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Aerospace Physiology Journeyman

Volume 2. Aerospace and Sensory Physiology

Extension Course Program (A4L)

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THE HUMAN BODY is a complex and very structured system that has been studied for thousands of years. In this volume we look at the human body and how it reacts to the flying environment.

In unit 1 we cover medical terminology and discuss the body systems that are affected by altitude. In unit 2 we describe the atmosphere around us and how the gas laws govern the body's reaction to reduced atmospheric pressure. We also cover mechanical effects of pressure changes, as well as decompression sickness, hypoxia, and hyperventilation.

In unit 3 we remind you about the altitude stresses placed on ourselves and the aircrew that we support. We also review the effects of vision, noise, and acceleration stressors, spatial disorientation as well as night vision classroom training, and the Barany chair demonstrations.

In unit 4 we tell you how to take care of students who may have reactions in the altitude chamber. Treatment of chamber reactors is a good closure to this volume because it is a vital part of why we serve as inside observers. Learning this information as if it were second nature is important for the safety of your students and fellow instructors.

A glossary of abbreviations and acronyms used in this course is included at the end of this volume.

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This volume is valued at hours 18 and 6 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Page

Please read the menu for Unit 1 and begin. ➔

Student Notes

Unit 1. Physiology Fundamentals

AS AN AEROSPACE PHYSIOLOGY (AP) technician, it is important to gain fundamental knowledge of the body systems that can be affected by exposure to altitude. Familiarity with body functions during normal conditions provides a better understanding as to how and why these functions can be affected and possibly cause serious problems for flyers. This unit covers general information regarding medical terms as well as basic anatomy and physiology of four of the major body systems.

1–1. Medical Terminology

To better understand anatomy and physiology, it is important to be familiar with basic medical terminology. In this section, we cover basic construction of medical terms as well as orientation and directional terms used when discussing anatomy.

201. Basic parts of medical terms

Medical terminology is the professional language of those directly or indirectly involved with patient care. Many of the words used in medicine are made up of parts that are also used in other words. Once you know the meanings of the basic parts of the words, you can put them together to understand the meanings of many medical terms. Since more than 75 percent of medical terms are derived from the Latin and ancient Greek languages, medical terms may seem strange and bewildering to you at first. Fortunately, there is a logical method found in medical terminology.

It is imperative that healthcare professionals communicate *accurately* and *efficiently*. One way to accomplish this is by having a “special language” of medical terminology. Medical terms meet the criteria of **accuracy** by providing exactness, correctness, and precision. This means we can express exactly what we mean, and others will interpret it exactly as we intended. Also, medical terms meet the criteria of **efficiency** by communicating a lot of information with fewer words or syllables.

All medical terms can be broken down into parts of the word. The basic parts of medical terms are called *stems (roots)*, *prefixes* and *suffixes*. Let us examine several combinations of those parts. For example, consider the term *electrocardiogram.* You had an electrocardiogram done as part of your physical exam to enter into the 4M0X1 career field. In this example we have two stem words: *electro* = electricity and *cardio* = heart, and a suffix: *gram* = record. With this one term we mean that you have a record of the heart’s electrical activity.

Stems (roots)

The stem or root is the part of the word that gives the *basic meaning* to the term. They are used in combination with prefixes and suffixes to add exactness and specificity. Medical terms are commonly built by adding a prefix to the beginning of the root word and attaching a suffix to the end of the word. Sometimes, a term may have two stems like in the term *stratosphere*. Instead of simply joining the two stems strat + sphere, we insert a vowel to say stratosphere. Let’s take a look at some examples of stem words and their meanings:

Stem (Root)	Meaning
Adeno	gland
Arthro	joint
Baro	weight, pressure
Cardio	heart
Cephalo	head
Costo	rib
Cranio	skull
Cyano	blue
Derm	skin
Dorso	back
Erythro	red
Fibro	fiber
Gastro	stomach
Hemo	blood
Hepato	liver
Histo	tissue
Hydro	water
Laryngo	voice box
Leuko	white
Lipo	fat
Mono	one
Neuro	nerve
Ophthalmo	eye
Ortho	straight
Osteo	bone
Oto	ear
Patho	disease
Pharyngo	throat
Phlebo	vein
Pneo	breath
Poly	many
Pyro	heat, fever
Rhino	nose
Stetho	chest
Tachy	rapid
Vaso	duct, vessel

Prefixes

The prefix is the part of the word that comes *before* the stem and augments or modifies the meaning of the stem. For example, part of your job is to work in a *hypobaric* chamber. In this example, *hypo* refers to less-than-normal, *baro* means pressure, and *ic* means pertaining to. Therefore, a hypobaric chamber pertains to less-than-normal pressure. The *o* in *baro* was dropped in this case to make the term easier to pronounce. This is often done when a root that ends with a vowel is followed by a suffix beginning with a vowel. Below are several examples of letters or groups of letters that can be used as prefixes.

Prefix	Meaning
a, an	absence of
ab, abs	away from
aero	air, gas
ad	toward
ambi	on both sides
ante	in front of
anti	against
auto	self, same
bi	two
bio	life
contra	against
de	away from, cessation
dia	through
dis	taking apart
ecto	outside
endo	inside
epi	on, upon
hemi	one-half
hyper	above, over, beyond
hypo	below, less than, under
inter	between
intra	within
meso	middle
meta	after, behind
para	abnormal
peri	around, surround
ost	after, behind
pre	before
retro	backward, behind
semi	one-half
sub	under, near
super	above, excess
supra	above, over
uni	one

Suffixes

The part of the word that comes *after* the stem and modifies or augments its meaning is called the suffix. Let us look at this term: *barotitis*. In this example, we have *baro* (pressure) as the prefix for *oto* (pertaining to the ear) followed by *itis*, which means inflammation. With this one term, we can express that someone has inflammation in the ear caused by pressure. The following list of suffixes completes your introduction to basic medical terminology.

Suffix	Meaning
ac, al	pertaining to
alg, algia	pain
asis	condition
cyte	cell
emia	blood condition
genic	formation
gram	record or picture
graph	record or picture
iasis, sis	condition
ic	pertaining to
itis	inflammation
logy	study of
meter	measurement
oma	tumor
osis	process
pathy	disease
phobia	fear
plasty	repair
plegia	paralysis
rrhagia	burst forth
rrhaphy	surgical suture
rrhea	flow, discharge
scope	Instrument of examination
scopy	act of examining
tomy	cutting operation

202. The language of anatomy

The basis of our job as aerospace physiology technicians is found in understanding anatomy and physiology. *Anatomy* is the study of the structure and shape of the body and body parts and their relationships to one another. This encompasses studying body structures that are easily observable as well as cells and tissues that can only be seen through a microscope. *Physiology*, on the other hand, is the study of the functions of all body structures, large and small. Knowing how the body works at ground level will help you understand how changes in barometric pressure can affect it.

Anatomical positions

We have a reference point to help us describe body parts and their positions. We refer to the standard position as the *anatomical position*, which means that the body is erect in a standing position. In other words, the arms are hanging at the sides with the palms facing forward, the fingers extended, the thumbs pointing away from the body and feet together.

Directional terms

When we need to describe where one body part is in relation to another, we use directional terms. Refer to the table below to better understand directional terms used in anatomy.

Term	Definition	Example
Anterior (Ventral)	Toward or at the front of the body	The breastbone is anterior to the spine.
Posterior (Dorsal)	Toward or at the backside of the body	The heart is posterior to the breastbone.
Medial	Toward or at the midline of the body	The heart is medial to the arm.
Lateral	Away from the midline of the body	The arms are lateral to the chest.
Superior (Cranial or Cephalad)	Toward the head end or upper part of a structure or the body; above	The forehead is superior to the nose.
Inferior (Caudal)	Away from the head end or toward the lower part of a structure or the body; below	The navel is inferior to the breastbone.
Superficial	Toward or at the body surface	The skin is superficial to the skeleton.
Deep	Away from the body surface	The lungs are deep to the skin.
Proximal	Close to the origin of the body part	The elbow is proximal to the wrist.
Distal	Farther from the origin of the body part	The knee is distal to the part.
Intermediate	Between a more medial or lateral structure	The collarbone is intermediate between the breastbone and shoulder.

Anatomical planes

Since the body is three-dimensional, we can refer to three basic planes. Anatomical planes (fig. 1–1) are imaginary lines separating the body into specific areas. They consist of the three main planes.

1. *Frontal*: An imaginary vertical plane that divides the body into anterior (front) and posterior (back) sections.
2. *Transverse*: An imaginary horizontal plane that divides the body into superior and inferior sections.
3. *Sagittal*: An imaginary plane that goes from top to bottom of the body dividing it into unequal right and left portions. Note: when this plane divides the body into equal left and right portions is referred to as *midsagittal* or *median* plane.

Anatomical posture

The table below contains the terms that describe the body positions commonly referred to in healthcare operations.

Term	Definition
Erect	The normal standing position of the body.
Supine	Lying position, anterior surface upward.
Prone	Lying position, anterior surface downward.
Lateral recumbent	Lying position, on either the right or left side.

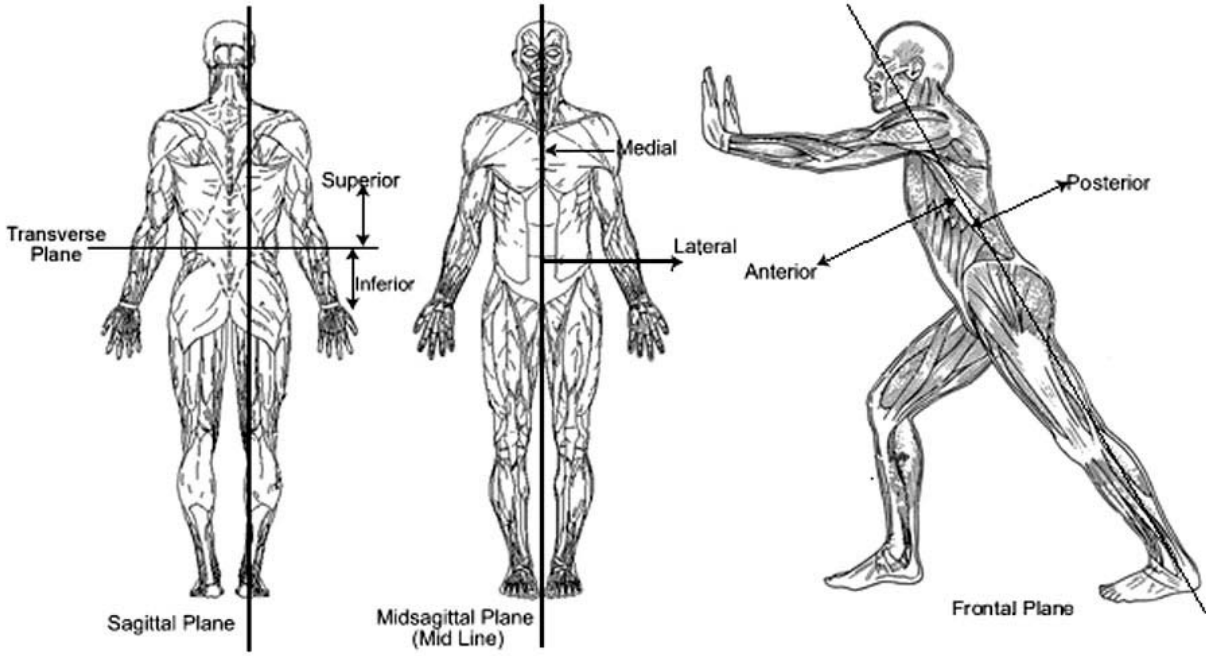

Figure 1–1. Anatomical planes.

Body cavities

This last section in the language of anatomy covers the terms used to refer to body cavities. Body cavities protect the organs contained within them. The cavities are divided and subdivided as follows:

Term	Definition
Dorsal	Cranial: formed by the bones of the skull; protects the brain.
	Spinal: formed by the vertebras; protects the spinal cord.
Ventral	Thoracic: formed by the ribs, sternum and diaphragm; protects the heart and lungs.
	Abdominopelvic: formed by the abdominal wall and diaphragm. It is further subdivided into: abdominal cavity that protects the stomach, liver, intestines and other organs, and pelvic cavity that protects the reproductive organs, bladder and rectum.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Basic parts of medical terms

1. From what two languages are the majority of medical terms derived?

2. Why do we have a special language for medical terminology?

3. What are the three basic parts of medical terms?

4. What does the stem (root) part of the medical term convey?

5. Supply the meanings of the following medical terms:

   (1) *Otoscope*.

   (2) *Intercostal*.

   (3) *Anemia*.

   (4) *Erythrocyte*.

   (5) *Neurology*.

   (6) *Rhinitis*.

   (7) *Cyanosis*.

   (8) *Intravascular*.

   (9) *Retrocranial*.

   (10) *Pericardial*.

202. The language of anatomy

1. Match each anatomical term listed in column B with its definition in column A. Items in column B may be used only once.

Column A	*Column B*
____ (1) Toward or at the front of the body.	a. Anatomy.
____ (2) Toward or at the midline of the body.	b. Physiology.
____ (3) Toward the head end.	c. Lateral.
____ (4) Toward or at the back side of the body.	d. Medial.
____ (5) Toward or at the body surface.	e. Superficial
____ (6) Away from the midline of the body.	f. Anterior.
____ (7) Away from the head end.	g. Posterior.
____ (8) Away from the body surface.	h. Proximal.
____ (9) Between a more medial or lateral structure.	i. Distal.
____ (10) The study of the structure and shape of the body and body parts and their relationships to one another.	j. Superior.
____ (11) Close to the origin of the body part.	k. Inferior.
____ (12) The study of the functions of all body structures, large and small.	l. Deep.
____ (13) Farther from the origin of the body part.	m. Intermediate.

2. Match each body organ listed in column A with the body cavity of which it is a part, listed in column B. Items in column B may be used more than once.

Column A	*Column B*
____ (1) Spinal cord.	a. Dorsal/cranial
____ (2) Liver.	b. Dorsal/spinal
____ (3) Lungs.	c. Ventral/thoracic
____ (4) Brain.	d. Ventral/admominopelvic
____ (5) Heart.	
____ (6) Stomach.	

1–2. Body Systems

Body systems are a series of interdependent organs functioning together to produce a result not possible if each were acting alone. Each system performs a distinct yet related function, and none can do its work without the cooperative actions of the other systems. Furthermore, a condition affecting one particular system's activity may affect another system as well. There are 10 major organ systems: integumentary, endocrine, digestive, urinary, reproductive, skeletal, muscular, nervous, respiratory and circulatory. For the purpose of our job in aerospace physiology, we will cover the last four of the systems just mentioned.

203. Cells and body tissues

The basic biological unit of the human body is the *cell*. Cells are responsible for the entire organization of all body structures and for the continuation of life processes. The grouping of cells with a similar structure and common function forms *tissues*. Two or more tissue types make up an *organ* that performs a specific function in the body. When organs group together to accomplish a common purpose, they form organ or *body systems*. In this lesson we cover the basics of the cell structure followed by the four primary types of tissue.

The cell

The cells of multicellular organisms vary in size, shape, and number of nuclei; however, they all have a common structure. Cells reproduce by division, replacing worn-out cells, building new tissue, and promoting body growth as a whole. The three general components of the cell are: *membrane*, *cytoplasm* and *nucleus*.

Cell membrane

The outermost layer of the cell is called the cell membrane. Think of it as the gatekeeper. This membrane is flexible and semipermeable (selective permeability) allowing certain materials to enter and leave the cell as needed and restricting the movement of others. The movement of materials across the cell membrane occurs through one of three ways: diffusion, osmosis, or active transport.

Diffusion

Diffusion is the movement of molecules or other particles from an area of higher concentration to an area of lower concentration until equilibrium is reached. When the latter happens, the diffusion continues but the flow is equal in both directions. The rate of movement depends on the size and temperature of the molecule. The smaller or warmer the molecule is, the faster it moves

Osmosis

Osmosis is a form of passive transport similar to diffusion. It involves a *solvent* (a liquid such as water) and a *solute* (particles in the liquid). When there is a difference in the concentration of solutes on both sides of a semipermeable membrane, osmosis occurs.

Active transport

This movement occurs against the normal gradient of concentration: particles move from an area of low concentration to an area of high concentration. This is only possible with the help of a molecule called *adenosine triphosphate* (ATP). The ATP is how the cell stores its energy until needed, such as during active transport.

Cytoplasm

The cytoplasm contains all of the living substances of the cell. It is a gel-like liquid where most cellular activities take place. The cytoplasm houses several *organelles*, or “little organs,” each with a distinct function within the cell. It is in the cytoplasm that *metabolism* occurs. *Metabolism* means change” and encompasses all the chemical reactions necessary to maintain life. In general terms, metabolism is responsible for generating, storing, and expending energy. In other words, cellular metabolism is the process of chemically changing or altering molecules so they can be used by the body. Metabolism depends on the digestive and respiratory systems to provide nutrients and oxygen, which in turn will be distributed to the body through the cardiovascular system.

Nucleus

The nucleus is the largest organelle in the cell. It is considered the “brain” or “control center” of the cell. The nucleus contains genetic material called *deoxyribonucleic acid* or DNA. The DNA is necessary for building proteins and for cell reproduction.

The tissues

As mentioned earlier, tissues are groups of cells that are similar in structure and function. The four primary body tissues are *epithelial*, *connective*, *muscle*, and *nervous* tissues (fig. 1–2). We will take a closer look at each one of them.

Epithelial tissue

Epithelial tissue is found throughout the body, covering all body surfaces, both inside and out. This type of tissue covers all organs, forms the inner lining of body cavities, and lines the inside of hollow organs. It is also the major type of tissue found in the glands. The primary functions of the epithelial tissue are to protect, absorb, filter, and secrete.

Connective tissue

Connective tissue is the most abundant type of tissue and it is found throughout the body. This tissue is classified according to its *extracellular matrix*, which is the nonliving substance found outside the cells. Depending on the type of connective tissue, the matrix may be liquid, semisolid, or very hard. The major classes of connective tissue are bone, cartilage, dense and loose connective tissue, and blood. Connective tissues have many functions but are primarily involved with protecting, supporting ,and binding other body tissues.

Muscle tissue

Muscle tissue is unique in that it has the ability to change shape by shortening or contracting in order to produce movement. The cells that make up the muscle tissue are elongated and are called *muscle fibers*. Muscle tissue can be found in different parts of the body, depending on its type. There are three types of muscle tissue: skeletal, smooth, and cardiac. These will be discussed in more detail under the muscular system lesson.

Nervous tissue

Nervous tissue is found in the brain, spinal cord, and nerves of the body. This tissue is made out of primary nerve cells called *neurons*. Neurons, along with other supporting cells, make up the structure of the nervous system.

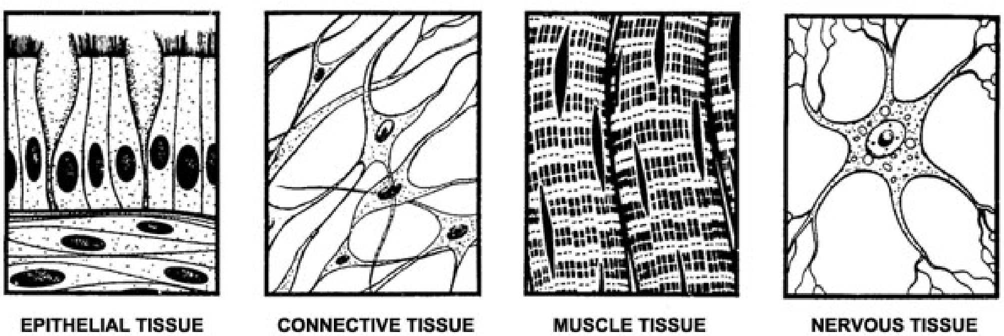

Figure 1–2. Types of tissues.

204. Muscular system

The muscles of the body are layered over the skeleton and largely define the shape of the body. Muscle tissue accounts for nearly half of the weight of the body. There are over 500 muscles that can be seen by the unaided eye while many others can only be seen through a microscope. The primary function of muscle is *contraction* or *shortening*, which makes the muscles unique when compared with other body tissues. In essence, muscles are responsible for all body movement.

Types of muscle

As with the muscle tissues mentioned in the previous lesson, muscles themselves are also classified as *skeletal*, *smooth* and *cardiac*. Next, we will take a closer look at each type of muscle (fig. 1–3).

Skeletal muscle

The skeletal muscle tissue is attached to the skeleton. Because of the repeated pattern of light and dark bands seen microscopically, skeletal muscle is described as “striated.” These muscle fibers can contract quickly, but can also tire just as fast. A bundle of muscle fibers is called a *fascicle*. Many fascicles are grouped together in a tough connective tissue called an *epimysium*. The epimysium blends into strong, cordlike *tendons* to anchor muscles or into sheet-like *aponeuroses* that attaches muscles to each other. It is also referred to as *voluntary muscle* because it is the only muscle that can be consciously controlled.

Smooth muscle

Smooth muscle tissue can be found in the walls of internal organs, or *viscera*, such as the stomach, intestines, bladder, and respiratory passages. In contrast to skeletal muscle, this muscle tissue is not striated but its spindle-shaped fibers give it a *smooth* appearance. These muscle fibers are relatively slow in contractions. This tissue is not under conscious control and is therefore considered *involuntary muscle*.

Cardiac muscle

Cardiac muscle is only found in the heart. It is similar in appearance to the skeletal muscle in that it too is striated. The cardiac muscle fibers are branching cells joined by special junctions called *intercalated disks*. These structures permit the unique action necessary for heart function. The cardiac muscle contractions are slow and steady, unless stimulated by the nervous system to go faster for short periods as when a person is running, for instance. Like smooth muscle, the cardiac tissue contractions occur involuntarily.

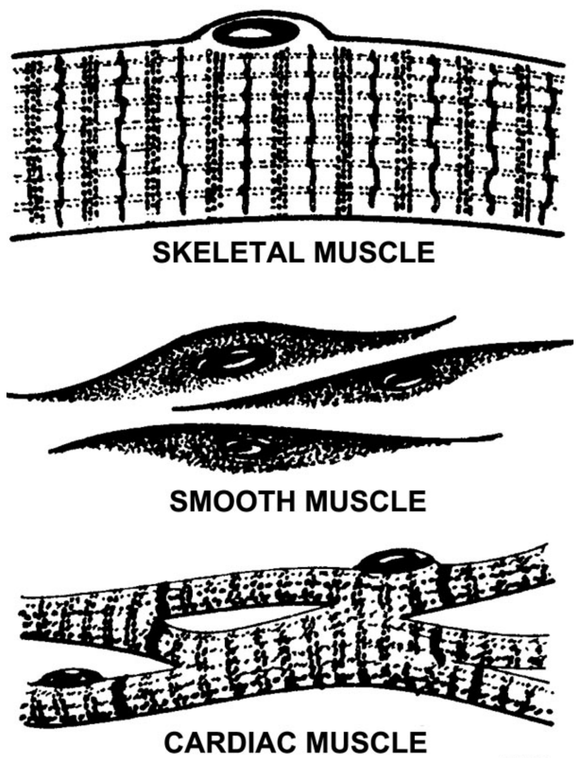

Figure 1–3. Types of muscles.

Muscle functions

The muscular system has four important roles in the body. We will briefly discuss each one of them.

Movement

Muscles are responsible for producing nearly all movements in the human body. This includes skeletal muscle actions when we move the body as a whole, as in jogging, or when merely making a facial expression. The actions of smooth muscles take care of vital functions that range from regulation of blood flow to moving the food along the digestive tract. Lastly, the cardiac muscle is responsible for the movement of the heart or heart beat.

Posture

In spite of the constant downward pull of gravity, skeletal muscles are the ones allowing you to maintain a standing or seated posture.

Joint stabilization

Aside from pulling on bones to create movement, skeletal muscles are a key structure in stabilizing the joints of the skeleton.

Heat generation

The skeletal muscles are largely responsible for maintaining a normal body temperature. When ATP (stored energy) is used in muscle contractions, some energy is released as heat. This chemical reaction makes it possible for the body to maintain its temperature.

Types of muscle contractions

When we think of muscle contractions, we can associate that with muscle shortening as it generates force. However, muscle shortening is not the only way a muscle can create force. Keep in mind that when a muscle contracts it is producing tension. The type of muscle contraction is determined by the motion of the joints or limbs engaged in the motion. The two types of contractions are *isotonic* and *isometric*.

Isotonic

Isotonic means “same tone” or tension. In isotonic contractions, muscle tension remains the same regardless of a change in muscle length. Lifting an object from a desk involves isotonic contractions. Isotonic contractions can be divided into concentric and eccentric.

Concentric

In concentric isotonic contractions, the muscle tension exceeds the resistance and the muscle shortens.

Eccentric

During eccentric isotonic contractions, the muscle tension is less than the resistance and the muscle lengthens.

Isometric

Isometric means “same measurement” or length. In isometric contractions, the length of the muscle remains the same regardless of a change in tension. An example of an isometric contraction would be carrying an object in front of you. The weight of the object pulls downward, but your hands and arms apply equal force upwards. Since your arms and are nor raising or lowering, your biceps are isometrically contracting.

Types of muscle actions

The brain coordinates muscles in groups to perform a particular movement. Based on that, we can categorize muscles by their actions into prime movers, antagonists, fixators, or synergists.

1. *Prime mover* – refers to the muscle “in charge” of the contraction of several muscles at the same time.
2. *Antagonists* – are those muscles opposing or reversing the movement of the prime movers.
3. *Fixators* – act to hold or stabilize a part so other muscles can perform movement.
4. *Synergists* – are the muscles that help the prime movers produce their movement or reduce unnecessary movement.

205. Nervous system

The nervous system is an extremely organized structure that makes it possible for the body to receive and respond to either internal and external factors or *stimuli*. All of the body's stimulus-response actions are coordinated and regulated by the nervous system. You may think of the nervous system as the ultimate communication network. The nervous system can be described based on its structure and its functions. Structurally, it is divided into two parts: the *central nervous system* (CNS) and the *peripheral nervous system* (PNS). In this section we will review the anatomy of the nervous system as well as its functions.

Structure of the nervous system

The basic structural unit of the nervous system is the *neuron* or nerve cell (fig. 1–4). These highly specialized cells transmit messages, or *nerve impulses,* from one part of the body to another. Each neuron contains three basic structures: a *cell body*, one or more cell processes called *dendrites*, and one *axon*. Dendrites carry nerve impulses to the cell body while axons carry nerve impulses away from the cell body.

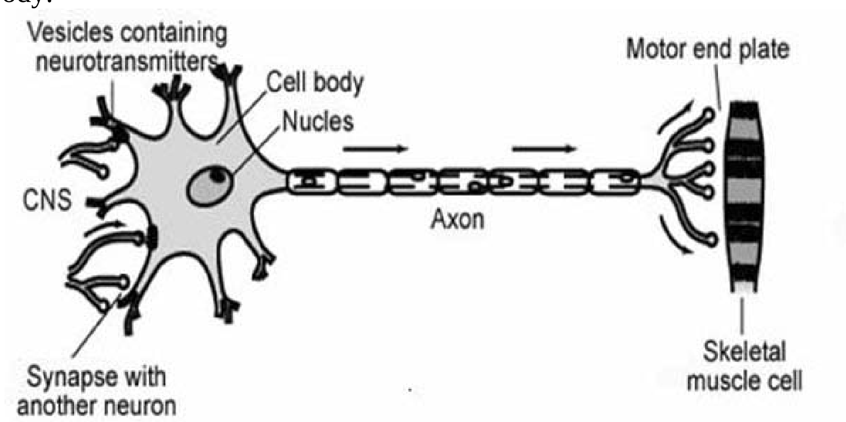

Figure 1–4. Neuron cell.

We can classify neurons according to their functions as described in the following table:

Neuron function	Description
Sensory (afferent)	Cells activated by physical stimuli. Once they receive (sense) stimuli from peripheral body locations, they pass the impulses (messages) to the brain or spinal cord.
Interneuron (association)	Cells activated by sensory neurons. They relay impulses between neurons within the brain and the spinal cord.
Motor (efferent)	Cells that conduct (transmit) impulses from the brain and spinal cord to the peripheral muscles and glands in the body in order to produce a response.

Other important structures of the nervous system include *nerves*. These are bundles of neuron fibers found outside the CNS. As with the neurons, the nerves are classified into three categories:

Nerve	Description
Sensory (afferent)	Nerves with sensory neuron fibers that transmit sensory information from receptors to the CNS.
Motor (efferent)	Nerves with motor neuron fibers that transmit impulses from the CNS to muscles and glands.
Mixed	Nerves with both sensory and motor neuron fibers.

Central nervous system

The CNS contains the majority of the nervous system, and it consists of the brain and the spinal cord, which are encased in the cranium and the vertebral column respectively. The CNS is the nervous system integrator and control center. It receives sensory information from the PNS and responds to that information with motor instructions. Both the brain and the spinal cord are protected by three continuous sheets of connective tissue called the *meninges*. The CNS is further protected by the cerebrospinal fluid contained within the meninges. This is a clear fluid that acts as a shock absorber for the CNS.

Brain

The brain receives and interprets impulses that result from stimuli and sends out responses for the body to react to such stimuli. The brain consists of a large mass of nerve tissue and is divided into three main parts: *cerebrum, cerebellum,* and *brain stem*. As we discuss the brain structure, refer to figure1–5.

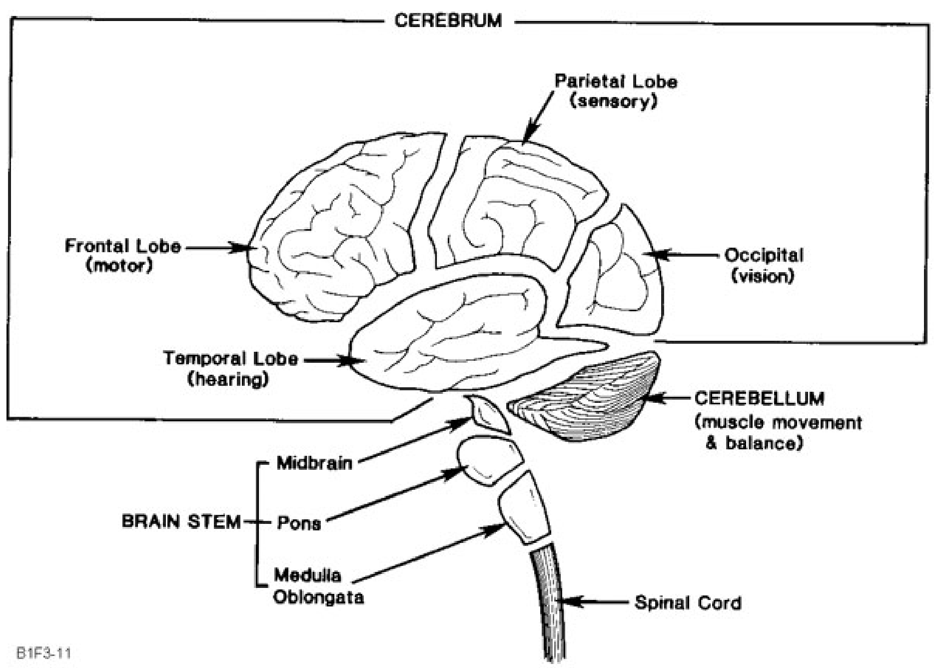

Figure 1–5. The brain.

- The cerebrum is the largest part of the brain and is considered the center of intelligence and personality. The area inside the cerebrum is responsible for storing knowledge (memory) and interpreting sensations. The cerebrum is divided into right and left hemispheres. Each hemisphere further subdivides into lobes named after the overlying bones of the skull. Each of these four lobes has a specialized function as described in the following table:

Lobe	Function
Frontal	The motor area; controls conscious movement, reactions and emotional responses.
Parietal	The sensory area; controls how we sense temperature, touch, pressure, and pain.
Occipital	The visual area; controls ability to recognize words, numbers and color.
Temporal	The auditory area; controls ability to recognize what we hear and to form memories.

- The cerebellum is the second largest part of the brain. Its primary functions are to coordinate muscle movements, posture and balance.

- The brain stem provides an ascending and descending pathway for nerve fibers. It consists of three parts: the *midbrain*, which controls some reflexes; the *pons*, which assists in regulating respiration; and the *medulla oblongata*, considered the control center for respiration and is also responsible for blood pressure, heart rate, and some reflex activities.

Spinal cord

The spinal cord connects a large part of the PNS to the brain by providing nerve impulses a two-way path to and from the brain. It also processes sensory information and is responsible for simple reflexes. The spinal cord exits the skull through an opening called the *foreamen magnum*. There are 31 pairs of spinal nerves, referred to as “mixed” nerves because they contain both sensory and motor axons.

Peripheral nervous system

The PNS consists of nerves found outside the CNS and is responsible for transmitting impulses between the body and the brain. The PNS serves as a bridge between the environment and the CNS. It has 12 pairs of *cranial nerves* and 31 pairs of *spinal nerves* stemming from the brain and the spinal cord, respectively. Cranial nerves control functions that are sensory, motor, or a combination of both. For example, the *olfactory* nerve is a sensory nerve that conveys the sensation of smell. Conversely, the *oculomotor* nerve is a motor nerve responsible for the eyeball muscles. The *vagus* nerve is considered a mixed nerve and regulates both digestive and heart activities. The PNS has two functional divisions: *somatic* nervous system and *autonomic* nervous system.

Somatic division

The somatic division includes sensory neurons that innervate the skin, muscles, and joints and provides sensory information to the CNS about muscle and limb position and about the environment outside the body. All our conscious awareness of the external environment and all of our voluntary motor activity (i.e., body movement) to cope with it are possible through the somatic division of the PNS.

Autonomic division

This is the second division of the PNS that contains the nerves responsible for involuntary or unconscious body movements. The autonomic division is responsible for monitoring the internal environment of the body and causing appropriate responses to take place. Involuntary muscle activities such as respiration, digestion, and circulation are prompted by the autonomic nervous system. The autonomic nervous system is further separated into two subdivisions: the *sympathetic* and *parasympathetic* divisions. These two subdivisions serve the same organs but perform the opposite effects. This relationship is key in maintaining *homeostasis*, which is the internal equilibrium of the body. Let’s now take a brief look at each one of these subdivisions.

Sympathetic subdivision

This subdivision is responsible for involuntary responses to stress. It is usually activated in emergency or extreme situations that require an immediate response. It is often referred to as the “fight-or-flight” reaction in which the body speeds up heart rate, increases breathing, and so forth. preparing the body for such situations.

Parasympathetic subdivision

The parasympathetic subdivision, on the other hand, returns the body to its “normal” condition. Generally speaking, the parasympathetic subdivision acts in opposition to the sympathetic subdivision by slowing down the heart rate, the breathing, and so forth.

206. Respiratory system

The respiratory system includes all air passages and organs involved in the exchange of gases, namely oxygen (O_2) and carbon dioxide (CO_2). Oxygen is required to support the metabolic processes that sustain life, and carbon dioxide is a waste product of metabolism. In simpler words, the primary function of the respiratory system is to supply the blood with oxygen in order for the blood to deliver it to all parts of the body. While respiration is defined as the exchange of O_2 and CO_2 between an organism and its environment, it also involves the exchange of these gases at the cellular level.

Structure of the respiratory system

The respiratory structure can be divided into upper and lower respiratory systems. The upper respiratory system includes the nose, the pharynx, and the larynx (fig. 1–6). The lower respiratory system includes the trachea, bronchi, and the lungs. We will now take a closer look at each one of them.

Nose

The nose is a framework of bone and cartilage covered by skin. The two external openings are called *nostrils* or *nares*. The nostrils join to form the nasal cavity, which is the space between the roof of the mouth (palate) and the base of the cranial cavity. A mucous membrane lines the entire cavity to include the *paranasal sinuses*. You could easily understand why conditions affecting the nasal mucosa, such as a common cold, can affect the sinuses. As air enters the nasal cavity, it is warmed and moistened before entering the lungs. In addition, hair-like structures called *cilia* filter the inhaled air by trapping small particles such as dust or bacteria. The motion of the cilia constantly cleanses the mucosa. The cilia "sweep" the mucous and bring trapped particles back into the throat, where it is either swallowed or expelled through the mouth. The mouth, or oral cavity, also acts as a passageway for air, but it plays a lesser role in breathing.

Pharynx

The pharynx, or throat, is the passageway lying between the nose and the larynx. It divides into three parts: the *nasopharynx*, *oropharynx*, and *laryngopharynx*. The upper part, nasopharynx, is an air passage only, and it contains the two *eustachian tubes* that connect to the middle ear. The lower portions, oropharynx and laryngopharynx, serve as a passageway for both food and air. The pharynx is also responsible for humidifying and warming the air.

Larynx

The larynx, or "voice box," is located in the middle of the neck and connects the pharynx to the trachea. The larynx has a role in routing air and food, and it also plays a role in producing sound (speech). It consists of a framework of cartilage plates. One flap of cartilage, the *epiglottis*, covers the airway during swallowing to prevent food and liquid from entering the trachea.

Trachea

The trachea, or "windpipe," begins at the lower end of the larynx and ends by dividing into right and left bronchi. A series of C-shaped cartilage rings keeps the trachea open and prevents it from collapsing. The cilia in the mucous membranes move continuously to drive dust particles and debris away from the lungs.

Bronchi and bronchioles

The trachea branches off into two main passageways known as the bronchi, one extending to the right lung and the other to the left lung. Each bronchus is further divided into smaller passages leading to each lobe within the lungs. Once inside the lobes, it continues to divide into smaller branches called bronchioles. Each bronchiole subdivides into several *alveolar ducts* that lead to *alveolar sacs*. Each of these sacs has a great number of small pockets called *alveoli*. This last structure is of utmost importance in respiration because it is in the alveoli where gas exchange occurs.

Lungs

The lungs are the primary organs of respiration. They are located inside the thoracic (chest) cavity and enclosed in a protective lining called *pleura*. The right lung has three lobes and the left lung has two. The base of each lung rests on the *diaphragm,* which is the main muscle of respiration.

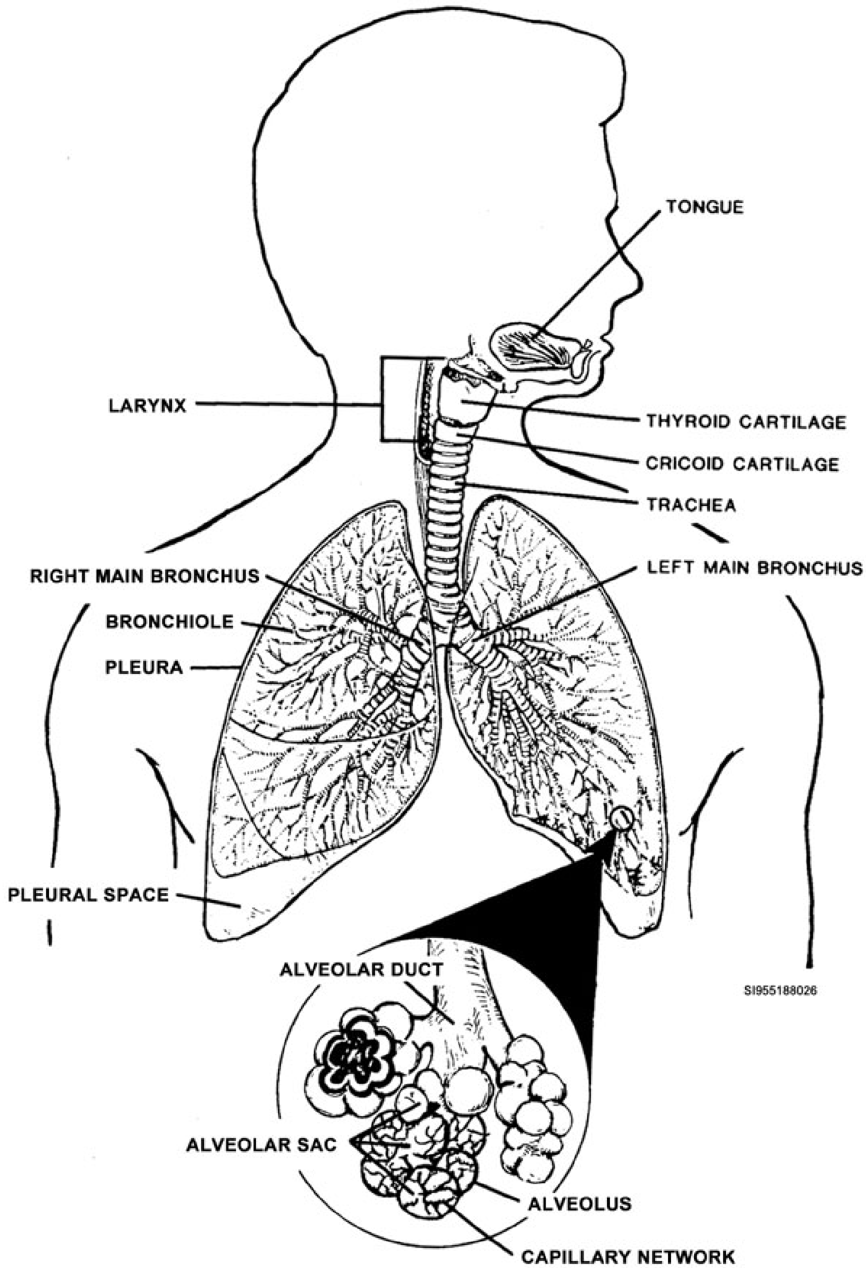

Figure 1–6. The respiratory system.

