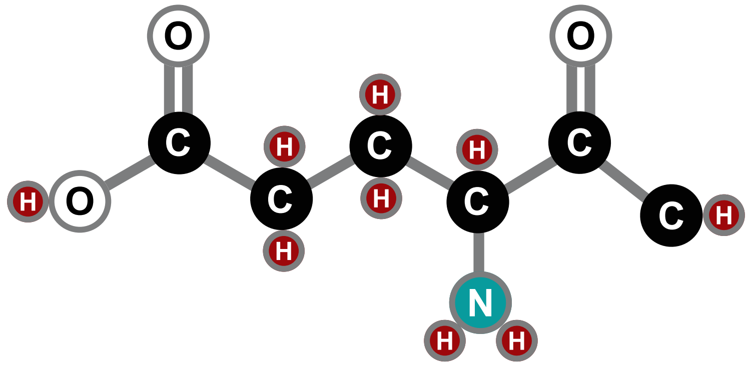
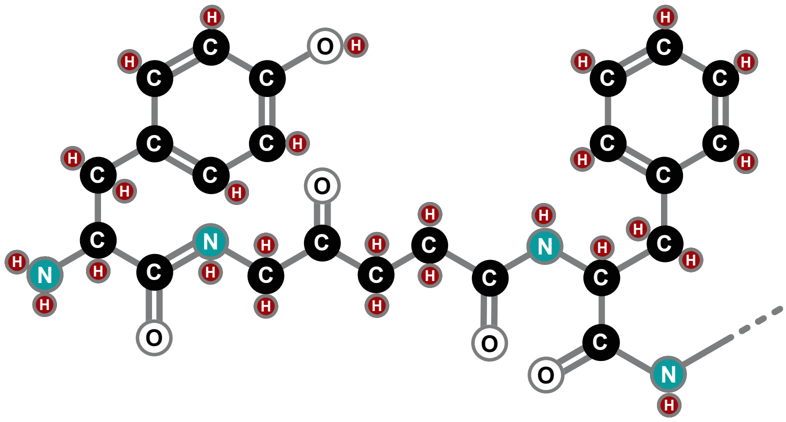
Module 2.1.3 Human physiology and its functions



2.1.3.1 The skeletal structure. As humans evolved and became bipedal, the shape of the skeleton adjusted accordingly. Legs became longer, the fully articulating thumb-like toe retracted to become the big toe we currently have that assists with upright walking. The vertebral column became stronger and the pelvis wider to accommodate the joining of the long bones of the legs with the body, as well as becoming stronger to support the vertical weight of the torso, arms and head. This process was aided by bone re-modelling that reacts to stresses placed upon bone.



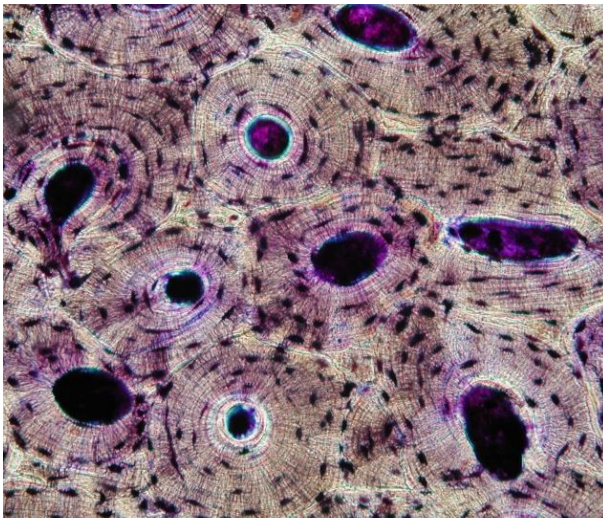


Figure 2.6 A cross section of bone showing the tubal structure of the osteons and the concentric rings of the lamellae that surround them.The osteocytes can be found between the lamellae and respond to stresses experienced by the bone such as fractures and other damage which then initiates bone repair which is part of bone re-modelling.

Department of Histology, Jagiellonian University Medical College. CC-by 3.0

Bones are responsible for hematopoiesis, the creation of new blood, which is generated in bone marrow. **Bones assist with homeostasis by producing osteocalcin which is a hormone that regulates the amount of insulin in the body** and assists with protecting against glucose intolerance and diabetes.

There are 206 bones in the human body. The smallest being the stapes in the middle ear and the largest being the femur, or thigh bone. They are divided into two main categories: axial and the appendicular. The 80 **axial bones include the skull, vertebral column and** [...] **provide sup**[...] **the skeletal** [...] **along the bo**[...] **against the f**[...] They accomm[...] such as the br[...] others.

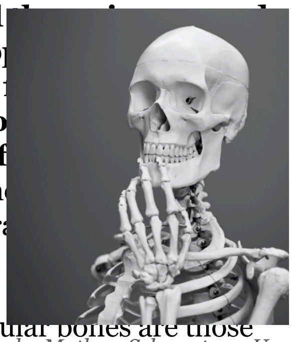


Photo by Mathew Schwartz on Unsplash

The appendicular bones are those that are attached—or appended—to the axial bones and which help us with mobility. They support the limbs and are attached to the axial

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bones by the shoulder blades and pelvis.

The shapes of the bones help to describe them. Long bones are greater in length then their width and include the long bones of the limbs but also the small bones in the hands and feet such as the metacarpals. Short bones such as the talus and scaphoid are wider than they are long, and the flat bones are thin and curved such as the scapula, sternum, and the cranial bones that make up the skull. Irregular bones are usually specialised bones and include the pelvis and vertebra and the bones of the face.

Within the bones there are two types of marrow: red marrow that produces blood cells, and yellow marrow that stores energy as fat. The material that makes up the bones consists of osteons which have a similar structure to sponge in some areas, or long tubes that run the length of the long bones. These osteons have concentric layers of lamellae where the collagen fibres are crisscrossed in each layer in the same way that the grain in layers of plywood are arranged. And in the same way that sponge structures provide flexibility and the crisscrossed grain of plywood gives it its strength, so do the sponge structure and tubular structure with crisscrossed collagen give the bones their strength and provide them with both flexibility and the ability to absorb tension and torsion and shock forces.

Within each tubular osteon are spaces for blood vessels and nerves, and between each layer that makes up the osteon is where osteocytes can be found. **Osteocytes trigger repair processes within the bone when they detect stressors acting it**. If they detect damage they will signal osteoclasts to commence bone re-modelling by removing damaged bone material which will then allow osteoblasts to commence rebuilding the bone in that area. This includes when the bone encounters stressors such as that through exercise. The result of this exercise-induced controlled stressing is a strengthening of the bone. Osteoclasts diminish with age which results in a weakening of the bone and a reduction in the signalling to re-generate bone material. (Whedon, G. Donald and Heaney, Robert Proulx)

2.1.3.2 Muscles and the skeletal system. Muscles turn chemical potential energy into mechanical kinetic energy through movement by contracting and then relaxing. They do not extend. **There are three types of muscle tissue: smooth muscle tissue, cardiac muscle tissue and the skeletal muscle tissue.**

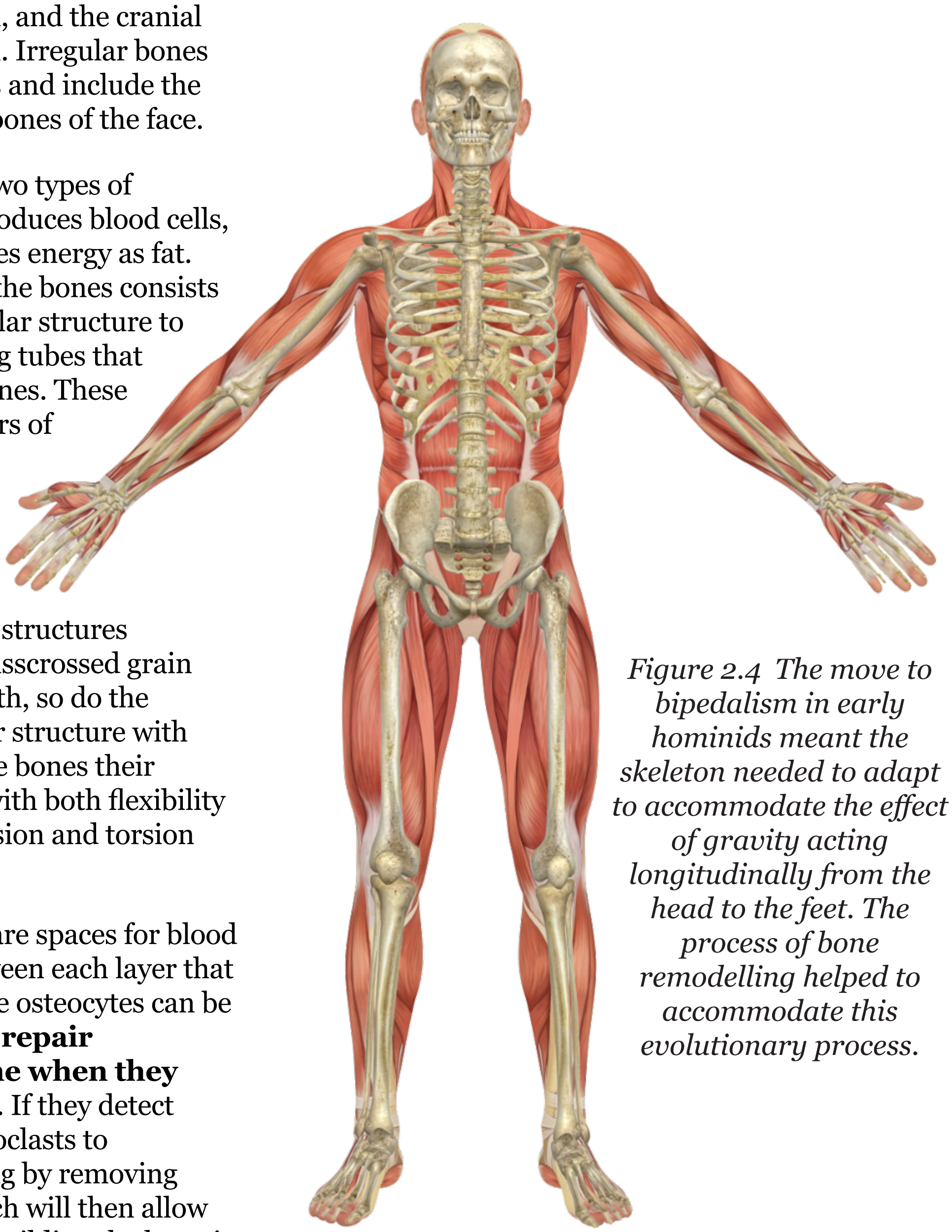

Figure 2.4 The move to bipedalism in early hominids meant the skeleton needed to adapt to accommodate the effect of gravity acting longitudinally from the head to the feet. The process of bone remodelling helped to accommodate this evolutionary process.

Smooth muscle tissues undertake the involuntary movements required by the body, such as breathing, digestion and other functions that do not require our conscious control. They are found in the visceral organs.

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Cardiac muscle tissue is not smooth muscle but it functions like smooth muscle because it also conducts involuntary movements without conscious thought, namely contracting and relaxing to push blood around the circulatory system. Lastly we have the **skeletal muscle tissue, so called because its primary function is to move the bones and ligaments** of the body. There are around 640 muscles in the human body.

Each of the large skeletal muscles has its own means of receiving blood to supply it with oxygen and nutrients, as well as a means of receiving neural signals through neurons. **When the brain signals to contract a muscle, ATP and calcium ions are released providing energy and heat and causing an action potential which results in two types of muscle filaments pulling towards each other.** It does this by the chemiosmosis of sodium into the muscle cell. Within the muscle cell are long filaments called actin and myosin. Calcium makes the actin receptive to binding with myosin. Meanwhile, the myosin filament reacts to the ATP and is energised by it and attracted to the actin. Both events cause the myosin to bind with the actin and in so doing pulls the actin filament. The myosin drops its ATP—converting it to ADP—and returns to its original position and then picks up another ATP, converts it to ADP almost immediately, links to another part of the actin and pulls it again. **This constant pulling and release, pulling and release is what causes the muscle to contract** and is the work performed, **while at the same time the conversion of ATP to ADP,** which is part of the process, **causes a phosphate bond to break which causes a small release of heat.**

Skeletal muscles are attached to bones by ligaments and when they contract, the bones move. The movement of the skeletal muscles are therefore dependent on motor signals from the brain in response to some sort of stimuli which causes a (normally) conscious command to action. Some responses to action involving skeletal muscles are involuntary such as a twitch, whereas other neural signals are unconscious commands to action. Examples are the cardiac muscle being signalled to contract or the diaphragm contracting to enable breaths to be drawn into the lungs for breathing. These examples of involuntary commands to action is part of the process of homeostasis. A cold body will try and generate heat by shivering. The rapid contraction and relaxing of a muscle in the form of shivering causes ATP to ADP reaction which releases heat. That will be discussed further in the section on stress. (crash course - Muscles Pt 1, / Alpert, Norman R. , Walker, Warren F. , Wood, Bernard , Crompton, Robin Huw , Warshaw, David M. , Newsom-Davis, John M. , Davies, Robert E. , Alexander, Robert McNeill , Curtin, Nancy A. and Gergely, John. "Muscle". Encyclopedia Britannica, 2 Jun. 2020, https://www.britannica.com/science/muscle. Accessed 15 June 2021. / Wikipedia https://en.wikipedia.org/wiki/Adenosine_triphosphate#:~:text=Adenosine%20triphosphate%20(ATP)%20is%20an,condensate%20dissolution%2C%20and%20chemical%20synthesis.)