Mechanics of respiration

Now that we know all the components involved in the respiration process, let us take a look at how they all work together. Normal breathing is repeated about 12 to 20 times per minute and is an involuntary function controlled by the nervous system unless overridden by other factors that we will discuss later in this section. The primary stimulus for breathing is the need to eliminate carbon dioxide—secondary to this is the need for oxygen. When we breathe, we *actively* inhale and *passively* exhale.

Inhalation

During inhalation, the diaphragm and external intercostal muscles contract and become smaller to create additional space in the thoracic cavity for the lungs to expand as they fill with air. The diaphragm moves downward while the contraction of the external intercostal muscles allow the ribs to move forward and slightly upward. As the volume of the thoracic cavity increases, the intrathoracic pressure and the pressure within the lungs decrease. When this happens, it creates a partial vacuum, which means that the intrapulmonary (lung) pressure is less than the atmospheric pressure. This in turn draws the air into the lungs until the pressure within the lungs equalizes with the atmospheric pressure.

Exhalation

During exhalation, the inspiratory muscles relax and return to their initial shape. When the volume of the thoracic cavity and the lungs is reduced, the intrapulmonary pressure increases above the atmospheric pressure. This causes the air to flow out to equalize the pressure. Under normal circumstances, exhalation is passive. However, as you will later learn, there are times when expiration will be active, as when "pressure breathing" with an oxygen regulator. The abdominal muscles contract and force the diaphragm upward and the rib cage inward. A significant compression of the lungs forces air out and exhalation occurs.

Control of respiration

We mentioned earlier that respiration is an involuntary process controlled by the nervous system, specifically by the medulla oblongata. However, the spontaneous rhythm generated in the medulla oblongata can be altered at least temporarily, by other inputs as discussed below.

Physical control

Even though our nervous system sets the basic rhythm of breathing, some physical factors can affect the rate and depth of breathing. Some of those factors include sneezing, coughing, talking, and exercising, among others.

Conscious control

We are all capable of consciously controlling our breathing rhythm, for example, holding your breath to go underwater. However, voluntary control is limited. Once the respiratory centers detect a low oxygen supply or blood pH, they will regain control of the breathing.

Emotional control

Emotional factors such as fear, anxiety, and apprehension cause a change in the rate and depth of respiration. This reflex mechanism may take precedence over normal chemical control.

Chemical control

The chemical factors in the control of respiration are the levels of carbon dioxide and oxygen, with carbon dioxide being the most powerful controller of respiration. The medulla responds to any changes in the acid levels of the blood.

Carbon dioxide acts as an acid by combining with water to form carbonic acid. Carbonic acid then dissociates into hydrogen ions and bicarbonate, a base. As the PCO_2 (partial pressure of carbon dioxide) increases in the blood, so does the concentrations of hydrogen ions that lower the pH (more acidic). This change is detected by the central chemoreceptors located in the medulla and increases respiration in order to remove CO_2 and return the blood pH back to normal. Relatively small changes in arterial CO_2 levels stimulate the rapid respiratory response.

Unlike with, CO_2 more dramatic changes in arterial PO_2 (partial pressure of oxygen) are required to stimulate a change in respiration. Changes in arterial PO_2 are detected by the peripheral chemoreceptors located in the aorta and carotid arteries, which then signal the respiratory centers in the medulla.

The peripheral chemoreceptors are more sensitive to decreased PO_2 than the central chemoreceptors. When PO_2 tension drops to below 60 millimeters of mercury (mm Hg), the peripheral chemoreceptors stimulate the respiratory center to increase ventilation.

Phases of respiration

The process of respiration involves four functional phases: ventilation, external respiration, gas transport, and internal respiration. We must keep in mind that these phases are linked through the process of diffusion. Problems in any of these phases can interfere with the respiration process altogether.

Ventilation

Ventilation is the mechanical function of respiration. This phase consists of the movement of air in and out of the lungs, which it is what we call breathing. In other words, it is the exchange of gas between the lungs and the environment. Breathing is regulated to provide adequate delivery of O_2 and removal of CO_2 according to the demands of metabolism. Problems in this phase directly affect other phases of respiration. These problems include hyperventilation, introduction of toxic gases, drowning, pneumonia, or ventilating the lungs with an insufficient amount of O_2 (hypoxic hypoxia).

External respiration

This phase refers to the gas exchange (loading of O_2 and unloading of CO_2) that occurs between the alveoli and the pulmonary capillaries. Gas exchange occurs passively via diffusion.

Gas transport

Blood circulation represents the transportation phase of respiration. Oxygen and carbon dioxide must be transported to and from the lungs and tissue cells via the bloodstream. Any factor altering blood flow or the blood's ability to carry O_2 and remove CO_2 disturbs the metabolic process.

Internal respiration

This phase is referred to as cellular respiration or utilization. This phase encompasses gas exchange between the capillaries and the tissues. Here, O_2 is unloaded from hemoglobin and CO_2 is loaded into the blood through diffusion. If ventilation or transportation phases are altered, the proper amount of O_2 delivered is affected, thus impacting metabolic processes at the cellular level.

Composition of air and gas exchange

By now you should have a very good understanding of the respiratory system. However, as aerospace physiology technicians we need to go deeper into what goes on with the air once we breathe it.

Composition of ambient air

With exception of some rare gases, our atmosphere consists mainly of nitrogen (N_2), O_2, and small amounts of CO_2. Air is about 78 percent N_2 and 21 percent O_2 (excluding the CO_2 and other gases that account for roughly 1 percent). At sea level (SL), this gas mixture exerts a total pressure (atmospheric pressure) of 760 mm Hg. This is in accordance with Dalton's Law, which states that "the total pressure is equal to the sum of the partial pressures." We discuss all gas laws in the next unit, but in the meantime we define the *partial pressure* as a measure of the concentration of a gas or pressure exerted by that gas in a mixture of gases. In other words, partial pressure is equal to the fractional concentration of a particular gas, times the total pressure of all the gases in the mixture. It is measured in millimeters of mercury and expressed with a preceding 'P'. To find the partial pressure of all gases we need to multiply the percentage of each gas by the total pressure of the mixture as shown below:

PN_2 = 78% x 760 mm Hg = 592.8 mm Hg

PO_2 = 21% x 760 mm Hg = 159.6 mm Hg

PCO_2 = .04% x 760 mm Hg = 0.3 mm Hg

Composition of alveolar air

With that in mind, let us discuss what happens to inspired air as it travels through the respiratory tract. The mucous membranes throughout the respiratory tract filter, warm, and humidify the inspired air. This added moisture, that is *water vapor*, is an important variable in discussing the composition of inspired gases. Water vapor exerts a pressure of 47 mm Hg in the alveoli at normal body temperature (98.6° F or 37° C) within the alveoli. Therefore, water vapor must be taken into consideration when calculating the partial pressure of the gases in the lungs.

To estimate the PO_2 in the alveoli, first subtract the partial pressure of water vapor (47 mm Hg) from the total pressure. Then multiply by the fractional concentration of inspired O_2. At sea level this is 21 percent (0.21). This volume is the PO_2 in the inspired air in the upper respiratory airways. Next, we have to account for the fact that a portion of the inspired air remains in the lungs and contains a fairly constant PCO_2 of 40 mm Hg. Therefore, by subtracting the PCO_2 from the PO_2 in the inspired air, we can estimate the PO_2 in the alveoli. The remaining pressure is due to N_2.

To determine the total pressure of the body's dry gases (N_2, O_2, and CO_2), subtract the pressure of water vapor from the mixture's total pressure. The total pressure of dry gases in the alveoli is 760 mm Hg minus the pressure of water vapor (47 mm Hg), equals 713 mm Hg. Another variable to consider is the partial pressure of CO_2 maintained in the alveoli. Alveoli maintain a constant CO_2 partial pressure of 40 mm Hg regardless of total barometric pressure. When determining the partial pressure of O_2 and N_2 in the alveoli, subtract these two constant values from the total pressure. At SL the alveolar partial pressures of N_2, O_2, CO_2, and water vapor are as follows:

P_AN_2	=	563.3 mm Hg*
P_AO_2	=	109.7 mm Hg*
P_ACO_2	=	40 mm Hg
PH_2O (water vapor)	=	47 mm Hg
Total Pressure	**=**	**760 mm Hg**

* Please note that for the discussion of this lesson, we will round the partial pressures as follows: PN_2 = 573 mm Hg and PO_2 = 100 mm Hg.

Gas exchange in the alveoli

As discussed above, nitrogen comprises the largest existing partial pressure within the alveoli (573 mm Hg); however, it is an inert gas. The body neither produces nor uses nitrogen. Normal respiration exchanges N_2 on a 1:1 (one-to-one) ratio with previously inspired N_2 unless there is a pressure change on the body. The exchange of water vapor also occurs on a 1:1 ratio, assuming the environmental humidity factor remains constant. The two remaining gases within the alveoli, PO_2 (100 mm Hg) and PCO_2 (40 mm Hg), are the primary gases in the alveolar gas exchange process. The partial pressures of each gas set up a concentration gradient, and in accordance with the law of gaseous diffusion, O_2 diffuses across the alveolar membrane and into the blood of the pulmonary capillaries. Diffusion occurs in both directions, but it is the difference between the partial pressures that determines the net direction of diffusion. Figure 1–7 reveals a significant difference between the partial pressures of O_2 and CO_2 within the alveolus versus the capillary blood that has returned from the body. The PO_2 and PCO_2 within the alveolus remain the same as long as there is a normal supply of O_2 and continual elimination of CO_2 through respiration. However, the blood returning to the lungs for reoxygenation contains O_2 at a partial pressure of only 40 mm Hg as a result the use of O_2 by body tissues. In the case of oxygen, the PO_2 in the alveolus is 100 mm Hg whereas it is 40 mm Hg in the returning venous blood. After gas exchange occurs, the net direction of the diffusion is from the alveoli to the blood that results in PO_2 of 100 mm Hg in arterial blood going from the lungs to the tissues.

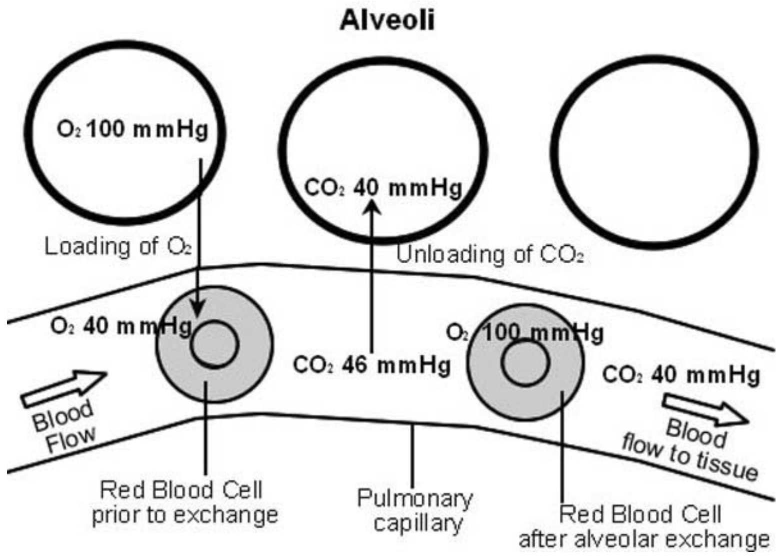

Figure 1–7. Gas exchange in alveoli.

In the case of carbon dioxide, alveolar PCO_2 is 40 mm Hg and 46 mm Hg in the venous blood. Once gas exchange occurs, the net direction of diffusion is from the capillaries into the alveoli resulting in an arterial PCO_2 of 40 mm Hg going from the lungs to the tissues.

Gas exchange in the tissues

The arterial blood arriving at the tissue level is oxygen rich, a result of O_2 diffusion into the blood from the alveoli. The gas exchange at the tissue level (fig.1–8) is a reversal of the gas exchange at the alveolar level. The oxygenated blood has a PO_2 of 100 mm Hg, while the PO_2 in the tissue is 40 mm Hg. The direction of O_2 flow is from the capillary into the tissue. A similar reversal exists for CO_2. The greater PCO_2 is now in the tissue at 46 mm Hg, resulting in diffusion of CO_2 into the capillary, which has a partial pressure of 40 mm Hg. Again, the law of gaseous diffusion governs gas exchange at the tissue level as well.

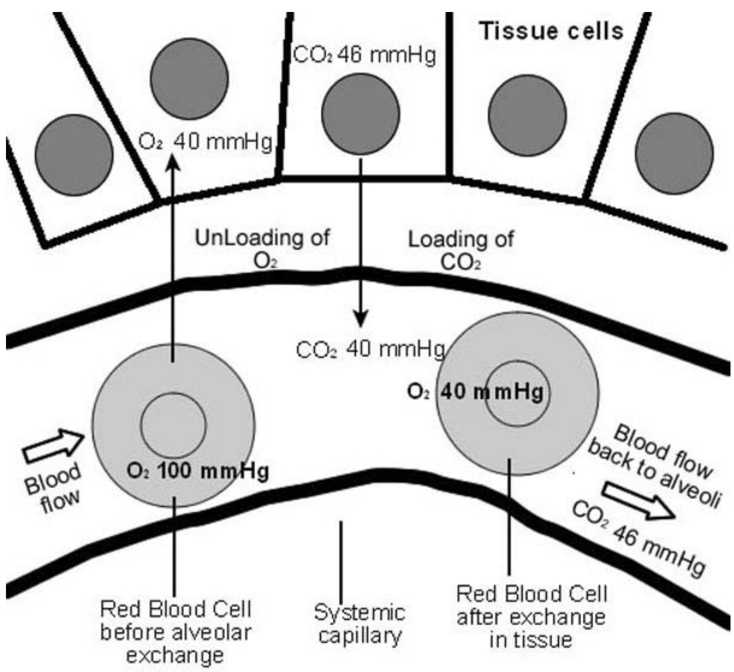

Figure 1–8. Gas exchange in tissues.

207. Circulatory system

The circulatory system, also known as *cardiovascular system*, consists of the blood, the heart, and blood vessels. The main function of this system is transportation. Using blood as a transport medium, the circulatory system carries oxygen and nutrients to all parts of the body and provides a means for the removal of waste products. The continuous movement of the blood throughout this system is achieved by the rhythmic beating of the heart. In this lesson we will cover the functions and the components of the circulatory system.

Functions of the circulatory system

The circulatory system operates with other body systems to maintain *homeostasis*. Through blood circulation, this system provides the following.

Nutrition

Nutrition involves the transport of nutrients such as carbohydrates, proteins, fats, vitamins, and minerals from the digestive organs to the cells

Excretion

Excretion picks up waste products from cells and delivers them to the organs where they are broken down and removed. For example, CO_2 is taken to the lungs, and ammonia is taken to the liver for elimination

Regulation

Regulation transports numerous hormones that regulate the activity of organs and organ systems. It also maintains the water, electrolytes, and acid-base balances within the body

Protection

Protection circulates antibodies and white blood cells throughout the body to fight against infection and disease

Body temperature

Body temperature serves as a temperature regulator by carrying excess internal heat to the lungs and body surfaces to release it into the environment

Composition of blood

Blood is a complex connective tissue made up of liquid and solid components. The liquid component (plasma) represents 55 percent of the total volume of the blood. The solid components *formed elements*, which make up the remaining 45 percent of the blood volume. These consist of red blood cells (*erythrocytes*), white blood cells (*leukocytes*), and platelets (*thrombocytes*).

Plasma

Plasma is 90 percent water and 10 percent solutes. Solutes give plasma a yellowish color and are the substances dissolved or suspended in solution. These solutes include nutrients, salts, proteins, and wastes. The proteins and salts in the plasma contribute to maintain the osmotic pressure and viscosity of the plasma. Plasma also contains dissolved gases (O_2, N_2, and CO_2).

Red blood cells

The primary purpose of red blood cells (RBC) is the transportation of O_2. These cells are biconcave disks containing *hemoglobin*, an iron-rich protein responsible for carrying O_2 in the blood. Each RBC contains up to 250 million hemoglobin molecules, each capable of binding four molecules of oxygen. Although the hemoglobin can carry CO_2 as well, it usually does not. RBCs do not have a nucleus and are produced by bone marrow.

An adult male’s RBC count ranges from 4.5 to 6 million per cubic millimeter of blood. People living at or above 10,000 feet mean sea level (MSL) have been found to have RBC counts as much as 30 percent higher than the average individual living at SL. Studies have shown, during high-altitude acclimatization, the body compensates for a decrease in PO_2 by increasing RBC production in the bone marrow. Therefore, each milliliter of blood can carry more O_2 and compensate for the deficient O_2 supply.

White blood cells

The primary purpose of white blood cells (WBC) is to defend the body and its tissues against foreign organisms such as viruses, bacteria, and tumor cells. The WBCs have the ability to move in and out of the blood vessels to carry out this function, passing between the cells that form the capillary walls. WBCs are present in the blood in much smaller numbers than RBCs. A normal adult has 4,000 to 11,000 WBCs per cubic millimeter of blood. WBCs are capable of self-locomotion, contain no hemoglobin, and are usually larger in size.

Platelets

Platelets are very small compared to the RBCs and WBCs. They are irregularly shaped fragments of larger cells formed in the red bone marrow to assist in forming clots. Within one to five seconds after an injury occurs, they adhere to damaged blood vessel linings and each other. This action causes a *scab* or *plug* to develop at the injured area, thus helping to stop the flow of blood into the tissues. There are about 250,000 to 400,000 platelets per cubic millimeter of blood.

Structure of the heart

The heart (fig. 1–9) is a hollow muscular organ about the size of a clenched fist. It is enclosed in a sac-like structure called the *pericardium*, and is located in a space between the lungs called the *mediastinum*.

Heart muscle

The cardiac muscle of the heart resembles skeletal muscle in that is striated. As you may remember from the lesson about tissues, it is an involuntary muscle.

Heart chambers

The heart is divided into four chambers: two upper chambers called *atria* and two lower chambers called *ventricles*. The heart functions as a double pump, receiving and expelling blood. Oxygen-poor blood flows from the body through the veins into the right atrium through the *tricuspid valve* into the right ventricle. The right ventricle sends the blood through the *pulmonary circulation*, *w*hich carries the blood to the lungs for gas exchange and then returns it to the left atrium. Blood then passes through the mitral valve to the left ventricle. From the left ventricle, blood is pumped to the aorta into the systemic circulation, which in turn supplies oxygen to all body organs.

Heart valves

Within the chambers of the heart are four valves that ensure a one-way flow of blood. There are two types of valves: two atrioventricular (AV) valves and two semilunar valves.

The AV valves permits blood to flow into the ventricles. The AV valve on the left side of the heart is called the *mitral*, or *bicuspid*, valve. This valve has two flaps or cusps—hence the name bicuspid. The AV valve on the right side of the heart is called the tricuspid valve that contains three flaps. (fig. 1–17). Each flap or cusp resembles a small leaf or triangle. The tips of the triangle hang freely into the ventricles when the heart chambers fill with blood. The pressure in the chamber increases when the ventricles contract, forcing the cusps upward. This action separates the atrium from the ventricle and prevents the blood from reentering the atrium. There are small bands of tissue attached to the underside of the cusp acting as an anchor to prevent the flaps from inverting.

The two semilunar valves, *pulmonary* and *aortic*, are also one-way valves. The pulmonary semilunar valve leads from the right ventricle to the *pulmonary artery.* The aortic semilunar valve is located between the left ventricle and the aorta. Each valve has three cusps operating just as the tricuspid valve mentioned above. However, the job of the semilunar valve is to prevent blood from reentering the ventricle once it has entered the major arteries. As the ventricles contract, the same pressure that forces the AV valves closed, forces the semilunar valves open. Once opened, the blood rushes into the main arteries, thereby increasing arterial pressure. As the ventricular chamber empties, the pressure decreases and the contraction ceases. The high pressure in the arteries creates a back pressure against the valves that snaps the valves close ensuring no back flow.

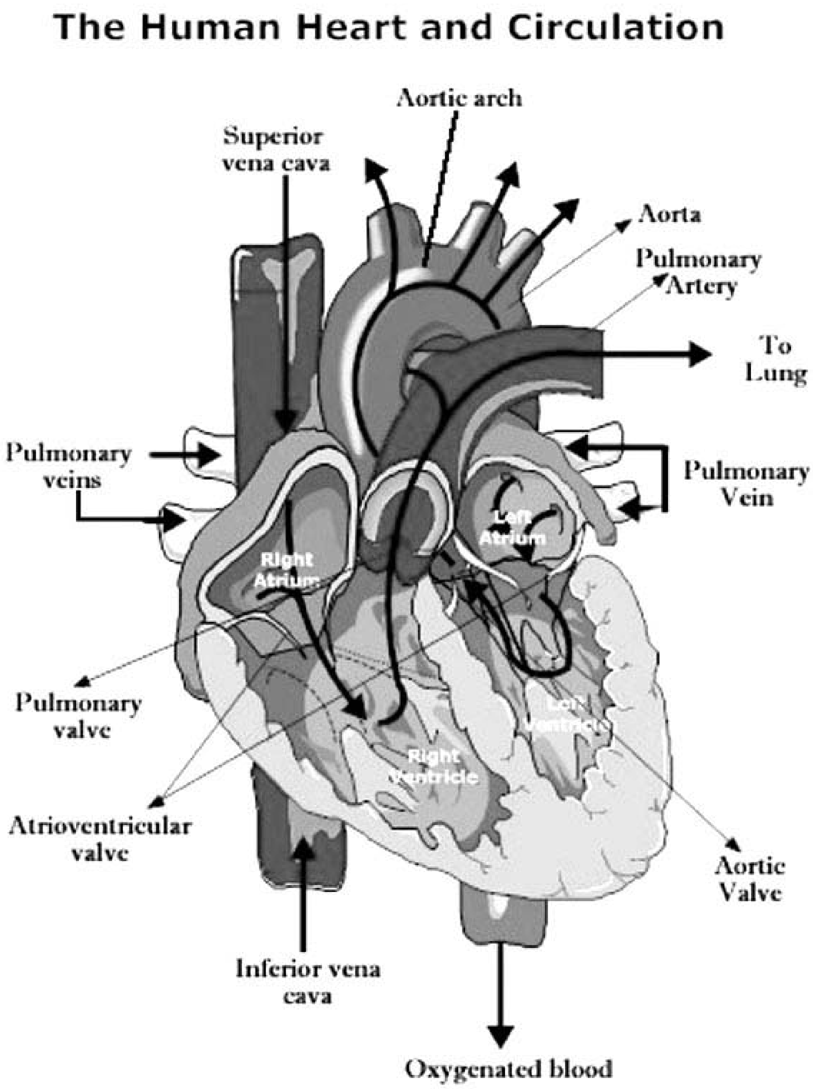

Figure 1–9. The heart.

Cardiac output

Cardiac output, or the volume of blood pumped out by the ventricles with each beat, depends on two basic factors: (1) the amount of blood pumped during each beat or stroke of the heart and (2) the number of times the heart pumps during a given period of time. These two factors are referred to as *stroke volume* and *heart rate*, respectively. A healthy heart pumps out around 60 percent of the blood that enters the heart. In an adult, the heart rate averages 75 beats per minute. Cardiac output is altered when the amount of blood pumped per stroke changes or the heart rate is altered.

Blood pressure

Blood pressure is expressed in two separate measurements: *systolic* = the pressure that blood exerts against the walls of the arteries during contraction (systole), and *diastolic* = the pressure that remains in the system when the heart muscle relaxes (diastole) between contractions. The average adult's blood pressure is generally 120/80 and is measured in mm Hg. The first number (120) represents systolic pressure and means contraction. The second number (80) represents diastolic pressure and means relaxation. In the *cardiac cycle*, or actions to complete one heart beat, systole begins with the closure of the AV valves (first heart sound) and ends with the closure of the semilunar valves (second heart sound).

The vascular system

The vascular system is composed of a series of arteries, veins, and capillaries. This system distributes blood from the heart's left ventricle to the body tissues and returns blood back to the heart's right atrium. It flows to the right ventricle from the right atrium and is pumped to the lungs. As blood flows through the lungs (the pulmonary circuit), it loses CO_2, becomes oxygenated, and is directed back to the heart via the pulmonary vein into the left atrium. Systemic circulation supplies parts of the body other than the lungs and derives its pumping force from the left ventricle. As blood returns from the lungs, it flows through the left atrium into the left ventricle and is subsequently pumped through the aorta to various body systems. The blood makes a double circuit going from the heart to the lungs, back to the heart, and then to the rest of the body.

Generally, oxygen-rich blood is carried in the arteries and oxygen-poor blood is carried in the veins. This is true in all instances except for the pulmonary system where oxygen-poor blood leaves the heart via the pulmonary artery and is returned as oxygen-rich blood by the pulmonary vein. Below we can appreciate the path of the vascular system:

heart → arteries → arterioles → capillaries → venules → veins → heart

Arteries

Arteries are thick, elastic vessels carrying blood away from the heart to the body. Their walls are strong and able to stretch and absorb pressure. Two great trunks, the aorta and pulmonary arteries, leave the heart and divide repeatedly until they become smaller vessels called *arterioles*. The heart forces blood into the arteries causing them to dilate every time it beats. The arteries then contract as the blood moves farther along in the circulatory system. This alternate dilation and contraction of the arteries is what we know as the *pulse*.

Capillaries

Capillaries are the smallest blood vessels and RBCs travel through them single file. The capillaries are a vital part of the circulatory system because it is through them that the transfer of gases and metabolites take place. They are composed of a very thin wall membrane that permits the distribution of O_2 and nutrients to all cells. Although blood pressure in the arteries is relatively high, it is considerably reduced as it flows through the capillaries.

Veins

The veins carry blood back to the heart. The structure of the veins is similar to that of the arteries, but they are not as strong in elasticity. The two largest veins are the *superior vena cava* and the *inferior vena cava*, both of which connect to the right atrium. After the blood has passed through the capillaries, it is collected in the *venules*—smaller branches of the veins—and returned to the heart via the veins. Veins are also characterized by a series of one-way valves located throughout the venous system helping to keep the blood flowing towards the heart and not backwards in the veins. Movement of blood through the veins is facilitated by body movement. During exercise for instance, the muscles contract and expand. The intramuscular pressure exerted on the veins by the surrounding muscles pushes the blood through the one-way valves and returns it to the heart. This pumping action prevents blood from pooling in the lower limbs.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

203. Cells and body tissues

1. What do we call groups of cells that are similar in structure and function?

2. What do we call two or more tissue types that are grouped together and perform a specific function?

3. What is the purpose of the cell membrane?

4. What are the three general components of the cell?

5. What key cellular function takes place in the cytoplasm?

6. What kind of tissue covers all surfaces of the body?

7. What kinds of tissues are primarily involved with protecting, supporting, and binding other body tissues?

8. What kind of tissue is found in the brain and spinal cord?

204. Muscular system

1. How much of your body weight is muscle?

2. What essential body function is carried out by the muscular system?

3. How are muscles classified?

4. Which type of muscle tissue is found in the walls of internal organs, such as the stomach, intestines, bladder, and respiratory passages?

5. What are the types of muscle contractions and how do they differ?

205. Nervous system

1. Into what two parts is the nervous system structurally divided?

2. What is the basic structural unit of the nervous system?

3. In what direction do dendrites and axons carry nerve impulses?

4. What are the three main parts of the brain?

5. What part of the brain functions to coordinate muscle movement, posture, and balance?

6. How many pairs of cranial nerves are there in the PNS? How many spinal nerves?

7. What type of nerves control functions that are sensory, motor, or a combination of both?

206. Respiratory system

1. Define *respiration*.

2. Name the structures involved in the process of respiration.

3. Name the three parts of the pharynx and how each passage is used.

4. What is the main muscle of respiration?

5. Explain what happens to the diaphragm and intercostal muscles during inhalation.

6. Name the ways respiration can be controlled by other inputs into the nervous system.

7. What is the most powerful controller of respiration?

8. Name and define the four phases of respiration.

9. State the composition of air and its percentages.

10. What happens to inspired air as it travels through the respiratory tract?

11. What two constant pressures must be subtracted from the total pressure to determine the partial pressure of oxygen and nitrogen in the alveoli?

12. After the alveolar gas exchange takes place, blood flowing from the lungs to the tissue will contain how much mm Hg pressure of oxygen? Of carbon dioxide?

207. Circulatory system

1. What is the main function of the circulatory system?

2. Name the five specific functions of the circulatory system.

3. Describe the regulatory function of the circulatory system.

4. Name the liquid and solid components of blood and their percentages of blood volume.

5. State the composition (percentage) of plasma.

6. What are solutes?

7. What is the primary purpose of red blood cells?

8. What is the primary purpose of white blood cells?

9. Name the four chambers of the heart.

10. What valves permit blood to flow into the ventricles?

11. What is the function of the semilunar valve?

12. What is stroke volume?

13. The heart beats approximately how many times per minute?

14. What type of circulation serves parts of the body other than the lungs?

15. What is the path of the vascular system?

16. Which vessels carry blood away from the heart?

17. What is the function of the capillaries?

18. How does body movement facilitate the movement of the blood through the veins?

Answers to Self-Test Questions

201

1. Latin and ancient Greek.
2. So healthcare professionals can communicate accurately and efficiently.
3. Stems (roots), prefixes, and suffixes.
4. The stem (root) conveys the basic meaning to the term.
5. (1) An instrument for examining the ear.
   (2) Between the ribs.
   (3) Without (decrease) blood volume.
   (4) Red (blood) cell.
   (5) Study of nerves.
   (6) Inflammation of the nose.
   (7) Blue condition (blueness of the skin due to lack of oxygen in the blood).
   (8) Within a vessel.
   (9) Behind the skull.
   (10) Around the heart.

202

1. (1) f.
   (2) d.
   (3) j.
   (4) g.
   (5) e.
   (6) c.
   (7) k.
   (8) l.
   (9) m.
   (10) a.
   (11) h.
   (12) b.
   (13) i.
2. (1) b.
   (2) d.
   (3) c.
   (4) a.
   (5) c.
   (6) d.

203

1. Tissues.
2. Organs.
3. It is a flexible and semipermeable structure that allows certain materials to enter and leave as needed, and restricts the movement of other materials.
4. Cell membrane, nucleus, and cytoplasm.
5. Metabolism.
6. Epithelial.
7. Connective.

8. Nervous.

204

1. Almost one-half.
2. Body movement.
3. Skeletal, smooth, and cardiac.
4. Smooth.
5. Isotonic and isometric. In isotonic contractions, muscle tension remains the same regardless of a change in muscle length; in isometric contractions, the length of the muscle remains the same regardless of the tension.

205

1. Central nervous system and peripheral nervous system.
2. Neuron or nerve cell.
3. Dendrites carry them to the cell body; axons away from the cell body.
4. Cerebrum, cerebellum, and brain stem.
5. Cerebellum.
6. 12 cranial; 31 spinal.
7. Cranial.

206

1. The exchange of oxygen and carbon dioxide between an organism and its environment.
2. Nose, pharynx, larynx, trachea, bronchi, and lungs.
3. Nasopharynx, oropharynx, and laryngopharynx. The nasopharynx is an air passage only and contains the two eustachian tubes that connect to the middle ear; the oropharynx and laryngopharynx serve as a passageway for both food and air.
4. Diaphragm.
5. They contract and become smaller to create additional space in the thoracic cavity for the lungs to expand as they fill with air.
6. Physical control; conscious control; emotional control; chemical control.
7. Carbon Dioxide (CO_2)
8. Ventilation - movement of air in and out the lungs (and/or exchange of gas between the lungs and ambient environment); external respiration – gas exchange between the alveoli and the pulmonary capillaries; gas transport - O_2 and CO_2 is transported to and from the lungs and tissue cells via the bloodstream; internal respiration – gas exchange between the capillaries and the tissues (referred to as cellular respiration or utilization).
9. About 78 percent nitrogen and 21 percent oxygen (excluding CO_2 and other gases that account for roughly 1 percent).
10. It is filtered, warmed, and humidified by the mucous membranes as it passes the respiratory tract.
11. 47 mm Hg water vapor and 40 mm Hg carbon dioxide.
12. $O_2$100 mm Hg; CO_2 40 mm Hg.

207

1. Transportation.
2. Nutrition, excretion, regulation, protection, and body temperature.
3. To transport hormones that regulate organ’s activities; it also maintains water, electrolytes, and acid-base balance within the body.
4. Liquid - plasma (55 percent); Solid - RBCs, WBCs, and platelets (45 percent).
5. 90 percent water and 10 percent solutes.
6. Substances that are dissolved or suspended in a solution and give plasma a yellowish color.
7. Transport oxygen.

8. Defends the body against foreign organisms such as viruses, bacteria, and tumor cells.
9. Right and left atria; right and left ventricles.
10 Atrioventricular valves.
11. To prevent blood from reentering the ventricle.
12. The amount of blood pumped during each beat or stroke of the heart.
13. 75 beats per minute.
14. Systemic circulation.
15. Heart to arteries to arterioles to capillaries to venules to veins to heart.
16. Arteries.
17. Transfer of gases and metabolites.
18. As the muscles contract and expand, they exert pressure in the veins pushing the blood through the one-way valves and returning it to the heart.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

Do not return your answer sheet to the Extension Course Program (A4L).

1. (201) The main reason we have a special language of medical terminology for healthcare professionals is so they can communicate
   a. quickly and correctly.
   b. accurately and efficiently.
   c. succinctly and efficiently.
   d. methodically and correctly.

2. (201) Medical terms can be broken down into what three basic parts?
   a. Root, suffix, and stem.
   b. Root, prefix, and stem.
   c. Stem, prefix, and clause.
   d. Stem, prefix, and suffix.

3. (202) The study of the structure and shape of the body and body parts and their relationships to one another is known as
   a. zoology.
   b. anatomy.
   c. physiology.
   d. physiometry.

4. (202) The study of the functions of all body structures, large and small, is known as
   a. biology.
   b. anatomy.
   c. physiology.
   d. body systems.

5. (202) Which imaginary plane divides the body into anterior and posterior sections?
   a. Frontal.
   b. Sagittal.
   c. Midsagittal.
   d. Transverse.

6. (202) The term *lateral recumbent* refers to the body position where the patient is lying
   a. anterior surface up..
   b. in the prone position.
   c. anterior surface down.
   d. on either the left or right side.

7. (202) What body cavity protects the heart and lungs?
   a. Ventral.
   b. Thoracic.
   c. Vertebral.
   d. Abdominal.

8. (203) All of the following are types of muscle tissue, except
   a. skeletal.
   b. smooth.
   c. elastic.
   d. cardiac.

9. (204) Muscle tissues comprise approximately what amount of total human body weight?
   a. 15 percent.
   b. 25 percent.
   c. 40 percent.
   d. 50 percent.

10. (205) The center of intelligence and personality is located in the
    a. cerebrum.
    b. cerebellum.
    c. occipital lobe.
    d. medulla oblongata.

11. (205) What part of the brain has the primary functions of coordinating muscle movement, posture, and balance?
    a. Cerebrum.
    b. Cerebellum.
    c. Temporal lobe.
    d. Medulla oblongata.

12. (205) What part of the brain is the control center for respiration?
    a. Cerebellum.
    b. Occipital lobe.
    c. Temporal lobe.
    d. Medulla oblongata.

13. (206) Normal breathing is repeated about how many times per minute and is normally what kind of
    function?
    a. 10 to 18; voluntary.
    b. 12 to 18; voluntary.
    c. 12 to 20; involuntary.
    d. 16 to 22; involuntary.

14. (206) What are the partial pressures of O_2 and CO_2 in the alveoli at sea level?
    a. PO_2 = 40 mm Hg; PCO_2 = 100 mm Hg.
    b. PO_2 = 47 mm Hg; PCO_2 = 40 mm Hg.
    c. PO_2 = 100 mm Hg; PCO_2 = 40 mm Hg.
    d. PO_2 = 573 mm Hg; PCO_2 = 100 mm Hg.

15. (207) The liquid part of the blood is known as
    a. plasma.
    b. glucose.
    c. platelets.
    d. hemoglobin.

16. (207) Transporting O_2 is the primary purpose of
    a. plasma.
    b. platelets.
    c. red blood cells.
    d. white blood cells.

17. (207) What type of blood cells has the capability of self-locomotion?
    a. Erythrocytes.
    b. Erythroblasts.
    c. Red blood cells.
    d. White blood cells.

18. (207) The heart is located in a space between the lungs called the
    a. mycardium.
    b. pericardium.
    c. intercardium.
    d. mediastinum.

19. (207) What two factors is cardiac output dependent upon?
    a. Stroke volume and heart rate.
    b. Stroke rate and heart volume.
    c. Diastolic and systolic pressure.
    d. Electrical frequency and blood pressure.

20. (207) The purpose of capillaries is to
    a. return blood to the heart.
    b. transport blood away from the heart.
    c. permit transfer of gases and metabolites.
    d. carry oxygen-rich blood from the lungs to the heart.

Please read the unit menu for unit 2 and continue. ➔

Student Notes

Unit 2. Physiology of Flight

PHYSIOLOGICALLY, THE HUMAN body adapts better to life on earth than in outer space. The body adjusts to a variety of changes on earth, including external temperatures, physical activity, and various climatic conditions. Aircrews in modern aircraft are sometimes exposed to environments beyond their normal adjustment capabilities. Low barometric pressure is a significant environmental change experienced at altitude, and the human body's inability to adjust to this low barometric pressure results in serious physiological problems. A thorough knowledge of flight physiology is important to the aerospace physiology (AP) technician. Since aircrews must be adequately prepared for high-altitude flight, the conditions created in the altitude chamber attempt to duplicate barometric and other environmental conditions of flight.

2–1. The Atmosphere and Gas Laws

Aerospace physiology personnel are responsible for instructing aircrew in the recognition, prevention, and treatment of altitude-related problems. The physical changes in atmospheric conditions at altitude, how these changes affect the human body, and how to deal with physiological problems are discussed in this section.

208. Effects of the atmosphere on the human body

Understanding anatomy and physiology is of little value without equally understanding the high-altitude environment. Humans can easily adapt to sea level (SL) environments and adjust to gradual changes in pressure. However, large and sudden changes occur during ascent above certain altitudes. Bodily functions fail and death can result without proper precautions.

Composition of atmospheric gases

Think of the atmosphere as a transparent envelope of air surrounding the earth. It is difficult to pinpoint the outer limits of the atmosphere, but a practical limit for our purposes is 1,200 miles. The composition of this envelope is actually a mixture of many gases. Nitrogen (N_2) and oxygen (O_2) are the most abundant gases in the atmosphere. Other gases are so low in percentage that we don't consider them in AP. Rounded off, the air is about four-fifths (78 percent) N_2 and one-fifth (21 percent) O_2. Although these gases are a mixture, each retains its own natural physical and chemical characteristics.

While the body does not metabolize N_2, our very existence depends on nitrogen's contribution to SL pressure. Atmospheric N_2 comes primarily from bacterial life and the process of decay. Plant life provides the O_2 we need. In return, plants receive a continuing supply of CO_2 (a metabolic waste product of animals).

Characteristics of atmospheric gases

Atmospheric characteristics are consistent, predictable, and governed by physical/chemical gas laws.

Percentages

One of the important characteristics of the atmosphere is the percentages of gases. The percentages of O_2 and N_2 remain relatively constant up to an altitude of about 55 miles. However, the actual pressure of these gases reduces greatly during ascent.

Temperature

Temperature decreases as altitude increases. Temperature lapse rate is the decrease in temperature during ascent from the earth's surface. This phenomenon produces a heat loss rate of 3.6° Fahrenheit (F), or 2° Celsius (C), with each 1,000 foot increase. The table below illustrates that this cooling effect eventually stabilizes at isothermal (constant temperature) altitude. This temperature change does not relate to the physiological problems discussed in this unit, but it is very important to aircrews facing possible exposure to a high-altitude environment.

Altitude	**Temperature**	
Feet	***Degrees C***	***Degrees F***
0	15	59
2,000	11	51.9
4,000	7.1	44.7
6,000	3.1	37.6
8,000	–0.8	30.5
10,000	–4.8	23.3
12,000	–8.8	16.2
14,000	–12.7	9.1
16,000	–16.7	1.9
18,000	–20.7	–5.3
20,000	–24.6	–12.3
22,000	–28.6	–19.5
24,000	–32.5	–26.6
26,000	–36.5	–33.7
28,000	–40.5	–40.9
30,000	–48.4	–48
32,000	–52.4	–55.1
34,000	–55	–62.3
36,000	–55	–67
38,000	–55	–67
40,000	–55	–67
NOTE: Degrees C = (5/9 Degrees F) –32 Degrees F = (9/5 Degrees C) + 32 Temperature remains constant above 35,332 ft. (Isothermal Layer)		

Pressure

Atmospheric (barometric) pressure decreases as altitude increases. Decreases in barometric pressure are responsible for some of the most serious flight physiology problems.

Barometric pressure is the combined weight of all atmospheric gases creating a force upon the earth's surface. Gravity causes this force to attract molecules earthward, and this force can be measured at any given point. SL barometric pressure is 760 mmHg. In AP, the pressure of a column is measured by a mercurial or aneroid barometer in pounds per square inch (lb/in^2) or mmHg. Atmospheric pressure also may be expressed in feet of elevation above SL, as depicted on an altimeter. Surface pressure values will vary daily due to several factors. Constantly changing surface temperatures and high-pressure and low-pressure weather areas cause pressure changes, which affect atmospheric layers. These variations in pressure are not great but could cause errors in aircraft altimeters. Recognition of this problem resulted in the setup of the US Standard Atmosphere. This document allows a comparison of standard pressure indices to actual pressure measurements for instrument corrections. A portion of the US Standard Atmosphere is shown below. These pressure values are always used in AP when discussing problems associated with reduced barometric pressure.