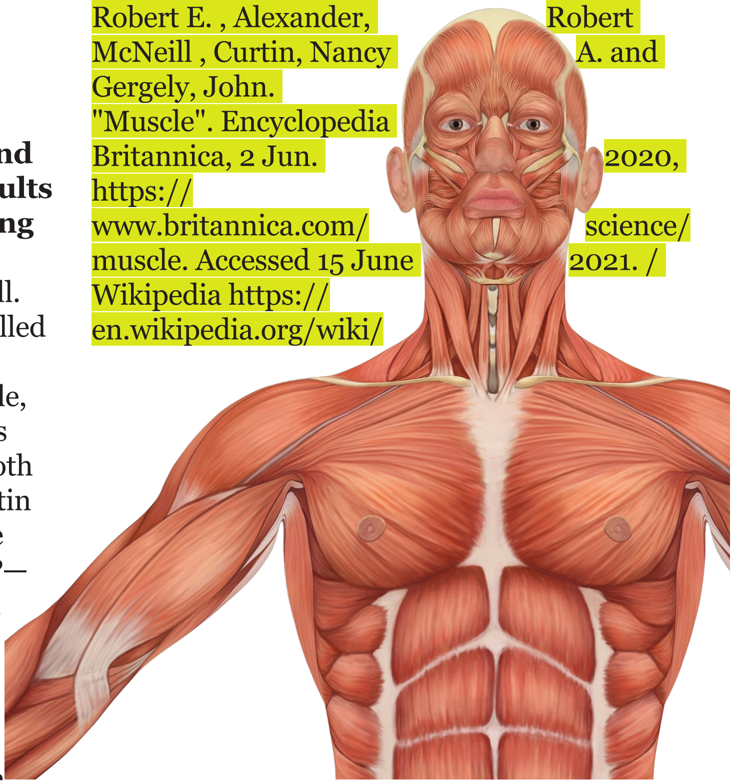

Figure 2.5 There are approximately 640 muscles in the human body, from the tiny stapedus in the middle ear to the gluteus maximus, the largest muscle by mass. But they are not the hardest working nor the strongest.

2.1.3.3 The heart and circulatory system. The heart is a hollow and muscular

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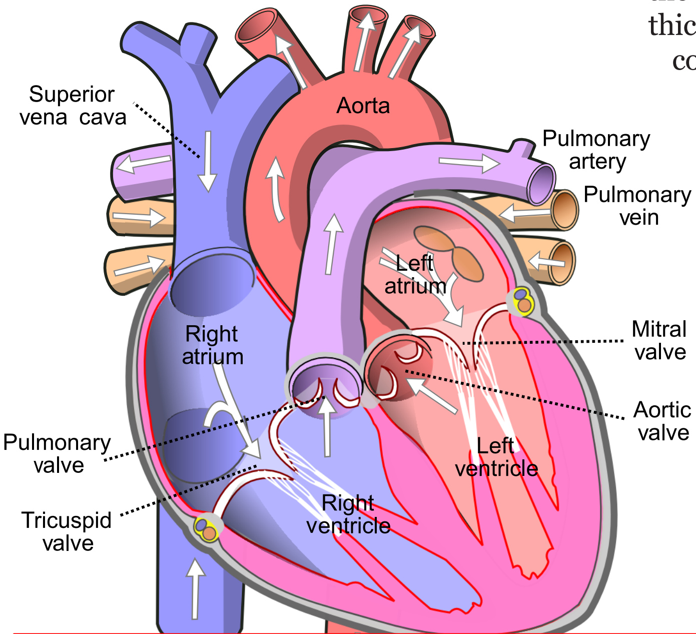
organ designed to pump blood through the body. It is located directly behind the sternum tending slightly to the left. **The heart can be considered to be a dual pump**; each half of the pump has two chambers, an upper atrium and the lower ventricle. **The right side of the heart pumps blood that is low in oxygen from the body into the lungs. The left side of the heart pumps blood from the lungs, which is high in oxygen, to the rest of the body**. In both cases it is the atrium of each side of the heart that receives the blood



through one phase of the heart beat called the diastole. The diastole is a relaxation of the ventricle and it is this relaxation that causes low blood pressure within the chamber causing the outlet valve to close and the inlet valve (tricuspid or mitral) to open. The ventricles then push the blood out of the heart and into the circulatory system through a second contraction via the outlet valves; the pulmonary valve for blood travelling to the lungs or the aortic valve for blood travelling to the body. Because the ventricles have to do the bulk of the work, they are particularly strong with the thickest walls (i.e. muscle tissue). Both of these contractions cause changes in the relative pressures within the chambers as the blood flows causing their respective valves to shut with an audible sound. The sounds can be heard through a stethoscope. The forcing of the blood out of the left ventricle causes the blood vessels to expand with the increased pressure. This can be felt as the pulse.

Heartbeat. The contractions of the heart, which constitute the heartbeat, do not happen simultaneously. Rather they happen in stages, or like a wave. First with the atria (atria is the plural of atrium) contracting above and then the

Age	Target heart rate zone 50 – 85%	Average maximum heart rate, 100%
20 years	100 – 170 bpm	200 bpm
30 years	95 – 162 bpm	190 bpm
35 years	93 – 157 bpm	185 bpm
40 years	90 – 153 bpm	180 bpm
45 years	80 – 149 bpm	175 bpm
50 years	85 – 145 bpm	170 bpm
55 years	83 – 140 bpm	165 bpm
60 years	80 – 136 bpm	160 bpm
65 years	78 – 132 bpm	155 bpm
70 years	75 – 128 bpm	150 bpm

Table 2.4. Target heart rates for exercise based on age.

flow, where it pushes it into the ventricle through the tricuspid valve on the right side and via the mitral valve on the left side. This occurs through the initial part of the heart's contraction. The ventricles receive the blood

ventricles contracting from the bottom up thus forcing the blood through the outlet valves into the pulmonary artery to the lungs or the aorta to the body. The delay between the initial contraction to the second contraction is about

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.2 of a second giving time for the chambers to fill. **For adult humans the resting heart rate of between 60 to 100 bpm is considered normal** with the lower the value being an indicator of a healthier cardio-vascular system. (Resting heart rate, 2021) During strenuous activity this can rise to as many as 200 bpm with the target rate for sustained exercise being 200 - your age in years (Target Heart Rates Chart, 2021)

Circulation, Blood and Respiration. The most important function of blood flow is the transportation of oxygen. In order for this to occur the blood needs to flow through the body in a continuous motion. This is called the circulation. The blood vessels that carry the blood are one-way vessels allowing blood to flow in one direction made possible by the shape of the inner layer of the vessels. The pathway of circulation goes as follows:

- **(From) the heart** – in particular the ventricles, that pumps blood to
- **the arteries** – that carry blood from the heart, to
- **the arterioles** – smaller arteries that can control the flow of blood to the organs, to
- **the capillaries** – small vessels with a very large surface area and very thin walls, to
- **the organs** – that take the nutrients and absorb and transport waste products, to
- **the venules and veins** – that returns the blood back to the heart.

Arteries are the major blood vessels that carry blood from the heart to the lungs or to the organs, depending on what part of the circulatory cycle is being considered. With thick walls they are able to withstand the high pressure of blood as it is pumped by the heart. The elasticity of the walls causes them to spring back to their original shape after the blood pressure reduces during the diastolic phase of a heartbeat. This recoil action helps to propel the blood—along with the action of the heart—and is part of the secondary circulation feature of blood circulation which helps to off-load the work of the heart. All arteries carry bright red oxygenated blood except for the pulmonary artery which carries blood from the heart to the

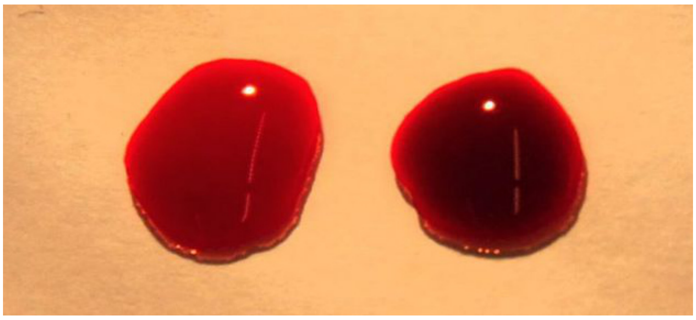

Figure 2.7 Two drops of blood. The droplet on the left that is brightly coloured red is heavily oxygenated blood whilst the one on the right is de-oxygenated.

lungs after it has returned from the other organs. The aorta which carries blood from the left ventricle to the body has the largest diameter of about 25 mm and can withstand the highest pressure.

Arterioles are smaller arteries. They carry blood from the arteries and deliver it to the capillaries in the tissues. The arterioles are able to constrict or dilate depending on demand. For example, during the activity of running, the tissues of the muscles in the legs may require extra blood. The arterioles can direct more blood to those muscles by restricting the blood flow to other areas of the body. This is necessary because the volume of blood remains the same and therefore apportioning blood must be done depending on which part of the body has the higher demand. The brain and the kidneys always have the same blood flow but other organs can have varied blood flow depending on bodily needs.

Capillaries are a network of very small and narrow blood vessels with a large surface area arranged in what is called a capillary bed. They also have very thin walls that are only one cell thick. In many cases blood cells must flow in single file, that is how narrow these vessels are. The thinness of the walls allows for the exchange of nutrients and waste by way of pressure differentials between the blood and the tissue.

Venules and Veins are relatively large vessels that transport blood from the organs and capillaries back to the atria in the heart.

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They are thinner than arteries but are more flexible and they tend to run between the muscle blocks and closer to the surface of the skin. Because they run between the muscle blocks, and with the help of one-way valves within the vessels, the contraction of the skeletal muscles helps with pushing the blood flow along in one direction. As in the arteries, this is part of the secondary circulation to assist the heart.

Blood and the Pulmonary and Systemic Circuits are two components of the blood circulatory system worth mentioning. The pulmonary circuit, as the name suggests, relates to the lungs (*pulmo* – Latin for 'lung'). This is the circuit of the blood going from the right ventricle through the capillaries around the lungs and back via the pulmonary vein to the left atrium. The systemic circuit start of the left ventricle and passes through the organs of the body before returning to the right atrium. There are three areas of the systemic circulation that are worthy of mentioning; coronary circulation which is the supply of blood to the heart via the coronary arteries; renal circulation, the supply of blood to the kidneys via the renal artery which takes about 25% of the blood flowing out of the heart and delivers it to the kidneys for filtration; and the hepatic portal circulation, where nutrients picked up by blood in the small intestines are taken to the liver and where access nutrients are stored. The liver also receives about 30% of its blood directly from the aorta via the hepatic artery.

The Lymphatic System can be considered to be a part of the circulatory system. Within humans there is a fluid known as the extracellular fluid, the main component of which is called tissue fluid. Plasma in the blood and tissue fluid are very similar and easily flow between each other. As blood flows to the capillaries, a pressure differential is created at that area of the capillary bed where the arteriole meets the capillaries. The fluid pressure in the capillaries is significantly higher than in the surrounding tissue. The result is fluid flow from the capillaries into the tissue which permits the transfer of oxygen and amino acids into the tissues. At the end of the capillary bed where the capillaries meet the venules, the pressure differential is reversed. The fluid pressure in the capillaries here is significantly lower whilst the fluid pressure in the tissues has remained the same. The opposite of what occurred previously. As a result, the movement of fluid is from the tissues into the capillaries which also carries waste products such as urea. Unfortunately, the transfer is not total and residual tissue fluid is left behind in the tissues. The draining of this excess tissue fluid is via the lymphatic system. The lymphatic system is a network of vessels that collects the fluid, called lymph, and returns it into the vena cava near the heart. The fluid moves through the vessels due to the constriction of muscles and the one-way valve design of the vessels. In this way the fluid is pumped in one direction only and does so without the benefit of a pump like the heart. The vessels also pass through the lymph nodes which produce a type of white blood cell that assist in helping to fight infection. If the tissue fluid is not removed, due to such things as high blood pressure or inactivity, then the fluid tends to build up around the ankles and feet. This is known as oedema.

Section 2.1.3.4 Blood and its qualities. Within the adult human body there is approximately five litres of blood. Its function is primarily to transport nutrients and O2 and hormones to the tissues and to carry CO2, urea and other wastes away from them. It also plays a role in the transference of heat and also in the fight against disease. Blood is composed of plasma, (which is a liquid and constitutes about 55% of blood), and blood cells, which are mainly red blood cells.

Plasma consists of water and dissolved molecules. Albumin is a plasma protein that helps to regulate the water and thus is able to help maintain normal volume and pressure. Immunoglobins along with white blood cells form the immune system. White blood cells attack infected or foreign cells while fibrinogen is a protein that enables the blood to clot.

Red Blood Cells are the most common types of blood cells and are biconcave in shape giving them a greater surface area and greater flexibility thus allowing them to pass through small capillaries. These cells are produced from

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stem cells in the bone marrow and are full of haemoglobin which allows them to carry respiratory gases. They live for about 120 days in the circulatory system before they are removed by the liver and spleen.

White Blood Cells constitute only 0.2% of blood cells. Like red blood cells they are formed in the bone marrow, but unlike red blood cells they have a nucleus but no haemoglobin. Most white blood cells only live a few days, however others can live for months or years and it is this longevity that provides us with immunity from repeat infections.

Platelets are tiny fragments of other cells that form in bone marrow and **assist with blood clotting by adhering to a wound and releasing certain clotting factors**. These factors then release other chemicals such as fibrinogen which stops the bleeding by producing a plot. If one of the factors, Factor VII, is malformed in a genetic abnormality, the condition of haemophilia exists and clotting will not occur. This occurs only in males and is potentially fatal.

Haemoglobin is a component of red blood cells and is responsible for the carriage of oxygen. The ability of haemoglobin to carry oxygen is largely dependent on the amount of iron available in the body during the creation of haemoglobin. The amount of oxygen able to be carried by one haemoglobin molecule can be up to 4 oxygen molecules.

Oxyhaemoglobin is the product formed during respiration as oxygen binds to the haemoglobin. The ability of haemoglobin to bind with oxygen is due to the two forms of haemoglobin, the taut form and the relaxed form. If the blood has a low pH level and a high concentration of CO_2 at the tissues, then these conditions favour the taut form which has a low affinity for oxygen and will release it. As can be seen by the situation high CO_2 indicates that the tissues and organs have metabolised, releasing CO_2 and searching for oxygen. If the haemoglobin molecule has released its oxygen molecule, then it is free to carry another gaseous molecule such as CO_2 which will bind to it and be taken away to the lungs to be exhaled. If the tissues and organs have not metabolised, then there will exist a higher level of O_2 and a lower pH level and it is this situation that favours the relaxed form of haemoglobin which binds to oxygen more readily.

Haemoglobin's Adhesion Properties are what makes it vital to human metabolism. But these properties which permit the transport oxygen allowance also bind with other gases that are toxic to humans. Carbon monoxide competes with oxygen and has an affinity for binding with haemoglobin which is 250 times greater than oxygen. Because carbon monoxide is a colourless and odourless gas, the effects of carbon monoxide poisoning may not be readily identifiable.

Section 2.1.3.5 The Senses. We take senses for granted, but what exactly is a sense? Think of the word 'sensor'. A sensor picks up information, and that information—once interpreted—is a sense. It is defined as the faculty of sensory reception. **It is the ability to detect external stimuli** and through a process known as transduction, converts these stimuli into nerve impulses in the form of electrical signals which are conveyed to the brain via neurons where they are interpreted as a smell or a taste and so on.

How Many Senses do we have? The manner in which we, as human beings, understand our physical position in the environment is through the perception of information that is received through our senses. Aristotle first classified the key human senses; sight, hearing, touch, taste and smell, and he surmised that through these five senses, human beings can understand where they are in the known universe.

But this limited value of senses has not allowed the real acceptance of other senses. **There is argument for up to 21 senses in the human body, but for our studies, we shall use nine**. They are:

- **Vision** (Sight) – the ability to receive through the eyes, photons of electromagnetic energy that are reflected off objects in the visible spectrum which excite cells on the retina and which cause

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electrical signals that are interpreted by the brain.

- **Audition** (Hearing) – the ability to receive the vibrations of pressure waves through the auditory organs which stimulate hair follicles which then induce electrical signals that are interpreted by the brain.
- **Gustation** (Taste) – the ability of the five types of chemical receptors on the tongue which react to chemicals that stimulate nerve endings and which induce electrical signals that are sent to and interpreted by the brain.
- **Olfcation** (Smell) – the ability of hundreds of different receptors to 'bind' to a particular molecular feature and which induce electrical signals that are interpreted by the brain.
- **Tactition** (Touch) – the ability of various receptors to perceive different pressures on the skin which then induce electrical signals that are interpreted by the brain.
- **Thermoception** (Heat) – the ability of thermoreceptors on the skin to sense the presence or absence of heat (ie hot or cold). (Homeostatic thermoceptors are different and are internal and provide feedback to internal body temperature).
- **Nociception** (Pain) – the ability of cutaneous (skin), somatic (joints/bones) and visceral (body organs) pain receptors to detect sensations which induce electrical signals that are interpreted by the brain.
- **Equilibrioception** (Balance) – the ability of the nerve endings in the vestibular apparatus of the middle ear to detect movement of fluid in the semi-circular canals which induce electrical signals that are interpreted by the brain.
- **Proprioception** (Body Awareness) – the ability of various parts of the body to detect the location of body parts regardless of the ability to sense that location through other senses.

we shall investigate separately the key senses that affect us in the aviation and other high-risk environments, namely:

- Vision
- Hearing
- Equilibrioception
- Proprioception

When considering a human's ability to sense its environment, one must consider the abilities of the individual senses in being able to detect and discriminate between various external stimuli. In some cases, the senses will change over time and the ability of senses will vary between individuals. The following element investigates these factors.

Sensory Threshold refers to a limit of ability to detect a change in a stimulus by the human sensory receptors. There are some key thresholds, such as:

- Absolute Threshold – below which a stimulus cannot be detected by sensory receptors.
- Recognition Threshold – that limit where recognition of a stimulus occurs, not just detection.
- Differential Threshold – the ability to detect a change between stimuli.
- Terminal Threshold – beyond this limit, the stimulus can no longer be detected (eg the upper (UV) end of the visual range of light which would be opposite to the lower (IR) end which would constitute the Absolute Threshold).

In flight simulators, acceleration can be simulated by tilting the simulator. After the acceleration simulation has ceased, the simulator can be returned to its 'baseline' position ready for the next simulation. If this return to baseline is done slowly and smoothly, (ie below sensory threshold), the pilot in the simulator will not be able to detect the movement.

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Sensory Sensitivity can relate to the detection ability of the sensory receptors or to the degree of sensitivity of a person to psychological and physical cues. In the former case, this may be due to a neurological condition such that the sensory receptors are not as finely tuned in some people as in others (eg one person has very good vision or a keen sense of smell). In the latter case, Highly Sensitive Persons (HSPs) suffer from a form of sensory overload where too many stimuli, or particular stimuli, cause a negative psychological reaction. This stimuli may be something as innocuous as the feel of a fabric against the skin, or the texture of a type of food, or an unpleasant smell that most others would not consider too bothersome. In its extreme form, it can lead to social problems, especially with interpersonal interaction and can manifest itself as extreme shyness or an inability to make eye contact or be touched by another person without feeling like being attacked. Another term used is sensory defensiveness. It is a component of autism in its extreme form, but in its milder form, can manifest itself as an inability to perform well under pressure (test-itis) or a feeling of being overwhelmed when being overloaded and can lead to a 'meltdown' type situation.

Sensory Adaptation refers to the condition whereby the senses 'get used to' a particular environmental context. Probably the most common example is night adaptation whereby after about 30 minutes of darkness, visual acuity is increased, in this case by the creation of more rhodopsin to enable the rods to perform at their peak. Other examples of sensory adaptation include the threshold shift experienced by the middle ear's ossicles where muscles attached to the ossicles will retract thus reducing the ability of the stapes to vibrate against the oval window (see section on the anatomy and physiology of the ear). The reduction in the sensitivity due to this muscle contraction reduces the hearing threshold (threshold shift) of the ear and can last for several minutes, hours or even days depending on its severity. This helps to protect the hearing organ from ongoing loud noises. (Smells are another example of how a sense will become adapted).

Sensory Habituation is similar to Sensory Adaptation, but where in adaptation, the sensors change their abilities to detect, in habituation the brain ignores what is being detected. For example, being in a room with a noisy air conditioner may be irritating at first, but after a while, the noise is no longer noticed. The ears still hear the noise... so there is no change in the capability of the sense, but the brain does not process it the same way. It does, however, become noticeable if it suddenly stops. Sensory Habituation occurs because the senses are designed to detect changes in the environment, not things in the environment that remain constant; noises, certain tactile feelings (like wearing jewellery). Eyes are not prone to habituation because of saccadic vision, whereby the eyes are constantly moving, even when staring at an object. Because of this, the eyes are presented with new scenes several times a second – even if the difference is below our visual differential threshold so that we don't notice it – and in this way, vision always remains alert.

Reflexes and Biological Control Systems. A reflex is a response to a stimulus. When discussing reflexes in the human body, we talk about reflex arcs. A reflex arc is the 'round trip' taken from stimulus to response that does not require the brain to process information. For example, if you step on a nail, you do not have to wait to receive the pain signal, think about what has happened, decide that you need to remove your foot and then actually remove your foot. The pain signal is received by neural sensory receptors (in this case a Nocioceptor – see below) and travels to the central nervous system which immediately causes a reflex action (ie moving the foot away from the item delivering pain). At the same time, the signal is sent to the brain, but the reflex arc has already reacted to the stimulus before the brain has a chance to process it. This function is found in higher animals and is a biological control system designed to protect the body from harmful situations. Reflexes are processed by the CNS and medical tests of simple reflex actions test the integrity of the CNS, such as the knee jerk patella test or the bicep jerk test.

Sensory Receptors. Sensory Receptors, or Senso Receptors that change one form of

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stimulus into another. The following table outlines the key Sensory Receptor types, their function and where they can be found in the human body.

- Baroreceptors
  Pressure (esp in blood)
  Arterial walls where they detect stretching or contracting of the walls which corresponds to changes in pressure. This is then transduced causing secretions to the heart which cause it to beat faster or slower thus changing blood pressure to stabilise it.

- Chemoreceptor
  Chemical stimuli (odours)
  CO_2 detecting in the medulla oblongata and aortas – detects CO_2/pH levels and causes deeper breathing,
  Olfactory epithelium (roof of the nasal cavity behind the nostrils) detects odours,
  Taste buds on the tongue detect taste.

- Mechanoreceptors
  Mechanical stress/strain
  Inner ear to detect sound and movement.
  Skin to detect items related to the sense of touch.
  Hair, detects changes in hair position.
  Muscle spindles detecting muscle stretch (reflex test).

- Nocioceptors
  Tissue damage/pain
  Any part of the body that can detect pain. This pain can be caused by thermal influences (heat/cold), Mechanical (stress/incision/tearing) and Chemical (chemicals, esp Capsaicin from the Capsicum).

- Osmoreceptors
  Water absorption of cells
  Hypothalamus in the brain. It will release vasopressin which changes the osmotic quality of the blood and will hold back water (resulting in concentrated urine).

- Photoreceptors
  Light
  The Retina. (See anatomy and physiology of the eye).

- Proprioceptors
  Body Position
  Not confirmed, but deduced to be in the inner ear, muscles and ligaments.

- Thermoreceptors
  temperature
  Skin, cornea and urinary bladder.

2.1.3.6 The Eye and Vision. Of all the sense organs, the eyes are the most important. More than 80% of the information taken in by the brain comes from our vision, and so the ability of a human to be able to see and understand what s/he sees is very important. The following sections provide information on this remarkable organ.

The Eye and its Anatomy. The diagram below shows the functional components of the human eye.

The Physiology of the eye. The sphere of the eye is approximately 20mm in diameter. The eyes sit in their ocular orbits, the cavities in the human skull that house the eyes, and move by means of ocular muscles that are attached to the sclera, the outer wall of the eye (also known as the 'white of the eye'.) In the front part of the eye, the sclera is replaced by the transparent cornea which forms the anterior (front) chamber. Behind the cornea is the iris which opens and closes and thus acts similar to the lens of a camera to regulate the amount of light entering the eye. Sitting behind the iris is the lens. The lens is biconvex, which means it curves outwards in the front and rear parts of the lens. The amount of curvature is determined by the ciliary muscles and it is this change of curvature by the muscles that allows for focussing of the eye on objects. This change in the optical power of the eye which allows vertebrates to focus is known as accommodation. This function becomes more difficult with age (see presbyopia below).

Light passes through the cornea and lens and into the main section of the eye known as the posterior (rear) chamber. This chamber is filled

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with a transparent gelatinous liquid called the vitreous humour. Directly behind the pupil and lens is the fovea centralis which shall be discussed later. On the rear of this chamber is an extra surface layer that sits on the Choroid and Sclera, called the retina. The rear part of the retinal layer, called the retinal pigment epithelium (RPE), is made up of photosensitive cells that detect photons of light which change the chemical makeup of rhodopsin or iodopsin (depending on the type of cell, see below). This chemical change will allow or prevent sodium ions from passing into the cell which changes the electrical potential of the cell. It is this electrical change – or charge – which is transmitted to the brain via the optic nerve. The whole process is called photo transduction (photo – light, transduction – from the electrical definition of the term meaning to convert from one form of energy to another form of energy - from the Latin meaning to lead across).

Rods and Cones. The cells on the retina responsible for photo transduction are commonly referred to as Rods and Cones due to their shape. The 6 to 7 million cone cells provide colour sensitivity but are not as sensitive to light as rods, which means that they can adjust more rapidly to changing light conditions than rods can. Cones are responsible for high resolution vision but require good light levels to achieve this. The 120 million or so rod cells are much more sensitive to light than cones are, but are not able to distinguish colour and it is reported that individual photons can trigger a rod into sensing light. The key photosensitive pigment in rods is called rhodopsin (aka visual purple). Rhodopsin can become bleached and desensitised due to bright lights and will take about 30 minutes to re-adapt its sensitivity. This is the average time required to attain optimum night vision in normal circumstances. Rods are also more sensitive to movement and since they predominate in the periphery of the retina, it is easier to notice something moving out of the corner of one's eye.

Another type of cell is the ganglion which is somewhat photo sensitive. In the figure above, the cones and rods are shown as different shaped cells. Both of which carry a pigment used in various light levels. The table below, derived from Kandel et al, shows key differences between rods and cones

Used for day vision (photopic vision) Used for night vision (scotopic vision)

Sensitive to direct light only. Has less pigment than rods (called Iodopsin), but pigment is able to detect three ranges of light frequency and can thus detect all colours. Very sensitive to light, including scattered light and low light levels due to high levels of one light sensitive pigment (Rhodopsin). This pigment cannot detect colours, though.

Loss of cones can cause day blindness which can result in being classed 'legally blind

Loss of rods leads to night blindness

Very good at resolving detail (High Visual Acuity)

Poor at resolving detail with low visual acuity

All cones located in FoveaNo rods in the Fovea, all in the periphery (20 times more rods than cones)

Visual Acuity and its Deficiencies. Visual Acuity (VA) is the ability to discriminate (resolve) the fine details of an object in a person's field of view. Visual acuity will determine a person's ability to define the limit of spatial discrimination. In other words, interpreting distances to various objects. In order to resolve detail, a focused image needs to be projected onto the fovea where the most number of cone cells are concentrated.

VA is limited by a number of factors such as the structure of the retina, the manner in which light falls on the retina and on the fovea in particular, and the interpretive ability of the brain. It is measured using a fraction of distance of the subject's VA over distance of an average VA. So a figure of 20/20 (imperial) or 6/6 (metric) means that the subject can see an item at 20 feet or 6 metres that an average person should be able to see at 20 feet or 6 metres. If VA is measured as 20/40 (6/12), then it means that the subject would have to

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stand 20 feet / 6m from an object to be able to see it as clearly as an average VA at 40 ft/12m. In other words, 20/40 vision is the same as 1 / 2 meaning it is half as good.

Deficiencies in vision can be caused by a number of reasons; congenital, disease related, injury related or age related. The most common defects are near-sightedness known as Myopia, far-sightedness, known as Hyperopia and reduction in VA due to age known as Presbyopia. Presbyopia is usually noticeable between 40 and 50 years of age and its symptoms include difficulty in focussing between viewing distances; difficulty in focussing at close range and fine print (short arms syndrome) and eyestrain when reading for long periods.