Altitude	Barometric Pressure	Difference/1,000 feet (mmHg)
Sea Level	760	27.9
1,000	732.9	
1,000	732.9	26.3
2,000	706.6	
9,000	543.2	21.6
10,000	522.6	
14,000	446.4	17.6
15,000	428.8	
24,000	294.4	12.6
25,000	281.8	
34,000	187.3	8.6
35,000	178.7	
49,000	91.5	4.2
50,000	87.3	
59,000	56.8	2.7
60,000	54.1	

Compressibility

Compressibility is an important characteristic of the gaseous atmosphere. An envelope results from gravity's effect on the gaseous atmosphere. This envelope has a constantly decreasing density with increasing distance from the earth's surface. Thus, the density of the atmosphere decreases with increasing altitudes due to the decreased pressure exerted by the air above it.

Ways to measure altitude

To measure the effects of the atmosphere on the human body, we must first be able to measure altitude. The three ways to express altitude include *true altitude*, *pressure altitude*, and *absolute altitude*.

True altitude

True altitude is the altitude of an object above mean sea level (MSL). The aircraft altimeter must be adjusted slightly to reflect local barometric conditions in order to show true altitude. By doing this, the altimeter actually measures barometric pressure (which constantly changes) and expresses this measurement in feet. The United States uses true altitude as a reference when flying below 18,000 feet. Adequate terrain clearance can be assured by checking maps and charts for terrain elevation. The pilot must cross-reference this information with the altitude shown on the aircraft's altimeter. Look at figure 2–1 while reading the following information.

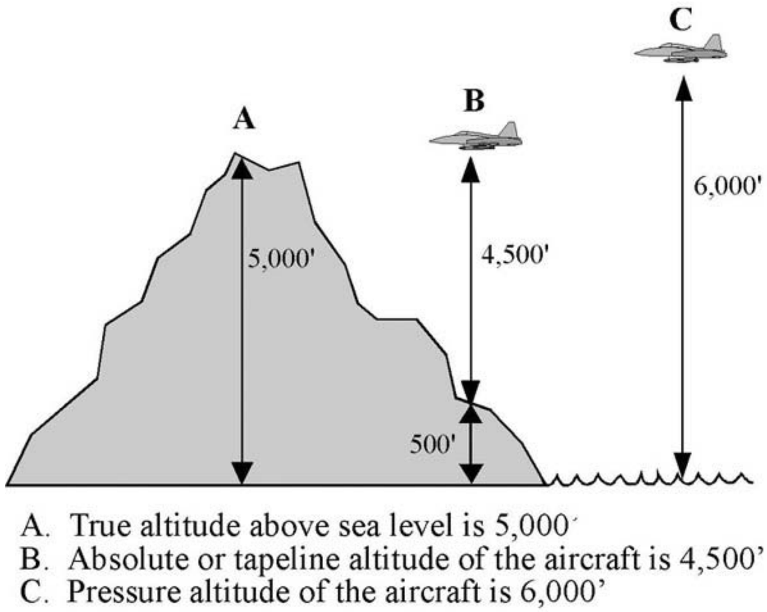

Figure 2–1. Types of altitude.

Pressure altitude

Pressure altitude is the altitude above the standard datum plane (SL on a standard day). The standard datum plane relates to the US Standard Atmospheric Pressure Table, listing SL as 29.92 in Hg. The setting of 29.92 in Hg is actually above or below SL on high- or low-pressure days. Pressure altitude always corresponds to the US Standard Atmosphere. For example, if the ambient atmospheric pressure is 379.4 mmHg, the pressure altitude is 18,000 feet. Setting the altimeter adjustment at 29.92 in Hg or SL always shows pressure altitudes. The United States uses this method of measuring at and above 18,000 feet. For altitudes at or above 18,000 feet, we may refer to those altitudes as flight levels (FL). For instance, a pressure altitude of 25,000 feet is referred to as FL 250; similarly, a pressure altitude of FL 500 is 50,000 feet. A pilot uses this information by adjusting the pressure altimeter to the local pressure at take off. When the aircraft reaches 18,000 feet, the pressure altimeter is adjusted to 29.92 in Hg to ensure all aircraft use the same measure for altitude.

Absolute altitude

Absolute altitude is the distance from the aircraft to the ground directly below. This value changes as terrain changes. To read it requires a radio or radar altimeter.

Absolute altitude also can be determined by subtracting the survey terrain altitude from the altitude of the aircraft above SL (true altitude). Absolute altitude is the minimum safe aircraft altitude and expressed as above ground level (AGL).

209. Gas laws governing the effects of atmospheric pressure

Air is a mixture of elemental gases. Each gas reacts independently to the physical and chemical laws affecting the combined gases. Understanding how these gases act in the atmosphere is of great importance when explaining the physiology of flight.

Boyle's Law

Boyle's Law explains the effects of pressure changes on the ears, sinuses, hollow organs of the body, and gastrointestinal tract. Boyle's Law states that a volume of gas is inversely proportional to the pressure exerted upon it, while temperature remains constant. The volume of a gas increases as barometric pressure decreases. For example, air in a balloon taken to altitude will expand as the balloon climbs. Similar expansion occurs with the gases in the hollow organs of the body, such as the stomach and gastrointestinal tract. This law explains that when atmospheric pressure is reduced during ascent, gases expand in volume and contract during descent as pressure increases. Various physiological reactions may occur such as ear and sinus pain and GI tract discomfort.

Gas expansion is significant to aircrew because of trapped gases in the body. These trapped gases are wet gases. That is, water vapor saturates the gas. Therefore, trapped gases of the body expand at a faster rate because of the constant pressure exerted by the water vapor. Wet gases expand twice their original size at 16,500 feet. On the other hand, dry gases (the balloon example) expand twice their original size at 18,000 feet, or one-half the earth's atmosphere. Since gases are always present in the hollow cavities of the body, aircrews must always take into account these gases present potential problems that may lead to physiological reactions if the gas within these cavities is not equalized by allowing it to escape.

Pressure Altitude in Feet	Dry Air Expansion	Wet Air Expansion
10,000	1 Volume	1 Volume
20,000	18,000 2 Volume	16,500 2 Volume
30,000	28,000 3 Volume	25,000 3 Volume
40,000	39,000 5 Volume	34,000 5 Volume

Law of Gaseous Diffusion

This law states that a gas will diffuse from an area of higher concentration to an area of lower concentration. Gas molecules exhibit rapid and random motion, in relation to temperature, density, and pressure. Gases under high pressure are vigorously active. There is a tendency for such molecules to migrate to areas of lower pressure. The movement of a gas from an area of high pressure to an area of low pressure is the process of diffusion. Refer to figure 2-2 as we discuss two examples of gaseous diffusion.

Example A

Consider O_2 enclosed in a sealed container partitioned by a membrane through which gas can diffuse. The concentration of gas on either side of the membrane is unequal in figure 2–2 and the arrow shows the direction of diffusion.

Example B

Consider a similar situation in which the permeable membrane separates several gases. The arrow below the individual gases shows the direction of movement of that gas in figure 2–2. Therefore, the partial pressure of a gas (on both sides of the membrane) determines the direction of diffusion of any one gas.

The physiological significance of gaseous diffusion concerns the transfer of gases. As we learned in the previous unit, O_2 and CO_2 transfer primarily during respiration and O_2 and N_2 during denitrogenation. The pulmonary capillary and capillary tissue junctions are actually very thin membranes through which the respiratory gases diffuse. As you may recall, the partial pressure of CO_2 in the capillary blood coming to the alveolus is 46 mm Hg. Carbon dioxide will diffuse from capillary to alveolus where the CO_2 partial pressure is 40 mm Hg. The blood finally leaving the pulmonary capillary will have a partial pressure of CO_2 of 40 mm Hg. Each gas in a mixture behaves independently. Different gases will diffuse in opposite directions across the same membrane if their partial pressure gradients are in opposite directions.

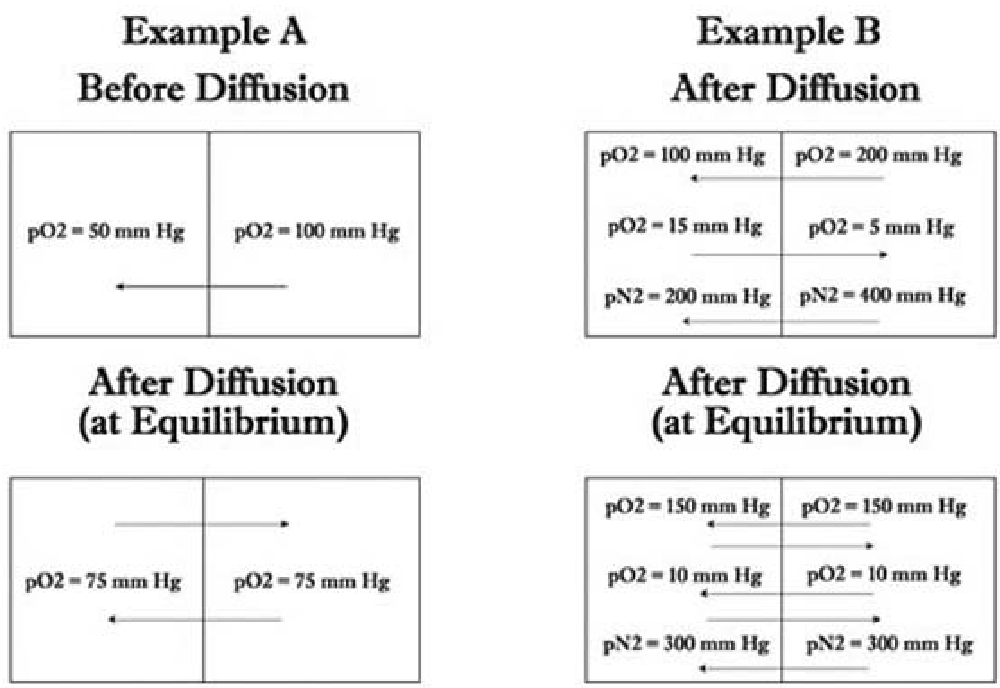

Figure 2–2. Diffusion of gases.

Dalton's Law

Dalton's Law states that the total pressure of a mixture of gases is equal to the sum of the partial pressures of each gas in the mixture. The pressure exerted by each gas in the mixture is independent of other gases. During ascent, the partial pressure of each gas in the air will decrease in direct proportion to the total air pressure. Dalton's Law explains how ascent leads to hypoxia. Although the percentage of O_2 in the air remains constant at 21 percent, its partial pressure decreases. Hypoxia, which we discuss later, results from a reduced force of O_2 from the environment to the organism.

Henry's Law

Henry's Law states that the amount of gas in solution varies directly with the partial pressure of that gas over the solution. When a liquid and a gas are in contact, gas molecules will move (diffuse) into the liquid. The partial pressure of the gas above the liquid and the solubility of the gas in the liquid determine the number of molecules moving into the liquid. However, the solubility is typically assumed to be constant. Therefore, the amount of a gas absorbed by a given liquid is directly proportional to the partial pressure of the gas above the liquid.

Henry's Law and gas solubility describe a purely physical process. In the human body, there are other factors that influence and change the process of gas uptake and elimination. Neither the solubility coefficient nor the temperature will (if both are constant) alter the proportionality. Henry's Law has an important role in the cause of decompression sickness. The physiological significance of Henry's Law is that half the N_2 in solution in the human body at SL comes out of solution at 18,000 feet. This is a result of a 50 percent reduction of the partial pressure of N_2. This phenomenon is responsible for altitude-induced decompression sickness.

Gay-Lussac's Law

Gay-Lussac's Law states that the pressure of a gas varies directly with its temperature, volume remaining constant. Keeping the volume of a gas constant and lowering its temperature will decrease its pressure. This law explains why pressure within an O_2 cylinder decreases if the temperature of the cylinder decreases and why the pressure within a cylinder increases if the temperature increases.

Since the pressure in an O_2 cylinder is directly proportional to its temperature, therefore it is important to take into account the environmental temperature when storing and using O_2 cylinders. This statement holds true even if you do not use the cylinder.

Temperature, when working with the gas, always refers to absolute temperature. Add 273 to the Celsius temperature to determine absolute temperature. Absolute temperature also can be expressed as Kelvin (K) since the absolute temperature scale and the Kelvin scale are the same. Therefore, 10° C equals 283 K. Gay-Lussac's Law has little direct physiological significance since body temperature remains fairly constant.

The table below summarizes the gas laws previously discussed. It includes the formulas and the importance (or physiological significance) that it has in aerospace physiology.

GAS LAWS	FORMULA	LAW STATEMENT	PHYSIOLOGICAL SIGNIFICANCE
Boyle's	**$P_1 V_1 = P_2 V_2$**	Volume of gas is inversely proportional to its pressure (temperature remaining constant).	Trapped gases in the body
Gaseous Diffusion	**n/a**	A gas will diffuse from an area of high concentration (or pressure) to an area of low concentration.	Transfer of gases in the body (O_2 and CO_2)
Dalton's	**$P_{total} = p_1 + p_2 + \ldots + p_n$**	Total pressure of a mixture of gases equals the sum of the partial pressure of each gas in the mixture.	Hypoxia
Henry's	**$P_1 A_2 = P_2 A_1$**	Amount of gas in solution is directly proportional to the partial pressure of that gas over the solution.	Evolved gases in the body
Gay Lussac's	**$P_1 T_2 = P_2 T_1$**	Pressure of a gas is directly proportional its temperature (volume remaining constant).	Storage of oxygen in containers
P = Pressure V = Volume A = Amount T = Absolute Temperature			

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

208. Effects of the atmosphere on the human body

1. What is the practical outer limit of the atmosphere?

2. What are the two major gases in air and by what percentages do they comprise the atmosphere?

3. What happens to temperature as altitude increases?

4. What is temperature lapse rate?

5. At SL, what is the standard barometric pressure in mm Hg?

6. What is the purpose of the US Standard Atmosphere?

7. Does the earth's atmosphere increase or decrease in density as one increases in altitude?

8. What is the definition of ***true*** *altitude*?

9. How is altitude notation expressed at 18,000 feet and above?

10. What is the difference between *true* altitude and *absolute* altitude?

209. Gas laws governing the effects of atmospheric pressure

1. How does Boyle's Law explain the effects of pressure changes in the hollow cavities of the body such as ears, sinuses, and GI tract?

2. Why is gas expansion significant to aircrews?

3. How does the Law of Gaseous Diffusion describe why gas moves from an area of high concentration to an area of low concentration?

4. What is the physiological significance of the Law of Gaseous Diffusion?

5. How does Dalton's Law explain that ascent to altitude may result in hypoxia?

6. What role does Henry's Law play in the cause of decompression sickness?

7. What is the practical significance of Gay-Lussac's Law when it comes to the storage of O_2 cylinders?

8. How do you get absolute temperature?

9. Why does Gay-Lussac's Law have little physiological significance?

2–2. Mechanical Effects of Pressure Change and Decompression Sickness

Hypoxia and hyperventilation are the more frequently observed altitude chamber and in-flight reactions. As a result, the attention given to other effects of barometric pressure change is often minimized. Other disorders can be as dangerous if not more dangerous than hypoxia. Mechanical effects of pressure change are largely preventable if the causes and mechanisms are understood. Hypoxia and decompression sickness (DCS) are discussed in depth in this section.

Decompression sickness is perhaps the least likely event to occur in flight. However, the seriousness of any DCS episode makes up for such a low occurrence probability. Manifestations of DCS range from mild joint pain to blindness and can lead to death. There is considerable variability in symptoms onset and severity from one individual to the next. Predicting individualized DCS under specific flight conditions is difficult. This requires everyone to be aware of its manifestations and the factors contributing to its development.

210. Mechanical effects of pressure change

The body can withstand enormous changes in total barometric pressure, in both hypobaric (altitude chamber) and hyperbaric (dive chamber) conditions. Air pressures in body cavities equalize with ambient pressure under normal conditions. The gastrointestinal tract, middle ears, paranasal sinuses, and respiratory tract are the body structures normally containing gas. This gas may be swallowed air or gases generated in the gastrointestinal tract. Pressure changes occurring outside the body influence these internal gases. Gases expand with decreasing pressure during aircraft or hypobaric chamber ascent. Gases contract during descent from these low-pressure environments. The mechanical response to decreased or increased pressure occurs in accordance with Boyle's Law.

Trapped gas

Gas expansion in body cavities is not a problem if the resulting pressure is relieved. Pressure normally equalizes between hollow organs and the ambient environment. However, difficulty can occur when the expanding gas cannot escape. This allows internal pressure to build. This is referred to as *trapped gas*. A greater expansion of the gas occurs within these organs as ambient pressure decreases. Organ walls are not perfectly elastic, and higher pressures can eventually produce varying degrees of pain.

Gas expansion

All body gases contain water vapor. Water vapor partial pressure (tension) directly relates to body temperature. Water vapor partial pressure remains constant at 47 mm Hg because body temperature is constant in most instances. Water vapor volume in a hollow organ increases at altitude. However, the partial pressure remains constant. The water vapor must be corrected to determine the total amount of expanding gas in an organ. In the preceding lesson, we illustrated the greater increase in volume of a wet gas versus a dry gas during ascent. Note that the increase is not linear.

Effects of pressure change on specific body cavities

Changes in pressure can be felt in the gastrointestinal tract, middle ear, sinuses, teeth, and lungs.

Gastrointestinal tract

Gastrointestinal tract discomfort, from gas expansion, is the symptom most frequently experienced with a decrease in atmospheric pressure. Fortunately, this discomfort is not serious in most individuals at low or intermediate altitudes. Above FL 250, however, enough distention may occur to produce severe pain. Moderate pain may even cause a reflex fall in blood pressure and fainting. The stomach and intestines normally contain a variable amount of gas at a pressure approximately equivalent to the ambient atmospheric pressure. Swallowed air is the primary source of gas found in the stomach and large intestine, which contain more gas (air) than the small intestine.

Gases formed as a result of the digestive process—fermentation, bacterial decomposition, and putrefaction of food undergoing digestion—are other contributors. Normal gastrointestinal tract gases are O_2, CO_2, N_2, and hydrogen sulfide. These gases occur in varying proportions, although the highest percentage of the gas mixture is always N_2. Extreme discomfort or even pain may result as stomach and intestine gases expand with altitude. When this occurs, the simplest way to relieve the discomfort or pain is through belching or passing flatus. However, if the individual is not relieved immediately by passing the gas, it may be necessary to descend to a lower altitude. Breathing difficulty at very high altitudes may result from gas expansion in the digestive organs, elevating the diaphragm.

Middle ear

The ear is divided into three main parts: external ear, middle ear, and internal ear. Figure 2–3 illustrates a cross section of the human ear with various parts named.

The external ear consists of the horn-like portion called the pinna and the external auditory canal. The eardrum separates the external ear from the middle ear at the end of this canal.

The inner ear is adjacent to the middle ear and is responsible for hearing and equilibrium. Atmospheric pressure changes may have an indirect effect on the inner ear, when one side is stimulated more than the other, causing alternobaric vertigo. This portion of the ear will be discussed in detail later in the text in relation to spatial disorientation.

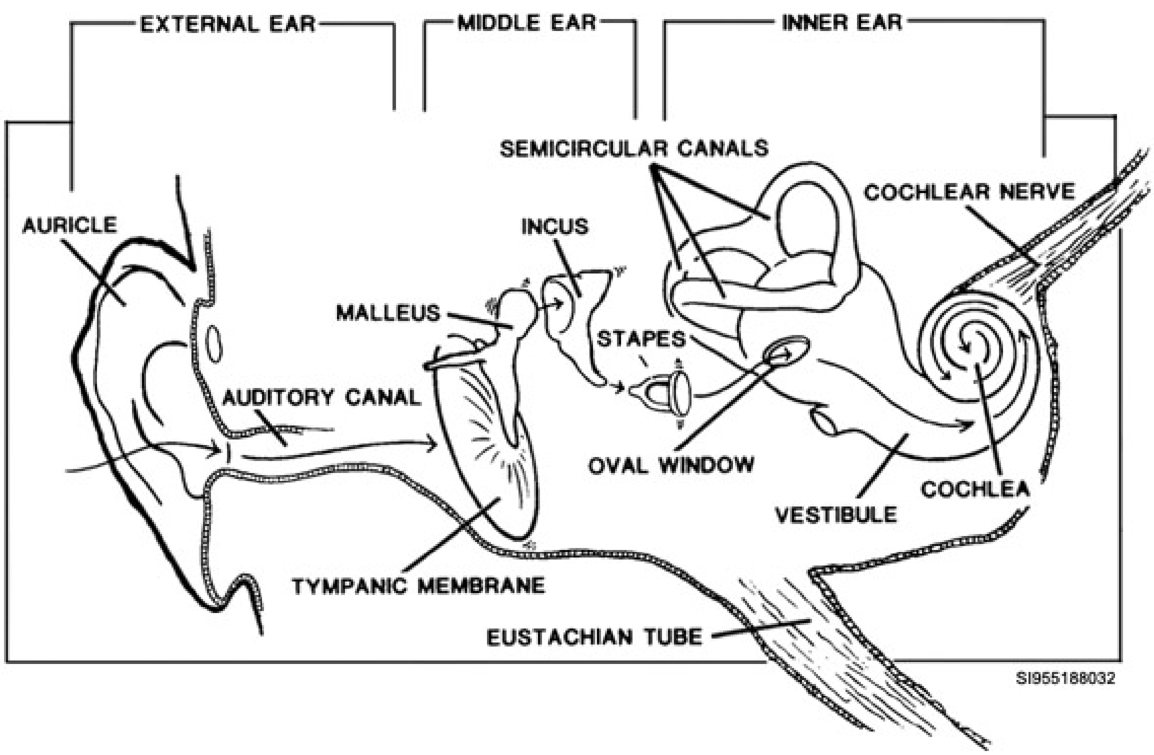

Figure 2–3. The ear.

The air contained in the middle ear also responds to atmospheric pressure changes causing discomfort for anyone who flies, but especially those who fly at higher altitudes.

The middle ear, located in the bone of the skull, contains the three tiny hinged bones labeled the *stapes*, *incus*, and *malleus*. These bones transmit vibrations from the eardrum to another membrane separating the middle ear from the inner ear. The middle ear connects to the back portion of the nasal passages on either side of the nasopharynx through a slit-like tube called the eustachian tube. The eustachian tube permits an equalization of pressure between the middle ear and the outside pressure. The middle ear is so small that it could be filled with just five drops of water.

Changes in the volume of air in the middle ear frequently cause concern for aircrew and students participating in altitude chamber flights. There is seldom any difficulty during ascent; most often the difficulty (ear block or *barotitis media*) occurs during descent. This difficulty is usually in the form of a sensation of fullness in the ear, a decrease in hearing, and pain. The pain becomes intense if the descent continues. If the pressure is not equalized across the eardrum (tympanic membrane), it may perforate.

Reduced barometric pressure during ascent causes an expansion of air in the middle ear. This air finds intermittent release through the eustachian tube into the nasal passages. As the pressure in the middle ear increases, the eardrum bulges outward until reaching a differential pressure of about 15 mm Hg. A small amount of air is then forced out and the eardrum resumes its normal position. There is a sensation of fullness in the ear, often accompanied by a *clicking* or *popping* sensation as the pressure releases, just before the air escapes into the eustachian tube.

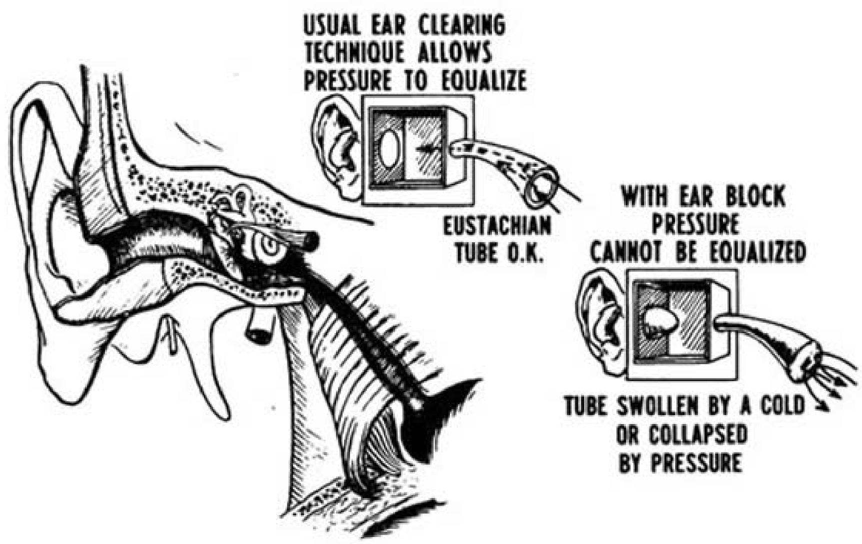

Figure 2–4. Pressure change in the ear.

During descent, pressure equalization in the ear does not occur automatically. The eustachian tube acts as a one-way valve allowing air to pass outward easily but resists passage in the opposite direction. Ambient air pressure rises above middle-ear pressure as barometric pressure increases (descent), forcing the eardrum inward. This pressure must be equalized (fig. 2–4).

Equalizing pressure during descent normally is not difficult. When your ears feel full, or at approximately 1,000-foot intervals, simply swallow, yawn, or tense your throat muscles. These procedures cause contraction of the pharyngeal muscle, opening the eustachian tube orifices. You can force air into the middle ear by closing your mouth, pinching your nose shut, and then forcefully exhaling through the nose if the previous maneuvers do not work. This procedure is called the *Valsalva maneuver*. It forces air through the previously closed eustachian tube into the middle ear, equalizing the pressure. A properly performed maneuver clears the ears, improving the descent rate without discomfort. The Valsalva maneuver should only be conducted during descent.

Sinuses

The sinuses are cavities in the bone of the skull that are lined with moist, mucous membrane. They connect to the outside by means of tiny slit-like ducts or tubes. The sinuses contain air and water vapor. Internal pressure is equal to outside barometric pressure under normal circumstances. The two sinus cavities most often involved with pressure changes include the frontal sinuses above each eyebrow, and maxillary sinuses in the cheekbones on either side of the nose (fig. 2–5).

The sinus ducts have openings into the nasal passages on either side. The volume of gas in the sinuses varies with pressure change and is regulated by a similar mechanism as the middle ear. The gas normally vents to the outside during ascent without discomfort. Air moves through the duct and back into the sinuses as barometric pressure increases (during descent). When pain occurs, it is usually on descent. The area of pain usually will let you know which sinuses are affected. If the pain is around the forehead or eyes, the frontal sinuses are affected. If the upper row of teeth is hurting, it is more than likely a maxillary sinus pain.

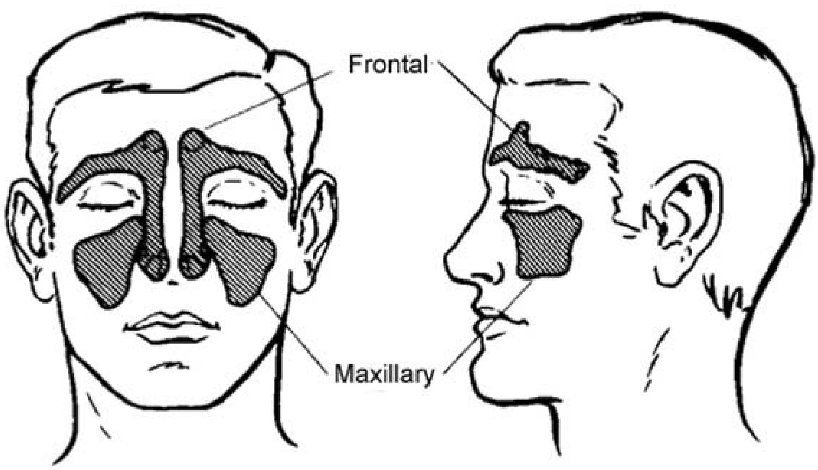

Figure 2–5. Sinuses.

Teeth

Dental diseases are not caused by barometric pressure changes. However, some pathological conditions dormant at ground level may be adversely affected by pressure changes, becoming exaggerated and painful. Almost all confirmed tooth pain (*barodontalgia*) occurs in restored teeth or teeth showing disease. The pain will be localized to one specific tooth. The altitude at which tooth pain starts varies. Pain in a given tooth may show remarkable constancy in the altitude at which it first occurs. The pain may or may not become more severe as altitude increases. Descent invariably brings relief, the pain often disappearing at the same altitude it first occurred. The incidence of barodontalgia is low, but it is usually severe, causing excruciating pain when it does occur.

Lungs

Air in the respiratory tract expands during a rapid pressure decrease (i.e., a chamber or aircraft rapid decompression). Expanding lungs vent air freely to the outside during decompression if breathing is normal. However, the lungs retain the expanding air if the breath is held, or a localized airway obstruction occurs (e.g., a tumor, mucous, or spasm). An obstruction creates overinflation and overpressurization of the lungs. Alveoli may rupture if the overpressurization is great enough (80 to 150 mm Hg). Depending on the path taken by the escaping air, the rupture creates one of three disorders: *air embolism*, *pneumothorax*, or *pneumomediastinum*.

Air embolism

Air moves back to the left atrium, left ventricle, and then into the systemic circulation if it escapes from ruptured alveoli directly into pulmonary veins. The primary site of damage is the central nervous system where bubble emboli obstruct arteries or arterioles, depending on bubble size. The symptoms and signs are dizziness, headache, unconsciousness, shock, or convulsions occurring very shortly after decompression. The occurrence during altitude exposure is rare.

Pneumothorax (collapsed lung)

The symptoms of pneumothorax are a sharp pain in the chest, shortness of breath, and shock due to the alveoli rupturing into the pleural cavity.

Pneumomediastinum

Air from ruptured alveoli moves to the vessels and bronchi of the mediastinum (the space containing the heart and great vessels). Increased pressure on these structures can produce pain beneath the sternum and shortness of breath.

211. Decompression sickness

Decompression sickness is an illness caused by reduced pressure on the body, resulting in the formation of bubbles and related symptoms. Knowledge of nitrogen's effects during wet diving has existed for many years. DCS was a recognized, if unexplained, problem connected with flying within 30 years of the historic flights by the Wright brothers at Kitty Hawk. Planes had ever-increasing flight performance, including the ability to fly higher. These higher altitudes resulted in *dysbarisms*, symptoms and disorders similar to caisson's disease (diver's bends). DCS was minimized only with the advent of pressurization systems in the late 1940s.

History and basic facts of decompression sickness

The maximum altitudes of early aircraft were relatively low; however, the development of supercharged reciprocating engines and jet engines permitted higher flights. An unacceptable aircrew DCS rate during World War II stimulated a great increase in DCS research. During this time, aircrews were screened to determine susceptibility to DCS by exercising them at altitude (FL 380). This severe screening process caused some deaths and was discontinued.

Though reliable pressurization systems have existed for several decades, some missions still exist where DCS remains a potential hazard. Aircraft may depressurize, exposing aircrew to high cabin altitudes. Decompression normally occurs due to a defect in the pressurization system or a breach in the aircraft pressure vessel. When this occurs the aircrews are quickly exposed to a reduced pressure environment that may cause DCS.

Very high altitude flights (above 50,000 feet) can cause cabin altitudes to rise above known DCS threshold altitudes. High aircraft cabin altitudes are not due to a pressurization system defect. Rather, the aircraft's maximum pressure differential is not sufficient to protect aircrew. Crew members on these aircraft usually wear pressure suits that automatically pressurize when the aircraft loses cabin pressure. It is not practical to pressure (inflate) the suit in advance due to reduced mobility.

Types of hypobaric exposure in aviation

Exposure to hazardous altitudes is not always accidental. Some missions require deliberate aircraft depressurization. A high altitude parachute drop, where the entire aircraft remains unpressurized, is the most common mission of this type. Both the aircrew and the parachutists are exposed to hazardous altitudes in this situation. Certain space operations also create the potential for DCS problems. For example, astronauts must wear pressure suits during extravehicular activity (EVA). The mobility of these suits is poor when pressurized to more than 4 pounds per square inch (psi). Therefore, suits are generally restricted to lower barometric pressures.

Some aircraft, such as the T–37 (which was retired in April, 2008), do not have pressurization systems and the aircrews remain exposed to ambient altitude. The “ceiling,” or maximum operating altitude, for this and any other unpressurized aircraft is FL 250. Yet even at this altitude, DCS is still a risk. Altitude chamber training, by design, also exposes students to low barometric pressures. This training is a calculated compromise between the need for realism and the definitive risk of DCS. Our advantage in the altitude chamber is the breathing of 100 percent oxygen prior to being exposed to lower barometric pressures. This process is known as *denitrogenation*.

Causes of decompression sickness

The initial condition leading to DCS is a reduction in the pressure applied to the body within a short period of time. Pressure reduction is most likely to occur during ascent in flight, while diving, or a combination of the two within a short period of time. DCS may occur concurrently with hypoxia. However, pressure reduction rather than O_2 deficiency remains the cause. Thus, aircrew flying at a high cabin altitude with O_2 equipment is still susceptible to DCS.

Bubble theory

Inspired gases in the lungs dissolve in the blood and move to the body tissues. Over an extended time, the dissolved gases in the body (principally N_2, O_2, and CO_2) have variable partial pressures between the various tissue compartments, and diffusion occurs between these compartments. Nitrogen is metabolically inert and experiences no net diffusion between the various tissue compartments while the atmospheric pressure remains constant. The tissues are considered saturated with N_2 because the dissolved N_2 is in equilibrium with the gaseous N_2 in the lungs.

Reducing atmospheric pressure also reduces the partial pressure of N_2 and O_2 in the alveoli. Partial pressure gradients (the driving force for diffusion) favor diffusion from the tissues to the blood and to the alveoli. Specifically, when the tissue tension of N_2 exceeds the alveolar tension of N_2, a state of supersaturation exists. This *excess gas* diffuses out of solution and is exhaled from the lungs.

The system’s gases remain dissolved as they transfer through the tissues and blood when the pressure reduction is slow. However, the degree of supersaturation may exceed a critical level, and bubbles may form in the tissues if the pressure reduction is fast. Once a bubble forms, any further decrease in pressure causes the bubble to grow. This *bubble theory* has become widely accepted as a major part of the study of DCS.

The bubble theory receives support as a result of (1) the symptoms of DCS usually preceding the appearance of bubbles and (2) descent or repressurization in a hyperbaric chamber causing a reduction and elimination of bubbles, and generally a resolution of symptoms. Bubbles associated with DCS may exist in virtually all body tissues.

Although the formation of bubbles appears to be a key step in DCS, the precise role of bubbles is not known. Additionally, the presence of bubbles does not mean you will experience symptoms of DCS since bubbles produced on the venous side (silent bubbles) do not produce symptoms.

Nitrogen supersaturation

Nitrogen appears to be the key gas in DCS development. Bubbles formed solely by the action of O_2 or CO_2 are unlikely because these gases have unique blood transport mechanisms. These gases are rapidly consumed or excreted, and the respiratory and circulatory systems control their concentration.

Nitrogen is not consumed, excreted, bound to other molecules, nor actively controlled. The solubility of N_2 in water is fairly low, but in some tissues such as fat, it is relatively high. Nitrogen diffuses slowly from these denser tissues to the blood. Therefore, supersaturation and bubble formations are more likely with nitrogen.

The key role of N_2 in DCS gains support from another observation. For example, decreasing total body N_2 before decompression reduces DCS incidence. Breathing 100 percent O_2 establishes a diffusion gradient to off-load N_2 from the blood to the lungs. In turn, this establishes a gradient to off-load N_2 from the tissues to the blood. Denitrogenation with O_2 (or *prebreathing*) is the current preventive treatment for DCS. The longer the denitrogenation time, the lower the body's residual N_2 stores, and the lower the chance of DCS. The degree of N_2 supersaturation is expressed by the following equation:

R (supersaturation ratio) = P N_2 (partial pressure or tension)/P_T (total pressure)

Methods to prevent DCS depend on decreasing the value of this ratio by either decreasing the tension of N_2 in the tissues and/or increasing total pressure.

Benefits of denitrogenation

The greatest progress in DCS research came with the discovery that breathing 100 percent O_2 before decompression decreased the chance of DCS. Although DCS continues to be a hazard of flight, the incidence is much lower. Nevertheless, use of high-pressure spacecraft and low-pressure space suits has renewed interest in DCS.

Denitrogenation is also effective in decreasing DCS symptoms even after their initial presentation. The high tension of O_2 encourages the diffusion of N_2 from existing bubbles and reduces further growth of existing bubbles. Denitrogenation is often used as the first treatment for DCS. This treatment, in addition to *hyperbaria* (recompression), decreases the N_2 content and compresses the size of the bubbles.

Below we can see how N_2 is eliminated during different time periods. The volume of N_2 exhaled during denitrogenation follows an exponential process. Off-loading is rapid early in prebreathing, but the rate decreases with time. This is a controlling factor that limits effectiveness. As time passes, the diffusion gradient decreases, so less N_2 per unit time is off-loaded.

Time in Minutes	Nitrogen Elimination
30	350cc
60	500–600cc
90	600–700cc
120	800–850cc
150	900–1,000cc

Signs and symptoms of decompression sickness

DCS can be identified through a wide variety of manifestations. The cause of each differs. Several factors, in addition to the length of denitrogenation, affect the incidence and severity of DCS. These manifestations are divided into five types:

1. Skin symptoms.
2. Bends.
3. Chokes.
4. Neurological manifestations.
5. Circulatory manifestations.

Skin symptoms

Symptoms can result from extravascular or intravascular bubble formation in the skin. In the first instance, sufficiently large extravascular bubbles mechanically stimulate sensory receptors. Bubble presence is apparent. Skin sensations (*paraesthesia*) most often described include itching, a feeling of insects on the skin, mild stinging or pin pricks, and alternating hot or cold sensations. Occasionally, numbness is noted. Skin symptoms are usually quite transient. A crepitus sensation, caused by subcutaneous emphysema, could theoretically occur if this form of DCS progresses without treatment.

Concurrent with the localized nature of skin symptoms is a characteristic flushed or mottled appearance of the skin. Irregular vasodilatation of the affected area may likely be the result of an axon reflex, although intravascular bubble formation (causing stasis) is possible.

Intravascular bubble formation may produce some of the same skin manifestations. Interruption of circulation to certain areas of skin may turn the skin pale and cause it to exhibit a mottled, cyanotic appearance or marbling. Damage may occur to blood vessel linings if bubbles aren't resolved, resulting in localized swelling.

Skin symptoms are not life threatening. Although they do not always precede other DCS symptoms, skin manifestations can serve as a warning that similar bubble formation is occurring elsewhere in the body. Hyperbaric treatment, or at least medical monitoring, is advised.

Bends

Pain in and around the joints, or less commonly in large muscle masses, is the *bends*. It is the most common manifestation of DCS and is often described as a deep and throbbing pain. With time the pain tends to radiate or extend along the limb. Although the most commonly affected joints are the knees, elbows, shoulders, and wrists, it may affect other joints such as those in the fingers. Severity ranges from barely perceptible to severe. There is a tendency for the person suffering from the bends to work the joint, trying to ease the pain. This is not effective and often increases the pain.

Pain from the bends, as with other DCS manifestations, often increases with time at altitude. Pain should decrease with descent, but in some cases the pain increases after return to ground level. Unfortunately, the decrease of pain during descent has at times convinced aircrew to continue the mission or not report the incident after landing.

Bends pain is commonly assumed to be less severe than more systemic forms of DCS, such as central nervous system disorders. However, bends pain is often progressive and can lead to total debilitation. The pain may prevent movement, which could hinder aircraft operations. Severe cases can lead to collapse, either directly by the effects of pain or by additional DCS manifestations discussed below. Note: Bends pain may not develop exclusive of other manifestations but may be the most prevailing.

Originally, the cause of bends pain was assumed to be evolved gas (bubbles) in the joints. This explanation is believed to be too simplistic. Radiographs show free gas may or may not be present in the joint when pain occurs. A more likely explanation involves free gas in the connective tissue in the area of the joints, possibly stimulating pain receptors.

Chokes

The *chokes* is a term used to describe a DCS disorder characterized by an individual having a sharp pain under the sternum that increases in severity during inhalation. The individual commonly has a feeling of suffocation along with obvious apprehension. The individual is often pale, sweating, and feels fatigued and faint. A dry, progressive, nonproductive cough is frequently present. Total collapse, because of reduced venous return to the left side of the heart, may occur in severe cases.

Chokes can be confused with an air embolism. However, the cause of an air embolism is a breach in the alveoli, thus permitting gases to enter the circulation. Holding your breath during ascent after a dive is the most common cause of an air embolism. An embolism also may occur if you hold your breath during decompression to a higher altitude. Ascent and subsequent expansion of alveolar air can burst the alveoli.

The chokes, on the other hand, are caused by nitrogen already in the circulation in gaseous form. After decompression, or during exposure to altitude, bubbles flow through the veins to the heart and lungs. Most often the progress of events leading to circulatory collapse is slower than that seen with arterial emboli. An arterial embolism can cause immediate debilitation and death in a short time, particularly if the embolus lodges in the central nervous system (CNS). True chokes, however, are primarily manifested in the lungs and has a longer course of progression.

Neurological manifestations – central nervous system disorders

These manifestations seem to be associated with disturbances within the brain or the spinal cord. Clinicians attempt to discriminate between brain and the spinal cord, but physiologists consider the events of equal importance. Signs and symptoms of CNS disorders may appear in virtually any body area and system. Perhaps the most common neurological manifestation involves the vision. Symptoms are commonly unilateral but may be bilateral. The results of neurological manifestations are rare but serious. Untreated symptoms often progress even after descent. Permanent defects have occurred and some deaths have been recorded in rare incidents.