Myopia can be caused by a lens that is too strong due to incorrect curvature or an overly large distance between the cornea and the fovea due to the eye being too long. In this case, the lens causes the light rays converging not on the fovea where the cones are, but rather, they converge in front of the retina within the vitreous humour. In **Hyperopia**, the opposite is the case with the lens being too weak due to incorrect curvature or the eye being too short. The focal point becomes theoretically outside the chamber of the eye. Both conditions can usually be corrected by diverging or converging lenses placed in front of the cornea as spectacles or contact lenses.

The Visual Field and Vision. Visual Field describes everything that can be seen by the viewer and relates to how light (photons) fall on the retina such that they can be detected and interpreted by the brain. This includes both central and peripheral vision.

Binocular Vision and Depth Perception. Binocular vision is literally the ability to see with two eyes (Bi – two, ocular – pertaining to the eye). Having binocular vision is advantageous, especially to humans who rely so heavily on vision, due to that fact that:

- It gives a wider field of view (200 degrees horizontally with both eyes working, but only 160 degrees with one eye working.)

- It provides distance approximation with objects that are relatively close due to parallax error and the brain's ability to interpret the error (also known as Stereopsis but commonly known as **depth perception**).

- It provides binocular summation, which is the ability of two eyes to be able to detect visual cues at lower sensory thresholds than one. In other words, a faint light is easier seen with two eyes than it is with one eye to a factor of the square root of 2 (ie 1.41 times better at detecting sensory stimuli).

Cues to Depth Perception. Depth perception is the ability to detect the distance a viewer is from an object. As was stated above, this ability – also known as stereopsis – is a function of binocular vision primarily, however there are circumstances where binocular vision is not available (eg one eye is damaged or unable to be used) or vision is modified (eg through optical equipment such as cameras, night vision devices, etc). In these cases, depth/ distance perception must be attained using other means and techniques. These techniques are called 'monocular cues' or 'depth perception cues' and provides information to the viewer to make judgements. Some cues are:

- Relative Size – this technique relies on experience to be able to judge the size of known objects and relate them to each other to see which one is further away than the other. The other is size constancy – an object cannot get smaller physically, therefore if it appears to be getting smaller, then it must be due to it moving away from the viewer and the retinal image becoming smaller.

- Interposition – where one object is positioned over (overlaps) another, then the overlapped object is deemed to be further away.

- Linear Perspective – when objects of a known distance or dimension subtend smaller and smaller angles, that is, when parallel lines seem to converge with increasing distance.

- Aerial Perspective – where objects appear to be less sharp, with less detail and more and more grey. This is to do with reduced visual acuity with distance and the increased

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number of particles in the air that scatter light and its effect on colour.

• Light and Shade – highlights and shadows provide information about texture and depth.

• Monocular Movement Parallax – parallax error causing the appearance that when the viewer moves his/her head, objects closer to the viewer seem to move opposite the direction of movement of the head and objects in the distance move with the direction of movement of the head.

Day Vision, Night Vision and Blind Spots. Photopic vision is the ability to see when the ambient light is effective. It is a requirement of cone cells to have sufficient light for them to be effective. Scotopic vision is the vision required under low light conditions and is this type of vision that primarily uses the rods cells of the retina. Between photopic and scotopic vision is mesopic vision which is used during periods of intermediate light (eg dawn or dusk). Mesopic vision uses a combination of rods and cones and is the least effective form of vision, with visual acuity being reduced along with colour discrimination. Thus operating in this environment or similar environment, such as at night using street lighting, can increase the likelihood of hazards associated with reduced visual acuity. In other words, driving or operating machinery at night under street lights or at dawn or dusk is extremely hazardous.

Day Blind Spot. Because the photoreceptor axions must pass information to the brain, they coalesce and leave the retinal area through an area of the eye known as the optic disk. There are no rods or cones in this area and so there is no ability to receive light information. This causes a blind spot. Because the location of the optic disk is not central on the retina, the other eye is able to compensate for the blind spot because its optic disk is also offset. If no binocular vision is possible, then there will be a break in the visual field.

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Night Blind Spot. The central part of the retina, directly behind the pupil, is used for photopic vision (see above). As such, it is primarily composed of light sensitive cones which are not effective for night vision. The Night Blind Spot is the result of this concentration of cones and causes a break in the visual field when looking directly at an object in low light conditions. To compensate for this night blind spot, it is recommended to offset one's vision by about 10 to 20 degrees in any direction. This will allow any photons being emitted/reflected from the object being viewed to fall directly on to the highest concentration of rods – the low light sensitive photoreceptors – and thus will maximise the effectiveness of night vision.

Intraocular Pressure and Glaucoma. The aqueous humour within the eye is a type of plasma and is contained between the cornea and the lens in what are known as the posterior and anterior chambers in the anterior (front) segment of the eye. It is not to be confused with vitreous humour which is the clear liquid in the main part of the eye. The aqueous humour is secreted by the ciliary epithelium near the ciliary muscles that control the curvature of the lens. The liquid provides nutrition for the eye's tissues and helps to maintain the shape of the eye through the pressure of the liquid, known as intraocular pressure (IOP) which is normally around 15mm Hg above atmospheric pressure. It flows from the posterior chamber into the anterior chamber and drains through a small canal between the cornea and the sclera. If too much humour is produced or drainage is blocked, a higher than normal pressure, known as ocular hypertension, occurs. This high pressure places pressure on the the retina and the weak point is the first to be damaged which corresponds to the optic nerve. This damage is glaucoma and it occurs in a predictable pattern, with peripheral sight being the first to be affected. Glaucoma can occur due to other factors not related to IOP, but intraocular hypertension is one of the most common and most easily treatable if detected early.

Other causes of glaucoma. Some other causes of glaucoma include:

• Congenital Glaucoma – an inherited defect causing eye sensitivity and excessive tears

- Exfoliative glaucoma – where material from other parts of the eye block the drain
- Pigmentary glaucoma – when parts of the pigment break off and block the drain
- Neovascular glaucoma – related to diabetes
- Trauma-related glaucoma – related to some injury to the eye.

Treatment for intraocular hypertension includes eye drops and ointments that increase fluid outflow or decrease fluid production. One method of treating glaucoma is through the use of medicinal marijuana. It is found that the THC in cannabis can reduce IOP by about 25% although the side effects can be more detrimental in some patients, especially those that cannot tolerate elevated heart rates.

Hypoxia and Vision and Colour Perception. The lack of oxygen to the tissues can have a marked effect on vision. In situations of hypoxic hypoxia – most commonly when at altitude – vision can deteriorate by up to 28% at 10,000' and even 10% at 5,000'. Daytime vision is not significantly affected up to 10,000' however night vision is. Up to 10,000', this is known as *the indifferent* zone, because effects on daytime vision are minor and can usually be compensated for by physiological processes. At approximately 15,000', night vision deteriorates by about 40% and accommodation decreases. Vision becomes blurred or double.

Colour vision is reliant on the cones in the fovea centralis. Loss of colour sensitivity due to hypoxic conditions at around 10,000' is exacerbated by falling light levels due to the reduced oxygenation of cone cells and the loss of visual luminence. Because the number of cones decreases the further from the fovea, the result is a requirement for a significantly higher scan rate in order to see objects clearly. There is also a corresponding increase in error rates. The upshot of these experiments is that when operating at 10,000' or above, visual loss can be expected especially night vision. In low light levels where mesopic vision is used, colour sensitivity is dramatically decreased and results in the need for higher scan rates and increased likelihood of errors associated with vision.

2.1.3.7 The ear and audition. The primary organ of audition, the ear is arguably the second most important organ in most industrial environments. It contains a means of hearing sound from the surrounding environment, but when combined with the middle and inner ear, provides a sense of balance as well.

The Ear and its Anatomy. The ear consists of a combination of flesh, cartilage, bone and organ tissue. The outer fleshy part is called the **pinna**, or **outer ear**. It aids in localising the origin of sound and amplifies the sound by about 5 to 6 dB. The ear canal, also known as the **auditory canal**, is a small channel that measures about 25mm and has a slight 'S' shape. It channels sound to the middle ear and also warms the air and provides protection to the ear drum, known as the **tympanic membrane**. This membrane marks the boundary between the outer ear and the middle ear. It vibrates in response to sound waves. On its inner surface are three connected small bones called **ossicles**. The first is the **malleus** (hammer) which is connected to the **incus** (anvil) and finally, the third bone is the **stapes** (stirrup). These bones and the area in which they are contained constitute the **middle ear**. This middle ear is vented to the external atmosphere through a tube called the **Eustachian tube** which is mucous lined and opens in the back of the throat at the **nasopharynx**. The stapes connects to the **cochlea** where it transmits the pressure energy to that organ, however it has a built in safety feature in a muscle called the **stapedius muscle** which, when the ear is exposed to a very loud noise, contracts along with the **tensor timpani tendon** and makes the stapes less capable of transmitting the pressure energy which protects the ear. The stapes is connected at a point of the cochlea called the **oval window**. This is where the inner ear commences and is where pressure energy is transmitted through the cochlea and into three chambers where small cells called **stereocilia** in the **organ of Corti** vibrate in sympathy

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with the pressure waves. It is these cells which transduce the vibration into sensory signals which are transmitted to the brain and are decoded as sounds. Also contained within the inner ear are three small channels known as **semi-circular canals** which contain fluid known as **endolymph fluid** which it shares with the cochlea. The relative movement of this fluid against small detector cell hairs is transduced as signals and sent to the brain where the brain interprets the movement and can detect its position in space, which is the sense of balance.

Audition and the Physiology of the Ear. (see Anatomy of the Ear) Sounds, or Acoustic energy as it is known, are basically pressure waves that pass through a medium, usually the air. These pressure waves impact the pinna, which channels it through the auditory canal where it impacts the tympanic membrane causing it to vibrate. These vibrations are transmitted to the malleus where they are amplified through the angular arrangement of the next bone, the incus. Finally, these waves are transmitted through the incus which is attached to the oval window of the cochlea and which creates a movement in the fluid of the cochlea. This movement of the fluid in the cochlea thus becomes hydraulic energy and it is this energy that causes membranes in the Organ of Corti to cause stereocilia to shear against another membrane called the tectorial membrane. This movement of the hair cells causes transduction which becomes electrical signals which are transmitted to the brain through the auditory nerve which are then interpreted as noise or sounds. This is called hearing or, more precisely, audition. To put it simply: pressure waves are amplified, cause mechanorecptors to vibrate and induce an electrical signal which the brain interprets as sound.

Hearing Loss. There are a number of reasons for hearing loss, but most fit into two main categories: conductive and sensorineural (aka perceptive). Sometimes, loss of hearing can be due to a combination of both, for example, Presbyacusis and an ear infection can combine to seriously degrade audition.

Conductive Hearing Loss is normally caused by some sort of blockage or damage to the outer ear or to the middle ear that prevents acoustic energy from being conducted through the hearing organ to the receptor cells in the cochlea. This damage may be acquired through disease or injury or it could be congenital. In both cases, medical treatment or surgery may be able to counter the problem which is manifested by a reduction in the loudness of sounds. Some of the reasons for conductive hearing loss include:

- Foreign objects in, or partial/full closure of the auditory canal
- Infections of the outer ear (eg from swimming) or the inner ear (especially common in children)
- Damage to the tympanic membrane
- Otosclerosis, a congenital condition where the bone grows around the stapes preventing it from transmitting pressure waves to the cochlea.

Sensorineural (Perceptive) Hearing Loss can be congenital or acquired and relates to damage around the inner part of the hearing organ, the cochlea, or the auditory nerve, as opposed to conductive hearing loss which centres around problems with the outer and middle ear. If the cochlea is damaged, then it is considered sensory hearing loss because the actual sensing is impaired. If the hearing loss is caused by damage to the auditory nerve, then it is considered neural damage because the impairment is in the transmission of neural signals. The result is a lack of loudness and of clarity. In some cases, the effectiveness of hearing aids is diminished. Some of the causes of sensorineural hearing loss include:

- Various drugs.
- Head Injuries.
- Various diseases and viruses (see text box below).
- Excessive exposure to noise.
- The ageing process.

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dB Level	Type of Noise	Aust & (US) time limits
190 dBA	Heavy weapons, 10m behind the weapon (max level)	
180 dBA	Toy pistol fired close to ear (maximum level)	
170 dBA	Slap on the ear, fire cracker explodes on shoulder, small arms at a distance of .5m (maximum level)	
160 dBA	Hammer stroke on brass tubing or steel plate at 1 m, airbag deployment very close at 30 cm (max level)	
150 dBA	Hammer stroke on anvil at 5 m (maxlevel)	
130 dBA	Loud hand clapping at 1 m distance (maximum level)	0.9 s (none)
120 dBA	Whistle at 1 m distance, test run of a jet at 15 m	7.2 s (none)
118 dBA	**Threshold of pain, above this fast-acting hearing damage in short action is possible**	14.4 s (none)
115 dBA	Take-off sound of planes at 10 m distance	28.8 s (28 s)
112 dBA		56 s (57 s)
110 dBA	Siren at 10 m distance, frequent sound level in night clubs and close to loudspeakers at rock concerts	
109 dBA		1.9 mins (1.9 mins)
106 dBA		3.8 mins (3.8 mins)
105 dBA	Chain saw at 1 m, banging car door at 1 m, racing car at 40 m, possible level with music head phones	
103 dBA		7.5 mins (7.5 mins)
100 dBA	Pers music with headphones, jack hammer at 10 m	15 mins (15 mins)
97 dBA	Hammering nails into wood.	30 mins (30 mins)
95 dBA	Loud crying, hand circular saw at 1 m distance	
94 dBA	Circular Saw cutting Hardwood	1 hr (1 hr)
92 dBA		(1.6 hrs)
90 dBA	Angle grinder outside at 1 m distance	2 hrs (2.5 hrs)
88 dBA	**Hearing damage possible if exposed for >40hrs/wk**	4 hrs (4 hrs)
85 dBA	Chain-saw at 10 m distance, loud WC flush at 1 m	8 hrs (8 hrs)
82 dBA		12 hrs (16 hrs)
80 dBA	Very loud traffic noise of passing trucks at 7.5 m, high traffic on an expressway at 25 m distance	16 hrs (Cont. OK)
75 dBA	Passing car 7.5 m, un-silenced wood shredder at 10 m	CONTINUOUS
70 dBA	Close to a main road by day, quiet hair dryer at 1 m	
65 dBA	**Bad risk of heart circulation disease at constant impact is possible**	
60 dBA	Noisy lawn mower at 10 m distance	
55 dBA	Low volume of TV at 1 m, vacuum cleaner at 10 m	
50 dBA	Refrigerator at 1 m, bird twitter outside at 15 m	
45 dBA	Noise of normal living; talking, or background radio	
40 dBA	**Possibly distracting when concentrating/learning**	
35 dBA	Very quiet room fan at low speed at 1 m distance	
25 dBA	Sound of breathing at 1 m distance	
0 dB	Auditory threshold	

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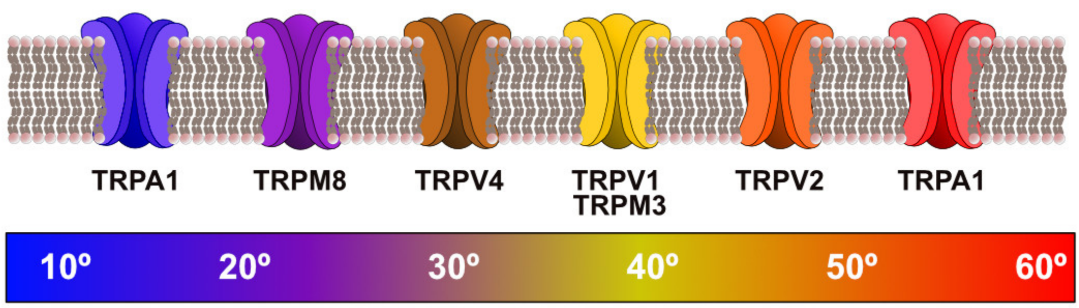
Section 2.1.3.8 The Inner Ear and Equilibrioception. The Inner Ear provides balance and hearing capability amongst mammals. For humans, both are vitally important in most industries and a lack of hearing and balance severely impairs human functionality. The following sections discuss this important organ.

The Inner Ear and its Anatomy. The Inner Ear comprises two main components; the Vestibular Apparatus, which includes the semi-circular canals and associated component, and the cochlea. Both of these organs have sensory cell bundles that take detected stimuli to the central nervous system and up to the brain.

The Cochlea is that part of the inner ear which is dedicated to hearing. The cochlea (Latin for snail) is an organ that has the outward appearance of a snail's shell in which is housed a three-chambered fluid filled tube that extends throughout the length of the 'shell'. These chambers are the scala vestibuli, the scala tympani and between them, the scala media, also known as the cochlea duct which contains endolymph fluid shared with the semi-circular canals. When a sound wave causes the ossicles to vibrate and the stapes to push on the oval window of the cochlea, the hydraulic pressure force is equal to the strength of the sound (loudness) and the speed of the movement of the ossicles is equal to the frequency of the sound (pitch). Along the length of the cochlea are tiny receptor cells that contain the small stereocilia. They are of varying length so that lower frequencies are detected by cells towards the end of the spiral and vice versa. The hydraulic force (strength and speed, or loudness and pitch) that has entered the cochlea through the oval window causes an impression in the wall separating the scala vestibule into the scala media where the pressure wave advancing along one chamber is cancelled out by the pressure wave advancing in the opposite direction in the other chamber. This corresponds to pitch and will determine which hair cells move and the force will determine how much they move. Too much force will cause the cells to bend so far that they break, resulting in permanent loss of those hairs and thus loss of the ability of detecting sound.

Linear and Vertical Acceleration. Like the ampulla in the SCCs, two small organs called otoliths, situated in an area of the vestibular apparatus called the vestibule, carry out a similar function, in that they use the shearing motion of hair cells to detect an accelerative movement, either longitudinally or vertically. These otoliths (oto – ear, lith – rock) contain small crystals of calcium carbonate called otoconia are contained within a gelatinous mix creating a mass which will 'lag' after an accelerative force is applied. It is this lag that causes the shearing force which will cause transduction in the hair cells resulting in an impulse that is sent to the brain and is interpreted as linear acceleration. With the radial acceleration detected by the SCCs and the linear acceleration detected by the otoliths – and confirmation by vision – the brain can detect movement of the head and, by proprioception the body. This latter effect also goes to explain the subjective postural vertical (shown below). The otoliths are called the **utricle**, which detects accelerations in the horizontal plane and the **saccule** which detects vertical.

The subjective vertical. The subjective vertical is an individual's assessment of what vertical is based on his/her perception of the



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environment. When this perception is incorrect or based on faulty or synthetic information (such as a computer simulation of the world, faulty visual cues or naturally occurring visual cues that lead to confusion such as cloud banks), the individual can make actions that are at odds with the real (objective) vertical and, if controlling an apparatus such as an aircraft, can make dangerous control inputs based on these erroneous perceptions. There are two components to the subjective vertical; the subjective visual vertical (SVV), based on what the individual sees and the subjective postural vertical (SPV), based on what the individual feels through proprioception. (See also Somatogyral Illusion below).

Section 2.1.3.9 Thermoception, nocioception and proprioception. When we talk about **nociception, what we're really talking about is the ability to detect pain.** Nociception is the neural process of detecting and classifying a noxious (painful) stimulus, but pain is the unpleasant sensory and emotional experience that is associated with tissue damage that may be real or imagined (Ewan St John Smith). Pain can be described as either acute or chronic, where acute pain indicates that it is continuously changing and transient; chronic pain, on the other hand, refers to pain that lasts longer than a few months, which would be considered to be the healing time of a serious injury. (Doody and Bailey) **We can classify pain as being nociceptive or neuropathic.**

Nociceptors are nerve endings that are activated in response to a painful stimuli. They are stimulated when they detect physical and/or chemical damage to the body. There are three types of nociceptors receptors: thermal, mechanical, and chemical.

There are two types of nociceptive pain: somatic and visceral. **Somatic pain can be considered skin or tissue pain** which is usually localised and identifiable. Oftentimes the painful area will be obvious to others in the way that the patient is holding, guarding or rubbing an area. **Visceral pain occurs in the organs** and its location is not as easy to identify.

Neuropathic pain is more difficult to understand but generally the pain **occurs because the nerves are reacting abnormally to stimuli or are being activated for no reason.** This type of pain may be caused by a lesion or a disease within the nervous system and could be either central, referring to the brain and spinal cord, or peripheral where it refers to the peripheral nervous system. Neuropathic pain often includes burning, numbness, pins and needles, or electric shock as descriptors for the type of pain. Some people may suffer from hyperalgesia which is an increased sensitivity to pain from stimulus that may not necessarily cause pain in others.

The nociceptive process consists of four stages: transduction, where the painful stimulus causes a release of sensitising substances that activate the nociceptors. Serotonin and histamine are examples. These cause an action potential within the neuron. The next stage is the **transmission**. The action potential moves from the site of the stimulus through the peripheral and central nervous systems to the brain. The third stage is **perception** where the individual becomes aware of the pain. The last stage is **modulation** where the perception of the pain may be altered by the release of substances that may change painful impulses of the stimulus. (Doody and Bailey)

Thermoception is the ability to detect heat. Transient receptor potential channels (TRPs) of different types will open and close at various temperatures resulting in a change in ion flow through the cell membrane that causes a change in the electrical potential which, in turn, results in a signal that goes through the same four stages as described above and interpreted as various temperatures. Some of the TRP's and nociceptors activate at the same temperatures, particularly the noxious cooling and heating ranges, resulting in a sensation of discomfort or pain. There are chemicals that mimic the sensation of heating and cooling such as capsaicin from the chili plant, or menthol respectively. This function has evolved to permit animals to find their preferred

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temperatures while avoiding noxious temperatures. This is a vital process to maintain thermal homeostasis. (Zhang).

Proprioception is the ability of an animal to 'know' where its body parts are without having to physically feel or see them. Of course, a person's limb can be seen or if it is touching an object it can feel that object and the looseness or tautness of skin also provides a clue as to what aspect the limb is at. But proprioception is critical to animals for them to ensure that they do not succumb to external forces that may cause them to injure themselves by uncoordinated movements or falls. Within the skeletal muscles are sensory neurons that respond to muscle stretch and induce an action potential signalling the brain via the CNS of the muscle length and rate of change. The rate of change is important to detect by sensory neurons because feedback from motor neurons that initiate muscle movements would be too slow. (Tuthill & Azim)

Section 2.1.3.10 Nervous systems and the brain. There are two critical systems within the human body to transmit neural signals to the brain and motor signals to the muscles. The two systems are the Central Nervous System and the Peripheral Nervous System, or CNS and PNS.

The Central Nervous System consists of the brain and spinal cord. The brain is encased in the neurocranium (skull) while the spinal cord is situated within the vertebral canal within the vertebrae. Both are suspended in cerebral-spinal fluid.

The Peripheral Nervous System consists of parts of the autonomic nervous system, cranial nerves and spinal nerves. It is the link between the CNS (brain and spinal cord) and the rest of the body including the visceral organs.

The brain is the centralised controller of the body's constituent parts. It receives and interprets signals from the senses and processes that data into information to help it comprehend the environment—physical, physiological and psychological—and what actions are necessary.

The brain is divided into three key parts: the forebrain; the midbrain; and the hindbrain.

The hindbrain controls the body's vital functions. This includes automatic functions such as respiration and heartrate. The hindbrain also contains the cerebellum which is responsible for those actions that are rote learned or that use 'muscle memory', automatic movements in response to external stimuli. Examples are playing the guitar or riding a bike.

The midbrain controls some reflex actions particularly for the eyes. Another key functions

Thromboses and embolism. Sometimes the clotting of blood within blood vessels is unwanted. Such clotting can block the flow of blood and is called thrombosis. If this occurs in the coronary artery it may cause the death of heart cells which is known as the coronary thrombosis. If the thrombus (the actual clot) dislodges and begins travelling through the circulatory system, this is known as an embolism. **Deep vein thromboses (DVT)s occur in major veins** and can block blood flow causing localised pain and swelling. DVTs occur mainly in the legs but may occur elsewhere in the body. Pulmonary embolism is an embolism that travels to the lungs obstructing respiration and decreasing oxygen supply. Risk factors for DVTs include:

- Genetic pre-disposition of blood clots
- Major trauma including surgery
- Infections and some diseases
- Immobility including:
  - Being on bedrest
  - Being sedentary for extended periods
  - Travelling for long periods (4+ hours such as being on an aircraft or vehicle).

3.3.2.11 **Blood Types** are a categorisation

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system related to the antigens found on the surface of red blood cells. An antigen is a type of carbohydrate that helps the body recognise foreign substances. There are four main categories with each category being either positive or negative. Blood typing means to identify the antigens in a blood sample and thus placing the blood into the classification system. This system is known as the ABO system and is based on the type A and type B antigens as well is the antibodies within the plasma. The red blood cells can carry the A antigen, the B antigen, both A and B antigens, or no antigens at all resulting in type A, type B, type AB, and type O blood types respectively. The type of blood will determine what blood can be donated or received by an individual based on the antigens on the red blood cells and the antibodies in the plasma. The antibodies will repel certain blood types if present.

3.3.2.14**Low Iron Levels** in the body have an effect on the production of haemoglobin. Haemoglobin is what is known as metalloprotein, meaning that it is a protein that contains a metal, in this case iron. Iron is absorbed into the body through the foods that are eaten. In particular such foods as oysters, leafy greens, meat, certain nuts such as cashews, eggs, prune juice and even licorice. There are two forms of iron: heme and non-heme. Non-heme iron is found in vegetables and fruits and other plant sources. Heme iron can only be found in animal flesh. Heme iron is readily absorbed into the body but non-heme iron is not. In order to increase the uptake of non-heme iron, foods rich in vitamin C should be included in the diet. But these foods must be eaten at the same time as the non-heme iron in order for the uptake to occur. Another way of increasing non-heme iron uptake is to include meat with the meal such that both heme iron and non-heme iron are absorbed simultaneously. Vegetarians are particularly prone to iron deficiency due to this inability of the body to readily absorb non-heme iron. Coffee and tea consumed at the same meal will also decrease iron absorption by up to 60%.

Where vitamin C helped with the uptake of iron, vitamin A helps with the release of iron stored in the body. In many cases the use of vitamin A and iron supplements may help relieve iron deficiency more than iron alone. Iron is used for various functions in the body and in the creation of haemoglobin in bone marrow. Excess iron is stored in the body for later use. Deficiencies in iron can be due to poor diet, blood loss, increased demand, excessive exertion, or a physiological inability to absorb iron. Women are particularly prone to iron deficiency due to loss of blood through menstruation or during pregnancy. A lack of iron can be manifested by lethargy and fatigue, usually due to the resultant lack of oxygen supplied to the organs through the lack of iron.

Section

3.3.3 **Blood Pressure, Diabetes and Other Blood Issues.** Blood pressure, also known as arterial blood pressure, is a measure of the pressure of blood during the contraction of the heart (a heartbeat) and the pressure of blood when the heart is at rest (between heartbeats). It is measured as a ratio and written as a fraction with the first number being the systolic pressure, from the Greek word systole meaning *to contract* and the second being the diastolic pressure from the Greek word diastole meaning *to separate.* The method of measuring blood pressure is by use of a sphygmomanometer, where the inflatable cuff is wrapped around the upper arm and inflated until blood flow ceases. Through a stethoscope, as the pressure is released, the recommencement of blood flow can be heard and this corresponds to the maximum blood pressure exerted by the contracting heart. This systolic pressure is measured in millimetres of Mercury. As the cuff continues to deflate, the sounds of the blood being forced through the vessels under pressure can be heard. When the sound ceases between heartbeats the corresponding pressure can be read and this equates to the diastolic pressure.

3.3.3.1 Hypertension is excessively high blood pressure and is said to be present if the systolic and diastolic pressure readings

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are greater than 140 and/or 90 respectively. The hypertension can be classed as primary or secondary where primary has no underlying medical cause (e.g. kidney or heart problems). Hypertension is a prime contributing factor to such conditions as heart attack, stroke, aneurysms, arterial disease and kidney disease and is associated with a reduction in longevity.