Circulatory manifestations

Attempting to segregate circulatory manifestations from other manifestations is difficult. Most likely, circulatory manifestations occur concurrently with, or are secondary to, other forms of DCS. Circulatory shock is usually the predominant sign. Although these manifestations may be secondary to other DCS forms, direct effects of bubbles on circulation to CNS vasomotor areas are likely factors.

Factors affecting the incidence and severity of decompression sickness

There are many factors affecting the onset and severity of DCS. High altitude is an obvious factor, but how high is too high? Individuals differ in amount of body fat, age, blood type, and previous injuries. There is no way to precisely predict when DCS will occur.

Altitude

Increased altitude contributes to an increased incidence of DCS. A higher altitude increases the degree of supersaturation, increasing the chance of bubble formation. Considerable debate occurs over the minimum altitude (threshold) for DCS. Recent evidence shows DCS is possible as low as 13,000 feet, but it is rare unless extended time is spent at that altitude. Although no discrete boundary exists, FL 250 is the most commonly cited threshold. . This altitude may be a reasonable supposition based on decades of unpressurized flights to FL 250 in USAF aircraft.

Indeed, very few cases occur in routine flight below this altitude, but aircrews must know of this potentially harmful situation. Studies continue to try to predict DCS risk for various altitudes and exposure times. However, results indicate the incidence of DCS is extremely variable and dependent on many, and often immeasurable, factors. Predicting DCS, in a training or operational flight scenario, is not possible. Any altitude exposure must be assumed to pose a risk.

Aircraft pressurization has largely decreased DCS incidence by maintaining a lower physiologic altitude (cabin altitude). However, cabin pressurization systems at extremely high flight altitudes (i.e., greater than 50,000 ft.) may not be sufficient to maintain safe cabin pressurization. More commonly, a loss of pressurization because of a system failure will expose aircrews to a higher risk.

Time at altitude

Increased time at altitude contributes to a greater incidence of DCS. It appears that if you remain at altitude long enough, N_2 stores would deplete, thereby decreasing the chance of DCS. However, altitude exposure itself decreases the denitrogenation rate. Bubble formation, pain, and incapacitation usually occur before tissue N_2 reduces to the extent that bubbles do not form or grow. More likely, silent bubbles already exist and increased time at altitude permits growth of bubbles that are otherwise not a problem at a smaller size. A rapid descent after decompression, and particularly after experiencing any manifestation of DCS, is critical in reducing the hazard of DCS. In most cases, descent (recompression) and landing as soon as possible eliminates the pain of simple limb bends.

Rate of ascent

A faster rate of ascent adds to a greater incidence of DCS. A slow ascent allows excess N_2 to remain in liquid form, so a supersaturated state is less likely. Rate of ascent probably has been overemphasized in the past. Generally, a rapid decompression taking a few seconds has about the same incidence as a decompression taking a few minutes. However, the risk decreases significantly if the decompression is slow.

Exercise

Exercising while exposed to altitude increases DCS incidence. The sliding movement of one tissue against another may be a contributing factor. Joint and muscle movement cause a shearing action, encouraging bubble formation. Contracting skeletal muscles, possibly causing areas of local turbulence, may also encourage bubble formation. Additionally, CO_2 content in exercising muscles may increase and diffuse into and enlarge N_2 bubbles. Individuals exposed to high altitude should minimize movement. Furthermore, any additional movement of the limbs (in the case of bends) may worsen the DCS condition. Some studies have shown that exercise during denitrogenation (or prebreathing O_2, as we discussed earlier), may decrease DCS incidence during a subsequent altitude exposure. Why? Because increasing blood flow to the muscles may accelerate N_2 off-loading. This factor and the effect of exercise on bubble formation after returning to ground level remain unproven. However, many anecdotal accounts suggest postflight exercise increases the probability of delayed DCS. In addition, postflight exercise-induced injury may mask DCS pain.

Finally, very serious DCS symptoms may arise if symptomatic bubbles caught in the lungs pass through to the arteries, as cardiac output increases blood flow in the lungs. Therefore, strenuous exercise should not be performed immediately after high-altitude exposures.

Body fat

Earlier studies emphasized that increased body fat increases the chance of DCS. This is because N_2 is about five times more soluble in fat than in water. It functions as a reservoir for the gas. Early studies involving DCS-related deaths noted, in most cases, that the victim was either obese or grossly obese. However, aircrews with slightly above average body fat percentages meeting current weight standards are not at a measurably increased risk.

Previous injury

There are many accounts of bends pain occurring in previously injured areas. No objective data is available for analysis to support this theory. However, injury may cause blood perfusion changes or may deposit scar tissue. These changes may decrease N_2 washout rates and predispose bubble formation in these areas. In addition, flying missions often involve extended periods in cramped conditions. Pain, not actually associated with bubble formation, may mimic bends pain.

Age

A correlation between age and DCS incidence before the age of 40 years is not clearly proven. However, the incidence of DCS does increase after age 40. Increased deposits of fat within connective tissues and changes in capillary density and permeability may be factors contributing to this effect.

Blood factors

Recent studies have shown that a person with elevated serum cholesterol, undergoing an experimental chamber flight, has an increased risk of DCS. Other blood factors, particularly those involved in clotting mechanisms, may also relate to DCS incidence. This is valuable information because these factors may serve as a predictor of those persons prone to form bubbles and develop DCS.

Prebreathing at altitude

Breathing 100 percent O_2 during ascent or at altitude is not as effective in eliminating N_2 as denitrogenation is at GL for an equal period of time. Denitrogenation at altitude is less effective because the diffusion gradient, not the volume, determines the rate of denitrogenation. Nitrogen is off-loaded more slowly and the probability of DCS increases.

Break in denitrogenation schedule

It was thought that extending the denitrogenation period due to a break in denitrogenation (breathing ambient air) could be compensated for by an equal amount of time. Studies have proven this assumption false. Breaks in denitrogenation usually occur when there is an equipment failure. For example, the O_2 regulator is accidentally reset to the “NORMAL O_2” setting (less than 100 percent), the mask is removed, or the mask fit is unacceptable.

Remember that the greatest amount of the body’s N_2 stores is off-loaded early during the denitrogenation period. Nitrogen partial pressure decreases rapidly during the early part of denitrogenation. The diffusion gradient strongly favors N_2 diffusion into the tissues with an interruption of denitrogenation, even short interruptions. The N_2 onload rate is faster than the N_2 off-load rate. Therefore, adding an equal amount of time to the denitrogenation period does not return N_2 tissue tension to a level equal to the previous tension (before denitrogenation interruption).

Restarting denitrogenation is a good rule to follow if the air-breathing period (break) exceeds a few breaths. Finally, be especially aware that a poor mask fit can increase the chance of DCS. Even small inward leaks can decrease the diffusion gradient and diminish the effectiveness of denitrogenation.

Individual variability

The variability of individual DCS susceptibility is great; however, the variability from one individual to the next is smaller. Under the same conditions, one person may develop DCS while another shows no signs or symptoms.

An individual who develops DCS under certain conditions is likely to manifest the same DCS symptoms under similar conditions. Individual susceptibility was the basis of the effort to screen the flyers prone to the bends during World War II. However, since the factors predisposing DCS are extremely complex, a single case of bends in an individual is not indicative of consistently recurrent problems during future exposures. Individuals who suffer bends often develop pain in the same area upon subsequent exposure, suggesting specific histological factors predisposing DCS in those areas.

Repeated exposure

There is a controversy about the effects of repeated exposure (i.e., successive altitude exposures). It appears that rapid successive exposures, occurring within minutes or a few hours of a previous exposure, increase DCS incidence during subsequent exposures. This is probably because some bubbles may remain from the previous exposure. Bubble growth is more likely under this condition. The incidence of DCS does not increase if the exposures occur on successive days. Keep in mind that the onset of symptoms appears sooner in subsequent exposures.

Scuba diving and flying

Altitude exposure after scuba diving increases DCS incidence. Furthermore, diving decreases the threshold where DCS manifestations begin. A lowered threshold can be seen even during flights on aircraft equipped with excellent pressurization systems, such as commercial airlines where cabin altitudes are usually maintained between 5,000 to 8,000 feet.

Scuba divers typically have elevated N_2 stores (supersaturated tissues) after returning to the surface. In addition, subclinical bubbles may form during a dive, fail to resolve on return to the surface, and expand while ascending to altitude.

Some special military operations limit the maximum cabin altitude of flight after determining the maximum diving depth and time at depth. However, limiting cabin altitude in practice is difficult to control. The USAF policy for all personnel, except special operations, is to forbid flight within 24 hours of a compressed air exposure for all normal flying operations.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

210. Mechanical effects of pressure change

1. What is the term given to gas that is not allowed to escape from the body?

2. Because the organs that contain gas are only partially elastic, what happens to individuals experiencing trapped gas?

3. Due to the body's nearly constant temperature, the partial pressure of water vapor remains at what mm Hg?

4. What symptom is most prevalent while experiencing gas expansion?

5. The gastrointestinal tract contains gases that maintain a fairly constant pressure. What is the normal pressure within this system?

6. What gases normally are present in the gastrointestinal tract?

7. What is the simplest way of relieving gas expansion at altitude from within the gastrointestinal tract?

8. If an individual experiences severe gas pain and immediate relief does not occur by passing gas, what is the next procedure to follow?

9. Name the three sections of the ear.

10. Name the three hinged bones within the middle ear.

11. When do the majority of middle ear problems occur?

12. What is the purpose of the eustachian tube?

13. Where does the air exit from the eustachian tube?

14. What recommended maneuvers, besides the Valsalva, can you use to clear the middle ear?

15. How do you perform a Valsalva maneuver?

16. What are the sinuses?

17. How does the gas within the sinuses vent during ascent?

18. Which sinuses are most closely associated with pressure changes?

19. During descent under normal conditions, how do the sinuses equalize?

20. In what type of teeth condition is pain most likely to occur during pressure changes?

21. At what altitude is tooth pain likely to disappear on descent?

22. Give examples of a lung obstruction that might cause overinflation during decompression.

23. When alveoli rupture, they may result in one of three conditions. Name them.

24. Which one of the conditions caused by ruptured alveoli is rare during altitude exposure?

25. What are the symptoms of a pneumothorax?

26. Where has the alveolar air penetrated when a student has a pneumomediastinum?

211. Decompression sickness

1. What is the cause of DCS?

2. When is a crew member likely to be exposed to reduced pressure environment and possibly DCS?

3. During space operations, when is the most likely time that astronauts would be exposed to greatly reduced pressures?

4. When is a reduction of pressure to the body most likely to occur?

5. What three principal gases have variable partial pressures between the various tissue compartments?

6. What are the tissues considered when the dissolved nitrogen and the nitrogen in the lungs are at equilibrium?

7. Partial pressure gradients favor diffusion within the body systems. What is the order of this diffusion?

8. Once a bubble form in the tissues, what will a further reduction in pressure cause?

9. Which two factors directly support the bubble theory?

10. Why is it unlikely that a bubble of either oxygen or carbon dioxide will form in the body?

11. Due to certain properties, nitrogen is more likely to cause DCS. Name these properties.

12. What factors have renewed interest in DCS?

13. Can denitrogenation be used even after DCS symptoms have manifested themselves? Why or why not?

14. During the prebreathing period, what controlling factor limits its effectiveness?

15. Why do skin symptoms manifest themselves?

16. Name some of the symptoms associated with skin symptoms.

17. Why do certain areas of the skin turn pale and exhibit a “marbled” appearance?

18. Typically, how do individuals describe the main symptom of bends?

19. After a period of time, how does the pain from bends tend to change?

20. Bends pain was thought not to be as severe as other DCS manifestations, but, if left untreated, what can it cause?

21. What are the characteristics of the DCS disorder known as *chokes*?

22. What other symptoms might be noted in a chokes patient?

23. True chokes primarily manifests itself in which part of the body?

24. Neurological manifestations are usually centered in what part of the body?

25. The most common neurological manifestation usually involves which function of the body?

26. Circulatory manifestations usually occur concurrently with other types of DCS. What is the primary sign of this type of DCS?

27. What is the minimum altitude (threshold) for DCS based on recent evidence?

28. What is the most commonly cited altitude threshold for DCS?

29. Why is it hard to predict when and where DCS will occur?

30. What in-flight maneuver is critical to prevent DCS after a decompression?

31. Why is a faster ascent rate more dangerous than a slow ascent rate?

32. In addition to nitrogen forming bubbles during DCS, what other gas may combine with the bubbles during exercise?

33. Some studies have shown that when you exercise during prebreathing, you may reduce the incidence of what?

34. Why do bends seem more likely to occur in a previously injured area?

35. What is known about DCS in individuals over the age of 40?

36. What blood factors have relevance to the incidence of DCS?

37. Why is denitrogenation at altitude less effective than at GL?

38. If you were repeatedly exposed to altitude, should you be concerned about DCS? Why or why not?

2–3. Hypoxia and Hyperventilation

No subject is more important in the AP program than hypoxia. Hypoxia has created problems for aircrew members ever since they ventured into the atmosphere. Your job is to train aircrews to recognize, treat, and prevent these problems.

You also must become familiar with the signs and symptoms of hyperventilation. It is important to note that hypoxia can lead to hyperventilation and vice versa. However, there are symptoms specific to each condition. Information on the cause as well as the signs and symptoms of both hypoxia and hyperventilation is presented in this unit.

212. Hypoxia types, causes, signs, and symptoms

Hypoxia is an area of serious concern for both the AP technician and for the aircrew. It has been, and without proper precautions will continue to be, the cause of many aerospace accidents and mishaps. Hypoxia can occur during each altitude exposure whether aircrew members are in a hypobaric chamber or on an actual aircraft flight. Every individual exposed to these environments must know what hypoxia is, what causes it, and the corrective measures to use should it occur.

You are required to know the subject well because of the dangers posed by hypoxia. All trainees must undergo hypoxia demonstrations in the hypobaric chamber in addition to required classroom instruction. Monitoring these demonstrations is one of the duties of inside observers/instructors. You must learn to recognize the outward signs of hypoxia in trainees and administer proper corrective measures when trainees cannot treat themselves. This unit’s discussion of hypoxia is in-depth and includes the causes, proper preventive measures, recognition, and treatment.

Definition of hypoxia

Hypoxia is a state of O_2 deficiency in the blood, cells, or tissues sufficient to cause an impairment of bodily functions. You should not confuse hypoxia with the commonly used medical term *anoxia,* which is a total lack of O_2. The term *hypoxia* is more appropriate in the aerospace environment (in aircraft) because usually the body tissues are not entirely without O_2.

You learned about the role of the circulatory system in supplying body tissues with O_2. Hypoxia occurs if the circulatory system fails for any reason to supply the tissues with sufficient O_2, or if the tissues are unable to use available O_2. Hypoxia may result from:

- Insufficient O_2 available to the lungs.
- Interference with O_2 exchange between the lungs and the blood.
- Reduction in the O_2-carrying capacity of the blood.
- Reduced blood flow.
- Interference with O_2 exchange between the blood and tissue cells.

Types of hypoxia

Hypoxia is classified according to the condition causing it. The four types of hypoxia are *hypoxic*, *hypemic*, *stagnant*, and *histotoxic*.

Hypoxic hypoxia

Hypoxic hypoxia occurs at lung level. It results from an interference of the transfer of O_2 through the walls of the alveoli into the capillaries, resulting in a decreased amount of O_2 in the blood, which reduces the amount of O_2 delivered to the tissue cells. There are several causes for this interference.

For example, breathing ambient air at low atmospheric pressure causes an alveoli O_2 pressure reduction. This decrease in O_2 partial pressure causes a reduction in the O_2 transfer between the alveoli and the blood, resulting in hypoxia. This type of hypoxia is often called *altitude hypoxia*. It is the most common type you will deal with as an AP technician. Many lives and aircraft have been lost due to hypoxic hypoxia.

Hypoxic hypoxia is produced in the chamber to allow aircrew to recognize it and treat it. Hypoxic hypoxia can occur in an aircraft due to any of the following situations:

- Loss of cabin pressurization.
- Malfunction of O_2 equipment.
- Improper use of available O_2 equipment.

Hypoxic hypoxia may also occur for other reasons, such as:

- Reduced pulmonary ventilation from any cause such as strangulation or drowning, preventing O_2 from reaching the alveoli.
- Pneumonia, where alveolar space fills with fluid, preventing the absorption of oxygen.
- Mixing of fully oxygenated blood with venous blood that reduces PO_2 of arterial blood in systemic circulation.

Hypemic hypoxia

Hypemic hypoxia results from a decrease in the O_2-carrying capacity of the blood, a reduction in blood quantity or quality. Quantity refers to circulatory system blood volume. Hemorrhage, and the resultant blood loss, is the primary cause of decreased blood volume. Reduced blood volume results in less O_2 reaching the tissues, thus producing hypemic hypoxia.

Quality refers to the ability of the available blood to transport O_2 to body tissues. Remember that RBC hemoglobin carries O_2 to body tissues and cells. Any factor that reduces the number of RBCs (or the ability of available hemoglobin to transport O_2) affects blood quality. Anemia is one such cause. Replacing blood volume with plasma or a plasma substitute rather than whole blood also creates a RBC level decrease, reducing the blood's O_2-carrying capacity.

Another prevalent cause of hypemic hypoxia is carbon monoxide (CO). It is present in cigarette smoke and the exhaust of automobile engines and jet engines. Carbon monoxide combines with hemoglobin 250 times more readily than does O_2. If both are present, CO will combine with the hemoglobin, thereby reducing the ability of the blood to transport O_2.

Stagnant hypoxia

Stagnant hypoxia results from a reduction of blood flow, either generally or in local regions of the body. For example, applying a tourniquet to a part of the body causes stagnant hypoxia. The blood flow beyond the tourniquet is reduced or stopped, and the O_2 in the blood rapidly depletes. Reducing blood flow means reducing circulation of that blood, resulting in insufficient O_2 reaching the tissue cells. Heart failure is another condition causing stagnant hypoxia. The heart lacks the strength to pump the blood at an adequate rate. This results in a form of shock created by the dilation of large internal blood vessels, causing the blood to pool or collect in the vessels.

Positive G-forces are a common cause of stagnant hypoxia important to aircrews. Executing turns and loops or pulling out of a dive can produce significant G-forces. The weight of these forces causes blood to pool in the lower portions or extremities of the body, creating a reduction in the amount of blood in the upper portion of the body. *Blackout* (complete loss of vision) and unconsciousness, due to the hypoxic condition of the brain tissue, is of particular concern.

Hyperventilation and high positive-pressure breathing also can cause stagnant hypoxia. Positive-pressure breathing can result in decreased cardiac output and a pooling of blood in the lower extremities and even more extensively in the larger vessels of the abdomen.

Histotoxic hypoxia

Histotoxic (tissue poisoning) hypoxia is the result of a toxic substance in the body. Tissue level is the toxic substance's site of action. Although the blood contains a normal amount of O_2, the cells will not use it if a toxic substance is present within the cells. Cyanide, alcohol, and similar drugs affect the cells' ability to use O_2. Carbon monoxide, in addition to its effects on the oxygen-carrying capacity of the blood, also interferes with the tissues' ability to absorb O_2.

Effect of hypoxia on major body systems

The nervous, cardiovascular, and respiratory systems are each affected by the different types of hypoxia. However, how body systems react to hypoxic hypoxia (or altitude hypoxia, as we mentioned earlier), is your primary concern.

Nervous system

The nervous system has a great requirement for O_2; therefore, an O_2 deficiency affects cerebral (nervous) tissue first. The retina of the eye is a direct extension of cerebral tissue, explaining why vision is the first sensory function affected by hypoxia. Decreased cerebral and visual performance results when O_2 requirements are not met. Unconsciousness occurs with prolonged O_2 deficiency, followed by complete cessation of cerebral activity. Body functions cease, irreplaceable brain cells are destroyed, and death is imminent. Altitude chamber hypoxia demonstrations must never progress to this point. The severity and duration of hypoxia exposures must be kept to a safe minimum, so that brain cell damage will not occur. Remember that hypoxia may temporarily impair brain tissue function.

Cardiovascular system

The lowered O_2 hemoglobin saturation, caused by decreased barometric pressure, is initially compensated for by an increase in cardiovascular and pulmonary activity. Oxygen-hemoglobin saturation below 87 percent hinders functional activity, and symptoms of hypoxia begin to develop. A 65 percent saturation is critical; the symptoms of hypoxia become severe. An individual can remain conscious for only a short time.

The cardiovascular and respiratory systems may compensate for hypoxia up to 10,000 feet. However, subsequent compensation is not adequate at higher altitudes. In addition, compensation below 10,000 feet may be inadequate if the individual smokes, consumes alcohol, or uses certain nonprescription, over-the-counter drugs. Above 10,000 feet, the heart rate may increase to a maximum of 40 beats per minute above normal. A moderate increase in systolic blood pressure may occur above 15,000 feet. Finally, normal blood flow is altered. The blood then bypasses the extremities to increase flow to the brain and the heart. The cardiovascular system usually maintains adequate circulation for a short time after respiration has stopped.

Respiratory system

An increase in the rate and depth of breathing is one of the first respiratory effects of hypoxia observed. This respiratory increase progresses as altitude increases. However, increased respiratory activity does not prevent hypoxia if O_2 hemoglobin saturation falls below 87 percent.

Factors that affect the severity of hypoxia

Several factors affect the onset of hypoxia, and it is important to emphasize the many variables. Hypoxia can occur at any altitude. For example, alcohol intake (histotoxic hypoxia) and cigarette smoking (hypemic hypoxia) are two self imposed stresses that may cause hypoxia on the ground even before take-off. When hypoxic hypoxia occurs in flight, the preexisting hypoxia conditions reduce the amount of time aircrews have to recover.

Individual tolerance

Individual tolerance depends on physiological factors such as RBC count, O_2 hemoglobin saturation, and elevation where you live. For example, aircrews acclimated to living in Denver, Colorado, at over 5,000 feet, should have a higher tolerance than those living in Houston at sea level. Individual tolerance is also based on how well the body systems compensate for O_2 deficiency. For example, respiration may increase more rapidly in one person than another. Physical fitness is a significant factor in individual tolerance. Physically fit individuals normally have higher altitude tolerances than obese or physically unfit individuals. Lack of sleep, dehydration, and alcohol or drug use reduces fitness and hypoxia tolerance. Anxiety, usually resulting from inexperience or personal stress, may also affect hypoxia tolerance.

Medication and drugs

Aircrews must not self-medicate because of potential negative effect on human performance. Cold medication can depress the central nervous system by causing drowsiness and reducing coordination. Alcohol, found in many medications, also depresses the central nervous system. Vasoconstrictors, such as *Afrin*, can cause a rebound effect. Laxatives can cause dehydration. Analgesics, such at aspirin and Tylenol, may mask an underlying illness. Additionally, drugs that are safe at ground level may cause problems in a low-pressure environment. Aircrews (as well as aerospace physiology personnel) should always consult a flight surgeon when ill.

Altitude

Altitudes above 10,000 feet cause hypoxia onset rates to increase. Alveolar O_2 partial pressure decreases with an increase in altitude until unconsciousness.

Rate of pressure change

The body’s physiological mechanisms (heart rate, respiration, etc.) can compensate, to some degree, to reduced pressure during very slow ascent rates. This explains why mountain climbers can easily climb to altitudes above 10,000 feet without using supplemental oxygen. In flight, however, the rapid rate of ascent may increase the hypoxia onset rate experienced by aircrews if flying unpressurized or if there is a loss of pressurization (such as a rapid decompression). If hypoxia symptoms are not recognized or emergency oxygen is not readily available and utilized, aircrews are likely to suffer from hypoxia.

Environmental temperatures

Extreme hot or cold temperatures can also increase incidence of hypoxia. Meticulous aircraft design ensures aircrews are not exposed to extreme temperatures. During high-altitude egress, aircrew members can decrease exposure to these severe conditions by using an emergency O_2 supply and free-falling to a safer altitude.

Time of useful consciousness

Time of useful consciousness (TUC) is the period of time from the interruption of O_2 supply (or exposure to an O_2 poor environment) to the time when *useful* function is lost. When TUC is exceeded, the ability to take corrective action is lost. Aircrews are unable to don oxygen equipment or safely control the aircraft. It is important to emphasize that impairment occurs long before unconsciousness.

The average TUC figures listed below were established by observing individuals at different altitudes while at rest without supplemental oxygen. Exercise or physical activity considerably reduces TUC. For example, at FL 250, the average TUC is 3 to 5 minutes. Yet, aircrew busy in flight (increased respiration) may have only one to 1.5 minutes at that same altitude before TUC is exceeded. In the table below you will notice that as altitude increases, TUC decreases.

Altitude	Time of Useful Consciousness
FL 180	20–30 minutes
FL 180	10 minutes
FL 250	3–5 minutes
FL 280	2.5–3 minutes
FL 300	1–2 minutes
FL 350	0.5–1 minutes
FL 400	15–20 seconds
FL 430	9–12 seconds

It is also important to understand how a rapid decompression (RD) will affect TUC. An RD is an explosive loss of pressurization. For example, if an aircraft is pressurized to 8,000 feet, cruising at 30,000 feet, and the aircraft loses a window, the aircraft will experience RD. There is usually a loud explosive noise, condensation in the air, wind, and possibly flying debris caused by the rapid pressure change. TUC decreases by as much as 50 percent when an RD occurs. At extremely high altitudes, aircrew experiencing an RD will only have seconds to don O_2 equipment before exceeding their TUC. Trainees should be able to recognize an RD and safely don oxygen equipment in such event.

Objective and subjective signs and symptoms of hypoxia

Altitude chamber flights permit trainees to experience and identify their individual symptoms of hypoxia under controlled conditions that also allows them to observe signs in others. Subjective symptoms of hypoxia are described as inward symptoms experienced by the individual. Several subjective symptoms of hypoxia are air hunger, blurred vision, and hot and cold flashes.

Hypoxia can be very difficult to detect because it is insidious. If there is an undetected slow decompression, symptoms come on slowly, and it can be extremely difficult to detect. Consequently, it is critical that all aircrew members be aware of not only their own subjective symptoms but also the objective symptoms of those around them. The objective signs and symptoms of hypoxia are those someone else observed in another person. A common objective symptom is *cyanosis* or a bluish discoloration of the skin most apparent in the fingernail beds and the lips.

Objective Signs of Hypoxia	Subjective Symptoms of Hypoxia
Cyanosis	Air Hunger
Increased respiration	Apprehension
Mental Confusion	Fatigue
Impaired Judgment	Nausea
Muscle Incoordination	Headache
Belligerence	Dizziness
Euphoria	Hot and Cold Flashes
Unconsciousness	Numbness
	Visual Impairment
	Tingling

The subjective symptom of air hunger may lead to the objective sign of increased rate and depth of breathing that can be easily noticed by others. Auditory cues that indicate confusion and lack of responsiveness are especially important for isolated aircrews that have no visual contact with other aircrew members.

Progression of hypoxia

Progression of hypoxia varies tremendously, depending on altitude, rate of ascent, duration of exposure. Hypoxia ranges from mild to severe. Air Force Instruction 11-202, *General Flight Rules*, volume 3, requires supplemental O_2 use above 10,000 feet. However, night vision can be affected as low as 5,000 feet. Pulse and breathing rate and depth also may increase.

Visual impairment and reduced judgment become more pronounced as altitude increases. With increased altitude, thinking becomes slow and muddled and calculations are unreliable. Memory is faulty, particularly for events in the immediate past. Reaction time is dangerously delayed in an environment where split-second decisions are often necessary. Frequently, trainees note impaired vision as a symptom but generally not until blurred or tunnel vision (complete loss of peripheral vision) occurs. The eyes can be dangerously affected long before aircrews or trainees recognize these dramatic symptoms.

Hypoxia effects on the nervous system become apparent in the 12,000 to 15,000 feet range. Impaired efficiency can be observed after 10 to 15 minutes. Drowsiness, loss of judgment, and loss of coordination become significant. Prolonged exposure can produce a headache.

At FL 180, mild hypoxia symptoms develop within five minutes and gradually progresses until TUC is exceeded (within 20 to 30 minutes). This altitude is ideal for demonstrating the effect of a low-oxygen environment on night vision. In a reduced-light environment, trainees use color charts to help look for visual changes. Most trainees are unaware that their vision is affected to such an extent.

Trainees' best opportunity to experience hypoxia symptoms is at FL 250 during the chamber flight. The students' main concern during this training is to experience and learn to recognize their individual hypoxia symptoms. Be sure to emphasize that hypoxia symptoms are usually easier to identify in the chamber without the distraction of flight duties. Dizziness, sleepiness, air hunger, headache, a sense of well-being (euphoria), and reduced vision are symptoms most frequently noted. Due to the insidious nature of hypoxia, coupled with the fact that aircrew members are concentrating on flight maneuvers and crew responsibilities during flight, it is much more likely for them to overlook their symptoms. The key is to impress upon trainees the need to respect the danger of hypoxia. Aircrews must constantly look for these symptoms and maintain good O_2 discipline.

Hypoxia demonstrations are most effective when trainees are divided into two groups. One group experiences hypoxia while the other group observes objective signs of hypoxia. Aircrews may note objective signs such as changes in personality (euphoria or belligerence), loss of muscle coordination, and cyanosis. As an inside observer, closely watch for signs indicating trainees are exceeding TUC. A total loss of coordination; an empty, vacant expression; or no intelligible response on the intercom may indicate exceeded TUC. Place trainees on O_2 immediately when they exceed TUC. Trainees may display muscle twitching or spasms, and on occasion, some momentarily stop breathing (*oxygen paradox*) when treated with 100 percent O_2. Oxygen paradox is generally not a problem. However, explaining that this is nothing more than the body's reaction to the sudden increase in alveolar oxygen can relieve anxiety in other trainees. Oxygen paradox resolves very quickly as the body adjusts to the 100 percent O_2. We cover oxygen paradox in more detail in unit 4 of this volume.

Preventing hypoxic hypoxia

Prevent hypoxic hypoxia (altitude hypoxia) by providing individuals sufficient O_2 to maintain safe oxygen-blood saturation levels. As previously stated, normal O_2 blood saturation is about 98 percent. The human body can tolerate a drop in O_2 blood saturation to 87 percent, equivalent to breathing ambient air at 10,000 feet. Adequate O_2 blood saturation can be maintained with O_2 equipment, aircraft pressurization systems, or a combination of both at flight altitudes above 10,000 feet.

Supplemental oxygen requirements

Supplemental O_2 is required at decreased ambient pressures. Pressure-demand O_2 regulators maintain O_2 blood saturation levels equal to breathing ambient air at 5,000 feet or below. This equipment satisfies tissue O_2 requirements up to FL 430. With the regulator's diluter-demand lever in the "NORMAL" position, the regulator senses altitude increases and automatically delivers the correct amount of supplemental O_2. The regulator delivers 100 percent O_2 automatically at FL 320. Aircrew members must use 100 percent O_2 above FL 340 to maintain a safe O_2 saturation level. Breathing 100 percent O_2 at FL 340 maintains oxygen blood saturation levels equal to breathing ambient air at SL. However, oxygen-blood saturation levels will drop when breathing only 100 percent O_2 above FL 340. For example, oxygen-blood saturation levels at FL 400 are equal to breathing ambient air at 10,000 feet. Above FL 400, oxygen-blood saturation falls below safe levels even with 100 percent O_2. In order to compensate for low oxygen-blood saturation, 100 percent O_2 is supplied under positive pressure. Pressure-demand regulators are used to satisfy this requirement for aircrews.

Cabin pressurization

Most multiplace aircraft maintain cabin altitudes below 10,000 feet during most operations to prevent hypoxia. For example, multi-place aircraft are generally pressurized below 10,000 feet, eliminating aircrew and passenger need for O_2 masks. However, O_2 equipment is available should the aircraft lose pressurization. Although fighter aircraft have pressurization systems, cabin altitudes frequently exceed 10,000 feet. Therefore, aircrews are required to continuously use an O_2 mask in conjunction with aircraft pressurization systems.

213. Hyperventilation causes, signs, and symptoms

Hyperventilation can also seriously affect aircrew performance. It is not uncommon for trainees, during initial chamber flights, or aircrew exposed to stressful and unfamiliar flight conditions, to hyperventilate. Inside observers must be familiar with the causes, signs, symptoms, and treatment of hyperventilation.

Causes of hyperventilation

Hyperventilation is the abnormal increase in rate and/or depth of respiration resulting in excessive CO_2 loss. Excessive loss of CO_2 causes a disturbance in the delicate blood acid-base balance, resulting in eventual loss of consciousness. Anxiety, nervousness, or apprehension caused by a stressful situation may result in hyperventilation. Positive-pressure breathing is also a likely cause.

Hyperventilation at altitude

Lung and blood O_2 partial pressure is reduced below minimum acceptable levels with hypoxia onset above 10,000 feet. Decreased O_2 levels stimulate the respiratory center via chemoreceptors in the aorta and carotid arteries. This stimulation causes increased breathing in an attempt to make up for O_2 deficiency. *Hypocapnia*, or the state of reduced carbon dioxide in the blood, occurs if the resulting hyperventilation is permitted to continue. Hypocapnia occurs when blood CO_2 levels fall below normal levels, creating a constriction of blood vessels leading to the brain. This vasoconstriction reduces circulation and causes blood pooling within the brain. Decreased O_2 within the pooled blood causes stagnant hypoxia in brain tissues. Unconsciousness may result from the cumulative effects of hypoxic and stagnant hypoxia of brain tissues.

Pressure breathing

Active inhalations and passive exhalations characterize normal breathing cycles. Pressure breathing from an O_2 regulator actually reverses the breathing cycle (i.e., passive inhalations and active exhalations). A reversed breathing cycle tends to cause overbreathing. Aircrew members eventually increase their rate and depth of breathing (hyperventilate) if overbreathing is not controlled. Overbreathing increases alveolar O_2 tensions and reduces the CO_2 level in the individual suffering the effects of hyperventilation. You can prevent hyperventilation by controlling the rate and depth of breathing while pressure breathing. It is important to prepare trainees for the uncomfortable and familiar sensation of breathing under positive pressure. To counteract the positive pressure from the regulator, they should be trained to allow the air to fill their lungs, pause, and then forcefully exhale. The more the instructor can prepare trainees for breathing under pressure in a low-stress environment, the more successful they will be in avoiding hyperventilation. If a student appears to be hyperventilating, a good technique to control respiration rate is to have the student talk.

Cerebral control

The brain stem maintains the automatic respiratory control for the body. This center can be overridden by the higher brain centers of the cerebral hemispheres. Examples of ways that the higher brain centers override the brain stem's respiratory control are voluntary control and the effects that emotions and pain have on breathing. Each is discussed separately.

Voluntary control

We are normally not conscious of respiratory rate because breathing does not require conscious effort. However, respiration rate can be voluntarily altered at will. Therefore, hyperventilation can be voluntarily induced or corrected by ensuring that the rate and depth of respiration are within normal limits.

Effects of emotions

Normal respiratory controls also can be subconsciously overridden. Fear, anxiety, stress, or tension, resulting from emotional or physical discomfort sometimes causes the normal control of breathing to be overridden. Emotion is probably the most frequent cause of hyperventilation during initial chamber flights and during initial aircrew flight training. It is probably the most common cause of hyperventilation in all types of flying.

Effects of pain

Pain closely parallels the effects of emotions, possibly predisposing individuals to overbreathe because of fear and apprehension. Hyperventilation can occur quickly when fear and apprehension are aggravated by physical discomfort. Pain-induced hyperventilation can also be regulated by voluntary control.

Signs and symptoms of hyperventilation

As with hypoxia, detection of hyperventilation depends on the ability to recognize objective signs and subjective symptoms. Trainees must recognize subjective symptoms, and inside observers must watch for objective signs in trainees.

Objective signs and subjective symptoms

The objective signs (observed by others) of hyperventilation include muscle twitching, muscle tightness, paleness, cold clammy skin, muscle spasms, rigidity, and unconsciousness. The subjective symptoms (experienced by trainees) include dizziness, faintness, slight nausea, numbness, coolness, muscle tremors, and tingling.

Similarity to hypoxia

Hyperventilation and hypoxia signs and symptoms are extremely difficult to differentiate due to the fact that they are very similar. Some symptoms of hyperventilation and hypoxia that are the same include faintness, breathing difficulty, muscle tightness, and feelings of apprehension. Fortunately, the recovery procedures are the same. However, there are two symptoms that are specific to hyperventilation. They are muscular spasms (*tetany*) and tingling usually experienced around the mouth and in the extremities. It is important to remember, though, in the high-speed flying environment, it is not advisable to try to differentiate between the two. Timely corrective procedures are the safest choices.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

212. Hypoxia types, causes, signs, and symptoms

1. Why is *hypoxia* a better term for oxygen deficiency in aircrew members than *anoxia*?

2. What are the four types of hypoxia?

3. Why would pneumonia cause hypoxic hypoxia?

4. Why does a loss of blood volume result in hypemic hypoxia?

5. In the case of anemia or use of plasma, what effect does this have on the blood?

6. Carbon monoxide combines very quickly with hemoglobin. How many times faster does carbon monoxide react as compared to oxygen?

7. What is a common cause of stagnant hypoxia for aircrews, and why?

8. Which two gases can cause histotoxic hypoxia?

9. Which type of hypoxia will you primarily be concerned with while working in this career field?

10. What is normally the first sensory function affected by hypoxia?

11. How does the body initially make up for lowered oxygen-hemoglobin saturation?

12. The cardiovascular and respiratory systems will make up for hypoxia until one reaches an altitude of how many feet?

13. After 15,000 feet in altitude, how will the body attempt to compensate for hypoxia, besides increasing respiration and heart rate?

14. What is usually the first obvious respiratory effect of hypoxia?

15. Why is physical fitness an important factor in individual tolerance?

16. What should aircrews do when feeling ill?

17. What may cause aircrews to experience an increased hypoxia onset rate during flight?

18. Your onset rate of hypoxia can be affected by the extreme cold of high-altitude egress. How can you compensate for this?

19. How were the average TUC figures established?

20. *Time of useful consciousness* (TUC) is a term for your mental and physical state after oxygen deficiency. At what altitude is the average TUC 3–5 minutes?

21. What is the purpose of chamber flights with regard to hypoxia?

22. Define *subjective symptoms*.

23. The subjective symptom of air hunger may lead to which objective sign?

24. At what altitude do the effects of hypoxia become apparent with regards to the nervous system?

25. After a prolonged exposure to altitudes between 12,000 and 15,000 feet, what would you expect as a side effect?

26. What teaching aid can you use to show the effect of hypoxia on night vision at FL 180?

27. During the hypoxia demonstration at FL 250 feet, what is the student's main concern?

28. Why would aircrew members tend to overlook their hypoxia symptoms?

29. What should be impressed upon trainees with regards to hypoxia? What should aircrews look for and maintain?

30. During the chamber mass-hypoxia demonstration, you split the students into two groups. What is the reason for this?

31. What objective signs and symptoms should an inside observer look for to determine if a student has exceeded their TUC?

32. Occasionally, a trainee may display muscle twitching or spasms when hypoxia is treated with 100 percent oxygen. What term best describes this reaction?

33. A pressure-demand regulator will maintain an adequate oxygen-blood saturation level to an altitude of how many feet?

34. At FL 400 with 100 percent oxygen in use, what is the altitude equivalent in terms of oxygen-blood saturation?

35. Most multiplace aircraft are pressurized to what altitude equivalent?

36. Why must aircrew members in fighter aircraft continuously wear oxygen masks?

213. Hyperventilation causes, signs, and symptoms

1. What causes hyperventilation?

2. What is hypocapnia?

3. What type of hypoxia occurs in brain tissues as a result of hyperventilation?

4. Why does improper pressure breathing sometimes induce hyperventilation?

5. During pressure breathing, what is the best way to prevent hyperventilation?

6. What are the three ways the higher brain centers of the cerebral hemispheres may override the brain stem’s automatic respiratory control?

7. How can hyperventilation be voluntarily corrected?

8. What is the most frequent cause of hyperventilation during initial chamber flights and during initial aircrew flight training?

9. Name the objective signs of hyperventilation.

10. Give examples of subjective symptoms experienced during hyperventilation.

11. Why are the symptoms of hyperventilation and hypoxia difficult to differentiate?

12. What two symptoms are unique to hyperventilation?

Answers to Self-Test Questions

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1. 1,200 miles.
2. Nitrogen, 78 percent and oxygen, 21 percent.
3. It decreases.
4. The decrease in temperature as one climbs to altitude from the earth's surface.
5. 760 mm Hg.
6. It allows a comparison of standard pressure indices to actual pressure measurements for instrument corrections.
7. Decrease.
8. Altitude of an object above MSL.
9. In flight levels (FL).
10. True altitude is the altitude above mean sea level (MSL), in which the aircraft altimeter must be adjusted slightly for local barometric conditions. Absolute altitude is the distance from the aircraft to the ground directly below and can be determined by subtracting the survey terrain altitude from the altitude of the aircraft above SL; it is expressed as altitude above ground level (AGL).

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1. The volume of wet gas expands and contracts in the hollow cavities of the body as atmospheric pressure increases or decreases and may result in physiological reactions such as ear and sinus pain and GI tract discomfort.
2. Trapped gas is always present in the body and must be considered for every flight pressurized or not because they may lead to potential physiological reactions if the gas is not allowed to escape and equalize.
3. Gas molecules exhibit rapid and random motion, but under high pressure these molecules become active and tend to migrate to areas of lower pressure.
4. Transfer of gases such as O_2 and CO_2 during respiration and O_2 and N_2 during denitrogenation.
5. Although the percentage of O_2 in the air remains constant at 21 percent during ascent, the partial pressure of O_2 decreases and may result in hypoxia due to the reduced force of O_2.
6. It explains why N_2 in solution in the human body at SL comes out of solution at 18,000 feet and forms excess bubbles that can lead to decompression sickness.
7. The pressure of gas within an O_2 cylinder varies directly with its temperature when the volume is constant so you need to be aware of the environmental temperature in order to properly store and use O_2 cylinders.
8. Add 273 to the Celsius temperature.
9. Because body temperature remains fairly constant.

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1. Trapped gas.
2. They experience variable levels of pain according to the amount of trapped gas and the elasticity of the organ affected.
3. 47 mm Hg.
4. Discomfort from gas within the gastrointestinal tract.
5. Approximately equivalent to the ambient atmospheric pressure.
6. Oxygen, carbon dioxide, nitrogen, and hydrogen sulfide.
7. Relieve the gas into the atmosphere by passing flatus or by belching.
8. Descend to a lower altitude.
9. The external, middle, and inner ear.
10. The stapes, incus, and malleus.
11. During descent.
12. It permits equalization of pressure between the middle ear and the outside pressure.

13. Into the nasal passages.
14. Swallow, yawn, or tense the muscles in the throat.
15. Close your mouth, pinch your nose shut, and blow through your nose.
16. Cavities in the bone of the skull lined with moist, mucous membrane.
17. Through tiny slit-like ducts or tubes into the nasal passages.
18. The frontal and maxillary sinuses.
19. Air moves back through the ducts into the sinuses.
20. In restored teeth or those with an existing disease.
21. It varies with the individual but is most likely to disappear at the same altitude that onset occurred.
22. A tumor, mucous, or a spasm
23. Air embolism, pneumothorax, or pneumomediastinum.
24. Air embolism.
25. Sharp pain in the chest, shortness of breath, and shock.
26. It has moved in the vessels and bronchi of the mediastinum.

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1. Reduced pressure on the body.
2. When a cabin decompression occurs.
3. During extra vehicular activity (EVA).
4. During ascent in flying or diving or a combination of the two within a short period of time.
5. Oxygen, nitrogen, and carbon dioxide.
6. Saturated with nitrogen.
7. Tissues to blood to alveoli.
8. The bubble to grow.
9. (1) The symptoms of DCS usually precede the appearance of bubbles;
   (2) Descent or repressurization in a hyperbaric chamber causes a reduction and elimination of bubbles, and generally a resolution of symptoms.
10. Because both of these gases have unique blood transport mechanisms.
11. Nitrogen diffuses slowly from denser tissues into the blood, does not bind to other molecules, is not exactly controlled, and is not consumed or excreted.
12. High-pressure spacecraft and low-pressure suits.
13. Yes, it will decrease the symptoms and can be used in tandem with recompression.
14. Off-loading is rapid earlier, but the rate decreases with time.
15. Because of extravascular or intravascular bubble formation in the skin.
16. Itching, stinging, pin pricks, hot or cold sensations.
17. Because of interruption in circulation.
18. A deep and throbbing pain.
19. It tends to radiate along the limb.
20. Debilitation, collapse, or additional DCS symptoms.
21. A sharp pain under the sternum that increases in severity with each breath. The individual may have a feeling of suffocation, apprehension, and fatigue.
22. The patient may be pale, sweating, fatigued, faint, and/or having a dry, progressive cough.
23. The lungs.
24. In the brain or spinal cord.
25. The vision.
26. Circulatory shock.
27. 13,000 feet.

28. FL 250.
29. Incidence is extremely variable and dependent on many, and often immeasurable, factors.
30. A rapid descent.
31. Slow rates permit excess nitrogen to remain in liquid form.
32. Carbon dioxide off-loaded from the muscles.
33. DCS during a subsequent altitude exposure.
34. Injury may cause blood perfusion changes or deposit scar tissue.
35. The incidence of DCS increases with age.
36. Serum cholesterol level and perhaps clotting factors.
37. Because the diffusion gradient off-loads N_2 more slowly and DCS probability increases.
38. Yes. Repeated, rapid exposures have a tendency to increase incidence of DCS.

212

1. Anoxia is a total lack of oxygen and hypoxia is a deficiency. In aircraft flights, body tissues are not entirely without O_2.
2. Hypoxic, hypemic, stagnant, and histotoxic.
3. Alveolar space fills with fluid, preventing the absorption of oxygen.
4. Less oxygen reaches the tissues with the loss of volume.
5. It reduces the blood’s oxygen-carrying capacity.
6. 250 times.
7. Positive G-forces, because they cause blood to pool in the lower extremities.
8. Cyanide and carbon monoxide.
9. Hypoxic (altitude) hypoxia.
10. Vision, as the retina is a direct extension of cerebral tissue.
11. By increased cardiovascular and pulmonary activity.
12. 10,000 feet.
13. By bypassing the extremities and increasing blood flow to the brain and heart.
14. Increased rate and depth of breathing.
15. Physically fit individuals normally have higher altitude tolerances than obese or physically unfit individuals.
16. Consult with a flight surgeon.
17. A rapid rate of ascent if flying unpressurized or if there is a loss of pressurization such as a rapid decompression.
18. Using supplemental oxygen and free-falling to a safer altitude.
19. By observing individuals at different altitudes while at rest without supplemental oxygen.
20. At FL 250.
21. To allow students to experience and identify their individual hypoxia symptoms under safe controlled conditions along with observing these signs in others.
22. Symptoms felt or experienced by the hypoxic individual.
23. Increased rate and depth of breathing.
24. Between 12,000 and 15,000 ft.
25. Drowsiness, loss of judgment, loss of coordination, and a headache.
26. A color chart.
27. To experience and recognize their individual symptoms of hypoxia.
28. Due to the insidious nature of hypoxia and the fact that aircrews are concentrating on flight maneuvers and crew responsibilities.
29. (1) The need to respect the danger of hypoxia.

(2) Symptoms and good oxygen discipline.

30. Separate groups allow students to observe the objective symptoms of hypoxia.
31. Total loss of coordination; empty, vacant expression; or no intelligible response on the intercom.
32. Oxygen paradox.
33. FL 430.
34. 10,000 feet.
35. To 10,000 feet or lower.
36. Cabin altitudes frequently exceed 10,000 feet.

213

1. An abnormal increase in respiration, resulting in CO_2 loss.
2. A condition where the carbon dioxide level falls below its normal level in blood.
3. Stagnant.
4. Due to the reversed breathing cycle, the subject may overbreathe and hyperventilate.
5. By controlling the rate and depth of breathing.
6. Voluntary control, effects of emotions, and effects of pain.
7. By ensuring the rate and depth of respiration are within normal limits.
8. Emotion.
9. Muscle twitching, muscle tightness, paleness, cold clammy skin, muscle spasms, rigidity, and unconsciousness.
10. Dizziness, faintness, slight nausea, numbness, tingling, coolness, and muscle tremors.
11. The signs and symptoms are very similar.
12. Muscular spasms (tetany) and tingling.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

Do not return your answer sheet to the Extension Course Program (A4L).

21. (208) As altitude increases, barometric pressure
    a. decreases.
    b. increases.
    c. stays the same.
    d. is not predictable.

22. (208) With regard to barometric pressure, which of these is not a unit of measure?
    a. Feet of elevation.
    b. Pounds of mercury.
    c. Pounds per square inch.
    d. Millimeters of mercury.

23. (208) True altitude during flight is measured by
    a. using a radar altimeter.
    b. using the preset barometric pressure on the altimeter.
    c. setting the aircraft altimeter to the standard barometric pressure.
    d. adjusting the aircraft altimeter slightly to reflect the local barometric pressure.

24. (208) The US Standard Atmospheric Pressure Table lists sea level as
    a. 47 in Hg.
    b. 47 mm Hg.
    c. 29.92 in Hg.
    d. 29.92 mm Hg.

25. (209) Which law explains the effects of pressure change on the trapped gases within the body?
    a. Boyle’s.
    b. Henry’s.
    c. Charles’.
    d. Gaseous diffusion.

26. (209) Which physiological problem is directly related to Henry’s Law?
    a. Decompression sickness.
    b. Decreased respiration.
    c. Increased respiration.
    d. Gas expansion.

27. (210) The partial pressure of water vapor within the body is directly related to the body’s
    a. size.
    b. mass.
    c. temperature.
    d. fat percentage.

28. (210) The normal partial pressure of water vapor within the body is constant at
    a. 45 mm Hg.
    b. 47 mm Hg.
    c. 50 mm Hg.
    d. 55 mm Hg.

29. (210) Of those gases found in the body's gastrointestinal tract, the highest percentage is
    a. carbon dioxide (CO_2).
    b. hydrogen sulfide.
    c. nitrogen (N_2).
    d. oxygen (O_2).

30. (210) What two sinus cavities are most often involved with barometric pressure changes?
    a. Maxillary and ethmoidal.
    b. Maxillary and bilateral.
    c. Frontal and ethmoidal.
    d. Frontal and maxillary.

31. (211) Breathing 100 percent oxygen prior to exposure to low barometric pressure reduces the incidence of decompression sickness by
    a. increasing the oxygen level.
    b. increasing the nitrogen level.
    c. decreasing the nitrogen level.
    d. decreasing the carbon dioxide level.

32. (211) In addition to skin symptoms, bends, and chokes, other signs of decompression sickness include
    a. respiratory and neurological manifestations.
    b. neurological and circulatory manifestations.
    c. respiratory and circulatory symptoms.
    d. neurological and vision symptoms.

33. (211) What evolved gas disorder is characterized by symptoms of sharp, substernal pain that increases in severity
    with inhalation, feeling of suffocation, and a dry nonproductive cough?
    a. Chokes.
    b. Bends.
    c. False chokes.
    d. Neurological manifestations.

34. (212) An individual's time of useful consciousness (TUC)
    a. decreases as altitude increases.
    b. decreases as altitude decreases.
    c. remains constant as altitude increases.
    d. remains constant as altitude decreases.

35. (212) Objective signs of hypoxia are those that are
    a. inward signs.
    b. outward signs.
    c. invisible symptoms.
    d. noticed by the subject.

36. (213) When a person hyperventilates due to hypoxia, what type of hypoxia does this cause?
    a. Stagnant.
    b. Hypoxic.
    c. Hypemic.
    d. Histotoxic.

37. (213) Which one of these is an objective sign of hyperventilation?
   a. Tingling.
   b. Numbness.
   c. Slight nausea.
   d. Unconsciousness.

Please read the unit menu for unit 3 and continue. ➔

Student Notes

Unit 3. Coping with Stress and Other Hazards of Flight

UP TO THIS POINT, we have discussed the dangers of the upper atmospheres and flight. While that environment can be brutal at times and life threatening, the actions we take on the ground before we fly can either reduce or multiply its affect. So, in this unit we begin with the human factors that we can voluntarily control: self-imposed stressors.

3–1. Human Factors

This section explains how the stresses aircrew members place on themselves can affect their performance in-flight. This area of instruction cannot be overlooked due to the consequences an aircrew member may experience if ignored. We conclude the discussion by looking at how aircrew members can overcome these stresses and remain focused to perform their duties in or out of the aircraft.

214. Self-imposed stressors

The concept of *human factors* covers a wide range of physiological and psychological topics attempting to explain why aircrew members have mishaps. A person's capacity to cope is decreased by self-imposed stresses. Therefore, we must understand the stresses that can occur in an aircrew member in order to teach others how to avoid and cope with them. The information within this unit of instruction is designed to help you understand the basic principles behind each stressor. The ability to relate experience, knowledge, and a "cause and effect" relationship is vital to understanding self-imposed stressors.

In the operational world of military aviation a crew member who catches the common cold or is diagnosed with the flu is not authorized to take even one of many over-the-counter (OTC) drugs available through civilian and military chain stores. Just as these restrictions affect crew members, aerospace physiology (AP) personnel are prohibited from self-medicating. Several Air Force instructions and medical standards (AFI 48-123, *Medical Examinations and Standards*) contain explicit direction prohibiting the use of OTC drugs. More importantly, conducting flying operations after being prescribed any controlled or noncontrolled medications is cause for serious alarm for all crew members in and out of the aircraft. In AFI 11–202, *General Flight Rules*, volume 3, it states the following: "A person must not act as a crewmember of an aircraft: While under the influence of or using a drug that affects the ability to safely perform assigned duties. Aircrew may not self-medicate except IAW AFI 48-123, *Medical Examinations and Standards*" (p. 22, par. 5.1.4.2).

Self-medication

Over-the-counter drugs are medicines that may be sold without a prescription, in contrast to prescription drugs. The name "over-the-counter" is somewhat confusing to some since these items can be found on the shelves of stores and bought like any other packaged product in some countries, while in others they may be bought OTC from the pharmacy. In contrast, prescription drugs are sold or dispensed via a military or civilian pharmacy counter. The term likely dates back to before self-service shopping became common when most goods were obtained by requesting them from a clerk at a sales counter; while prescription drugs required a visit to the doctor first—these drugs could be purchased "over the (sales) counter" just like other goods. Some medicines considered safe in general terms may be available in general stores, supermarkets, gas stations, and so forth.

The rules vary considerably from country to country. In the United States, the manufacture and sale of OTC substances is regulated by the United States Federal Food, Drug, and Administration, better known as the FDA.

As a general rule, OTC drugs are primarily used to treat a condition that does not require the direct supervision of a doctor and must be proven to be reasonably safe and well tolerated. OTC drugs are usually also required to have little or no abuse potential. One of the oldest OTC drugs is aspirin.

Effects of over-the-counter drugs

OTC drugs interfere with or modify normal body functions in different ways. The effects of OTC drugs are divided into primary, side, synergistic, and idiosyncratic effects.

Primary effect

The primary effect of each type of drug is the desired or intended effect of the drug on the individual. For instance, a person takes an OTC decongestant because they are congested. The primary effect of the decongestant is to dry up the nasal passages and sinuses.

Side effects

The side effects are those effects known to accompany a drug but are additional to its primary or desired effect. For example, if you take a decongestant to clear up your sinuses, you may also experience the side effects of an increased heart rate and blurred vision.

Synergistic effects

These occur when the primary or side effect of a drug is modified in function or intensity when taken in combination with another drug. The effect of the drugs combined is greater than would be expected from the individual drugs (in a synergistic reaction, the sum of the whole is greater than the sum of the parts, or 1 + 1 = 3). For example, combining a decongestant with caffeine increases the stimulant effect above the normally expected level.

Idiosyncratic effects

These are effects that are unusual and unexpected. Just as certain individuals have unexpected allergic reactions to types of food, some individuals may have unexpected adverse reactions to certain types of drugs. Although rare, an aircrew member self-medicating with an OTC drug may experience an unexpected reaction to a drug.

Types of over-the-counter drugs

The kinds of OTC drugs that aircrew members take contain chemicals that fall into several broad categories. These categories are decongestants, antihistamines, vasoconstrictors, painkillers, and diet pills. Some OTC drugs contain more than one type of these chemicals. Let's look at each of these categories.

Decongestants

Decongestants are normally found in cold remedies and act as a stimulant. They shrink inflamed mucous membranes and clear up nasal passages and sinuses.

The side effects of decongestants are detrimental to aircrew members. They can produce shakiness, increased heart rate, blurred vision, increased dehydration, dizziness, nausea, and headaches.

Therefore, self-medicating with decongestants increases physiological stress and decreases an aircrew member’s capacity to cope.

Antihistamines

These reduce nasal congestion due to allergies and colds. They are normally found in OTC drugs combined with other compounds such as decongestants. Antihistamines relieve congestion by blocking the release of histamine, which is responsible for swelling of the nasal mucous membranes in an allergic reaction. The result is a decrease in mucous production and possible relief from the itching and watering of the eyes.

An undesirable side effect of antihistamines is the depressant nature they have on the central nervous system (CNS). Drowsiness is the most common effect, but they also cause diminished alertness and decreased reaction times.

Vasoconstrictors

These are topical drugs sprayed in the nose (nasal sprays). They act to constrict blood vessels in the nose and sinuses, resulting in a reduction of inflammation and swelling. The dangers of using vasoconstrictors are two-fold. First, dizziness, blurred vision, tremors, and headaches may occur if a vasoconstrictor is used prior to flight. There is also the chance of the medication wearing off prior to descent and landing, allowing the tissues to swell and increasing the chance of blocked sinuses or ears. The second danger occurs after the prolonged use (roughly three days) when the nasal tissue becomes addicted to the drug. If vasoconstrictor use is discontinued, after the tissues are addicted, the tissues increase mucous production.

Painkillers

Almost everyone uses painkillers. Primary OTC painkillers are aspirin or acetaminophen (e.g., Tylenol®). Aspirin is used to relieve mild pain or headache and to relieve fever. Aspirin and acetaminophen can cause stomach irritation as a side effect. Ibuprofen is a third type of OTC painkiller. Unfortunately, the side effects are more serious than the two previous OTC drugs. Side effects may include dizziness, skin rash, or blurred vision.

Diet pills

Diet pills contain the same medications found in decongestants. They are stimulants with unwanted side effects. These include nervousness, tremors, increased blood pressure and heart rate, dehydration due to increased sweating, and sleep disturbances. There is also a significant synergistic effect when diet pills are used in conjunction with caffeine. The effect includes a marked increase in blood pressure and increased dehydration.

If a person needs to lose weight, it can be done without the use of diet pills. A sensible diet and a regular exercise program are a much healthier and safer alternative.

Types of controlled drugs

A controlled (*scheduled*) drug is one that use and distribution is tightly controlled because of its abuse potential or risk. *Controlled* drugs are rated in the order of their abuse risk and placed in “*schedules”* by the Federal Drug Enforcement Administration (DEA). The drugs with the highest abuse potential are placed in Schedule I, and those with the lowest abuse potential are in Schedule V. Some examples of drugs in these schedules are as follows:

Schedule I

These are drugs with a high abuse risk. These drugs have NO safe, accepted medical use in the United States. Some examples are heroin, marijuana, and crack cocaine.

Schedule II

Like the Schedule I drugs, Schedule II drugs have a high abuse risk but also have safe and accepted medical uses in the United States. These drugs can cause severe psychological or physical dependence. Schedule II drugs include certain narcotic, stimulant, and depressant drugs. Some examples are morphine, oxycodone (Percodan®), methylphenidate (Ritalin®), and dextroamphetamine (Dexedrine®).

Schedule III, IV, or V

These are drugs with an abuse risk less than Schedule II and also have safe and accepted medical uses in the United States. Schedule III, IV, or V drugs include those containing smaller amounts of certain narcotic and non-narcotic drugs, antianxiety drugs, tranquilizers, sedatives, stimulants, and non-narcotic analgesics. Some examples are acetaminophen with codeine (Tylenol® No.3), paregoric, hydrocodone with acetaminophen (Vicodin®), and diazepam (Valium®).

Alcohol use

Perhaps the oldest drug known, alcohol is a legal drug having toxic effects on the body. It is a central nervous system depressant. Alcohol is absorbed through the stomach and upper tract of the small intestine and distributed throughout the body by the circulatory system. The concentration of alcohol in the brain and nervous tissue rapidly approaches the same concentration as in the blood because of the extensive blood flow through these tissues. As the alcohol reaches the tissues, it's absorbed by the cells and causes histotoxic hypoxia by disrupting cellular metabolism.

Short-term effects

As a result of the histotoxic effects of alcohol on the brain and nervous tissues, higher brain function is impaired. Marked psychological reactions are experienced, the most common being the impairment of judgment and performance, reduction of inhibitions, abnormal behavioral shifts, and a bolstered sense of immorality. Physiologically, the person becomes anesthetized and suffers degraded sensory and motor skills, decreased visual acuity, degraded communication ability, and loss of balance.

Alcohol has other effects on the body that are of particular concern to aircrew members. Alcohol affects the fluid in the inner ear that is used for orientation. This effect may contribute to spatial disorientation and airsickness. Additionally, small amounts of alcohol are sufficient to significantly disrupt sleep patterns, leading to mental and physical fatigue.

Alcohol, being a sedative, deprives the body of receiving the necessary mental restorative sleep called rapid eye movement (REM) sleep. Failure to achieve REM (or deep) sleep leads to attention problems and decreases an aircrew member's ability to cope with in-flight stresses.

Residual effects

The range of effects depends on the amount of alcohol ingested. The body metabolizes pure alcohol at a constant rate of one ounce in three hours. Therefore, by drinking a six-pack of beer (72 oz.), six glasses of wine (18 oz.), or six shots of whiskey (6 oz.), a person ingests approximately three ounces of alcohol (0.5 oz. of alcohol per 12 oz. beer, 3 oz. of wine, or 1 oz. of distilled spirits). In this situation, it takes the body at least nine hours to metabolize the alcohol.

AFI 11–202, *General Flight Rules*, volume 3, states the following: "A person must not act as a crewmember of an aircraft: While under the influence of alcohol or its after effects. Alcohol and its after effects can adversely affect flight duties that impact safety of flight. Aircrew shall not consume alcoholic beverages within 12 hours of takeoff" (p. 22, par. 5.1.4.1).

Therefore, aircrew members can calculate the amount of alcohol they drink, stop drinking 12 hours prior to takeoff, and be legal and safe, right? Unfortunately no, it is not that simple. Remember, "…while under the influence of alcohol *or its after effects*." This statement means that if an aircrew member is suffering from a hangover—or even a headache—as the result of alcohol, he or she is not legal to fly. The bigger picture is not one of legality but safety. A person may be legal after 12 hours, but is it safe?

When alcohol is consumed, it disrupts the body's ability to regulate water and leads to dehydration. The production of antidiuretic hormone (ADH) decreases, causing the body to think there is more water in the system than required. Therefore, water is lost through frequent urination. When this excessive urination happens, water is lost from the spaces between cells (interstitial spaces) and tissues shrink, creating abnormal tension on body organs. This abnormality is particularly prevalent in the tissues surrounding the brain, resulting in a painful headache. Additionally, your body is fatigued and communicating that you must rest and recuperate. Unfortunately, the only cure for a hangover is time, rest, drinking plenty of nonalcoholic fluids (preferably water), and eating a balanced diet.

The best method to avoid the dilemma of suffering a hangover and the residual effects of alcohol is abstinence. If this option is unrealistic or undesirable, moderation of alcohol intake, drinking plenty of water with the alcoholic drink, and not drinking 24 hours prior to flight increases your ability to successfully complete a mission.

Basic facts about tobacco

Tobacco use is the leading preventable cause of premature death in the United States. It is estimated that directly or indirectly, tobacco causes more than 400,000 deaths in the US annually, a figure that represents nearly 20 percent of all US deaths. These deaths have been attributed to a number of conditions defined as tobacco related, including heart disease (115,000 deaths), cancer (136,000), chronic pulmonary disease (60,000), and stroke (27,000). According to a study published by the British medical journal *The Lancet*, the rate of tobacco-related mortality throughout the entire developed world also averages about 20 percent of all deaths.

There are approximately 47 million smokers in the US**.** About 23 percent of adults smoke as well as about 30 percent of adolescents. It is widely acknowledged that people who haven't used tobacco by age 21 are likely to remain nonsmokers. What is undeniable, however, are statistics showing that the average age of first tobacco use in the US is 13.

Tobacco is a plant that comes in two varieties, nicotiana tabacum and nicotiana rustica. Nicotiana tabacum is a South American herb with leaves containing 2–8 percent nicotine and serves as the source of smoking and smokeless tobacco and is the basis of huge health problems.

This plant is classified in the nightshade family, which also includes potatoes, tomatoes, eggplant, and red peppers. All contain nicotine. However, the concentration of nicotine in those vegetables is far lower than the level in tobacco.

Nicotiana rustica is the most cultivated of the two and the source of all the tobacco produced in the US. The raw leaves are dried and shredded and then rolled into cigarettes or cigars or packaged as pipe or chewing tobacco or as snuff. Tobacco is the only organic source of nicotine, which is its addicting agent. In addition to nicotine, tobacco smoke contains some 4,000 different gases and particles, including "tar," a conglomeration of many chemicals, which is especially harmful to the lungs. Among the harmful gases in tobacco smoke are nitrogen oxide, carbon monoxide, and cyanide. More than 40 carcinogens—chemicals capable of causing cancer— have been identified in tobacco smoke.

Nicotine

Nicotine is classified as a drug of abuse because of its addictive characteristics. Nicotine is also a highly toxic drug. For example, if 60 milligrams of nicotine (an amount approximately the size of a match head) is ingested, it is sufficient to cause death in humans within minutes. The amount of nicotine in three average cigarettes can cause death if injected intravenously.

Smoking is the primary means by which aircrew members expose themselves to nicotine. Nicotine is readily absorbed by the lungs and reaches the brain within eight seconds after inhalation. Nicotine acts as a CNS depressant but, if combined with caffeine, it has the opposite effect (stimulant).

With the increased social stigma attached to smoking and the increased awareness of the health hazards associated with it, many people think that switching to smokeless tobacco is a favorable alternative. Nicotine is not absorbed well in the mouth and if swallowed causes severe gastric upset and vomiting. Unfortunately, chewing or dipping tobacco increases the incidence of mouth, gum, tongue, and cheek cancers.

Carbon monoxide

Carbon monoxide (CO) is one of the major by-products of tobacco smoke. The danger to a smoker is the effects on the oxygen-carrying capacity of the blood (hypemic hypoxia). CO binds to hemoglobin in the red blood cells roughly 200 to 250 times greater than oxygen. Smoking three cigarettes is sufficient to raise the body's physiological altitude 5,000 to 7,000 feet because of the increased amount of CO in the blood. Your visual acuity is decreased because of decreased oxygen transport to the eyes.

The effect of smoking on the aircrew member is decreased resistance to hypoxia because of the CO load on the red blood cells. Motor skills also may be affected because of the effect of nicotine on the nervous tissues and peripheral blood vessels. The long-term effects of smoking include (1) increased stress on the respiratory system due to lung damage, (2) increased cardiovascular disease due to increased atherosclerosis (blocking and hardening of the arteries), (3) increased threat of forming blood clots, and (4) the danger of cancer and other long-term diseases caused by tobacco smoke by-products.

Nutrition

In order for your body to function, it must have fuel to burn. The fuel your body uses is a sugar called glucose. When you eat, the glucose liberated during the digestion process enters the bloodstream and is transported to the organs and the tissues needing it, or taken to the liver where it is stored as glycogen.

Nervous tissue (the nerves and the brain) and retinal tissue (photoreceptive tissue in the back of the eyes) are both dependent on blood sugar levels to function. When glucose levels in the blood fall below levels adequate to supply these tissues, the liver converts glycogen to glucose and releases it into the blood stream.

Hypoglycemia

Hypoglycemia results when the glycogen stores in the liver are depleted and there is not enough glucose in the bloodstream. Hypoglycemia means "low blood sugar" and has a variety of causes. The most common cause is skipping meals or eating foods that are predominately simple sugars. Other causes are high protein/low carbohydrate diets and diets where a person does not eat for extended periods of time (fasts or starvation diets).

Short-term symptoms

Some of the short-term symptoms include shakiness, decreased mental ability, physical weakness, irritability, fatigue, and sleepiness. These symptoms arise within four to six hours after your last meal.

Simple carbohydrates are absorbed into the blood quickly, causing the blood sugar level to rise dramatically. As the blood sugar rises, the brain senses there is too much glucose in the blood and signals the pancreas to release insulin into the bloodstream. This action removes glucose from the blood and takes it to the liver. Unfortunately, if the blood sugar levels are high, insulin removes most of the sugar, leaving a blood sugar level that is lower than before the sugar level changed.

However, if you have a meal of complex carbohydrates (pasta, potatoes, and whole wheat breads), hypoglycemia does not occur as quickly because of the rapid digestion and rapid metabolism of the simple sugars. Complex carbohydrates, proteins, and fat require more time for digestion and utilization. Their glucose is slowly released into the blood and stored in the liver over a period of time. This process avoids erratic shifts in metabolism.

Long-term symptoms

Long-term symptoms can include convulsions and fainting, usually occurring as a result of large swings in blood sugar levels. One of the major effects is a lapse in mental processes. When the brain cannot get the glucose it needs from the blood, it begins to slow down. For a crew member, common symptoms are math errors, checklist errors, and a decreased attention span, which cause miscommunication errors and perceptions errors.

Prevention

The number one defense against hypoglycemia is to eat regularly. When meals are missed, snacks of complex carbohydrates are more beneficial than candy bars and soft drinks.

The bottom line in nutrition and flying is to eat sensible meals containing complex carbohydrates low in fat, at regular intervals. If a person is accustomed to three meals a day, they should not try to skip a meal, since the glycogen stored in the liver may become depleted. Avoid fad diets or high protein/low carbohydrate diets designed to build bulk. A high protein, low carbohydrate diet can lead to serious metabolic problems. Furthermore, protein is an inefficient source of energy and is primarily used to build muscle and bone. Carbohydrates, however, are efficient sources of energy and are easily converted to glucose.

Dehydration

Dehydration, like hypoglycemia, is a major contributor to fatigue. There are varying degrees of dehydration, with different symptoms. Unfortunately, most people are constantly in a slightly dehydrated condition. When dehydration is combined with the flying environment, aircrew members fatigue quickly and are at a higher risk of experiencing decompression sickness, spatial disorientation, visual illusions, airsickness, loss of situational awareness, hypoxia, heat stress, and G-induced loss of consciousness.

The first common indication of dehydration is a sensation of thirst. At this point you are about 2 percent dehydrated or about 1.5 quarts (1.6 liters) low in water. If flying in a pressurized aircraft while 2 percent dehydrated, the level of dehydration increases rapidly. In an aircraft pressurized to 8,000 feet mean sea level (MSL), the cockpit air is about 9 to 11 percent humidity, causing water loss as you breathe. Combine this water loss with the diuretic effects of caffeinated drinks (coffee, colas) and you quickly become 3 percent or more dehydrated.

At a dehydration level of 3 percent, a person may experience sleepiness, nausea, mental impairment, and mental and physical fatigue. An aircrew member who flies after a night of consuming alcohol will reach the 3 percent dehydration level more quickly than other crew members because of the diuretic effects of alcohol. In addition to mental impairment, dehydration decreases the ability to do physical work (performing an anti-g straining maneuver for example).

The best way to prevent the problems of dehydration is to drink plenty of water before, during, and after a flight or physical activity. If water is unappealing or unpalatable, drinks that are low in sugar, nonalcoholic, and decaffeinated may be substituted. Many crew members prefer “sports drinks.” These drinks are fine, but they contain high amounts of salt that the body normally does not need. In addition, some of the drinks are heavily sugared. Usually, a person doesn’t lose enough salts or electrolytes during normal activity to warrant the use of these types of drinks. However, if “sports drinks” are preferred over water, then choose ones that are nonalcoholic, decaffeinated, and not heavily sugared. Staying hydrated before, during, and after flying or activity has a pronounced positive effect on a person’s performance.

Fatigue

Fatigue is defined as a state of diminished mental and physical efficiency. Unfortunately, fatigue is an insidious stressor because crew members usually become mentally fatigued before they become physically fatigued. Fatigue increases when aircrew members self-medicate, fly when they are sick, suffer from a hangover, are dehydrated, are hypoglycemic, or have any combination of these stressors. This fatigue affects their ability to safely accomplish their mission.

Fatigue is normally caused by the common day-to-day activities a crew member performs. However, problems also arise when the crew member fails to gain adequate rest. Then short-term fatigue evolves into long-term fatigue. Fatigue can be further divided into the two categories of acute and chronic fatigue.

Acute fatigue

Acute fatigue is short-term fatigue caused by normal daily activities of a crew member. It is remedied with a good night's sleep and rest. Unfortunately, if acute fatigue is not handled, chronic fatigue is created.

Chronic fatigue

Chronic fatigue is long-term fatigue caused by a variety of factors. For instance, when you fail to get adequate rest and sleep for several days, you become chronically fatigued. Other major causes of chronic fatigue in crew members include interrupted or poor sleep patterns, circadian rhythm shifts, illness, successive long missions with minimal recuperation time, and succumbing to self-imposed stresses.

Disruption of circadian rhythm

Everyone has a circadian (circa = about, dian =a day) rhythm or "body clock," which is roughly a 23 to 26 hour cycle of body functions. These cyclic body functions include endocrine gland function (hormones, etc.), metabolic processes, and body temperatures. These functions help control sleep-wake cycles and directly affect your alertness and performance. This cycle is repetitive day in and day out with little change. When your circadian rhythm is disrupted, chronic fatigue can become a major factor in your performance. There are two basic types of circadian rhythm problems: sleep cycle disruptions and circadian rhythm desynchronization due to rapid time zone changes.

Sleep cycle disruptions

Sleep cycle disruptions normally occur when aircrew members must fly during hours they would normally be sleeping. Examples are late night or very early morning flights. In addition, aircrew members involved with war games or exercises (remaining on duty for extended periods of time) suffer sleep cycle disruptions.

If you're forced to wake up early over a long period of time, seven to 10 days for instance, then you lose a part of your sleep cycle that is vital to mental alertness. You can experience mental fatigue, resulting in a reduced attention span and concentration and an increase in thinking and perceptual errors. You also fall asleep much easier and can experience "micro sleeps" in which the brain briefly slips into dream activity. Fortunately, micro sleeps last only a few seconds but are dangerous and indicate that you are very fatigued.

You can attempt to minimize or eliminate sleep cycle disruptions by adjusting the time you go to bed. The adjustment compensates, to a degree, for the early morning wake-ups, and your circadian rhythm eventually adapts to getting up early.

Circadian rhythm desynchronization

This problem is commonly known as "jet lag." It occurs when you cross time zones (transmeridian travel). For the aircrew member, jet lag is a serious problem that can jeopardize flight safety. Physiologically, the body requires 24 hours to completely recover from every one-hour shift in time zone. To nonflyer crew members who are changing permanent-duty assignments, this time zone shift is not a problem since they stay in that location and do not need to fly. However, it is a problem for aircrew members. They may not be able to take the required time to completely recover from the time shift. Operational demands rarely permit aircrew members numerous days off to resynchronize.

For an aircrew member who does not remain in one time zone for more than 24 hours, the problem of circadian rhythm desynchronization is compounded. Its negative effects, and subsequent sleep loss, on the member's ability to function mentally and physically are critical. Most of the problems relate to decreased mental information-processing abilities, decreased mental agility, impaired judgment and decision-making skills, decreased communication and problem-solving skills, and increased irritability.

When you change time zones, you basically have four options at your disposal. You should be the one to decide which one(s) to use.

1. Stay on home time.
2. Slowly adapt to the new time zone naturally.
3. Force your routine to conform to the local time in order to rapidly adapt to the new time zone.
4. Combine aspects from the first three.

Other variables affecting fatigue

In addition to sleep cycle and circadian rhythm disruptions, there are other variables you should consider. These are factors like the direction in which you are traveling, the number of time zones you cross, the amount of time between flights, the difficulty of the flights, and the type of food available at each stop.

Direction of travel

Transmeridian flight involves traveling east or west across different time zones. If you travel eastbound, you are essentially traveling ahead of time.

Aircrew members experiencing an eastbound circadian shift have trouble falling asleep at local times, trouble rising at normal local times, and lose mentally restorative sleep. These problems are similar to those associated to westbound travel with one major problem added. Because their body clock is slow to respond naturally to the new time zone (24 hours to adapt to a one-hour change in time), they do not obtain the sleep necessary to correct for fatigue.

Your body has an easier time adjusting to westbound travel. Circadian desynchronization is still evident, but the physiological signs are not as severe as eastbound travel. The primary reason westbound travel is easier is that you're traveling backward in time. The effect is that you get tired earlier in the day and wake up earlier in the morning. The result is that you're mentally efficient early in the mornings, but your capabilities decrease more rapidly toward the afternoon. It still may take you a few days to adapt naturally to the new time zone, but you can tolerate the physiological changes better than if you were traveling east.

If your direction of travel is north or south, the time zone does not change, so there is no effect on circadian rhythm.

Number of time zones

Consider the number of time zone changes. This gives you an idea of the degree of jet lag you are going to encounter and helps you decide how to deal with its effects. If you fly eastward and only cross three time zones, you may not experience serious circadian rhythm desynchronization. However, if you fly to Saudi Arabia (11 hours ahead of a west-coast base), you may experience serious performance decrements within a day or two of your arrival.

Time between flights

How long you stay in one time zone impacts the methods you use to cope with circadian rhythm disruption. If the time between landing and the next flight is short (13 to 24 hours), you should plan your rest period differently than if there is a longer time between flights.

The shorter the time interval between landing and the next flight, the more you need to maintain your home-time rest and sleep habits. If the duration between landing and the next flight is long, then you need to adjust your rest and sleep cycle. Adapt your circadian rhythm to local time and gain the rest you need before another flight.

Relative difficulty of next flight

This is a major consideration. Many times you experience a new flying environment that has different local procedures than your home base. If you fly in a foreign country, the terminology used by controllers could be different and cause confusion in the cockpit. If you're fatigued, you are less able to adapt to new flying environments and demands.

In addition, there may be portions of the flight that require above-average alertness. Examples are low-level flying, aerial refueling, ordinance delivery, or other such tasks. Consider these demands as you form a plan to cope with fatigue. Be aware of the fatigue factor during the later stages of a flight.

Availability of dining facilities

In addition to rest, your body needs nourishment to provide energy. One of the ways to help adapt to a new time zone is a good diet. However, you may not have access to dining facilities due to the arrival time or place. If facilities are not available, consider taking "combat snacks" (nonperishables consisting of complex carbohydrates). Also, don't start a weight loss program on the road. Most common weight loss diets (low-calorie intake) are added stressors, and your body will not be able to cope.

Decreasing the effects of fatigue

There are many ways crew members can try to compensate for the effects of fatigue. First, always start scheduled flights well rested, especially when scheduled for extended missions or transcontinental travel. This proper rest often requires cooperation from family members. Naps (no longer than two hours) are strongly recommended prior to night flights. Minimize your use of alcohol and tobacco, and keep yourself hydrated.

Diet also can be used to reduce the effects of fatigue. Avoid high-fat, high-carbohydrate meals in order to reduce drowsiness. Instead, eat a meal high in protein with moderate carbohydrates.

Staying active is important. If possible, get up and move around periodically during a flight. Turn on cockpit lights. Then turn then down 30 minutes before landing to restore night vision.

Caffeine use

Caffeine is a tasteless substance occurring naturally in plants and found in a variety of beverages, medicines, and foods. Coffee is the most popular source of caffeine in the American diet. You also can receive significant amounts of caffeine from carbonated beverages, tea, OTC drugs, and chocolate.

Caffeine acts as a powerful CNS stimulant. Caffeine's popularity is due to its ability to elevate mood, mask the feeling of fatigue, and increase the capacity for work. In low doses caffeine may not be harmful. However, ingesting high levels of caffeine may be related to a variety of acute and chronic ailments.

Most people regard caffeine as a safe stimulant and don't actively monitor their intake. As they consume caffeine-loaded products, they remain unaware of the potential negative side effects of caffeine. The effects of caffeine and its withdrawal symptoms are as follows:

Effects of Caffeine	Withdrawal Symptoms
Dehydration Restlessness Nervousness Faulty thinking Disturbed sleep	Headaches Restlessness Sense of disquiet Aching joints and muscles

Addiction

Caffeine is addictive. A person who needs 400 mg of caffeine in a 24-hour period to function is considered addicted to caffeine. However, you also can develop sensitivity to the drug. If you're addicted to caffeine, you may experience some withdrawal symptoms when, and if, you decide to quit. It is advisable to reduce your intake gradually instead of quitting "cold turkey."

Caffeine has synergistic effects when used in combination with other drugs. Its stimulant effect on the body significantly increases when used in combination with decongestants or nicotine. Unfortunately, the negative side effects of this combination—sweating, increased blood pressure and heart rate, sleep disturbances, and shakiness or tremor—are not desirable in crew members.

Dehydration

Anytime you drink caffeinated beverages during flight, you should also drink water. The combination of a pressurized cabin (humidity below 9 to 11 percent increases the water lost during respiration) and the diuretic (makes one urinate more often) effect of caffeine cause an increased dehydration rate. The result is increased mental and physical fatigue and less-than-peak performance. Drinking water or other noncaffeinated beverages during flight helps offset the negative effects of caffeine.

215. Stress management

Stress can be both positive and negative. How you manage it is important in both personal and professional life. You must learn to manage the stresses that are part of your everyday life. To begin managing stress, you have to first understand what it is and what it does—how it affects you physically and mentally.

Stress

Stress is the normal reaction to any demand placed on a person, either physically or mentally. You need stress because it serves as a motivator and an indicator (increased heart rate, respiration, perspiration, etc.) that helps prepare you to respond. If there is little stress, you are underaroused and inattentive. On the other hand, if there is too much stress, you limit your ability to perform.

Inherent in humans is a biological response to a crisis situation. For example, when suddenly confronted by a crisis situation, an involuntary physiological process begins. Adrenaline is produced, causing the eyes to dilate, increasing the heart rate, stopping digestion, directing blood to the large muscle groups, and increasing perspiration. These responses prepare you to confront the crisis or run away from it (a response known as "fight or flight").

Financial, family, professional, and social responsibilities are a few of the stresses that may confront you. Many of these are self-imposed. Even if these stresses are not self-imposed, they may lead to negative behavior associated with self-imposed stress.