3.3.3.2 Hypotension is unusually or excessively low blood pressure below 90/60 mmHg. Hypotension is not often diagnosed based purely on blood pressure readings unless there are noticeable symptoms present. In people who are particularly fit, low blood pressure is a byproduct of their fitness, but in others it could be a sign of loss of blood, shock or some other underlying medical condition such as an endocrine or neurological disorder. Low blood pressure may also be accompanied by dizziness and fainting.

3.3.3.3 **Heart Disease** associated with hypertension is due to the excessive stress put on the walls of the arteries. This can be coupled with the build-up of fatty deposits due to an inadequate diet. The stress on the arteries can weaken them and the fatty deposits can break off and form a clot. A heart attack occurs when the muscle of the heart fails or is damaged due to the loss of blood flow to the heart and the subsequent loss of oxygen. A person with high blood pressure risks arterial damage, blocked arteries, blood clots in the arteries and weakened arterial walls which, over time, become narrower. Atherosclerosis – the narrowing of the arteries from such things as poor diet, high cholesterol, genetic disorders, etc, will significantly contribute to the risk of stroke, heart attack and other events.

Figure 3.20 An angioplasty is a procedure to help open arteries suffering from partial blockage. A balloon is inserted into the artery and inflated which often removes small blockages. In more severe cases, a vascular stent – a small wire tube – is inserted and expanded by the balloon after which the balloon is removed leaving the stent opening the artery..

Figure 3.21 Example of Atherosclerosis and the narrowing of the arteries.

3.3.3.4 There are a number of ways to control high blood pressure and the associated risks of heart disease and heart attack, including with medication. The Mayo Clinic has listed 10 ways to control high blood pressure without medication.

- Lose extra kilograms and watch your waistline.
- Exercise regularly.
- Eat a healthy diet.
- Reduce sodium in your diet.
- Limit the amount of alcohol you drink.
- Avoid tobacco products and second-hand smoke.
- Cut back on caffeine.
- Reduce your stress.
- Monitor your blood pressure at home and make regular doctor's appointments.
- Get support from family and friends.

Category	**Systolic (mm Hg)**	**Diastolic (mm Hg)**
Hypotension (too low)	<90	<60
DESIRED	90-119	60-79
Pre-Hypertension	120-139	or 80-89
Stage 1 Hypertension	140-159	or 90-99
Stage 2 Hypertension	160-179	or 100-109
Hypertensive Crisis	>/= 180	or >/=110

Table 3.6 The American Heart Foundation's recommended ranges for the classification of Arterial Blood Pressure for adults. The Heart Foundation of Australia uses the same figures as shown above.

3.3.3.5 **Hypoglycaemia and Diabetes.** Hypoglycaemia is the condition of low blood sugar (glucose) to a level below 4 millimoles per litre which is approximately 70 milligrams per 100 millilitres of blood. It is most commonly found in Type 1 diabetics, although it is not uncommon amongst Type 2 diabetics. People with hypoglycaemia will feel hungry and tired and will need a 'rush' of sugar or other glucose rich food or drink. Hypoglycaemia can be

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caused by a number of events such as missing or delaying a meal or not eating enough carbohydrates or exercise or exertion that is more strenuous than expected. **Diabetes** is the condition where insulin, the hormone necessary for converting glucose into energy, is not produced in enough quantity to do the job. As a result of the glucose not being converted, it remains in the blood. Glycemia is a measure of blood sugar levels. There are two main types of diabetes:

- **Type 1 Diabetes** – the pancreas stops making insulin and because glucose cannot be used for energy, the body starts burning its own fat for energy which produces an accumulation of chemical compounds which in turn causes a condition known as ketoacidosis, which is potentially life threatening. Type 1 Diabetics will require up to 4 insulin injections per day and test their glycaemia several times a day. It is primarily genetic and cannot be prevented, even with lifestyle. Symptoms include:

  - Excessively thirsty, passing more urine.
  - Always hungry.
  - Tired and lethargic.
  - Cuts that heal slowly, itching, skin infections.
  - Headaches and dizziness.

- **Type 2 Diabetes** – the pancreas does not make enough insulin. It is primarily a genetically (passed down) disease but lifestyle will increase the likelihood of it occurring. Type 2 Diabetics normally require medication and lifestyle changes. The symptoms of Type 2 Diabetes are the same as Type 1 Diabetes. Risk factors for Type 2 Diabetes are:

  - Have a family history of diabetes
  - Over 55 or over 45 and overweight and/or high blood pressure
  - Over 35 and from an Aboriginal or Torres Strait Islander background
  - Eat unhealthily
  - Smoke
  - Do not undertake regular physical activity.

3.3.3.6 **Blood Donations.** The process of blood donation takes a little over one hour including administration and recuperation. To fill one bag of blood takes approximately 10 minutes, donating platelets, red cells or plasma. It may take up to 2 hours using a different process. It is not uncommon to feel faint or even fall unconscious after donating blood. Physiological reasons include the actual loss of blood volume causing the dizziness, and psychological reasons include witnessing the process of your own blood being taken away. Blood has a shelf life of six weeks and a person can donate again after twelve weeks. Because of the lethargic effects of giving blood, and the reduction of haemoglobin supply, it is advisable not to operate heavy machinery or be involved in other high risk activities immediately after donation. Transport Canada recommends waiting 48 hours before piloting an aircraft. In Australia, according to CASA and their guidance on the preparation of operations manuals, 24 hours is the recommended time between blood donation and a flying assignment.

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Section

3.3.4 **The effects of acceleration on blood circulation.** Linear acceleration has little effect on circulation, however radial acceleration may cause a reduction in blood pressure to the head, and in particular to the eyes, resulting in grey out or black out. It may also cause pooling of the blood in the lower limbs. One other effect is that of the body's ability to sense blood pressure and compensate for it in a timely manner. Baroreceptors in the circulatory system measure the blood pressure and cause a response by means of adrenaline rush and increased heart rate. If BP is decreased rapidly and artificially through acceleration then the ability of the body to recover rapidly may be diminished and loss of consciousness may be the result. The effects of this is most widely felt in aerobatics rather than in normal flying.

Section

In the previous section we mentioned that the heart was a striated muscle that acted like a smooth muscle in that it performed involuntary actions such as contracting and relaxing.

The circulatory system circulates blood through a system of channels called blood vessels, ranging in size from the aorta and arteries through the smaller veins and even smaller capillaries. The heart is the pumping mechanism that pushes blood through that system. The blood transports oxygen and nutrients to the muscles and organs where it is converted to work, energy, heat or stored for later use. The blood continues through the circulatory system carrying away from the muscles and organs any waste products of the metabolic process including carbon dioxide.

The heart contains four chambers: the left atrium and right atrium sit above the left ventricle and right ventricle. The left and right sides are separated by a wall called the septum.

Blood is pumped through a process called the cardiac cycle. This occurs when the sinoatrial node, a small group of cells located in the heart, produces an action potential which is transmitted to the cells in the atria and ventricles causing them to contract. As these chambers contract they pressurise the blood inside them. The atria contract prior to the ventricles, forcing blood from the atria into the ventricles. The ventricles then contract forcing the blood out through the blood vessels. The lub-dub sound of the heart, when heard through a stethoscope, is the sound of the one-way valves closing as the pressure decreases when the heart relaxes.

From the right ventricle blood leaves the heart through the pulmonary artery and proceeds to the lungs where it is oxygenated. System pressure then brings the blood back to the heart and it enters the left atrium thence the left ventricle as the heart contracts and relaxes. From the left ventricle blood flows through the aorta where it is sent to the rest of the body carrying oxygen and nutrients for the organs and muscles. (How the Heart Works | NHLBI, NIH, 2021)

Being a muscle, the heart also requires oxygen, so some of the oxygenated blood travelling through the aorta is diverted through coronary arteries back to oxygenate the heart tissue.

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Module 2.1.4 Natural Stressors

2.1.4.1 Homeostasis and cybernetics. The body is a system. Just as humans can create systems, such as a car or the goings on of an airport, individual components are expected to work together to accomplish an activity. The same applies to the system of the human body where individual components combine to create an organism that is able to accomplish activities.

When any part of that system deviates from its 'steady state' of normal operation, it is considered to be under stress. Normal bodily functions will usually activate to bring the stressed organ or sub-system back to its steady state of normal operation. This return-to-normal is the body's homeostasis, that is to say, the natural tendency for a system or a part of a system to return to its normal steady state of equilibrium.

As we saw in the previous element on The Human Mind, Maslow's Hierarchy of Needs requires the basic human physiological needs to be satisfied first before physical and psychological needs are satisfied. Psychological stress will be covered later in how it affects the body, but for now we shall look at the basic physiological functions, needs and how they must be balanced for effective health. The human body requires the following basic needs to be met:

- Feeding/Nuitrition and the intake of foodstuffs to allow for physiological functions of growth, re-growth/repair and normal internal bodily 'environment.
- Movement of the body and its parts
- Respiration entailing breathing and the breakdown of food within the cells of the body.
- Excretion and the removal of waste products of internal chemical reactions and excess food and water.
- Sensitivity and Responsiveness to changes in the internal and external environment (see section on senses for further details).
- Growth of the body including re-growth and repair of parts that are damaged.
- Reproduction to perpetuate the species.

[1]

During the 1980s, Roper, Logan and Tierney, three prominent British nurses, drew upon the work of US nurse, Virginia Henderson, and created a taxonomy of activities,nown as the Activities of Daily Life (ADLs) that could be expected of a human being as the basis for maintaining health, particularly in the nursing environment. This list of 12 activities were used to assess a person's health on initial contact and then with follow-on contact. The 12 ADLs are:[2]

- Breathing
- Eating and Drinking
- Eliminating
- Mobilising
- Controlling Body Temperature
- Maintaining a Safe Environment
- Sleeping
- Personal Cleaning and Dressing
- Working and Playing
- Communication
- Expressing Sexuality
- Dying

All of these 12 ADLs, with the exception of 'Dying' fall under the first three levels of Maslow's Hierarchy of Needs: Physiological Needs, Safety and Security, Belonging and Affection.

Module 2.2.2 The Atmosphere and Gas Laws

The Atmosphere is the term used to describe a layer of gases surrounding a body and held in place by that gravity's body mass.

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Figure 3.3 The space shuttle Endeavour sits in low Earth orbit above the atmosphere of the Earth. Space is said to begin at approximately 100,000m or 328,000 feet where the atmosphere starts to become noticeable.

Whilst the Earth's atmosphere is constituted of numerous gases, the most important to life on this planet is, of course, oxygen. The first production of oxygen was said to have occurred during the Great Oxygenation Event or the Oxygen Catastrophe, where cyanobacteria – also known as blue-green algae – began producing oxygen as a by-product of photosynthesis.

Figure 3.4 Blue Green Algal bloom. This cyanobacteria is the origin of oxygen on Earth.

This release of free oxygen caused the extinction of all life on the planet because free oxygen is toxic to living organisms. Fortunately, the life that was made extinct was anaerobic organisms, small microbes that do not require oxygen to exist and that find oxygen toxic. The human body requires oxygen to have a particular pressure for effective respiration. This is achieved by mixing it with a higher proportion of an inert gas, namely Nitrogen. The Earth's atmosphere has some key aspects:

- The composition is approximately 78.08% Nitrogen, 20.95% Oxygen, with the balance made up of water vapour, argon, carbon dioxide, and some hydrogen and helium.

Figure 3.5 The Atmosphere's Gases

- The atmosphere is/can be divided into four layers based on temperature – the troposphere, stratosphere, mesosphere and thermosphere.

- Humans occupy and operate in the troposphere and are affected by weather systems which are predominantly found and active within this layer. The weather systems follow a rough pattern based on cells of high and low pressure and directional flow of air.

Figure 3.6 The directional flow of air and the key pressure cells of the atmosphere

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Table 3.2 Altitude Relationships with atmospheric and biological pressure and temperature.
(HPa – Hectopascals, mmHG – millimetres of mercury, PO2 – Partial Pressure of Oxygen, PAO2 – Partial Pressure of Oxygen in the trachea based on water vapour pressure of 47mmHG for a 37 degree environment) The altitude highlighted in bold roughly equates to the limit of permanent human habitation where PAO2 is about half that at sea level.)

3.2.1 **Oxygen Requirements of the Body.** Cellular respiration requires oxygen (O_2). The human body requires oxygen in the breathing process which, in turn, supplies oxygen to tissues and cells for regeneration and also to assist with metabolism which creates energy and heat for the sustainment of the body. The process of oxygen transfer requires a pressure differential and a means through which the gases pass into the body. These are explained as the Gas Laws and the Metabolism and Respiratory System shown below.

Figure 3.8 Partial pressure differentials allow for the transfer of O2 and CO2 into and out of the body.

3.2.2 **Gas Laws.** There are a number of laws related to gases, but of interest to us in the aviation industry and allied industries are three key laws:

- Boyle's Law – *For a fixed amount of an ideal gas at a given temperature, the pressure and the volume of the gas are inversely proportional.* The formula can be written as $P1V1 = P2V2$ or $PV = k$ (where p is the pressure of the gas and V is the volume of the gas and k is the constant). Basically, what this means is that if the volume increases, then pressure must decrease so as to remain in constant proportions to each other. The opposite also occurs where if pressure increases, then volume must decrease. This law is important in aviation because it says that if we take a gas up to altitude, and that gas' volume remains constant, then it will try and equalise with the surrounding lower pressure of the atmosphere by expanding. For a gas that's trapped inside the human body, this can have a significant and damaging effect on the body and can cause debilitating pain.

Figure 3.9 Boyle's Law states that the volume of a gas will change when the pressure changes; if one goes up, the other comes down and vice versa. This has implications for us if operating in situations where environmental pressure changes such as SCUBA diving or flying at altitude, especially in unpressurised aircraft. Any gas trapped in the human body will expand or contract depending on the external pressure unless the trapped gas can be released. This can cause discomfort, serious injury or death. In this diagram, the image at left shows pressure of 2 units and a corresponding volume of 2 units. Decrease the pressure on the gas to 1 unit and the volume expands to 4 units. (See decompression below)

- Dalton's Law – *The pressure of a mixture of gases is the sum of all the partial pressures of the individual components.* What this means is that each component of a gas (which may include water vapour) will have an individual pressure. If all the pressures are added together, the total will be equal to the pressure of the gas mixture. For example, if we take a parcel of dry air at 1000 HPa, then the 21% of the gas that is made up of oxygen, will have a partial pressure of 210 HPa – 21% of the total pressure of the dry air. This is important because it explains how oxygen, as a component of total gas, has its own pressure which becomes the driving force for the oxygen to pass through barriers such as lung tissue. This law has to be read in conjunction with Henry's Law (below).

Figure 3.10 An example of Dalton's Law where Gas A with a pressure of 300 mm HG and Gas B with a pressure of 400 mm HG are mixed together. The total pressure will be 700 mm HG but the partial pressure of each constituent gas remains the same at 300 and 400 mm HG respectively.

- Henry's Law – *At a constant temperature, the amount of gas that is able to be dissolved in to a volume of liquid is directly proportional to the partial pressure of that gas if it is equilibrium with that liquid.* This is important to us because it explains how gases can be 'absorbed' into the blood such as oxygen (which is good for us) and nitrogen (which is not so good). It also explains why if there is not

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enough oxygen in the atmosphere, the blood cannot 'collect' more oxygen molecules.

3.2.3 **Metabolism and the Respiratory System.** Metabolism describes the physical and chemical processes that occur within living tissue of aerobic organisms. These processes create new tissue, replace old tissue, convert chemicals found in food to energy, dispose waste materials and reproduction.

Figure 3.11 The Respiratory System of the Human Body.

3.2.3.1 **The Respiration Process.** Respiration is the transport of oxygen from air to tissue cells and the removal of carbon dioxide. About 82 to 85% of the oxygen breathed in is replaced by carbon dioxide. There are four stages to human respiration:

- Ventilation – the movement of air to the alveoli of the lung
- Pulmonary gas exchange – where gas moves from the alveoli into the pulmonary capillaries through diffusion
- Gas Transport – where gas is transported from the pulmonary capillaries via the circulation system to the peripheral capillaries in the organs
- Peripheral gas exchange - from the tissue capillaries into the cells and mitochondria

The main function of respiration is gas exchange. As this occurs, the chemical balance of the blood changes which changes the alkalinity of the blood and the amount of carbon dioxide in the blood, both of which, in turn, trigger further respiration.

Section

3.2.4 **Hypoxia and Decompression.** The lack of oxygen in the circulatory system is hypoxia and can be caused by a physical absence of oxygen in the air (hypoxic hypoxia), inability of the blood to carry oxygen because of a toxin which displaces oxygen eg carbon monoxide (histotoxic hypoxia), a loss of blood volume (hypemic hypoxia) and poor oxygen carrying ability of the blood (anaemic hypoxia). Some of the causes of hypoxia listed above may be as follows:

- **Histotoxic Hypoxia** – toxins in the blood may displace oxygen (such as nicotine which has a higher propensity for binding with haemoglobin than oxygen does) thus reducing the useable amount of oxygen for the tissues.

- **Ischemic (Hypemic) Hypoxia** – in order for oxygen to be carried, the flow of blood needs to be constant. Heart failure, stagnation of the blood flow or other conditions may prevent the movement of blood and therefore the movement of oxygen. Ensuring blood flows by exercise and hydration can help counter mild cases of this, such as when seated for a long period of time.

- **Anaemic Hypoxia** – when the oxygen carrying capacity of the blood is reduced. Because iron is vital to haemoglobin's oxygen carrying capacity, a lack of iron will cause a reduction in the ability of blood to transport oxygen.

- **Hypoxemic Hypoxia** – The lack of oxygen due to deficiency in the body (lung disease) or hypoventilation. One of the reasons for hypoxemic hypoxia could be due to the lack of oxygen at altitude. Apart from deliberately ascending to height (eg mountain climbing), the most likely cause of inadvertent hypoxic hypoxia will be due to decompression of a pressurised aircraft. Anoxia is the complete loss of oxygen in a given volume.

Symptoms of hypoxia vary between individuals, but the most common are:

- Headaches
- Decreased reaction times
- Impaired judgement
- Incoherence or inability to formulate cogent thoughts

- Drowsiness and perhaps euphoria committing errors.

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- Cyanosis in extreme cases (blueness of the fingernails and lips).

3.2.4.1 **Decompression (air) and Time of Useful Consciousness.** Aircraft involved in high altitude operations will normally have a capability to keep the cabin pressurised at pressures suitable to sustain human function. This pressurisation is accomplished by a cabin pressurisation system. In a typical system, the cockpit, cabin and cargo holds are incorporated into a sealed unit which is able to maintain an air pressure higher than that outside the aircraft – the ambient pressure. Pressurised air is pumped into the sealed unit by cabin superchargers which deliver constant volumes of air. Air is released from the sealed unit by an outflow valve. It is this valve that can control the pressure within the cabin; increase the outflow and the cabin pressure decreases and vice versa. The pressure in the cabin is referred to using the equivalent pressure in the atmosphere. In most commercial systems, the pressure in the cabin is equivalent to that found at around 8000'. This is known as 'cabin pressure altitude'. The role of pressurisation is to prevent hypoxia, decompression sickness and the effects of cold. The loss of pressurisation within an aircraft cabin – decompression – has significant ramifications if it is unexpected, the most critical of which is hypoxia resulting in loss of consciousness. Hypoxic Hypoxia is the result of a lack of available oxygen to transport to the tissues which could be due to lung disease or other physical factors, but is most common in regimes where there if physically not enough oxygen in the air, such as at altitude.

3.2.4.2 According to an ATSB Report, in an 11-year period ending in March 2006, there were 517 pressurisation failure events in Australia, two of which led to accidents resulting in 10 deaths from the ensuing crashes, four hypoxia incidents and four ear barotrauma incidents due to the emergency descents. The primary cause of pressurisation failures leading to unexpected decompression were failures of the system (44%), or door problems resulting in the next highest percentage of failures (12%) then system failures (8%). Human error induced failures constituted 5% of failures either by the operator (aircrew) or maintenance personnel

3.2.4.2 **Decompression Sickness and effects on flying.** Decompression Sickness (DCS) is normally associated with the human body moving from high pressure environment to a lower pressure environment. Cases of DCS occurring due to flight are known, but usually only involve flight in unpressurised aircraft above 25,000'. DCS is due to Henry's Law (see above) and relates to inert gases (usually Nitrogen in most cases due to its partial pressure in normal atmosphere) being dissolved in the blood at high pressure and then being released as bubbles of gas when the pressure reduces. An example of this is the opening of a soft drink bottle. Carbon Dioxide is dissolved into the liquid under pressure during production. The gas remains dissolved whilst the liquid is under pressure. When that pressure is released, such as opening the bottle, the CO2 becomes visible as small bubbles in the liquid. The same effect can occur in the aviation environment. This effect would occur usually only above 25,000' for a person who has not been subjected to air at greater pressure than that found at sea level. In other words, if the person has not been breathing compressed air, then s/he is unlikely to experience DCS at altitudes below 25,000'. SCUBA diving requires breathing compressed air, and so DCS is most common in SCUBA divers and the effects are exacerbated when a SCUBA diver experiences reduced pressure such as during flight or ascending high terrain (eg mountain climbing or crossing high mountains).

Figure 3.12 US Sailors in a decompression chamber. DCS requires treatment in a decompression chamber for extended periods to return the patient to the pressure at which the effect took place and then slowly returning him/her to normal atmospheric pressure.

3.2.4.3 For SCUBA divers, the breathing of compressed air at depth means that close attention needs to be paid to the amount of time spent underwater. Calculated times, known as 'Dive Tables' are used by divers to ensure that they are aware of any pauses in the ascent to the surface that are required. These pauses are known as 'Decompression Stops', or 'Deco Stops' (pr DEE-co) and allows the normal respiration to expel the nitrogen being released into the respiratory system. If a diver requires decompression stops and does not execute them, or cuts them short, then s/he may suffer from DCS which is commonly referred to as 'The Bends' due to the fact that the symptoms often manifest as pain at the elbow or knees or other 'bends' in the body where the bubbles in the blood will often coalesce causing pain. The table below describes the types of DCS, where the bubbles will most commonly form in the body and the signs and symptoms.

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3.2.4.4 The Federal Aviation Administration's Civil Aviation Medical Institute discusses at length the effects of DCS.

DCS Type **Bubble Location** **Signs & Symptoms**
(Clinical Manifestations)
BENDS Mostly large joints of the body (elbows, shoulders, hip, wrists, knees, ankles)• Localized deep pain, ranging from mild (a "niggle") to excruciating. Sometimes a dull ache, but rarely a sharp pain.
• Active and passive motion of the joint aggravates the pain.
• Pain can occur at altitude, during the descent, or many hours later.
NEUROLOGIC Brain •Confusion or memory loss and Headaches
• Spots in visual field (scotoma), tunnel vision, double vision (diplopia), or blurry vision
• Unexplained extreme fatigue or behaviour changes
• Seizures, dizziness, vertigo, nausea, vomiting and unconsciousness may occur
Spinal Cord • Abnormal sensations such as burning, stinging, and tingling around the lower chest and back
• Symptoms may spread from the feet up and may be accompanied by ascending weakness or paralysis
• Girdling abdominal or chest pain
Peripheral Nerves• Urinary and rectal incontinence
• Abnormal sensations, such as numbness, burning, stinging and tingling (paraesthesia)
• Muscle weakness for twitching
CHOKESLungs • Burning deep chest pain (under the sternum)
• Pain is aggravated by breathing
• Shortness of breath (dyspnoea)
• Dry constant cough
SKIN BENDS Skin •Itching usually around the ears, face, neck arms, and upper torso
• Sensation of tiny insects crawling ove the skin
• Mottled or marbled skin usually around the shoulders, upper chest and abdomen, accompanied by itching
• Swelling of the skin, accompanied by tiny scar-like skin depressions (pitting oedema)

Table 3.4 Decompression Sickness and the effects of bubble location on the human body.

3.2.5 **Trapped Gases and Barotrauma**. Barotrauma refers to injuries caused by pressure, in particular, changes of pressure. Key barotraumas that affects the aviation environment are:

- **Trapped gases in the**
  - middle ear
  - sinuses
  - dental work and surgical wounds.
- Dissolved gases in the blood (as previously discussed)

3.2.5.1 The middle ear contains the auditory organs and the vestibular organs. The air inside this area is vented to the outside atmosphere via the Eustachian tube. The Eustachian tube is about 4cm long and connects the middle ear to the back of the nasopharynx at about nostril level. It is normally closed but its capabilities vary greatly between individuals. Most people will have no real problems with manipulating the tube's opening whilst others will. As the environmental pressure changes (by climbing to altitude or diving to depth), the pressure in the middle ear needs to change to match it. This is called equalization. If the Eustachian tube is not blocked, this may happen naturally or may be assisted by stretching the muscles in the back of the throat (yawning or using the Valsalva or Frenzel techniques). If the tube is blocked by a deformity or by mucous from a cold, then the equalization may not occur. The result will be a stretching of the eardrum as the pressure changes. This stretching, known as distension, will cause significant pain.

Figure 3.13 The Middle Ear is vented to the outside atmosphere through the Eustachian tube. It is filled with liquid and air. If the Eustachian tube is blocked and air cannot escape, and the outside atmospheric pressure changes (such as during flight), then the trapped gas may expand or contract, causing stress against the tissue, especially the ear drum, causing pain.

3.2.5.2 The sinuses and trapped air in dental work are further considerations. The sinuses vent into the nasal passages and can become blocked with mucous, especially during times of illness. This trapped air can be affected by Boyle's Law (see above) such that even the minor changes in atmospheric pressure from day to day can cause a pressure build up and result in headaches and discomfort. Large changes in pressure, such as SCUBA diving or flying may result in significant discomfort and trauma. Some medications aim to dry out the sinuses and thus relieve this pressure, however many medications have side effects which may adversely affect a person's ability to operate at his/her optimum (See section on drugs later in this element).

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Figure 3.14 The facial sinuses which can suffer as a result of trapped gases.

Section

3.2.6 **Hyperventilation – types, factors, symptoms, treatment.** Hyperventilation is rapid or deep breathing in excess of what is considered normal for a person of a similar age and sex such that the partial pressure of CO_2 in the alveoli becomes deficient. Sources disagree on what constitutes rapid breathing, but 10L/min of inhaled air is considered to be the upper limit of normal air intake.

3.2.6.1 **Types of Hyperventilation** can be classified as chronic or acute. Chronic may be due to lung disease, diabetes, etc whereas acute may be due to an anxiety attack causing rapid, shallow breathing. Hyperventilation syndrome is a form of overbreathing due to a psychological trigger like stress or panic or anger whereas hyperventilation due to illness or injury is a physiological reaction to a physiological event.

3.2.6.2 **Factors of Hyperventilation** are such things as anxiety or panic (most common), lung or heart disease, drugs, ketoacidosis, severe pain, pregnancy and stress.

3.2.6.3 **Symptoms and Treatment** are many and varied. Symptoms can include:

- a feeling of bloating and belching.
- chest pain.

- confusion.
- dizziness.
- dry mouth.
- muscle spasms or numbness in the extremities.
- heart palpitations.
- shortness of breath.
- sleep disturbances.

Treatment for psychologically induced hyperventilation syndrome can include:

- Consciously trying to control your breathing rate.
- Reducing O2 intake and increasing CO2 intake by reducing the openings to the respiratory system (blocking a nostril and closing the mouth so as to breathe through one nostril).
- Using the paper bag method whereby breathing into a paper bag increases the uptake of CO2 thus balancing the CO2 levels in the blood expelled by rapid breathing.
- If the hyperventilation is anxiety or stress induced, having the assistance from a friend of family member by way of reassurance is very helpful to bring down a person's breathing rate.

Module 3.4

3.4 **<u>The Nervous System.</u>** The nervous system in the human being controls all the biological processes and movements of the body as well as receiving and interpreting stimuli from the external environment through the network of human senses. It consists of two primary areas: the Central Nervous System (CNS) which receives and processes the information, and the Peripheral Nervous System (PNS) which detects the stimuli through the senses and sends information to the CNS via electrical impulses.