Put demands in perspective

Doing well in your job, living comfortably, and being a good parent are all worthwhile aspirations, but they are not life-threatening situations. You can't control the reflexive physiological process that activates in a crisis situation, but you can control what you *perceive* as a crisis situation; so don't overreact. Always keep your supervisors informed. They may be able to help you deal with some of these stresses.

Maintain a healthy lifestyle

Entertainment and hobbies provide a healthy balance in life. Save some of your energy for yourself. A healthy balance will make the energy you expend on your job and your family more effective and meaningful. The flying environment is a demanding one. It's constantly changing and requires a total mental and physical commitment. Any factor or condition that distracts you from your job is important and must be given adequate attention.

Eliminate self-imposed stress

Smoking, excessive drinking of alcohol, self-medicating, poor nutrition, and lack of exercise are stressful in and of themselves and make it more difficult to deal with other stresses. Avoid these behaviors.

Exercise

Studies show that certain lifestyle factors directly contribute to health and well-being. You control many of these factors such as diet, alcohol use, rest, self-medication, stress management, and exercise. Taking proper care of your body reduces self-imposed stresses such as fatigue and hypoglycemia. Exercise is one tool you can use to increase your performance and increase your resistance to fatigue. There are many benefits of an exercise program, one of which is to help minimize the effects of fatigue. A well-rounded exercise program should incorporate both aerobic and anaerobic exercise.

Aerobic exercise

In aerobic exercise, the muscles use oxygen along with fat and glucose to produce energy. Running, swimming, bicycling, and walking are examples of aerobic exercise. There are many benefits of aerobic exercise. A person who is in good aerobic condition has a higher basal metabolic rate (BMR), less body fat, lower blood pressure, greater stamina, and more energy. Your heart and lungs are in better condition than those of an aerobically unfit person. In the flying environment, aerobically fit crew members have a greater resistance to fatigue.

Anaerobic exercise

In anaerobic exercise, the muscles also use oxygen along with fat and glucose for fuel; however, they don't completely metabolize it and lactic acid is formed. Lactic acid is the substance that causes the characteristic "burn" sensation when working out with weights. Anaerobic activities are weight lifting, sprinting, sit-ups, push-ups, and pull-ups. These activities train the muscles to burn fuel without oxygen and tend to increase muscle mass and strength. A person who is in good anaerobic condition can contract and maintain muscle contractions for longer periods of time than anaerobically unfit people. In the flying environment, muscle contractions are important in the performance of the anti-g straining maneuver (AGSM) used when pulling positive Gs.

Anaerobic versus aerobic conditioning

Aerobic activity causes a cardiopulmonary (CP) system reaction. For instance, after jogging for a few minutes, you start to breathe faster and harder, begin to perspire, and increase your heart rate. Conversely, anaerobic training does not necessarily cause a systemic CP reaction but tends to isolate muscle groups and work them at a high intensity. For example, performing arm curls with 50 pounds of weight causes the muscles in your arms to work anaerobically, fatigue, and "burn" (due to lactic acid). However, you don't experience a systemic response to the exercise. Therefore, both aerobic and anaerobic conditionings are needed to achieve total fitness. Also, regardless of the type of exercise program you develop, you experience an added benefit of decreased fatigue and stress. Finally, exercise helps to release the psychological stresses encountered in day-to-day activities.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

214. Self-imposed stressors

1. What are the four effects that OTC drugs can cause?

2. Why are the side effects of decongestants detrimental to aircrew members?

3. What type of over-the-counter drug (OTC) is used to reduce nasal congestion due to allergies and colds? What are some of its side effects?

4. What type of hypoxia is caused by the consumption of alcohol?

5. What is the best way to avoid the dilemma of suffering a hangover and the residual effects of alcohol?

6. How much greater will carbon monoxide bind with red blood cells than oxygen?

7. What is the most common cause of hypoglycemia?

8. What is the number one defense against hypoglycemia?

9. What is the best method to prevent dehydration during aircraft flights or physical activity?

10. What is the definition of *fatigue*?

11. What is the normal cycle of our body’s circadian rhythm?

12. What is the most popular source of caffeine in the American diet?

13. What activity will help offset the negative effects of caffeine?

215. Stress management

1. Define stress.

2. The physiological response to a crisis situation that prepares you to confront a situation or run away is known as what?

3. How can you put the demands of everyday living in perspective?

4. Name the ways you can reduce or eliminate self-imposed stress.

5. What activity can help you increase performance and resist fatigue?

6. A well-rounded exercise program should incorporate what two types of exercise?

3–2. Sensory Physiology

The brain, not the eyes, perceives sight. That may sound strange, but it's true. Rays of light from external objects focus on the retina. The light rays' energy cause chemical changes that, in turn, cause a transmission of nerve impulses via the optic nerve to the visual area of the brain's cortex. The cortex is where nerve impulses are translated into *sight*.

In this section, we start with the fundamentals of sight and how vision can be affected during flight. We also cover other flight hazards like noise, acceleration, and spatial disorientation. You will see that these areas are interrelated; yet, each hazard poses a separate and unique problem for aircrews.

216. Vision concerns for flyers

This lesson presents information on vision structure, function, and problems. Remember, the eyes are merely receptors of sight. You need to understand how various light levels affect vision.

Anatomy of the eye

The eye (fig. 3–1) is a highly specialized sensory organ located deep within a bony orbit (pocket) of the skull that protects the eye from injury. Each eye is an independent sensory organ, yet together they perform their function binocularly, providing a single visual perception (impression) even when in motion.

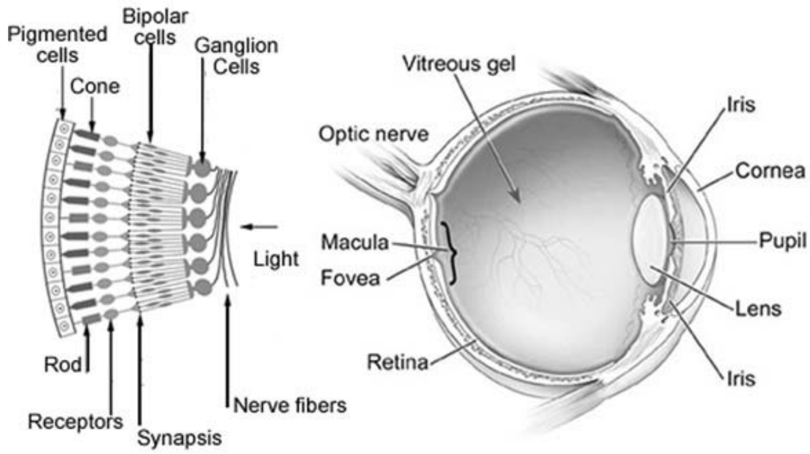

Figure 3–1. The eye, rods, and cones.

Sclera and cornea

The sclera is the outer layer of the eye—a tough, opaque protective covering. This covering surrounds the eyeball entirely except for a small segment covered by the cornea. The cornea is merely a small *modified* area of the anterior sclera. It is the projecting, transparent part of the eye through which light first travels. The sclera is resistant to stretching and tearing and provides strength to the fluid-filled eyeball. It aids in maintaining the shape of the eye.

Aqueous humor

The aqueous humor is the *transparent* fluid filling the space between the cornea and the lens (where a visual image is changed in order to see near and far). The cornea does not contain blood vessels. Therefore, the aqueous humor provides the cornea with necessary nutrients. As a unit, the cornea and aqueous humor refract light rays entering the eye.

Iris

The iris is a thin, circular-shaped membrane giving the eye its color. It resembles the shutter of a camera and surrounds the pupil (the opening through which light rays pass). The iris regulates pupil dilation and contraction, thereby controlling the amount of light entering the posterior portion of the eye. This action of the iris is a necessary function in order for the eye to adjust to varying degrees of brightness. For example, the pupil contracts (shrinks) on bright sunny days to protect the eye from excessive brightness that may cause injury. The pupil dilates (lets in more light) at night or on cloudy days.

Lens

The crystalline lens (a transparent body just behind the pupil) is the second place within the eye where light refracts. It is biconvex (both surfaces curve outward), refracting light toward the center. The function of the lens is to focus light upon the retina. The lens automatically changes its shape to accommodate near or distant vision. The shape of the lens assures the image (we see) remains focused on the retina. This light refraction causes the image on the retina to be inverted. However, what we actually see is upright because of the way the brain's optic center interprets the impulses.

Vitreous humor

The vitreous humor is the *transparent* fluid of the inner chamber of the eye. This substance also supports the lens and the retina. The vitreous humor is very similar to the aqueous humor, having the same density. Vitreous fluids normally exert pressure of about 20 to 25 mm Hg on the walls of the eye (intraocular pressure), maintaining the eye shape. Intraocular pressure is of prime importance in the loss of vision during positive g maneuvers.

Suppose an individual, with a systolic blood pressure of 120 mm Hg, is subjected to a force of five positive Gs. The G-force, acting on the column of blood between the heart and the head, increases the weight of the blood in this column to five times normal. This reduces the blood pressure at eye level to 10 mm Hg. (Each g reduces eye-level blood pressure by 22 mm Hg).The 10 mm Hg of blood pressure is not enough to overcome intraocular pressure, and blood flow to the retina stops. The optic nerve ceases to function within several seconds because of hypoxia, and blackout occurs. However, the person does not lose consciousness.

Retina

The retina is the inner layer of the eye, and it extends across the back of the eye and forward to cover about two-thirds of the eye's inner surface area. The retina is modified cerebral tissue, developing embryologically as an extension of brain tissue. Like brain tissue, it requires a continuous O_2 supply to maintain activity. This brain tissue relationship is why vision is the first body function affected by hypoxia.

The retina is composed of nerve cells, fibers, and supporting tissue. Light passes through the intraocular fluid, focuses on the retina, and stimulates light-sensitive nerve cells (rods and cones). These cells convert light energy to electrical nerve impulses. These impulses are conducted from the retina to the brain via the optic nerve. The optic disc is the site where the optic nerve enters the eye. The optic disc is void of rods and cones, leaving a blind spot in the eye's visual field. The fusion of the nervous impulses from both eyes in the brain successfully avoids a blind spot in the visual field.

The light-sensitive cells of the retina are called *rods* and *cones* because of their shape. Rods (which are not color sensitive) are used for night or low-intensity light vision. Cones are used principally for day or high-intensity light vision. Some of the characteristics of day and night vision are due to the distribution pattern of rods and cones on the retina. The fovea does not contain a lot of rod cells, but it contains a high concentration of cone cells. The cones are closely packed together and become more widely spaced in the periphery. It is this dense array of cone cells in the fovea that gives individuals a high-visual resolution as well as color vision. Therefore, we say the fovea is the area of the eye with the sharpest vision.

Each cone cell in the fovea connects to a single nerve fiber leading directly to the brain. The single nerve connection of each foveal cone to the brain means each cone cell generates a nerve impulse that when stimulated by high light levels produce visual acuity. On the other hand, many rods may connect to each nerve fiber outside the fovea. Therefore, a very dim light that does not stimulate the cone cells could send a nerve impulse to the brain. The periphery of the retina, where the rods concentrate, is about 10,000 times as sensitive to light as is the fovea. Rod cells are the principal light-sensitive cells used for night vision because they are more sensitive to light.

Three types of vision

We use three types of vision to see objects under varying conditions. We use mainly *photopic* vision in daylight, *scotopic* at night, and *mesotopic* during dawn and twilight.

Photopic

Photopic (cone) vision is used to detect color under daylight conditions and ordinary artificial illumination. The human eye instinctively moves to inspect an object and get the object image to fall on the fovea. The fovea, the area of sharpest vision, automatically fixes on the object. Humans must unlearn this instinctive reflex to see effectively at night. The foveal cones do not receive enough energy to initiate a nervous impulse to the brain at low light levels. A 2°–3° area in the center of the visual field is blind because of the absence of rods in the foveal area. Therefore, you cannot see an object at night if you look directly at it or attempt to focus on it.

Scotopic

Scotopic (rod) vision is used in dim light, such as moonless starlight. Scotopic vision, which also has the 2°–3° central blind spot, is totally color-blind and has 20/200 to 20/400 visual acuity. At night you must consciously make scanning movements to keep the image of the object being examined off the fovea. Another characteristic of rod vision is that the images fade away completely when your eyes are held stationary for more than three to 30 seconds. The image is lost because, as the rods reach photochemical equilibrium, the nerve impulse stops. Scotopic vision demands searching movements of the eyes to find an object. Slight eye movements (scanning) must be used once the image is located to keep the object in sight.

Mesotopic

Mesotopic vision is a combination of cone and rod vision. It is used at dawn or twilight, when the surrounding luminance is slightly above the minimum level required for cone vision. Mesotopic vision is a transition between photopic and scotopic vision, where the level of illumination ranges between 0.01 (light from a full moon on new snow) to one foot-candle (the amount of light on a white sheet of paper held one foot from a standard candle). Central (foveal) acuity is about one-half as good at 0.1 foot-candle versus average daylight illumination.

Effects of decreased light on vision

The dark of night has a profound effect on vision. You've known what it's like going from a lighted area of your home to the darkness outside (with no lights on) or even suddenly losing your auto headlights at night. You can't distinguish colors or details at night either, although individuals vary in how well they adapt to dim light.

Dark adaptation

Your eyes slowly adapt to darkness when transitioning from a lighted area to a darkened area. Objects that were at first invisible slowly come into view (dark adaptation). Progressive regeneration of a photosensitive substance occurs in the rods, creating a photochemical shift in the direction of substance accumulation. This substance is called *rhodopsin* (or visual purple). It bleaches very rapidly when exposed to bright light and regenerates slowly during 30 to 60 minutes of dark adaptation. The greatest percentage of regeneration occurs during the first 30 minutes. Dark adaptation requires increased visual purple and occurs slowly. You can lose sensitivity to dim light by turning on a bright light for as little as five seconds—the more light, the less visual purple. Vitamin A is believed to be essential to the regeneration of visual purple. Vitamin A deficiency will impair night-vision ability, but excessive ingestion of vitamin A does not improve dark adaptation and could be harmful.

Loss of color perception

Color perception is not possible with rod cells. Therefore, the color of objects at night cannot be determined. However, you can distinguish between light and dark colors at night but only in terms of reflected light intensity. Colors at night are perceived as shades of gray. Bright signal flares and other brightly illuminated colored lights can be properly identified because they stimulate the cone cells.

The night blind spot

Everyone has a central blind area in dim light caused by the fovea centralis. As previously stated, to perceive an object in dim light, the image must not fall on the fovea. At three feet, the visual field blind spot is a circle about 1.25 inches across; at 30 feet, the blind spot measures about 12.5 inches across, and at 100 feet, it measures about 3.5 feet across. Imagine the size of the blind spot at 1,000 feet, when it grows to about 35 feet across. Figure 3–2 shows how you might lose an object in the blind spot of the visual field. To locate an object within the fovea, you must use off-center vision. To keep that object in view, you have to use scanning techniques or continuous small movements of the eyes.

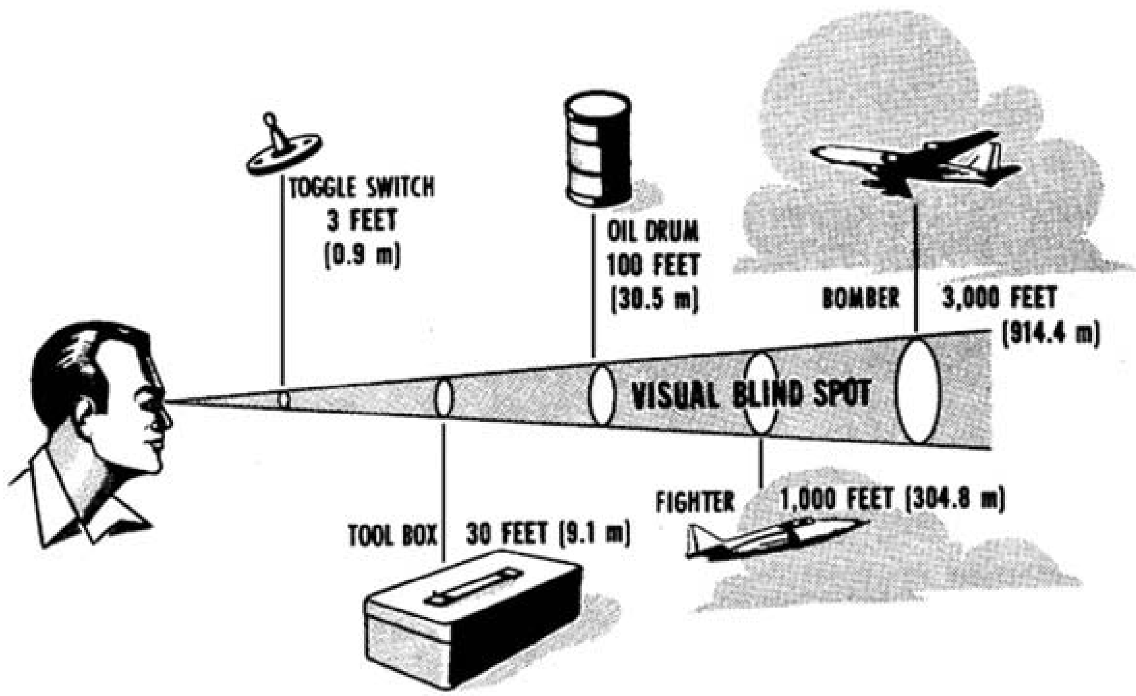

Figure 3–2. Effect of blind spot on vision.

Loss of acuity

Perception of detail is impossible at night. This is because object identification at night must depend upon the perception of generalized contours and outlines instead of small distinguishing features. Reduced visual acuity at night results from the many rods connected to each nerve ending in the area of the retina *outside* the fovea. The cones *in* the fovea, on the other hand, connect individually to nerve endings, giving greater visual acuity under daylight conditions. Since visual acuity at night is so poor, the size of objects becomes extremely important. At night, an unlighted aircraft can be seen from about 1,000 feet only if you use off-center vision.

Visibility at night

Decreased light at night increases distortion through aircraft windscreen. The reflection of interior lights off the windscreen's interior surface affects the contrast between an object and its background. For these reasons, dirt, grease, and scratches on canopies and windscreens are serious handicaps at night. Keep transparent panels clean and turn off or dim the lights if possible within the aircraft during night operations.

Effect of exposure to sunlight on subsequent dark adaptation

Experiments show that exposure to bright sunlight has a cumulative and adverse effect on dark adaptation. Exposure to intense sunlight for two to five hours definitely decreases sensitivity at low brightness levels. This decrease may persist for as long as five hours after exposure. In addition, working in bright sunlight decreases the rate of dark adaptation and increases the loss of night visual acuity and range. These effects are cumulative and persist for several days. Therefore, working in bright sunlight, while on call for night duties, requires the use of suitable sunglasses to maintain night vision.

Individual variation

There is considerable variation among people and their ability to see in dim light. Those with the best night vision can see with only one-tenth the illumination required for similar visual acuity by those with the poorest night vision. A person with good day vision may not have good night vision. Most people can increase their ability to see at night by practicing off-center vision in dim light. Practice is effective enough in most people to double their night-vision efficiency.

Special night-vision concerns for the flyer

Colored lights, carbon monoxide poisoning, vitamin deficiency, and altitude—all of these have an effect on aircrew members' vision.

Artificial aids for dark adaptation

Rod cells require at least 30 minutes of complete darkness to attain maximum sensitivity (rhodopsin buildup) unless they have been exposed recently to high-light levels. Your eyes dark adapt satisfactorily after 30 minutes in a dark room. However, it's impractical for aircrews to sit in a dark room for 30 minutes before each mission, so artificial aids were devised for dark adaptation. Aircrews can wear red-lens goggles to dark adapt even while in fairly bright light. These goggles filter out shorter wavelength light rays and allow only longer wavelength red light to enter the eye. Red light stimulates cone cells, thereby improving visual acuity. Red light also stimulates rod cells ever so slightly, allowing rhodopsin (visual purple) to build up in these cells.

Red-lens goggles decrease the possibility of harmful effects from accidental bright-light exposures, especially when transitioning from lighted operations buildings to darker ramps. Unfortunately, these goggles interfere with the ability to read maps, magazines, and newspapers. In addition, red goggles do not provide the same degree of adaptation that is provided by 30 minutes of complete darkness.

Red lighting of cockpit instruments has been a tradition since World War II, with the intent to retain the greatest rod sensitivity possible while permitting an effective illumination for foveal vision. However, this lighting is not as important in today's high-performance aircraft because of electronic aircraft, navigation, and target-detection devices. Low-intensity, white cockpit lighting is preferred. White light provides a more natural visual environment within the aircraft without degrading the color of objects that are not self-luminous.

Visibility of colored lights and surfaces at night

Red and blue-green objects, or red and blue-green illuminated objects, do not maintain the same relative visibility when illumination is reduced. Short wavelength colors (blue and blue-green) are superior in visibility at low illumination than other colors. In addition, blue-tone lights appear more readily in peripheral vision than red lights because of the lower sensitivity of the peripheral rods to long wavelengths. Less impairment of dark adaptation occurs when reading instruments and other data at night under red lighting. Dim orange, yellow, or white lights may be used (in order of decreasing value) but reduce night vision.

Disadvantages of red light

Although red light is most desirable for dark adaptation preservation, it is not the preferred color to be used in the cockpit. Viewing objects under red lighting is more difficult because normal color relationships are disturbed; in other words, color differentiation is lost under red light. In addition, brightness values are greatly distorted. Objects that are normally red appear very light, and green and blue objects appear very dark. As a result, the colored range markers on instruments and the colors on maps and charts become less meaningful. Also, red light comes to a focus behind the retina, making a person hypermetropic (farsighted) for red. Therefore, farsighted pilots find red cockpit lighting an additional disadvantage. These difficulties with red light make its use advisable only in crew compartments where outside vision is paramount. Even here white light is used when needed for map reading and for instrument flying when the aircraft is being radar guided from the ground.

Carbon monoxide and night vision

Hypoxia resulting from CO poisoning affects visual acuity, brightness, discrimination, and dark adaptation; so does hypoxia resulting from reduced O_2 partial pressures. As little as 5 percent CO in the blood affects the visual threshold and raises the physiological altitude. Smoking three cigarettes in succession may cause a temporary 4 percent blood CO level. This CO increase creates a visual sensitivity equal to that experienced at about 8,000 feet without supplemental O_2. Even minor concentrations of CO can negatively impact aircrew performance, particularly during night operations.

Effects of food on night vision

Vitamin A and possibly vitamins B and C are chemical factors essential to good night vision. You should know which foods contain these vitamins and eat them regularly. Eggs, butter, cheese, liver, apricots, peaches, vegetables, and cod liver oil are all high in vitamin A content. Whole-grain cereals, green vegetables, and peanuts are good sources of vitamin B. Vitamin C is found largely in citrus fruits, tomatoes, and cabbage. Questions about an adequate diet should be referred to the flight surgeon, along with suspected cases of vitamin deficiency. Vitamin deficiencies may decrease night vision, but an excess of these vitamins does not improve it. In fact, too much vitamin A can be harmful.

Effect of altitude on night vision

Reduced O_2 at high altitudes increases the time required for dark adaptation and decreases night-vision capability. The change begins between 5,000 to 6,000 feet unless you're breathing supplemental O_2. Night vision at 10,000 feet is about 75 percent of SL effectiveness when you breathe atmospheric air without supplemental O_2. Therefore, you may wish to use supplemental O_2 from SL to altitude during night operations. One hundred percent O_2 is not required because the object is to maintain the blood-oxygen content equivalent to 5,000 feet or below. The automix lever of the O_2 regulator should be set in the NORMAL OXYGEN position.

Visual illusions

Visual illusions cannot be disregarded when examining low-light condition problems encountered by aircrew. Several types of illusions fall into this category: glare effects, autokinetic movement, light blending, and reduction of visual clues.

Glare effects

A sudden bright light entering the eyes causes a rapid loss of sensitivity when the eyes are dark adapted. Objects in the visual field seem to disappear. A significant proportion of image loss occurs even before the eyelids close, but full adaptation to the new light will take several seconds. The two eyes act independently during dark adaptation and light exposure. If light exposure occurs during night operations, closing one eye preserves the major part of its dark adaptation. However, the exposed eye loses all its dark adaptation. If possible, you should close both eyes to avoid retinal sensitivity loss. The practical importance of the procedure is obvious. If vision is demanded while the glare persists, you should keep one eye closed.

Autokinetic movement

If you stare at a fixed light in an otherwise dark room, you soon experience the illusion of an erratically moving light, that is, the autokinetic phenomenon.

Light blending

Confusion between ground lights and stars is a common problem during night operations. Many incidents have occurred where pilots have put their aircraft into very unusual attitudes trying to keep the "stars" (ground lights) above the horizon. Pilots also have mistaken certain ground-light geometric patterns for stars. Examples include mistaking freeway lights for runway lights and lines of ground lights for horizons. Figure 3–3 shows two types of these illusions.

Reduced visual clues

Pilots have reported confusion in determining where approach lights end and runway lights begin when a double row of approach lights join with runway boundary lights. Pilots sense a climb when flying an approach into a gradually thickening fog; to compensate, they may descend too low. Under certain conditions, approach lights can make the aircraft seem higher when it is in a bank than when its wings are level. Pilots have also reported the impression that they are in a bank when actually flying level if one row of runway lights is brighter.

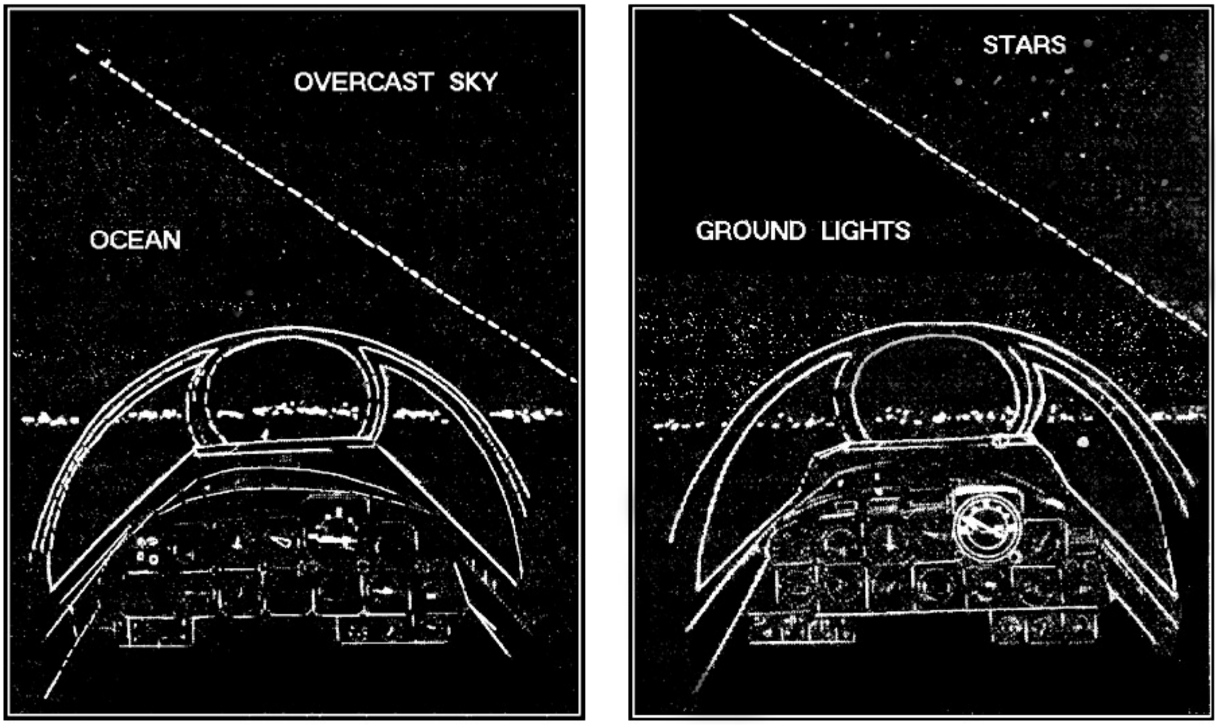

Figure 3–3. Blending earth and sky.

Another illusion may occur if a single row of lights is used along the left side of the approach path. A pilot may misinterpret approach perspective and correct to the left to center the lights. This correction causes the touchdown point to be too far left of the runway as the aircraft crosses runway threshold. One of the major hazards of approach and glide-slope systems is the dissimilarity of airfield systems, complicating the pilot's task of making approach and landing height and distance judgments. A standardized approach lighting system has not yet been adopted.

Reduced visual cues, received by the pilot during night and inclement weather landings, complicate the distance judgment problem. Confusing approach and runway lights are always a danger.

217. Night-vision training

You received night-vision training during the apprentice course. These classes were aimed at helping you develop the trainees' inherent visual abilities to the greatest possible degree. Although the ability to see at night varies from person to person, experience shows that most people never learn to use their night vision efficiently. Yet, proper training can markedly improve night-vision ability.

Night-vision training improves aircrew attentiveness, scanning techniques, and mental interpretation of the images within the eyes. This training is intended for aircrews with normal but untrained night vision. It is not a method of testing night-vision abilities. However, a trained person with fair vision may see more at night than an untrained person with superior vision. This lesson provides suggestions to consider as you set up your night-vision training program.

Arrange the classroom

The physical arrangement of the classroom is an important consideration. Overcoming the problems of trainee seating, projector location, and light proofing the classroom are difficult. Yet, these things help the trainees receive the best instruction possible in the existing facility.

The classroom should be totally lightproof. Even a slight light seepage into the classroom impairs dark adaptation and image identification. Finally, try seating the trainees at equal distances from the screen, with an equal division of trainees on either side of the projector.

Conduct the demonstrations

Resources, classroom environments, and instructor techniques can vary from unit to unit. Therefore, night-vision demonstrations also can vary. Despite these variances, there are particular areas that must be included in your lesson plans. However, always follow the procedures of your particular unit.

Dark adaptation

Demonstrate the benefits of dark adaptation by providing night-vision (red) goggles to some of the trainees before class. As a minimum, allow these trainees to wear the goggles for at least 10 to 15 minutes before the night-vision demonstration begins. Once the demonstration starts and the classroom is dark, instruct the trainees to remove their goggles. Then begin to gradually increase the illumination level behind a preselected slide. The dark-adapted trainees should notice the projected image at a much lower illumination than those trainees who did not use red goggles to dark adapt. This should demonstrate to all trainees the benefits of dark-adapting during low levels of illumination. Remind the trainees that dark adaptation also can occur by sitting in a darkened room or a room illuminated with only red light. You may recall that the rods in your eyes (used for night vision) are insensitive to red light.

Off-center vision

Previously, you learned about the blind spot created by the fovea centralis. This area of the eye is used during daylight illumination to focus on an object. However, the natural practice of focusing on an object results in a blind spot during low-light (night) conditions. This blind spot occurs because of inactive cone cells. A common blind-spot demonstration uses the aircraft silhouette slide. Bring the silhouette to trainees' attention and instruct them to locate a point on the aircraft's flight path. When trainees focus on their chosen point, they should experience a disappearance of the silhouette as it enters the preselected area. The silhouette should reappear as it passes through the area. The key principle to learn is the need to use peripheral (or off-center) vision to locate objects under low-light conditions. In other words, you can make up for the blind spot by looking to one side of an object.

Color vision

Review all slides at different illumination levels during your slide presentation. Slight increases in illumination levels gradually make color perception possible as the cone cells in the retina begin to function. Mesotopic vision—the combination of rods and cones—is dominant when you begin to identify colors.

Purkinje phenomenon

The Purkinje phenomenon occurs as sensitivity in the eye shifts from longer to shorter wavelengths during dark adaptation. Present a red and blue slide under a high level of illumination to demonstrate this effect. The red and blue are of equal luminance at high-light intensity. Gradually lower the light level. After transition to pure rod vision, the blue shades will appear brighter than the red.

Loss of visual acuity

Visual acuity (the ability to identify image details) diminishes with light intensity. Trainees see acuity increase when looking at various slides under increasing illumination levels. They will begin to identify objects on the slide that were not visible while the light was not as intense.

Averted vision and scanning techniques

Remember that focusing on an object at low illumination levels creates a blind spot. Encourage your trainees to practice averted vision/scanning techniques. With practice, they can improve their ability to combat conditions contributing to object-perception failure (blind spots). Teach trainees to look to one side of an object so they may identify it in dim light. A black and white silhouette is a good slide to practice averted vision. Colored slides are not suitable to demonstrate averted vision. Choose slides that do not present gray areas of vague image outlines at high levels of illumination.

To practice scanning techniques, use slides that present a detailed landscape in combination with a moving aircraft silhouette. The method you use will depend on the object you view, the type of aircraft, its shape, and so forth. A preferred method of scanning is to follow a system of parallel lines, covering the entire field of vision. Discourage trainees from staring at an area where they suspect the object is located, yet they do not perceive its shape. Instead, instruct them to look at that area intermittently to avoid fixation.

Increased contrast threshold

Point out this effect during a review of the slides. The review will show that at times you cannot see even large items when the contrast is low, due to diminished visual acuity. Only objects of high contrast can still be seen.

Glare effect

You can show this phenomenon by switching the glare light on several times while the trainees are looking at a slide. Flash the light for one-, three-, and 10-second exposures. After each flash, trainees can measure recovery time by their ability to identify details in the slide. Repeat the cycle, but this time have the trainees wear red goggles to demonstrate the protection provided from glare effects. Repeat the glare-light cycle a third time, only this time, ask the trainees to keep one eye closed and covered with the palm of their hand. Have them compare the vision in both eyes with each exposure. They will notice a remarkable difference in vision between the two eyes.

This third demonstration also is an effective way to show how the eyes function independently. Explain to your trainees that their eyes perceive “afterimages” following glare exposure. These afterimages affect their vision for varying lengths of time. The length of the effect depends on the length of the exposure. The afterimages appear as “whiteout” areas within the field of vision. Flyers can compensate for the whiteout by using their peripheral vision. To show this problem, ask the trainees to look at the glare source. Turn it off and they will have a central afterimage. For a considerable time they cannot see low-luminance images in their direct line of vision. If trainees use indirect (off-center) vision, they can see the same feature much sooner. Be sure to discuss with them how to use the part of the retina not affected by this afterimage to see cockpit instruments.

Autokinetic movement

Ask the trainees to stare at a single, fixed light in a darkened room. They will soon begin to experience the illusion that the light has begun to move erratically. This illusion is known as autokinetic movement. The problem that results from this phenomenon is that an aircrew will focus all their attention on the moving light. Thus, they become unconcerned with everything else. A pilot flying in a formation may focus on the leading aircraft’s lights, causing him to break formation as he tries to follow the lights’ perceived erratic movement.

Following the guidance provided above and practicing with seasoned instructors will help enhance your presentation. Practice for this class is essential, since both you and your trainees are in a totally darkened room.

218. Noise hazards

Training facility equipment creates a significant amount of noise. As a hypobaric and hyperbaric chamber crew member, you’re automatically placed in this hazardous noise environment. Firing the ejection seat trainer or operating a variety of power equipment subjects you to hazardous noise. Several jobs are performed in association with aircraft operations, placing you near ground power equipment. Indeed, each of these tasks is a noise hazard. When exposed to hazardous noise environments, you must understand the risk of possible hearing loss and practice the principles of protection.

Factors that contribute to hazardous noise

Noise, simply defined, is unwanted or unsolicited sound. Examples include loud music, aircraft engines, vehicle horns, loud conversation, and so forth. Noise can be practically classified as sound that becomes a source of annoyance. Its intensity and duration creates a potentially damaging effect on hearing.

Repeated exposure to potentially hazardous noise can interfere with job efficiency and safety through distraction and annoyance. Dangerous noise levels also may interfere with communications. Most importantly, unsafe levels can result in temporary or permanent hearing loss. General fatigue and headaches are additional side effects.

Hearing loss, due to unprotected noise exposure (especially during initial exposure), reduces hearing acuity. Hearing loss due to noise is dangerous in nature. The degree of damage may be serious by the time the individual notices hearing impairment. Hearing loss occurs when the hair cells within the cochlea of the inner ear become fatigued beyond the point of recovery. No known medical or surgical treatment can correct hearing loss due to noise. Frequency, intensity, and duration of noise exposure are the most important factors in determining risk.

Frequency

Alternating compression and rarefaction of air above and below atmospheric pressure create sound waves. Frequency is the number of times per second that these sound wave oscillations occur. By convention, one oscillation per second is termed 1 hertz (Hz). Thus, a frequency of 100 cycles per second is 100 Hz. The human ear is normally responsive to frequencies between 20 and 20,000 Hz (the audible range). Low-frequency sound (below 20 Hz) is infrasonic and high-frequency sound (above 20,000 Hz) is ultrasonic. Normally, neither is audible to the human ear. High-frequency noise is more damaging than low. The whine or whistle commonly heard around a jet engine at idle is a good example of high-frequency noise.

Intensity

Intensity (loudness) is the magnitude of an acoustic event. This is a measure of the pressure of sound waves in the ear canal. Sound pressure levels (SPL) increase millions of times between the normal threshold of human hearing and maximum safe levels. The convenient term *decibel* (dB) is used as a measure of these pressures in order to avoid the use of large complex numbers. The dB is a logarithmic expression of the ratio between the sound pressure being measured and the lowest sound pressure detectable by a normal human ear at 1,000 Hz. An example of the logarithmic nature of the dB expression is the sound pressure impinging on the eardrum increasing tenfold between 100 and 120 dB. The term *A-weighted noise level* (dBA) refers to a reading on a sound level meter that closely approximates the response of the human ear. The noise intensity that significantly impairs normal voice communication is about the same as the level that begins to pose a risk to hearing. A feeling of fullness in the ears or noticeable ringing in the ears, after being in a noisy environment, may signal overexposure. Fullness and ringing in the ears usually accompany temporary hearing threshold shift or hearing loss. Symptoms subside within a day or two and create a false sense of relief. Each overexposure’s residual, permanent noise-induced hearing loss is subjectively small and often remains unnoticed until the collective loss is handicapping. Noise requiring you to speak in a loud voice at 1 foot or shout at 3 feet can be considered hazardous. Although noise levels of 120 dBA may produce ear pain in some individuals, significantly lower levels will produce permanent hearing loss. This factor helps account for the insidious and painless nature of noise-induced hearing loss.

Duration

Duration is simply the time length of exposure. The criterion for hazardous noise exposure begins at 80 dBA for a 16-hour day. This means that 80 dBA for 16 hours is a permissible unprotected exposure. Reduce this time limit by one-half for each 4 dBA increase above 80 dBA. For example, 84 dBA is safe for only eight hours per day. Unprotected exposure to levels exceeding 115 dBA is not safe regardless of the exposure time. High-intensity impulse noise of short duration can be very damaging. For example, the firing of an M-16 rifle equals 170 dBA. The table below shows the maximum safe daily exposures with their respective dB ratings.

Example	dBA	Maximum Exposure Time Unprotected
C-5 at Cruise	80	950
C-130 at Cruise	92	120
T-38 at Cruise	96	60
F-16 at Cruise	98	45
T-37 at Cruise	104	15
Rock Band	115	2.2

Sources of hazardous noise within aerospace physiology

Among the many sources of hazardous noise are the flight line, jet engines, ground power units, and training equipment like the hyperbaric and hypobaric chambers.

Flight line

Many AP technicians routinely perform direct flight-line support of flying operations. Virtually all duties associated with these flight-line operations involve some degree of noise exposure. It is beyond the scope of this course to identify all the particular noise levels associated with flight-line operations. However, it is extremely important that you are aware of the potential hazards and employ proper protective measures when in this environment. Remember, ground support equipment and the aircraft itself are both sources of flight-line noise.

Aircraft ground operations

The aircraft is a significant source of noise during ground operations. Aircraft operational checks often require the engines to operate at various power settings. The noise level generated by these settings may reach 130 dBA or higher. Actual noise levels depend on your position or location in relation to the aircraft. Wear personal ear protection when entering a flight-line area.

Ground support equipment

Ground support equipment, particularly ground power units, generate potentially hazardous noise ranging from 91 to 122 dBA. Wear ear protection since all units produce an auditory risk.

Training facilities

The list of potential noise-producing sources is almost endless. However, training equipment operations and maintenance are areas of particular concern around an AP training facility. The exact noise levels associated with AP equipment operation depends on many factors. They include room design, phase of operation, implemented noise reduction steps, and so forth. Potential danger remains. Here are some areas of primary concern.

Hyperbaric chamber operations

Noise measurements within hyperbaric chambers have registered sound pressure levels of 136 dBA during ventilation. Operating some compressors also produce a significant noise level that varies according to the physical layout of the compressor room.

Hypobaric chamber operations

A general noise level for hypobaric chamber operations has not been determined. Again, it depends on the physical location as well as other factors. Installing mufflers on hypobaric chambers help to reduce noise levels. Helmets and headsets afford additional protection.

Maintenance operations

Some power tools are used in the maintenance section of a training facility. Just because they are small doesn't mean they are not a source of concern. Remember that an electric razor held three inches from your ear might produce a SPL of about 90 dBA. Consider the noise level associated with the equipment listed below. Keep in mind that any SPL greater than 84 dBA is hazardous.

Equipment	SPL/dBA
Rapid decompression*	110
Vacuum Pump (KT 850)*	94
Ingersoll Rand Compressor*	86
Lawn Mower	97
Saber Saw	109

*Measurements taken at Brooks City-Base with each piece of equipment operating separately.

These noise levels are approximations. Actual noise levels will vary depending on models, power setting, and the environment where you use the equipment.