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Section

3.4.1 **The Central Nervous System (CNS)** The CNS is located centrally within the body and is also central to the functioning of the nervous system. Its two key functional areas are the brain and the spinal cord and the basic building block is the cell called the neuron.

3.4.1.1 The neuron is a nerve cell that specialises in transmitting information throughout the human body by means of electrical or chemical signals. There are a number of different types of neurons, such as:

- Sensory (afferent) Neurons – as the name suggests, these cells transmit information from the sensory organs to the brain.
- Motor Neurons – work in the opposite direction insofar as transmitting information. These neurons transmit motor information from the brain to the muscles.
- Interneurons – transmit information between neurons.

Neurons differ from other cells in that they do not reproduce, thus the expression: "killing brain cells," for once brain cells (neural cells) die, there is no regeneration. New connections between neurons can form, however. The long length of a neuron, called the axon, can extend for up to a metre in humans.

Figure 3.23 A typical neuron cell.

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3.4.2.1 The role of the brain physiologically is to generate muscle activity or to control the secretion of hormones. It consists of three core sub-divisions:

- **The Brainstem** – the core of the brain which is composed of the midbrain which connects the hindbrain and the forebrain.

- **The Forebrain** – this is the central processing unit and is responsible for receiving and processing signals from the senses, for cognitive thought and language, as well as motor skills.

- **The Hindbrain** – this is the extension from the spinal cord through which sensory information is conducted and the area in which balance and equilibrium is maintained. Also in this area is the medulla oblongata which is responsible for automatic body functions such as breathing, digestion, heart rate and the like. From the medulla oblongata extends the other key area of the CNS, the spinal cord.

3.4.2.2 The Spinal Cord is the second area of the CNS. It is long and tubular and is found within the backbone, or vertebral column, stretching from the occipital bone to the lumbar region of the backbone, specifically L1 and L2 vertebrae. The spinal cord performs three key functions:

- As a pathway for neural signals that conduct motor information which travels down the spinal cord along the neuraxis.

- As a pathway for neural signals that receive signals from the senses, and thus travel up the spinal cord along the neuraxis.

- A central processing area for certain reflex actions.

Problem	**Remarks**
Epilepsy	storms of abnormal electrical activity in the brain causing seizures
Meningitis	inflammation of the membrane covering the brain
Multiple sclerosis	the myelin sheaths protecting the electrical cables of the central nervous system are attacked
Parkinson's disease	death of neurones in a part of the brain called the midbrain. Symptoms include shaking and problems with movement
Sciatica	pressure on a nerve caused by a slipped disc in the spine or arthritis of the spine and, sometimes, other factors
Shingles	infection of sensory nerves caused by the varicella-zoster virus
Stroke	a lack of blood to part of the brain

Table 3.7 Problems of the Nervous System derived from the Victorian Government's Better Health Channel website

Section

3.4.2 **The Peripheral Nervous System.** The nerves connect the CNS to the rest of the body where a nerve is the mass of neurons outside of the CNS. This network of nerves outside the CNS is the Peripheral Nervous System, PNS. The PNS contains nerves that mirror each other; one for the left side and one for the right side. This makes the nerves 'bilateral.' There are 12 pairs of cranial nerves and 31 pairs of spinal nerves.

3.4.2.1 The **cranial nerves** of the PNS are usually mostly related to those senses and movements of organs around the head, such as eye movement, receiving information through the retina, actions of the inner ear, but they also are directly related to the senses. Many of the nerves have motor and sensory components; the motor components of the nerves transmit signals from the brain to muscles outside the brain and the sensory components allow signals to come to the brain from the body's sensory organs.

3.4.2.2 The **spinal nerves** are probably better known for the unfortunate accidents that cause spinal cord injury, the location of which may determine how much of the body is left paralysed. The 31 pairs of spinal nerves have two roots, both of which emanate from the spinal cord and combine to emerge through small openings between each vertebra known as intervertebral foramen (except for the first spinal nerve pair that emanates from just below the brain. The nerves are labelled C1 to C8 for the cervical nerves, T1 to T12 for thoracic nerves and L1 to L5 for the lumbar nerves and S1 to S5 for the sacral nerves. One last nerve is related to the coccyx and is called the CX nerve.

Figure 3.24. The Spinal Nerves are classed from the vertebral segment from which they emanate. See the accompanying table for effects of misalignment or irritation of these nerves on the body.

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3.5 **The Senses.** We take senses for granted, but what exactly is a sense? Think of the word 'sensor'. A sensor picks up information, and that information – once interpreted – is a sense. It is defined as the faculty of sensory reception. It is the ability to detect external stimuli and through a process known as transduction, converts these stimuli into nerve impulses in the form of electrical signal which are conveyed to the brain where they are interpreted as a smell or a taste and so on.

Section

3.5.1 **How Many Senses do we have?** The manner in which we, as human beings, understand our physical position in the environment is through the perception of information that is received through our senses. Aristotle first classified the key human senses; sight, hearing, touch, taste and smell, and he surmised that through these five senses, human beings can understand where they are in the known universe.

3.5.1.1 But this limited value of senses has not allowed the real acceptance of other senses. There is argument for up to 21 senses in the human body, but for our studies, we shall use nine. They are:

- **Vision** (Sight) – the ability to receive through the eyes, photons of electromagnetic energy that are reflected off objects in the visible spectrum which excite cells on the retina and which cause electrical signals that are interpreted by the brain.

- **Audition** (Hearing) – the ability to receive the vibrations of pressure waves through the auditory organs which stimulate hair follicles which then induce electrical signals that are interpreted by the brain.

- **Gustation** (Taste) – the ability of the five types of chemical receptors on the tongue which react to chemicals that stimulate nerve endings and which induce electrical signals that are sent to and interpreted by the brain.

- **Olfcation** (Smell) – the ability of hundreds of different receptors to 'bind' to a particular molecular feature and which induce electrical signals that are interpreted by the brain.

- **Tactition** (Touch) – the ability of various receptors to perceive different pressures on the skin which then induce electrical signals that are interpreted by the brain.

- **Thermoception** (Heat) – the ability of thermoreceptors on the skin to sense the presence or absence of heat (ie hot or cold). (Homeostatic thermoceptors are different and are internal and provide feedback to internal body temperature).

- **Nociception** (Pain) – the ability of cutaneous (skin), somatic (joints/bones) and visceral (body organs) pain receptors to detect sensations which induce electrical signals that are interpreted by the brain.

- **Equilibrioception** (Balance) – the ability of the nerve endings in the vestibular apparatus of the middle ear to detect movement of fluid in the semi-circular canals which induce electrical signals that are interpreted by the brain.

- **Proprioception** (Body Awareness) – the ability of various parts of the body to detect the location of body parts regardless of the ability to sense that location through other senses.

3.5.5.2 Of the above senses, we shall investigate separately the key senses that affect us in the aviation and other high-risk environments (see following modules):

- Vision.
- Hearing.
- Equilibrioception.
- Proprioception.

Section

3.5.2 **Sensory Threshold, Sensitivity, Adaptation, Habituation.** When considering a human's ability to sense its environment, one must consider the abilities of the individual senses in being able to detect and discriminate between various external stimuli. In some cases, the senses will change over time and the ability of senses will vary between individuals. The following element investigates these factors.

3.5.2.1 **Sensory Threshold** refers to a limit of ability to detect a change in a stimulus by the human sensory receptors. There are some key thresholds, such as:

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- Absolute Threshold – below which a stimulus cannot be detected by sensory receptors.

- Recognition Threshold – that limit where recognition of a stimulus occurs, not just detection.

- Differential Threshold – the ability to detect a change between stimuli.

- Terminal Threshold – beyond this limit, the stimulus can no longer be detected (eg the upper (UV) end of the visual range of light which would be opposite to the lower (IR) end which would constitute the Absolute Threshold).

In flight simulators, acceleration can be simulated by tilting the simulator. After the acceleration simulation has ceased, the simulator can be returned to its 'baseline' position ready for the next simulation. If this return to baseline is done slowly and smoothly, (ie below sensory threshold), the pilot in the simulator will not be able to detect the movement.

3.5.2.2 **Sensory Sensitivity** can relate to the detection ability of the sensory receptors or to the degree of sensitivity of a person to psychological and physical cues. In the former case, this may be due to a neurological condition such that the sensory receptors are not as finely tuned in some people as in others (eg one person has very good vision or a keen sense of smell). In the latter case, Highly Sensitive Persons (HSPs) suffer from a form of sensory overload where too many stimuli, or particular stimuli, cause a negative psychological reaction. This stimuli may be something as innocuous as the feel of a fabric against the skin, or the texture of a type of food, or an unpleasant smell that most others would not consider too bothersome. In its extreme form, it can lead to social problems, especially with interpersonal interaction and can manifest itself as extreme shyness or an inability to make eye contact or be touched by another person without feeling like being attacked. Another term used is sensory defensiveness. It is a component of autism in its extreme form, but in its milder form, can manifest itself as an inability to perform well under pressure (test-itis) or a feeling of being overwhelmed when being overloaded and can lead to a 'meltdown' type situation.

3.5.2.3 **Sensory Adaptation** refers to the condition whereby the senses 'get used to' a particular environmental context. Probably the most common example is night adaptation whereby after about 30 minutes of darkness, visual acuity is increased, in this case by the creation of more rhodopsin to enable the rods to perform at their peak. Other examples of sensory adaptation include the threshold shift experienced by the middle ear's ossicles where muscles attached to the ossicles will retract thus reducing the ability of the stapes to vibrate against the oval window (see section on the anatomy and physiology of the ear). The reduction in the sensitivity due to this muscle contraction reduces the hearing threshold (threshold shift) of the ear and can last for several minutes, hours or even days depending on its severity. This helps to protect the hearing organ from ongoing loud noises. (Smells are another example of how a sense will become adapted).

3.5.2.4 **Sensory Habituation** is similar to Sensory Adaptation, but where in adaptation, the sensors change their abilities to detect, in habituation the brain ignores what is being detected. For example, being in a room with a noisy air conditioner may be irritating at first, but after a while, the noise is no longer noticed. The ears still hear the noise… so there is no change in the capability of the sense, but the brain does not process it the same way. It does, however, become noticeable if it suddenly stops. Sensory Habituation occurs because the senses are designed to detect changes in the environment, not things in the environment that remain constant; noises, certain tactile feelings (like wearing jewellery). Eyes are not prone to habituation because of saccadic vision, whereby the eyes are constantly moving, even when staring at an object. Because of this, the eyes are presented with new scenes several times a second – even if the difference is below our visual differential threshold so that we don't notice it – and in this way, vision always remains alert.

Section

Table 3.10 The various sensory receptors and the function they perform.

Figure 3.26 The various sensoreceptors for the various senses. Each one senses a form of data from the environment, be it an odour molecule, a photon or pressure and transmits an electrical signal to the brain through the central nervous system where those signals are decoded and interpreted by the brain.

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dB Level	Type of Noise	Aust & (US) time limits
190 dBA	Heavy weapons, 10m behind the weapon (max level)	
180 dBA	Toy pistol fired close to ear (maximum level)	
170 dBA	Slap on the ear, fire cracker explodes on shoulder, small arms at a distance of .5m (maximum level)	
160 dBA	Hammer stroke on brass tubing or steel plate at 1 m, airbag deployment very close at 30 cm (max level)	
150 dBA	Hammer stroke on anvil at 5 m (maxlevel)	
130 dBA	Loud hand clapping at 1 m distance (maximum level)	0.9 s (none)
120 dBA	Whistle at 1 m distance, test run of a jet at 15 m	7.2 s (none)
118 dBA	**Threshold of pain, above this fast-acting hearing damage in short action is possible**	14.4 s (none)
115 dBA	Take-off sound of planes at 10 m distance	28.8 s (28 s)
112 dBA		56 s (57 s)
110 dBA	Siren at 10 m distance, frequent sound level in night clubs and close to loudspeakers at rock concerts	
109 dBA		1.9 mins (1.9 mins)
106 dBA		3.8 mins (3.8 mins)
105 dBA	Chain saw at 1 m, banging car door at 1 m, racing car at 40 m, possible level with music head phones	
103 dBA		7.5 mins (7.5 mins)
100 dBA	Pers music with headphones, jack hammer at 10 m	15 mins (15 mins)
97 dBA	Hammering nails into wood.	30 mins (30 mins)
95 dBA	Loud crying, hand circular saw at 1 m distance	
94 dBA	Circular Saw cutting Hardwood	1 hr (1 hr)
92 dBA		(1.6 hrs)
90 dBA	Angle grinder outside at 1 m distance	2 hrs (2.5 hrs)
88 dBA	**Hearing damage possible if exposed for >40hrs/wk**	4 hrs (4 hrs)
85 dBA	Chain-saw at 10 m distance, loud WC flush at 1 m	8 hrs (8 hrs)
82 dBA		12 hrs (16 hrs)
80 dBA	Very loud traffic noise of passing trucks at 7.5 m, high traffic on an expressway at 25 m distance	16 hrs (Cont. OK)
75 dBA	Passing car 7.5 m, un-silenced wood shredder at 10 m	CONTINUOUS
70 dBA	Close to a main road by day, quiet hair dryer at 1 m	
65 dBA	**Bad risk of heart circulation disease at constant impact is possible**	
60 dBA	Noisy lawn mower at 10 m distance	
55 dBA	Low volume of TV at 1 m, vacuum cleaner at 10 m	
50 dBA	Refrigerator at 1 m, bird twitter outside at 15 m	
45 dBA	Noise of normal living; talking, or background radio	
40 dBA	**Possibly distracting when concentrating/learning**	
35 dBA	Very quiet room fan at low speed at 1 m distance	
25 dBA	Sound of breathing at 1 m distance	
0 dB	Auditory threshold	

Module 3.8

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Group 2 - The Individual Context1

Module 2.1.1 Surviving in the biosphere 3

Module 2.1.2 Evolution and the human body 7

Module 2.1.3 Physiology and functions 10

• Trapped gases in the 6