Self-protection measures for hazardous noise

Take protective measures when noise interferes with communications or poses a risk to hearing. Single or multiple types of protection can be used, depending on the severity of exposure.

Reduce or eliminate the noise

The best solutions to a noise problem are (1) eliminate the noise, (2) separate yourself from the noise, or (3) reduce the noise to an insignificant level. For example, move an engine run-up area to a distant location or change the exhaust angle to take advantage of directional characteristics. Likewise, isolate the hyperbaric compressor and other noise-producing training equipment. Keep these types of equipment separate from heavy staff- and student-use areas as much as possible.

Wear protection devices

A large variety of devices can protect your hearing from the harmful effects of noise. Devices include earplugs, earmuffs, communication headsets, and helmets. All ear protectors seem to be more effective in reducing high-frequency noise above 1,000 Hz versus low-frequency acoustic energy. Consider this characteristic when estimating the success of protective devices in given spectrums of noise. Details on the amount of protection provided by various types of ear protectors are in Air Force Occupational Safety and Health Standard (AFOSH STD) 48-20, *Occupational Noise and Hearing Conservation Program*.

Earplugs

Insert-type earplugs are probably the most common types of ear protection used. They range from wads of dry cotton to custom-molded ear canal inserts. The V-51R (molded plastic, single-flange earplug) is very effective. The V-51R is available in five sizes, providing a suitable fit for more than 95 percent of all personnel. The plugs must be fitted individually by qualified aeromedical services personnel, and each ear may require a different size plug. The user receives instructions on proper insertion and care of these earplugs. A properly fitted insert earplug should reduce noise by 20 to 25 dB in the range from 300 through 4,800 Hz. Earplugs provide slightly more protection against low-frequency noise than do earmuffs or headsets.

Earmuffs

These are standard-issue items. You can put on earmuffs and remove them easily, making them more convenient than earplugs. However, earmuffs are bulky and sometimes interfere with other tasks or with headgear. The ear cups on the muffs reduce the amount of ambient noise that reaches the ear, thereby improving communications. Most earmuffs will reduce sound as much as properly fitted earplugs. The muffs tend to provide slightly better high-frequency protection and slightly less low-frequency protection than do the plugs.

Headsets

Communication headsets, including muff-enclosed and helmet-enclosed earphones, provide some protection against high-frequency sound. However, they are not very effective against low-frequency sound. Some special communication headsets provide as much noise protection as regular earmuffs. You must consider the type of communication transmitted through the headset when estimating auditory risk. When you use communication headsets (including flight gear), place the microphone directly in front of your lips to cancel the maximum amount of noise from the unit.

Combinations

Use a combination of ear protection when exposed to high-intensity noise. Any good earplug is usually enough protection for sound intensities to 115 dB. Use a combination of plugs and earmuffs when you are around large amounts of noise. The total protection of V-51R earplugs with standard earmuffs is about 30 to 35 dB for frequencies between 300 to 4,800 Hz. Many individuals are skeptical when told that ear protection usually improves speech reception during noise exposure. The protected ear is stimulated at a lesser intensity, reducing the discomfort and distortion commonly found in high-level noises. These reductions improve hearing.

Reduce time of exposure

A hearing risk may exist even when noise is reduced as much as possible and maximum ear protection is used. A good example is jet engine operations involving noise intensities above 140 dB. In such circumstances, the only alternative is to reduce the exposure time. Personnel who must work in an area containing potentially hazardous noise must have audiometer checks regularly. These checks detect hearing loss in the extremely sensitive range that otherwise may be undetectable. These checks are also useful in the early detection of situations where protective devices are improperly worn.

219. Effects of speed, acceleration, and G-forces on the body

Aircraft with high thrust-to-weight ratios and low wing loading dominate the tactical air forces. These aircraft can generate rapid onset and sustained high G-forces that provide a tactical advantage during aerial combat. However, this advantage also places the fighter aircrews under greater physiological stress than ever before. This section lays the foundation for understanding accelerative forces and their consequences in fighter aviation.

An AP technician must understand spatial disorientation in addition to acceleration. Spatial disorientation describes the negative result of sensory illusions. Spatial disorientation is a problem because the pilot *believes* the illusion is real.

Sensory illusions occur when the organs of equilibrium (the visual system, vestibular apparatus, and proprioceptive system) provide conflicting information to the brain. The sensory systems also may conflict with actual conditions of aircraft attitude, position, or motion. (By attitude, we mean the position of the aircraft in relation to the ground.) If the pilot believes this erroneous information instead of the aircraft instruments, spatial disorientation results. This type of disorientation is a major contributing factor in many aircraft accidents. One study concluded that many fatal aircraft accidents were a direct result of spatial disorientation. In addition, all pilots are susceptible to, and have experienced, sensory illusions while flying.

Speed

Speed describes the magnitude of motion. It can be expressed in knots (kt), miles per hour (mph), feet per second (fps), or meters per second (m/s). Airspeed is usually stated in knots, 1 knot = 1 nautical mph. The following formulas are useful in converting the different units:

1 kt = 1.15 mph	1 kt = 0.514 m/s
1 kt = 1.69 fps	1 mph = 0.869 kt

Effects of acceleration

By acceleration, we mean a change in speed, in direction, or in both at the same time. The key word is *change*. Aircraft maneuvers produce three types of acceleration: linear, angular, and radial. Each has a profound effect on aircrew senses.

Linear acceleration

Imagine an aircraft flying straight and level (wings and body parallel to the ground) with a cruising speed of 250 kt (287.5 mph). No acceleration is occurring because there is no change in speed or direction. Now let the pilot increase the speed to 350 kt (402.5 mph). This is called linear acceleration because speed is changing while direction stays the same. When we refer to linear acceleration in AP, the change can be either an increase or a decrease in speed.

Angular acceleration

The two other types of acceleration involve changes in direction but not simply turning the aircraft to the right or left like a car. To understand, you need to study figure 3–4 closely and imagine the aircraft going through changes in attitude.

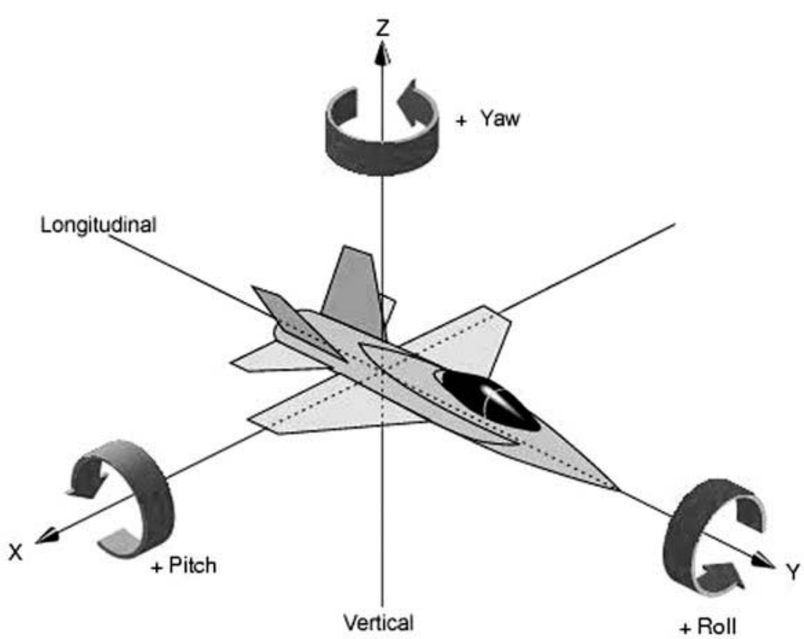

Figure 3–4. Pitch, roll, and yaw.

Let's start, as before, with the aircraft straight and level. There are three changes we can make to this attitude:

1. *Pitch* – to raise or lower the nose.
2. *Roll* (bank) – to rotate the aircraft lengthwise like a log rolling in water.
3. *Yaw* – a flat rotation, like turning your hand with your palm flat on a table.

Making these changes, either alone or in combination, produces angular acceleration. Angular acceleration is a measure of how fast the pilot rolls *into* or *out of* a turn. Also, angular acceleration may result from a simultaneous change in speed and direction, such as when speed increases during the *down side* of a loop. More importantly, these three changes relate directly to the function and operation of the semicircular canals and to orientation, as you will see.

Radial acceleration

Changing from straight and level flight to some other attitude—rolling into a right turn for example—produces angular acceleration. However, what happens after the change is complete and the aircraft is established in a constant-rate turn at a constant speed? Radial acceleration occurs. The change in attitude is complete in this case, but the aircraft and crew are changing direction. As you can imagine, aircrew members are subjected to constantly changing forces of acceleration as the aircraft undergoes various maneuvers.

To get a complete picture of the situation, put the aircraft you've been imagining at the beginning of the runway illustrated in figure 3–5, and then follow the sequence of maneuvers (nos. 1–13). Notice that linear acceleration occurs only when the aircraft is flying in a straight line and, even then, only when the speed of the aircraft changes (1, 3, and 11). Traveling in a straight line (7 and 13) while climbing or flying straight and level does not produce linear acceleration. Therefore, there must be a change in speed to produce linear acceleration.

Any change in attitude, such as bringing the nose down to enter straight and level flight or rolling into a turn, produces angular acceleration (2, 4, 6, 8, 10, and 12). When the change in attitude is complete, the aircraft will either be flying straight or be established in a turn. Remaining in a constant-rate turn produces radial acceleration (5 and 9). Radial acceleration also can be produced in a loop by maintaining a constant speed and changing direction. Therefore, radial acceleration occurs only in turns. As you examine figure 3–5, follow the maneuvers with the consequent type of acceleration experienced:

Maneuver	**Type of Acceleration**
1. Takeoff, on the runway increasing speed.	Linear
2. Nose up, entering ascent.	Angular
3. Established angle of climb, increasing speed.	Linear
4. Roll to left to enter constant rate turn.	Angular
5. Established in constant rate turn.	Radial
6. Roll back to wings level climb.	Angular
7. Constant rate climb, speed, direction.	None
8. Roll to right to enter constant rate turn.	Angular
9. Established in constant rate turn.	Radial
10. Roll back to wings level climb.	Angular

Maneuver	Type of Acceleration
11. Constant rate climb, decreasing speed.	Linear
12. Bring nose down to level off.	Angular
13. Straight and level, constant speed and direction.	None

Effects of G-forces

There is one more important factor to look at before discussing the body's reaction to the previously considered acceleration forces. When we talk about acceleration, we're generally referring to change. Gravity (g) is a measure of the force imposed on the body as a result of these changes. To understand the concept, let's begin with one g. This is equal to the force of gravity without any additional factors occurring, such as change in speed or direction. This, of course, is what we feel all the time. Gravity is simply the force that holds objects on the earth and keeps us from drifting off into space. As we refer to G-forces, we're simply comparing the acceleration force imposed on the body to the force of gravity.

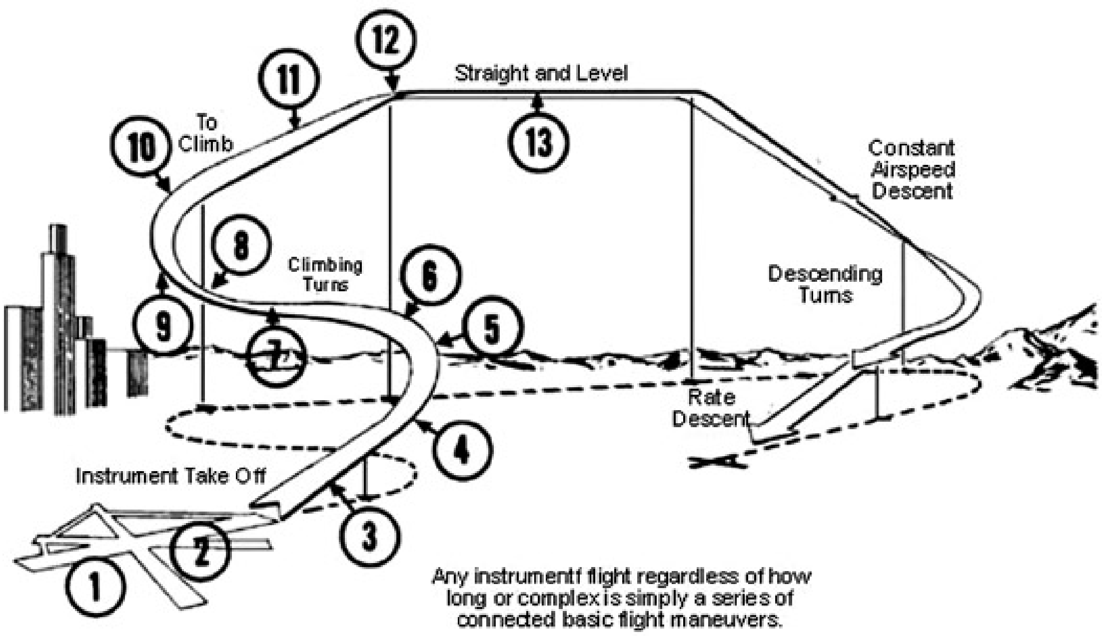

Figure 3–5. Acceleration example.

You've experienced increased gravity by stepping on the gas or making sharp turns with your car, pushing you back into the seat or making you lean to one side. The same thing occurs in an aircraft, only to a much greater degree and in any direction. Since 1 g is equal to the force of gravity, a 2 g maneuver occurs when aircrew members are accelerated with a force two times greater than gravity. Positive gravity is the force pushing an individual down into the seat; negative gravity is the force pushing an individual up into the restraints.

Think of the effect of g-forces on the body as weight. Without getting into the physics of the situation, an individual's relative weight increases while experiencing varying G-forces. For example, a 200-pound pilot in a 4 g maneuver would weigh 800 pounds. You can demonstrate this phenomenon by swinging a piece of string with a weight on the end. As you turn the string faster, the weight feels heavier. This leads to several physiological problems:

1. Mobility or freedom of movement is greatly decreased.
2. Respiration becomes difficult.
3. The cardiovascular system is strained, as blood pools in areas opposite the direction of acceleration.
4. Vision may decrease due to any of the following:
   - Reduced blood circulation.
   - Pooling of blood in the area of the eyes.
   - Changes in the position of the crystalline lens.
   - The eyelids pushing over the eyes.

Understanding the effects of acceleration and G-forces is important. It's even more important to fully appreciate the range of problems facing aircrews during acceleration. This is especially true since G-forces also contribute significantly to the occurrence of spatial disorientation.

220. Effects of spatial disorientation

The forces discussed so far combine in flight to bombard aircrew senses. Now is a good time to discuss how well equipped or, more appropriately, how poorly equipped we are to maintain orientation in the flying environment. Sensory illusions occur as a result of conflicting information from sensory systems.

Aircrew members receive thorough classroom instruction on the organs of equilibrium and the physiological response of the body during aircraft maneuvers. As an AP technician, it is your goal to make "believers" of aircrews by demonstrating spatial disorientation. Therefore, you must be familiar with the forces acting on the body during aircraft maneuvers, the body's response to these forces, and the nature of specific illusions. Later, we provide information on how to demonstrate these illusions in a meaningful manner.

Orientation or equilibrium refers to how an individual actually perceives position, attitude, and motion in relationship to the center of the Earth. In other words, can aircrews answer questions such as, "Are you in a right or left turn?"or "Are you ascending or descending?" These simple questions may sound silly to the nonflyer, but you'd better save judgment until the end of this lesson. We think you will change your mind.

There are three sensory systems (fig. 3–6) especially important in helping maintain orientation and balance:

1. The visual system.
2. The vestibular system of the inner ear, including the semicircular canals and the otolith organs.
3. The proprioceptive system, which relies on how the whole body (organs and muscles) receives and interprets stimuli.

Normally the brain receives this combined information and the result is *spatial disorientation*. Our first clue that orientation in the aircraft is no easy matter comes from our knowledge that two of the three sensory systems are unreliable in flight—the vestibular and

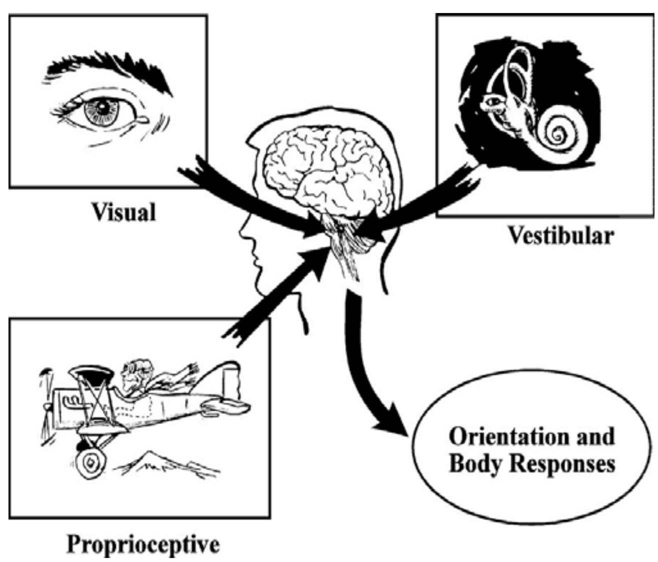

Figure 3–6. Sensory systems.

the proprioceptive systems. So, let's begin our discussion with the sense we can depend upon most often—vision.

Vision

Vision is the most important of the three orientation senses to the pilot, primarily because it's the only system that works reliably in flight. However, there are certain types of spatial disorientation that affect even the eyes. You have already studied the function and limitations of the eye. The eyes are very useful in telling the pilot the aircraft's position in relation to the ground. Yet this valuable service becomes limited at high altitude because it becomes increasingly difficult to make judgments based on a reference point on the ground.

Another situation creating decreased reference points outside the aircraft is when flying in instrument meteorological conditions (IMC). Here, due to inclement weather, clouds, and so forth, there are no fixed points outside the aircraft. Pilots become very susceptible to sensory illusions when they cannot see the horizon or other ground reference points. However, they always have access to extremely reliable and precise information: instruments on the aircraft, giving true information about aircraft attitude in relation to the Earth's surface.

This brings us to the most important decision aircrew can make in controlling the aircraft—the decision to rely upon the visual sense. They must believe the instruments and not allow false information provided by the other senses to mislead them. Our job is to provide quality instruction in this area so aircrew will make the right choice when confronted with disorientation.

Vestibular apparatus

The inner ear contains the vestibular apparatus which has the semicircular canals and the otolith organs. Both of these structures contain hair cells that, once stimulated by motion or gravity, detect angular acceleration, linear acceleration, and tilt and send the message to the brain. The semicircular canals detect rotation in the pitch, roll, and yaw planes and angular acceleration. The otolith organs inside the *vestibule* (cavity at the base of the semicircular canals) of the vestibular apparatus can detect the intensity of gravity and linear acceleration (fig. 3–7). Next we discuss each in more detail.

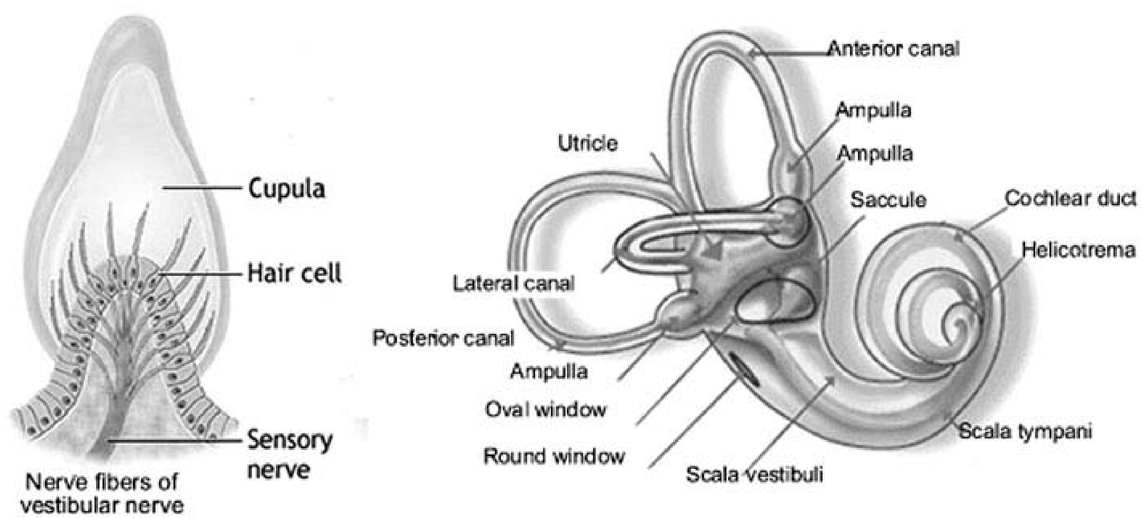

Figure 3–7. The vestibular system.

Semicircular canals

The semicircular canals respond to rotation and, in the aircraft, angular acceleration (fig. 3–8). They sit in exactly the same position in each inner ear. Notice that each canal rests in a different plane. Therefore, the canals may respond to rotation in three directions or planes.

Nod your head up and down and picture the canal that is rotating like a tire. The rotation of this canal starts a slower motion of a fluid (endolymph) within the canal. In normal head movements, you can even think of this fluid as remaining stationary. A structure called the cupula protrudes into the fluid. The cupula bends as the canal turns because of the "stationary" fluid. This bending of the cupula stimulates the hair cells that send the message of rotation to the brain. You can illustrate this response for yourself. Simply stir a glass of water with a small paintbrush; note how the bristles bend in a direction opposite the rotation. However, keep in mind that in the semicircular canals, it's the whole glass turning and the hairs are attached to the glass. Additionally, when you move your head forward, the fluid forces the hairs back. As you raise your head back up, the opposite occurs.

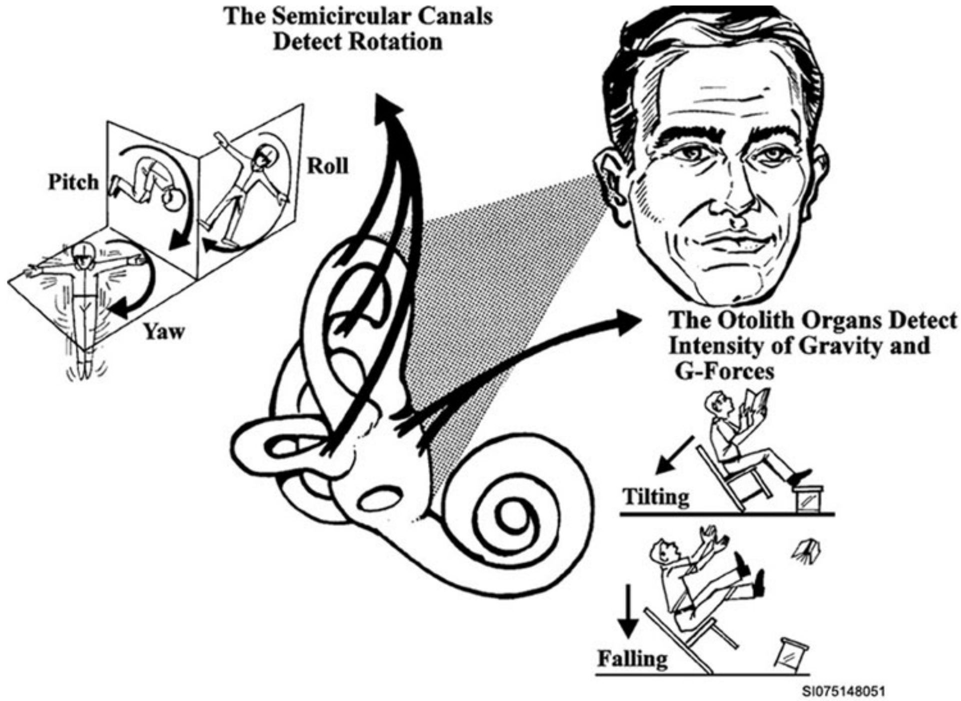

Figure 3–8. The semicircular canals.

Now picture yourself seated in an aircraft and increasing or decreasing the pitch. The same response occurs when you nod your head up and down. Do the same with the other canals. Swing your head from right to left with your head upright (motion in the yaw plane).

A key point is that the message sent to the brain is simply rotation. In normal circumstances (e.g., nodding your head forward), the cupula and hair cells return to an upright position, and no message is sent when the abrupt rotation stops. It's the other vestibular organs that tell you your head is leaning forward. The semicircular canals are very effective in routine daily activities due to the limited amount of angular acceleration and the inputs to the brain by the other senses.

So far there is no apparent problem, but think about what would happen if you maintain the rotation for more than just a few seconds, like for example, during a prolonged turn in the aircraft. Initially, it's the motion of the fluid in the canal that bends the cupula and hair cells. After a while, the motion of the fluid catches up with the rotation of the canal. This is much like stirring that glass of water until the brush and the water are moving at the same speed. This is called *equilibration*. The fluid and the canal are rotating at the same rate when the semicircular canal has equilibrated. At this point, there is no friction between the hairs and the fluid. Therefore, the cupula and hair cells, like the brush in the glass, stand upright. The message to the brain is no rotation. This equilibration is the basis for several illusions in the aircraft and the key to our spatial disorientation demonstrations.

Equilibration leads to another false sensory input when you suddenly stop the rotation of the semicircular canal. The fluid within the canal continues to move and the cupula and hair cells move in the direction opposite the original rotation. Now you get the sensation of turning the other way when you are not turning at all.

The problems related to angular acceleration can affect any of the semicircular canals. Additionally, two canals can be affected, creating a false sensation from the third canal. This is a particularly dangerous situation. Specific illusions are addressed later.

Otolith organs

The otolith organs provide orientation information by responding to changes in the position of the head. As with the semicircular canals, otolith organs contain sensory hair cells. However, in this case they protrude into a gelatinous membrane, which contains crystals called otoliths. Gravity causes this otolithic membrane to move when you tilt your head. This motion bends the sensory hairs that send the message of a change in head position to the brain. Figure 3–9 shows the effect of changes in head position on the otolith organs. When your head is upright, the hair cells generate a "resting" message.

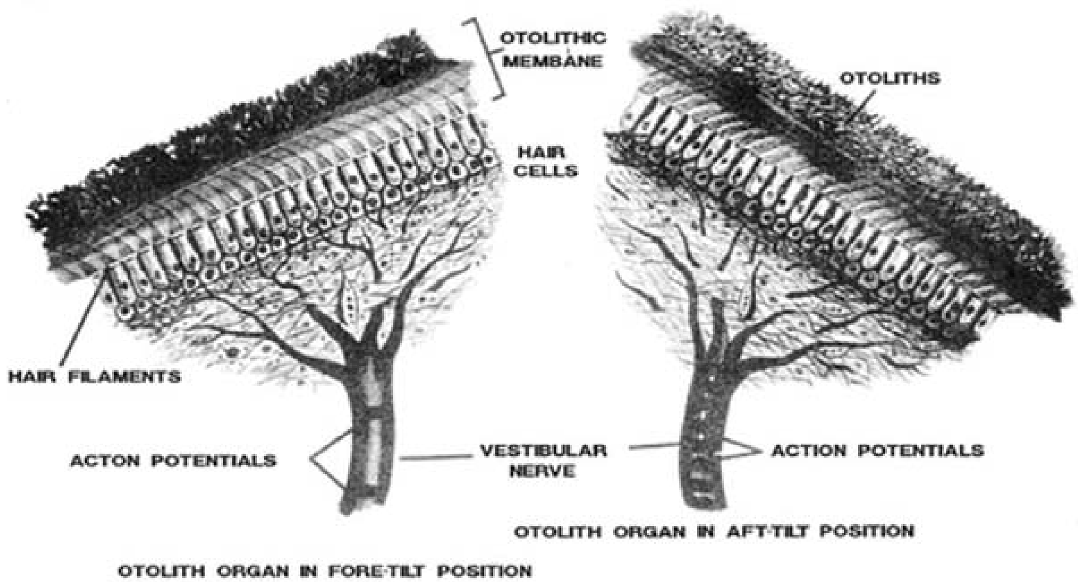

Figure 3–9. The otolith organs.

The problem with the otolith organs in flight is that they can't tell the difference between a tilt of the head and linear acceleration. For example, increased speed (linear acceleration) in level flight causes the sensory hairs to tilt back. The result is an illusion of the whole body tilting backward. This is much like holding a very limber fishing pole straight up in the air. If you move your hand forward very quickly, the upper portion of the pole lags. Again, this illustrates the need for a visual reference (trusting the instruments) for aircrews to get accurate information about the aircraft's attitude.

Proprioceptive system

Proprioception actually refers to the combined input from sensors all over the body—muscles, nerve endings, and so forth. Sensors reveal the position of each part of the body in relation to the other and to gravity. To prove that it works, touch your nose with your eyes closed. The input required to accomplish this delicate task includes information from the vestibular apparatus, from sensors below the skin, and sensors within the muscles and tendons.

Despite the various sources of information within the flying community, we still refer to the proprioceptive system as *seat of the pants*. Pressure on the buttocks when seated, on the feet when standing, and on the back when lying down stimulates subcutaneous pressure receptors.

The proprioceptive system, like its vestibular counterpart, can easily be fooled in flight. The aircraft might be upside down at the top of a loop, but if G-forces are pushing you into the seat as if you were right side up, you may *sense* that you are right side up. Once again, visual reference is the key. Trusting seat-of-the-pants sensations instead of the instruments, while experiencing assorted accelerative forces, can be a fatal mistake!

None of the sensory inputs we discussed are likely to cause a problem while a crew member has visual references outside the aircraft. In this case, the brain will ignore erroneous inner ear and proprioceptive information and rely on information the eyes are providing. This is because the visual cues always override all other sensory information. However, problems may occur when visual references outside the aircraft are lost. The brain then must make itself "believe" what the eyes are seeing (on the instruments) and ignore all other sensory input. Since this is a learned task, not instinctive, it may be very difficult under stressful conditions to ignore certain sensory information, even if erroneous.

221. Spatial disorientation trainer

The Barany chair (fig. 3–10) is an excellent trainer because it permits trainees to experience and witness some of the effects of spatial disorientation. The Barany chair is simply a rotating chair with a large bearing system to ensure smooth operation. The wheel surrounding the chair provides a means of steady control, such as slowing the rotation by hand without jerking the trainee. Controlled rotation is important when subtle changes in speed are needed. Due to the severity of some reactions, trainees must use the lap belt.

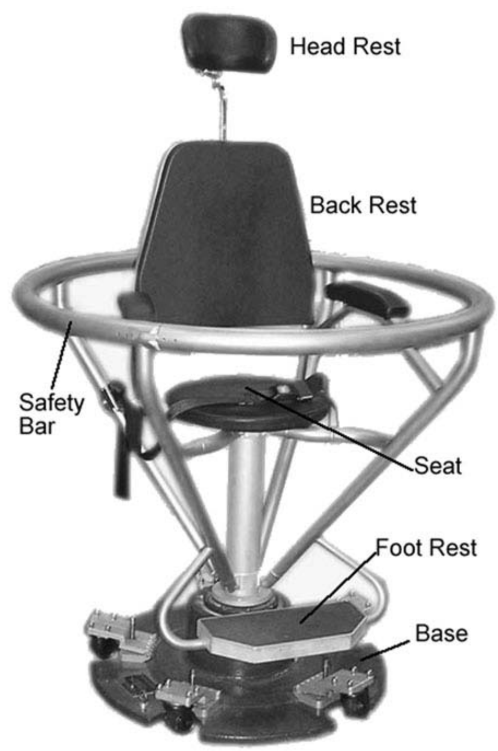

Figure 3–10. Barany chair.

Barany chair procedures for specific illusions are addressed throughout this lesson. A good rule to remember (and apply to all demonstrations) is this: spinning the chair like a helicopter rotor is not required for good results. About 15 rotations at 25 revolutions per minute (rpm) are sufficient. Exact timing is not necessary, but practicing in advance gives you a good "feel" for the amount of rotations required. Never forget there are limitations to Barany chair demonstrations. Primarily, the chair does not subject the trainee to all forces experienced in flight. The demonstration shows only the response of the semicircular canals to angular acceleration.

The first illusions and problems considered are those caused by semicircular canal stimulation. The adverse effects of motion on the semicircular canals can be easily and effectively demonstrated with the Barany chair. Illusions created by otolith-organ stimulation also are discussed.

Nystagmus demonstration

While nystagmus is not an illusion, it's a problem because it involves involuntary eye movements, making vision difficult. Nystagmus can occur when there is stimulation of any of the semicircular canals. When the canal responds to rotation in one direction, the eyes tend to sweep slowly in the opposite direction, then jerk back to the center position. This repeated sweep and return makes it appear as if the eyes are jerking in the direction of the rotation. The canal affected determines which way the eye moves (up, to the right, etc.).

There is only one solution when nystagmus occurs in flight: focus your eyes on a single instrument. This is difficult at first, but it truly reduces the time it takes to recover. Both the onset of nystagmus and the recovery technique can be demonstrated in the Barany chair.

Two demonstrations are necessary. In the first demonstration, have a trainee sit upright in the chair facing the class. Explain that you will rotate the chair for awhile and stop the chair in the original position. Use three trainees near the front of the room as “aircraft instruments.” The trainee in the chair needs only to keep his or her eyes closed until the rotation is stopped (in about 20 seconds). Once the chair is stopped, ask the trainee to open his or her eyes and cross-check the “instruments.” That is, glance quickly at each of the three preselected trainees (an almost hopeless task). Nystagmus will be obvious to both the trainee in the chair and the observers.

Begin with the same procedure in the second demonstration, except instruct the trainee to stare directly at a single “instrument.” Nystagmus is again obvious, but recovery time should be shorter.

Graveyard spin demonstration

Before you can understand graveyard spin, you must understand a spin. In a spin, the pilot has lost control of the aircraft.

An aircraft doesn’t stay in the air solely because of the power of the engines. As the plane moves forward, an area of low pressure (or faster moving airfoil) develops over the top of the wing and higher pressure (or slower moving airfoil) under the wing pushes the aircraft up. We call this, appropriately enough, *lift*. A pilot may exceed the limitations of the aircraft by pulling the nose up too sharply at high speed; or the pilot may reduce the speed too much while maintaining level flight. Either way, the pressure of the airfoil over the wings becomes greater than the pressure under the wings, resulting in a stall. This simply means there is no longer any lift, causing the aircraft to fall to one side or the other. When this happens, the aircraft may enter a spin.

The motion of the aircraft, while in the spin, may be a flat rotation. Yet, this doesn’t mean the aircraft will have a wings-level attitude in the air. As a matter of fact, it usually doesn’t. In the most common stall situation, the aircraft will be in a nose-high attitude. As the stall occurs, the aircraft actually falls over to one side. It then enters the spin with the nose pointing lower and lower toward the ground as the spin continues.

Keep in mind that we certainly haven’t gone very deep into flight dynamics; that’s not our purpose. All we’re really interested in is the motion of the aircraft while in a spin. The same angular acceleration can be produced in the classroom using the Barany chair. Of course, there are several other forces acting on the pilot while in the aircraft. Yet, the mechanism producing the graveyard spin problem is the rotation of the fluid in the semicircular canal.

Always relate trainee experiences during Barany chair demonstration to what may actually occur in flight. Ensure each trainee sits upright in the Barany chair. The trainee’s sole responsibility is to show the direction of rotation with the thumbs as you spin the chair. You can use a blindfold and ear protectors to prevent visual and auditory input.

Rotate the trainee in a clockwise direction to simulate a spin to the right, or clockwise. The trainee will show he or she feels no rotation after about 20 seconds. This is like the pilot in a spin who no longer senses the spin. Of course, this occurs when the fluid in the middle ear has begun to spin at the same rate as the chair. Stop the chair abruptly and the trainee will point to the left with his or her thumbs (counterclockwise, or opposite the original direction of rotation). The abrupt stop forces the fluid to rotate in the opposing direction. This is the same vestibular input experienced by the pilot who has just performed a maneuver to pull the aircraft out of a spin. Now the aircraft is flying straight and level, but the pilot feels as if the aircraft is spinning in the opposite direction.

The pilot must decide to trust the instruments at this point. The instruments show the aircraft in straight and level flight. Yet, without a visual aid, sensory input may cause the pilot to enter a graveyard spin. Remember that the semicircular canal is indicating rotation or spin opposite to the original direction. Therefore, the pilot will place the aircraft right back into the original spin if he or she responds to this sensation. There may not be enough distance between the ground and the aircraft to regain control for a second time if this decision is made.

Graveyard spiral demonstration

The graveyard spiral is very similar to the graveyard spin. In fact, the demonstration in the Barany chair is the same. Again, the source of the problem is fluid rotation in one of the semicircular canals. The difference is that the aircraft is in controlled flight; specifically, a constant-rate coordinated turn.

You've probably noticed that when an aircraft turns, it rolls in the direction of the turn. The pilot maintains a constant aircraft bank angle (slant) and continues the turn. This is done to keep the wings moving through the air in order to maintain equal pressure or lift. The aircraft will continue in this controlled turn and gradually descend without further control input.

What if the pilot enters a turn so gradually that the turn goes undetected? What would happen if the pilot entered a turn, became distracted, and then forgot he was still in the turn?

These problems are more common than you might think. As in the graveyard spin, the trainee no longer senses the turn and thumbs point up after about 20 seconds of rotation. This, of course, represents the constant-rate coordinated turn. The pilot may not realize the aircraft is in a turn if he or she forgets to look at the flight instruments. Remember that the pilot no longer senses a turn. Therefore, the aircraft continues in the spin.

This means that when an aircraft naturally starts to descend, the only sensory input the pilot receives indicates descent. Instincts tell the pilot to pull back on the stick as descent is detected. Another reaction may be to increase power to bring the nose back up to what is perceived to be level flight. This only makes the turn tighter, resulting in the graveyard spiral. Unless the pilot checks the instruments, the spiral will become tighter and tighter until he or she loses control of the aircraft, or until the aircraft impacts with the ground.

Notice that in the graveyard spiral, the flyer never gets the sensation of turning in the opposite direction. An important point to bring out during the Barany chair demonstration is this: even a sense of no rotation is illusion enough to be fatal.

Coriolis demonstration

We have seen the effect of stimulation of a single semicircular canal; that is, a false sensation of rotation. In both of the previous vestibular illusions, the aircraft maneuver produced angular acceleration. The pilot, by keeping his or her head upright with minimal movement, was essentially subjecting the semicircular canals to the same motions as the aircraft. However, don't forget that the vestibular apparatus also responds to head movements.

With this in mind, think of the coordinated right turn. You know that in a short time, the semicircular canal involved will equilibrate. Now what happens if the pilot suddenly bends over to pick up something on the floor? One canal is already affected by the turn of the aircraft. (As your trainee bends forward, a second canal responds to the forward rotation of bending over.) The message the brain receives is a false sense of rotation in the third canal. Note that the third canal was never "physically" affected at all. In this case, the result is a powerful sensation of roll to the right (the direction of the turn).

Pilots who turn their heads to the side while bending forward during a turn create an illusion of combined roll and dive/climb. This also may cause the pilot to correct the aircraft attitude before checking the instruments.

To demonstrate this illusion, seat a trainee in the Barany chair with his or her head bent forward and turned to either side. Ask the trainee to keep his or her eyes closed until rotation ceases. Rotate the trainee for about 20 seconds in a clockwise direction. Instruct the trainee to sit up when you stop the chair. You also may have the trainee open his or her eyes and try to point at some predetermined object. The effect can be quite dramatic. The trainee will immediately fall over to the right.

What happens when an aircraft is in a coordinated turn and aircrew rotates their heads forward/back as they turn to the side? This action evokes a powerful sensation of *pitch* and *roll*. Try to predict a trainee's reaction in the Barany chair. Follow the steps below to create the desired reaction. Remember that the student may need your help recovering from the illusion. Below are some suggested techniques for doing this.

Creating the illusion

1. Rotate the trainee with his or her head bent forward and turned to the right.
2. Stop the chair and instruct the trainee to sit up. The illusion of dive and roll to the right will cause the trainee to fall forward and lean to the right. Lending a hand in recovery is easier if you stand to the right of the trainee.

Helping in recovery

The demonstration has made its point if the trainee reacts violently. Therefore, it won't hurt anything to speed recovery time. Keep the following items in mind while helping a trainee:

- Place a firm hand on the trainee's shoulder to provide a reliable proprioceptive input to the brain.
- Instruct the trainee to remain still to avoid further semicircular canal stimulation. Remaining still proves to aircrews that they can help speed their own recovery time. Aircrews must remain still in the aircraft and concentrate on the instruments.

If nystagmus occurs, remind the trainee to focus on a single instrument to stabilize the eyes. Tell him or her to cross-check instruments and disregard vestibular inputs to the brain.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

216. Vision concerns for flyers

1. What is the sclera?

2. Name the two segments of the eye that light travels directly through.

3. Which part of the eye controls the amount of light entering the posterior portion of the eye?

4. Why is the lens of the eye biconvex?

5. What is the normal intraocular pressure?

6. What part of the eye has the sharpest vision, and why?

7. In dim light, which light-sensitive cells in the retina are stimulated?

8. What must aircrews do to compensate for the 2°–3° central blind spot?

9. Why do you lose an image if you stare at it at night?

10. How is one *foot-candle* of light defined?

11. What does the term *dark adaptation* mean?

12. Which part of the eye contains the substance called *visual purple*?

13. What happens to this visual purple when the eye is exposed to bright sunlight?

14. What vitamin deficiency will impair night vision, and what will happen if you have an excess of this vitamin?

15. If you can normally only see in shades of gray at night, why can you identify the colors of flares?

16. What should you do to keep an object in sight in a darkened environment?

17. What causes loss of visual acuity at night?

18. Certain parts of an aircraft's cockpit may become a hazard at night. What are some of these items?

19. If you are working in bright sunlight, while on call for night duties, what are you advised to do?

20. What is the drawback to wearing red goggles in order to adapt to the dark?

21. In order of preference, what are the best colored lights to use with instruments in a darkened cockpit?

22. Why are red lights not preferred for use in the cockpit?

23. What could cause someone to become hypermetropic (farsighted) during night flights?

24. How does carbon monoxide affect vision?

25. Which foods are good sources for vitamin A?

26. Which foods are sources of vitamins B and C?

27. If you breathe only atmospheric air at 10,000 feet, what happens to your night vision?

28. When subjected to a sudden bright light at night, what happens to objects that are known to exist?

29. What procedure is recommended if you suspect that you may be subjected to bright light after your eyes have dark adapted?

30. If you stare at a fixed light in a darkened room or other environment, what seems to happen?

31. Inclement weather and night flying cause what kind of visual problems for pilots?

217. Night-vision training

1. What is the recommended seating arrangement during a night-vision demonstration?

2. When do trainees remove the dark adaptation goggles?

3. What device is used to aid students in dark adaptation?

4. What method is recommended to demonstrate the effect of the night blind spot?

5. How do you demonstrate loss of visual acuity during the night-vision demonstration?

6. How many times is the glare light used during the demonstration?

218. Noise hazards

1. How does noise interfere with job efficiency and safety?

2. Medically speaking, when does hearing loss occur?

3. What are the most important factors in determining risk of noise exposure?

4. Define *frequency*, as related to noise.

5. How is frequency of sound measured?

6. Which type of noise is more damaging to hearing?

7. A “dBA” or “A-weighted” noise level refers to which process?

8. What are two signs of a possible overexposure to noise?

9. Exposure to noise levels beyond what dBA is not safe regardless of the exposure time?

10. What are some likely sources of hazardous noise for AP personnel?

11. Besides the aircraft itself, name another noise hazard of working around aircraft.

12. What is the main danger from noise in the aerospace physiology training facility?

13. Name the factors in an aerospace physiology unit that determine noise levels.

14. What factors reduce noise in the hypobaric chamber?

15. What are the best solutions to a noise problem?

16. What should you wear on your ears to protect you from the harmful effects of noise?

17. The single-flange earplug comes in how many sizes?

18. Earmuffs are constructed much differently from earplugs. What are the pros and cons of earmuff construction?

19. A combination of V-51R earplugs with standard earmuffs provides protection at what frequency range?

20. When full hearing protection is used but the sound levels are still high, what is the recommended plan for these individuals?

219. Effects of speed, acceleration, and G-forces on the body

1. Why is spatial disorientation a problem?

2. When do sensory illusions occur?

3. Define *acceleration*.

4. Describe linear acceleration.

5. Angular acceleration is concerned with a change in which three possible factors?

6. What is the cause of radial acceleration?

7. Positive “Gs” push your body in which direction?

8. What is a simple demonstration of G-forces that you can do without a vehicle or aircraft?

9. Name three physiological problems associated with G-forces.

220. Effects of spatial disorientation

1. Define *orientation* or *equilibrium*.

2. What is the most reliable sensory system during flight?

3. When does vision become limited in use during flight?

4. What are the two structures of the vestibular apparatus? How do they differ?

5. What is the term used to identify the time when the fluid in the semicircular canal and the canal itself are rotating at the same rate?

6. When the cupula and hair cells are no longer bending in response to the fluid in the semicircular canal, which illusion will occur?

7. When your head is upright, the hair cells of the otolith organs send what message to the brain?

8. What is the major problem with the senses transmitted by the otolith organs?

9. What does the proprioceptive system depend on for input?

10. What is another term for the proprioceptive system?

11. What must you do to overcome all of the possible spatial disorientation problems?

221. Spatial disorientation trainer

1. How many rotations at 25 rpm are needed to demonstrate sensory illusions?

2. What is the primary drawback to using the Barany chair for demonstrations?

3. Which sensory apparatus is affected by the demonstration?

4. What determines the direction of eye sweep during nystagmus?

5. What position is the trainee in during a nystagmus demonstration?

6. What causes “lift” for an aircraft?

7. If a trainee is seated upright and is spun in a clockwise direction, which way will the trainee feel he or she is traveling when abruptly stopped?

8. What maneuver is responsible for the graveyard spiral?

9. Why do pilots get trapped into a graveyard spiral?

10. When the aircraft is spinning, what happens to pilots' vestibular apparatus when they bend over abruptly?

11. In an actual aircraft during a constant-rate coordinated turn, what powerful sensation does the pilot feel during this maneuver?

Answers to Self-Test Questions

214

1. Primary, side, synergistic, and idiosyncratic.
2. They can produce shakiness, increased heart rate, blurred vision, increased dehydration, dizziness, nausea, and headaches. Therefore, self-medicating with decongestants increases physiological stress and decreases an aircrew member's capacity to cope.
3. Antihistamines; side effects include the depressant nature antihistamines have on the CNS. Drowsiness is the most common effect, but they also cause diminished alertness and decreased reaction times.
4. Histotoxic.
5. Abstinence.
6. 200 to 250 times.
7. Skipping meals or eating foods that are predominately simple sugars.
8. Eat at regular intervals.
9. Drink plenty water before, during, and after a flight or physical activity.
10. A state of diminished mental and physical efficiency.
11. 23 to 26 hours.
12. Coffee.
13. Drinking water.

215

1. The normal reaction to any demand placed on you, either physically or mentally.
2. Fight or flight reaction.
3. Control your perceptions of situations, and don't overreact.
4. Stop smoking, don't drink alcohol excessively, avoid self-medicating, get proper nutrition, and exercise.
5. Regular exercise.
6. Aerobic and anaerobic.

216

1. The tough, outer layer of the eye that surrounds the eyeball except for the small segment covered by the cornea.
2. Cornea and lens.
3. The iris (which gives the eye its color) controls dilation of the pupil, allowing light into the eye.
4. To refract the light toward the center and focus light on the retina.

5. 20 to 25 mm Hg.
6. The fovea due to its concentration of cones.
7. Rods.
8. Consciously make scanning movements to keep the image of the object being examined off the fovea.
9. When the rods reach equilibrium, the nerve impulse stops.
10. The amount of light falling on a white sheet of paper if a candle is held one foot away.
11. The eyes slowly adapt to a lower level of lighting via regeneration of photosensitive substances.
12. The rods of the eye.
13. It bleaches out rapidly.
14. Vitamin A. An excess will not improve your dark adaptation and could be harmful.
15. The light from the flares stimulates the cone cells.
16. Use scanning techniques or continuous small movements of the eyes.
17. It is the result of many rods connected to each nerve ending in the area of the retina outside the fovea.
18. Lights in the cockpit, reflections off the windscreen, and dirt, grease, or scratches on the windscreen.
19. Wear suitable sunglasses in the sunshine.
20. They impair your ability to read maps, magazines, and newspapers, and do not provide as good an adaptation as 30 minutes of complete darkness.
21. Blue or blue-green, dim orange, dim yellow, or dim white.
22. Because normal color relationships are disturbed making objects more difficult to see under red lighting; in other words, color differentiation is lost under red light. Also, brightness values are greatly distorted and objects that are normally red appear very light, and green and blue objects appear very dark.
23. The use of red light.
24. It degrades visual acuity, brightness, discrimination, and dark adaptation.
25. Eggs, butter, cheese, liver, apricots, peaches, vegetables, and cod liver oil.
26. Vitamin B: whole grain cereals, green vegetables, and peanuts. Vitamin C: citrus fruits, tomatoes, and cabbage.
27. It's only about 75 percent of sea level effectiveness when you breathe atmospheric air without supplemental O_2.
28. They seem to disappear.
29. Close one eye to protect the night vision in that eye.
30. The light will seem to move about erratically (autokinetic phenomenon).
31. They complicate landing and cause distance judgment problems, along with confusing the identification of approach and runway lights.

217

1. Arrange all trainees at an equal distance from the screen and evenly divided on either side of the projector.
2. After they are seated and the demonstration starts.
3. Night-vision red goggles.
4. Instruct trainees to focus on an aircraft's location during the silhouette slide without using peripheral or off-center vision.
5. By increasing the light intensity while viewing the slides. Acuity becomes more acute as the light intensity increases.
6. A total of nine times, (i.e. one-, three-, and 10-second exposures; this is accomplished three times each).

218

1. By distracting and annoying us, by interfering with communications, and by possible hearing loss, and by causing us fatigue and headaches.
2. When the hair cells in the cochlea of the inner ear become fatigued beyond the point of recovery.
3. Frequency, intensity, and duration.

4. The number of times per second that oscillations (sound waves) occur.
5. In hertz (Hz).
6. High-frequency noise.
7. A reading on a sound level meter that closely approximates the response of the human ear.
8. A fullness in the ears or ringing in the ears.
9. 115 dBA.
10. The flight line, jet engines, ground power units, and training equipment like the hyperbaric and hypobaric chambers.
11. Ground support equipment.
12. Training equipment operations and maintenance.
13. Room design, phase of equipment operation, and noise reduction steps taken.
14. Installing mufflers and wearing helmets or headsets.
15. Eliminate the noise, separate yourself from the noise, or reduce the noise to an insignificant level.
16. Personal ear protection: earplugs, earmuffs, communication headsets, and/or helmet.
17. Five.
18. (1) Pros include the following: they are convenient and easy to take on and off and provide slightly better high-frequency protection. The ear cups on the muffs reduce the amount of ambient noise that reaches the ear, thereby improving communications. Most earmuffs will reduce sound as much as properly fitted earplugs.
    (2) Cons include the following: they are bulky and sometimes interfere with other tasks or with headgear. They provide slightly less low-frequency protection than do the earplugs.
19. About 30 to 35 dB for frequencies between 300 to 4,800 Hz.
20. Limit the individual’s time exposure to the noise, use maximum ear protection, and have frequent audiometer checks of their hearing.

219

1. Because the pilot believes the illusion is real.
2. When the organs of equilibrium (the visual system, vestibular apparatus, and proprioceptive system) provide conflicting information to the brain.
3. Change in speed, direction, or both at the same time.
4. A change in speed (either increase or decrease) while direction remains the same.
5. Pitch, roll, or yaw.
6. A constant rate of turn or other maneuver at a constant speed.
7. Downward into your seat.
8. Twirl any object on the end of a string. The faster it spins, the heavier it seems.
9. Mobility is decreased, respiration becomes difficult, blood pools, vision is decreased, circulation is reduced, eyelids push over the eyes, and position changes occur in the crystalline lens.

220

1. Refers to how an individual actually perceives position, attitude, and motion in relationship to the center of the Earth.
2. Vision.
3. Flying at high altitudes and during instrument meteorological conditions.
4. Semicircular canals and otoliths organs. The semicircular canals detect rotation in the pitch, roll, and yaw planes and angular acceleration whereas the otoliths organs detect the intensity of gravity and linear acceleration.
5. Equilibration.
6. The feeling of no movement or rotation.
7. A “resting” message.

8. They cannot tell the difference between head tilt and linear acceleration.
9. Combined input from sensors all over the body, including muscles and nerve endings.
10. Seat of the pants.
11. You must make yourself believe what you are seeing on the instruments, ignoring all other sensory inputs.

221

1. About 15.
2. It cannot demonstrate all forces experienced in flight.
3. The semicircular canals.
4. The direction of eye sweep is directly linked to the semicircular canal affected.
5. Sitting upright in the chair with eyes closed until asked to open eyes to cross-check the “instruments.”
6. Forward motion combined with an area of low pressure (or faster moving airfoil) develops over the top of the wing and higher pressure (or slower moving airfoil) under the wing.
7. Counterclockwise.
8. Usually a controlled flight constant-rate coordinated turn.
9. They usually no longer feel the spin or turn after the first 20 seconds.
10. Their second and possibly third semicircular canal may become affected.
11. Pitch and roll.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

38. (214) What are the major categories of over-the-counter (OTC) drugs taken by aircrew members?
    a. Tylenol, Robitussin, ibuprofen, and aspirin.
    b. Vasoconstrictors, painkillers, diet pills, and aspirin.
    c. Decongestants, antihistamines, painkillers, and ibuprofen.
    d. Decongestants, antihistamines, vasoconstrictors, painkillers, and diet pills.

39. (214) If Captain Jones departed Langley AFB, Virginia, and arrived at Beale AFB, California, a time change of three hours, how long will it take him physiologically to recover completely from the time shift?
    a. 24 hours.
    b. 36 hours.
    c. 72 hours.
    d. 96 hours.

40. (215) During anaerobic exercise, what substances do the muscles use to produce energy?
    a. Nitrogen and glucose.
    b. Oxygen, fat, and glucose.
    c. Glycogen, fat, and oxygen.
    d. Glycogen, fat, and nitrogen.

41. (216) What light-sensitive cells of the retina are used for night or low-intensity light vision?
    a. Rods.
    b. Cones.
    c. Photopic.
    d. Rhodopsin.

42. (216) What is the size of the night blind spot of the eye’s fovea?
    a. 1°–2°.
    b. 2°–3°
    c. 3°–4°.
    d. 4°–5°.

43. (216) At low illumination, instruments lit with what wavelength color are superior in visibility?
    a. Blue.
    b. White.
    c. Orange.
    d. Yellow.

44. (216) At an altitude of 10,000 feet without supplemental oxygen, how effective is your night vision as compared to sea level?
    a. 75 percent.
    b. 80 percent.
    c. 90 percent.
    d. 95 percent.

45. (216) When the light in a dark room seems to move of its own accord, the phenomenon is known as
    a. light blending.
    b. the glare effect.
    c. the Purkinje phenomenon.
    d. the autokinetic phenomenon.

46. (217) A slide showing which one of these objects is best to demonstrate averted vision and scanning techniques?
    a. Flight line.
    b. Black and white silhouette.
    c. Air Force Academy Chapel.
    d. Towers and telephone lines.

47. (217) During a night-vision demonstration, you should switch on the glare light for a maximum exposure time of
    a. five seconds.
    b. six seconds.
    c. nine seconds.
    d. 10 seconds.

48. (218) In determining risk to noise exposure, which factor is not important?
    a. Intensity.
    b. Duration.
    c. Frequency.
    d. Sensitivity.

49. (218) Normally, the human ear responds to a frequency range of
    a. 10 to 20,000 Hz.
    b. 10 to 25,000 Hz.
    c. 20 to 20,000 Hz.
    d. 20 to 25,000 Hz.

50. (218) Which statement is true regarding a comparison between earmuffs and earplugs?
    a. Earmuffs are much worse than earplugs at total noise reduction.
    b. Earmuffs provide slightly better high-frequency protection.
    c. Earmuffs provide slightly better low-frequency protection.
    d. There is no difference between the two.

51. (219) Airspeed is usually stated using what type of measurement?
    a. Knots.
    b. Miles per hour.
    c. Feet per second.
    d. Meters per second.

52. (219) A pilot in a constant-rate turn at a constant speed is experiencing what type of acceleration?
    a. Radial.
    b. Linear.
    c. Angular.
    d. Singular.

53. (220) During flight operations, which sensory system is the most dependable?
    a. Vision.
    b. Hearing.
    c. Vestibular.
    d. Proprioceptive.

54. (221) What speed in revolutions per minute (rpm) is recommended for Barany chair demonstrations?
    a. 10 rpm.
    b. 15 rpm.
    c. 20 rpm.
    d. 25 rpm.

55. (221) During a demonstration of the Coriolis illusion, how is a trainee seated in the Barany chair?
    a. Bent over with head straight.
    b. Sitting straight up with eyes open.
    c. Sitting straight up with eyes closed.
    d. Head bent forward and turned to either side.

Please read the unit menu for unit 4 and continue. ➔

Student Notes

Unit 4. Chamber Reactions

SEVERE PHYSIOLOGICAL emergencies are not common but they do happen. Without a doubt you will help people with a variety of general hypobaric-related problems during your career. These reactions can range from mild discomfort to severe pain to serious emergency situations. You learned the physiology behind reduced barometric pressure problems; now we discuss the standard procedures to follow when confronted with almost any chamber reaction.

4–1. Treatment of Common Chamber Reactions

As previously noted, some reactions are more likely than others to occur on any given chamber flight. Reactions may occur during the ascent or descent portions of a flight or even after the flight. A trainee who experiences a reaction during a chamber flight is referred to as a *reactor*. We start this section discussing reactions caused by the effects of barometric pressure changes, followed by the treatment of hypoxia and apparent psychological reactions.

222. Treating for mechanical effects of pressure change

Reactions occurring due to expanding trapped gases are always a possibility. However, we must remember that the possibility of an evolved gas problem cannot be ruled out. In any event, both gas-related problems are the product of the mechanical effects of pressure change.

Problems with ears and sinuses

Generally, ear problems on ascent are limited to a slow venting of expanding gas. Instruct trainees to equalize the pressure (vent) by moving their heads or jaws from side to side or by pinching off the nostrils and swallowing. If a trainee experiences difficulty equalizing, you can also instruct the chamber operator to level the chamber and descend if necessary. Never instruct trainees to use the *Valsalva maneuver* (forcibly exhaling against a closed glottis) on ascent. Doing so only forces more air into the eustachian tube, thus aggravating the problem. Trainees with upper respiratory infections should not be allowed to participate in chamber training.

Ear and sinus descent reactions make up the bulk of all chamber reactions. During descent, watch the trainees very carefully for signs of discomfort. The first indication of a possible reaction usually can be noticed by watching a student's eyes. Trainees experiencing difficulty should immediately give a predetermined level-off signal to level the chamber. It is the inside observer's job to give the level-off signal if a trainee has a problem and does not give the level-off signal. Your next step depends upon your assessment of the problem's severity.

Ear blocks (barotitis media)

Probably the most common reaction you will see in the chamber is an ear block. This reaction varies from mild discomfort to acute pain. Instruct the trainee to point to the painful area and indicate the degree of distress. Ascend the chamber 2,000 feet (bounce) if the student is experiencing pain. Always request a bounce if a trainee reports pain. Bouncing the chamber should immediately relieve the pain.

Sometimes trainees simply “fall behind” in equalizing the pressure or “clearing their ears.” In these cases, instruct trainees to perform a good Valsalva maneuver. Trainees should tilt their head toward the opposite side of the affected ear, pinch their nose and try to blow. This stretches the eustachian tube, making the ear block easier to clear. Use regulator pressure if this method is not effective. Use the regulator’s “TEST MASK” toggle and instruct trainees to cough or swallow against the pressure. Using a vasoconstrictor may be necessary to prevent subsequent blocks. Vasoconstrictors narrow the blood vessels in the eustachian tubes causing the tubes to open up and help equalize the pressure. *Afrin* is an example of a vasoconstrictor.

The last step should be the *Politzer* bag. Explain the use of the Politzer bag to trainees before using it. The procedure begins by instructing the trainee to hold a mouthful of water without swallowing. Insert the tip of the Politzer bag into the affected nostril and pinch the nose closed. On a predetermined signal, the trainee swallows the water. Watch the Adam’s apple, and as it rises, squeeze the bag. The air pressure forced into the nasal passage should clear the trainee’s ear or sinus block. You should slow the descent of the chamber, giving the trainee more time to clear the ears and sinuses. Refer the trainee to the flight surgeon for possible postflight treatment.

If a Valsalva clears the ear block, simply direct the trainee to pay closer attention to clearing the ears. Emphasize to trainees to never let pressure in the ear build to a painful condition. Progressing to a point of pain only makes the ears more difficult to clear.

Sinus blocks (barosinusitis)

Sinus area discomfort does not usually occur during ascent or descent if the sinus ducts are open. However, a sinus duct may become blocked if the opening is malformed or swollen due to an upper respiratory infection. A blockage at the opening of the duct within the sinus may occasionally occur during ascent. The blockage prevents the expanding gas from venting to the outside and causes localized discomfort as the pressure builds up within the sinus.

The degree of pain depends upon the pressure difference across the sinus duct. Sinus pain most often occurs during descent. The pressure must be equalized as rapidly as possible to prevent excessive pain. The Valsalva maneuver is usually effective in clearing mild sinus blocks. However, the direction of the chamber must be changed if the pain is too great. After resolving the condition, using vasoconstrictors and slowing descent rates usually prevents a recurrence. Once a trainee has experienced a sinus block, inside observers must be ready to act should a subsequent block occur.

Students who may feel they have a sinus problem should be checked by the Aerospace Physiology Officer (APO) or flight surgeon before the flight because the associated pain can be severe and occur with little or no warning. In some sinus-block cases, bloody mucous may discharge from the nasal passages. This condition is not serious and should not alarm the trainee or the observers.

Problems in gastrointestinal tract

If gas in the gastrointestinal (GI) tract expands beyond a feeling of fullness, it can result in pain. If trainees experience mild abdominal pain, inside observers should instruct the chamber operator to level the chamber and encourage the reactors to expel the gas. The reactor may find it helpful to stand, place a foot on the chamber seat, and lean forward. Massaging the abdomen from the bottom right side of the rib cage downward towards the left leg also helps expel gas. Use caution when allowing reactors to stand since there is a possibility they may faint. Descending the chamber may aid the reactor in expelling the gas. If the reactor is unable to expel the gas, you should transfer the reactor to the lock and descend the lock to ground level. Refer the reactor to the flight surgeon if pain persists at ground level

Problems with teeth

Level the chamber if a trainee experiences pain in the area of the teeth and determine which tooth is causing the problem. Descent can relieve tooth pain, which is medically known as *barodontalgia.* Remove the reactor from the chamber and refer him or her to the flight surgeon. Pain in the upper teeth area during ascent may be referred pain from a maxillary sinus block. Flight surgeons refer reactors to the dental clinic if the pain is not a result of a sinus block.

Sometimes, what seems to be a maxillary sinus block can actually be tooth pain. Tooth pain is very rare on descent, although it can be very painful when it happens. Inside observers should be sure to level the chamber and determine which tooth is causing the pain. Suspect a maxillary sinus block if it involves the upper teeth. At the APO's discretion, continue descent and refer the reactor to the flight surgeon.

223. Treating hypoxia

Typically, trainees experience hypoxia during planned hypoxia demonstrations in the chamber. During these controlled demonstrations, emphasize to the trainees to remain off oxygen *only* until they recognize their personal hypoxia symptoms. Trainees must return to 100 percent oxygen at the end of the demonstration. The goal is for them to correct for hypoxia on their own. Feel free to assist trainees when they need help returning to oxygen, connecting their equipment, and so forth. However, trainees should try to follow normal aircraft procedures for a hypoxia incident. Indeed, trainees who do not return to 100 percent oxygen on their own fail this particular objective of the flight.

Hypoxia incidents that occur outside planned chamber demonstrations warrant immediate attention. Aerospace physiology trainees as well as aircrew members need to have specific hypoxia treatment procedures in place in the event that they require treatment for a hypoxia incident. Regardless of the type of oxygen equipment used in various aircraft, the most important factor is for each trainee/aircrew member to have a specific treatment procedure. As a minimum, treatment should include the following steps:

- Administer supplemental oxygen.
- Check oxygen equipment.
- Monitor breathing.
- Descend the aircraft/chamber.

Administer supplemental oxygen

Providing adequate supplemental oxygen is of prime consideration in the treatment of hypoxia. The common treatment is 100 percent oxygen. Below FL 340, and assuming the equipment is fitted and operating properly, 100 percent oxygen reestablishes the sea-level equivalent of oxygen-blood saturation. The addition of positive pressure speeds recovery from severe hypoxia. Above FL 400, positive pressure and 100 percent oxygen is required to recover from hypoxia.

Monitor breathing

A reactor's respiratory rate and depth may increase (hyperventilation) because of decreased oxygen-blood saturation. Trainees will not completely recover from hypoxia until they control this hyperventilation. A breathing rate of about 12 to 20 breaths per minute is desirable. The increased breathing accounts for the similarities of hypoxia and hyperventilation symptoms—both are treated the same.

When oxygen is restored through the mask and regulator, trainees may experience a momentary increase in the severity of their symptoms called an *oxygen paradox*. This phenomenon occurs during sudden reoxygenation. A hypoxic individual starts hyperventilating, which reduces carbon dioxide. A reduction of carbon dioxide tells the nervous system to constrict (narrow) blood vessels to stop the hyperventilation. Once oxygen is restored, vasodilatation (blood vessels expansion) occurs but also blood pressure drops slightly affecting respiration and making it more difficult for the oxygen to be delivered to the brain. This aggravates the hypoxia symptoms momentarily and may even cause trainees to want to remove their oxygen mask. Eventually, the blood's carbon dioxide pressure increases enough to resume normal respiration. In severe oxygen paradox cases it can result in muscle spasms and unconsciousness for as long as 30 seconds. Decreased vision, mental confusion, dizziness, and nausea may also accompany oxygen paradox.

Check oxygen equipment

Poor oxygen discipline is the most frequently reported cause of hypoxia. Reports include the failure to use oxygen when required and inadequate oxygen equipment checks. Check equipment before a flight and monitor it during the flight to reduce the occurrence of this potential hazard. Inspect oxygen equipment whenever you suspect it may be a potential cause of hypoxia. Correcting malfunctions help bring immediate relief of the hypoxic condition. Prevent future incidents by reporting all equipment deficiencies or malfunctions.

Occasionally, oxygen contamination causes hypoxia symptoms. Suspect oxygen contamination if the previously prescribed treatment does not correct the problem. It is important to note how all trainees or aircrew members using the oxygen source would react if contamination were the cause of hypoxia in the chamber or aircraft. Use an alternate oxygen source, such as the emergency oxygen cylinder or portable assembly. Descend as soon as possible and have the contents of the oxygen system analyzed.

Descend

Increasing the alveolar partial pressure of oxygen helps correct for hypoxia. Increasing ambient oxygen pressures by descending also makes up for malfunctioning equipment. Report all hypoxia incidents to the flight surgeon.

Remember it is not uncommon for trainees to exceed time of useful consciousness during controlled hypoxia demonstrations. There is no further cause for alarm if trainees recover rapidly. However, treat hypoxia incidents as serious reactions when they occur during other than controlled demonstrations.

224. Treating psychological reactions

Apprehension, hyperventilation, claustrophobia, and the feeling of suffocation are some of the more common psychological reactions your trainees may exhibit. On the other hand, these reactions may have a physiological basis.

Another psychological problem is the trainee who chooses to conceal physiological problems. This trainee is particularly difficult because it is entirely up to you to recognize something is wrong. For example, this trainee may try to withstand abdominal pain to the point of collapse. A trainee also may conceal an ear block until the eardrum ruptures. A trainee may even remain off oxygen during demonstrations to the point of unconsciousness.

There are several possible reasons for this type of behavior. Trainees may feel showing distress is a sign of weakness. A woman may feel a strong desire to avoid the appearance of needing special treatment. To some, a chamber reaction may show a physiological deficiency or the inability to perform adequately. Trainees may try to hide problems for fear of not being able to complete the course or may be under considerable pressure to finish on time. None of these attitudes are justifiable, but they do exist. Careful observation is the only way to identify such trainees in these cases. Learn to “read” trainees’ eyes as you gain experience. Their eyes will frequently show distress, alerting you to inquire further. Trainees will tell you of a specific problem when they are directly questioned. You can also look for observable signs of hyperventilation or notice the trainee touching or rubbing a particular area as if in pain. For example, if a trainee places his or her fingers near the external ear canal, this may indicate ear pain.

Hyperventilation

Hyperventilation often occurs when trainees become apprehensive about the chamber flight. However, hyperventilation occurs most often after trainees begin pressure breathing or during a hypoxia episode. Hyperventilation can be detected by watching the flow indicator on the oxygen regulator for an increased breathing rate.

Inside observers should remind trainees to slow their breathing rate when they think trainees are hyperventilating. Instructing reactors to talk out loud is an excellent method of slowing the breathing rate. Simultaneously, the observer should confirm the reactor is receiving 100 percent oxygen and, depending on altitude, should ensure he or she is receiving pressure from the regulator. During hyperventilation, the blood vessels in the brain may constrict. Directing reactors to place their head between their knees may help with cerebral vasoconstriction by increasing the blood flow to the brain. You may even want to place the reactor in a horizontal position. Reactions are serious when reactors are unable to control their rate and depth of respiration. Remove reactors from the chamber and refer them to the flight surgeon.

Treatment in aircraft is much the same as in the chamber. The main difference is aircrews must depend on themselves to recognize and treat the problem. Inform aircrews to treat suspected cases of both hypoxia and hyperventilation the same because their symptoms are similar. Place additional emphasis on deliberately reducing the rate and depth of breathing.

Claustrophobia

Many trainees are apprehensive about altitude chamber flights. This fear or anxiety does not normally manifest itself as a chamber reaction beyond a mild case of hyperventilation. However, a claustrophobic trainee may not tolerate the oxygen mask within the confines of the chamber once the chamber door closes. This type of reactor requires patience and understanding to help reduce fears. The best approach is to work with the trainee before the chamber flight. Sit the trainee inside the chamber with the door open to practice breathing with an oxygen mask on.

Rushing or crowding a claustrophobic trainee will probably cause problems during the flight. Transfer trainees to the lock if they insist on leaving the chamber during the flight. Then remove them from the chamber and recommend an examination by the flight surgeon.

Suffocation

A trainee who experiences a sense of suffocation may or may not suffer from a psychological problem. A sense of suffocation may lead to apprehension and anxiety. However, you should consider all the following possibilities when someone reports a feeling of suffocation.

A trainee may have difficulty breathing when wearing an oxygen mask for the first time. There is also a slight collapse of the MBU-5/P mask during inhalation. The trainee may believe there is something wrong with the equipment. A simple explanation of mask operation usually eliminates this fear. Next are some of the common causes of suffocation.

Regulator off and 100 percent oxygen

Trainees may put their masks to their faces and drop the masks away immediately, saying they cannot breathe. The regulators are probably off, and the diluter levers are set to 100 percent. This setting prevents any gaseous flow from reaching the user.

Mask valve

Humidity or moisture in the mask may cause the inhalation/exhalation valve to stick. Trainees usually report difficulty on exhalation in this case, and the problem usually occurs during initial mask connection. Intermittent “TEST MASK” pressure, with the mask disconnected, may dry out the valve and eliminate the problem. Also, with the mask up, have the student cough against the “TEST MASK” pressure. This may help to loosen a “sticky” valve. If oxygen flow does not help, the trainee may have a faulty valve and need to be exchanged for another mask.

Positive pressure

A trainee may report difficulty exhaling during the chamber flight. A lack of experience with positive-pressure breathing may be the problem. If you know the regulator is delivering pressure, simply discussing the problem can help. However, do not overlook the obvious. Check that the trainee has not accidentally placed the regulator in the "EMERGENCY" position.

Connector regulator unit-60/P quick disconnect

Again, the obvious is not always apparent. If the trainee suddenly reports difficulty inhaling while using the oxygen equipment, suspect the connector regulator unit (CRU)-60/P connector. You may remember this restriction is a built-in feature of the connector. Its purpose is to warn users they have become disconnected from their on-board supply hose.

If available, you may move the student to another regulator and see if the problem resolves. If after considering all of the above the trainee continues to complain of suffocation, remove him or her from the chamber and refer them to the flight surgeon.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

222. Treating for mechanical effects of pressure change

1. What causes ear problems during ascent?

2. What is the recommended procedure for a student who has ear problems on ascent?

3. What reactions make up the bulk of problems on descent?

4. What is your responsibility should a reactor not give a level-off signal?

5. Which regulator setting is used (along with coughing or swallowing) in order to clear the ear(s)?

6. What are the procedures for using the Politzer bag?

7. What can cause sinus blocks?

8. What should be done with students who feel they may have sinus problems prior to the flight?

9. Which direction should you massage the abdomen to relieve abdominal pain?

10. If a student cannot expel the gas, what procedure should be taken?

11. As an inside observer, what is the first thing you do for a student complaining of tooth pain?

12. If a reaction on descent involves pain in the upper teeth, what should you suspect as the problem?

223. Treating hypoxia

1. As a minimum, what should be considered when developing a hypoxia treatment plan?

2. When treating severe hypoxia or hypoxia above FL 400, what is recommended in addition to 100 percent oxygen?

3. What causes hyperventilation after a hypoxia incident?

4. Severe oxygen paradox may result in what symptoms?

5. List the accompanying effects of oxygen paradox.

6. How can you reduce the occurrence of oxygen equipment malfunction?

7. What would you suspect as a problem when all normal procedures fail to treat the hypoxia problem?

224. Treating psychological reactions

1. How can you identify trainees who are having reactions but try to hide their problems?

2. How can you detect hyperventilation?

3. If a trainee is unable to control the rate and depth of breathing, what is the recommended procedure?

4. What two attributes should you possess in order to deal with a severely claustrophobic student?

5. How can you reduce the fear and anxiety of a severely claustrophobic student prior to the flight?

6. If humidity or moisture is trapped in the inhalation/exhalation valve, what usually occurs?

7. What is the main problem for trainees during the pressure-breathing portion of the chamber flight?

8. If you have tried every option within the chamber to relieve a trainee's feeling of suffocation to no avail, what is your final option?

4–2. Treatment of More Serious Reactions

As you participate in more and more chamber flights, you will get more comfortable when treating common chamber reactors. However, you also need to be prepared to handle reactions that do not occur so frequently, therefore, are not so familiar. In this next section, we cover what we consider emergency reactions and the proper procedures to follow. At the end of this section, we review what to look for and how to record vital signs.

225. Handling emergency reactions

Remember to take all reactors seriously. We discussed few reactions that may lead to removal from the chamber. However, there are other reactions requiring immediate emergency steps due to their severity. Some of these reactions are collapse, extreme pain, syncope, air gas embolism, pneumothorax or pneumomediastinum, and all types of decompression sickness (DCS). There are specific steps to follow in handling these reactors.

Conditions requiring treatment and/or removal

The procedures for removing a reactor from the chamber depend on whether the reactor is *ambulatory* (able to walk) or unconscious. The information we present here will help prepare you to make the correct decisions in any given situation. Keep in mind the choices you make affect not just the reactor, but also the remaining trainees.

Syncope

This condition is characterized mainly by a loss of consciousness. Hypoxia, hyperventilation, decompression sickness, air embolism, heart attack, and shock are a few of the many possible conditions responsible for loss of consciousness. Immediate treatment includes assessing the situation by taking vital signs. Follow the treatment procedures for an unconscious reactor and initiate cardiopulmonary resuscitation (CPR) as necessary.

Air gas embolism

The effective treatment for an air gas embolism (AGE) is to administer 100 percent oxygen and descend to ground level. Transport the reactor to the nearest hyperbaric facility for further treatment.

Pneumothorax

The treatment for pneumothorax is immediate descent to ground level. Once on the ground, the physician may choose to insert a chest tube to remove the air in the chest cavity, thereby reinflating the lung.

Pneumomediastinum

Again, the treatment procedure is immediate descent and referral to the flight surgeon. Pneumothorax and pneumomediastinum are extremely rare in both aircraft and chamber operations.

Treating decompression sickness

Decompression sickness is indeed a serious reaction, and it does occur during altitude chamber training flights. Denitrogenation before ascent significantly reduces DCS incidences, but many hours of denitrogenation would be for total protection. The same is true for operational flying. Whether or not you plan to fly unpressurized—or a loss of pressurization occurs accidentally—the development of DCS symptoms must not be taken lightly. Treat all cases of decompression sickness as an emergency.

If you suspect a trainee or crew member has developed decompression sickness, immediately remove the individual from the flight following the procedures below. On the ground, the physician and the APO can determine the type of treatment necessary. Treatment may range from simple observation at ground-level oxygen therapy or hyperbaric treatment.

Delayed DCS manifestations are possible after returning to ground level, even if symptoms were not present at altitude. Trainees must be made aware of the possibility of postflight symptoms because they are no longer under APO supervision after they leave the AP training facility.

Removing emergency reactors

When an emergency reaction occurs, the most important step after assessing the situation is to determine the removal procedure. The following information will help you make the correct decision in most situations.

Ambulatory reactor

In most cases, the lock compartment is used to evacuate ambulatory reactors. Regardless of the specific cause of the problem, ensure the reactor breathes 100 percent oxygen during the move into the lock and descend to GL. Simply place the reactor on a portable oxygen assembly and help the reactor into the lock compartment, placing him or her in a horizontal position. Start descent in the lock after the APO has determined the rate of descent.

Continue the training profile after the reactor is removed. Keep in mind, the other trainees may have developed considerable anxiety about the chamber flight as they watched you remove the reactor. Take time to calm their fears. Make sure they are ready to continue with the training. If you do not, additional reactions may result from their anxieties.

The lock observer (also referred to as inside observer no. 3 or IO3) monitors and records the reactor’s pulse and respiratory rate. In addition, IO3 notes and records all pertinent signs and symptoms. This information assists the flight surgeon to diagnose and treat the reactor. The IO3 also should help alleviate the reactor’s anxiety, pain, and discomfort.

Keep the reactor on 100 percent oxygen while escorting him or her to the recovery room. Replace the portable oxygen supply with the recovery room's oxygen supply system. Begin annotating the reactor's symptoms, vital signs, and time of entry to the recovery room. Keep the reactor on 100 percent oxygen and continue recording vital signs or new symptoms every 15 minutes until directed to stop by the flight surgeon. You will need this information to complete the AF Form 361, Chamber Reactor/Treatment Report.

The APO and IO3 remain with the reactor until the flight surgeon arrives. Return the lock to altitude at the direction of the APO.

Unconscious reactor

The basic principle applied to handling unconscious reactors is to assume the worst until you determine otherwise. High altitude is no place to take chances because the causes of unconsciousness are so variable. Therefore, follow these general procedures for an unconscious reactor under APO guidance.

The first step is to administer 100 percent oxygen and to simultaneously place the reactor in a horizontal position with his or her feet elevated. Ensure an open airway. If consciousness is regained, place the reactor on a portable oxygen assembly, breathing 100 percent oxygen without pressure. Record the reactor's pulse, respiration rate, and the time.

Under APO guidance, descend the chamber to ground level if the reactor has not regained consciousness. The seriousness of the reactor's condition governs the rate of descent. If the reactor regains consciousness during the descent, transfer the reactor to the lock. Place the reactor in a horizontal position and continue 100 percent oxygen.

Direct the other trainees to continue to clear their ears when the entire chamber has descended with an unconscious reactor. Observe and assist these trainees with potential reactions.

Place the unconscious reactor on a stretcher and continue to administer 100 percent oxygen at ground level while moving the reactor to the recovery room. Replace the portable oxygen supply with the recovery room's oxygen supply system. Continue with 100 percent oxygen until the flight surgeon discontinues its use. Continue to monitor and record symptoms and vital signs of unconscious reactors as you would a conscious reactor.

It is very important to closely monitor the unconscious reactor. If vital signs fail, perform CPR until the flight surgeon arrives. If the chamber flight continues, return the lock to altitude at the direction of the APO.

226. Recording vital signs

If you are IO3, you will be the first person attending to the reactor in most cases. You may be required to make decisions and perform tasks normally done by other medical personnel. Under most circumstances, you are required to obtain only the reactor's blood pressure reading, pulse, and respiration rate. However, you may want to record additional data for the medical staff—any additional observations—such as seizure activity, muscle response to normal activity, and verbal responses from the reactor.

You learned the basic procedures for checking vital signs during the apprentice course. It is always a good idea to refresh your skills if you have not performed these procedures in awhile. This keeps you proficient and builds your confidence. Be sure to take all vital signs at 15-minute intervals.

Blood pressure

Blood pressure (BP) is normally measured and recorded at systolic and diastolic levels. Systolic pressure is the level of the pressure in the arteries during contraction of the left ventricle, representing the highest level of arterial pressure. Diastolic pressure is the level of pressure in the arteries during relaxation of the heart, representing the minimum level of arterial pressure. The difference between systolic and diastolic pressure is called *pulse pressure*.

Blood pressure is recorded by reading systolic pressure over diastolic pressure, such as 120/80, which is considered normal. Blood pressure readings vary with a person's age, sex, and genetic makeup. Other factors affecting BP include time of day, activity level, emotions, diet, and general physical condition. You will need a stethoscope and sphygmomanometer (blood pressure cuff) in order to measure BP.

Be sure the ear pieces of the stethoscope angle forward to follow your ear canals and that they sit securely. The most common sphygmomanometer in our physiology flights is the aneroid type. The cuffs come is small, medium, and large; make sure you select the proper cuff size. The new digital sphygmomanometer is now used in most medical treatment facilities eliminating the need to use a stethoscope to take BP.

The brachial artery located in the upper part of the arm (biceps) is the most common site for measuring BP. However, avoid arms with intravenous (IV) already in place; this is especially important for hyperbaric patients. Wrap the cuff snugly around the upper arm once the pulse is located, centering the bladder over the brachial artery. You should be able to get only two fingers under the cuff when it is properly placed. Position the cuff so the lower edge is one to two inches above the elbow. Locate either the brachial or the radial pulse and continue to palpate it as you inflate the cuff. Note the point where you can no longer feel a pulse and continue to inflate the cuff for about another 30 mm Hg. Place the diaphragm (flat side) of the stethoscope over the brachial pulse and gradually deflate the cuff. Systolic pressure is the point where you first hear pulse sounds. Continue deflating the cuff until the sounds either disappear or become very muffled. That point is the diastolic pressure. Annotate the results and which arm you used to take the BP.

As previously stated, the best way to get and stay proficient in the management of vital signs is to periodically practice the procedures. This will improve your ability to take, record, and maintain a reactor's vital signs if and when the time comes.

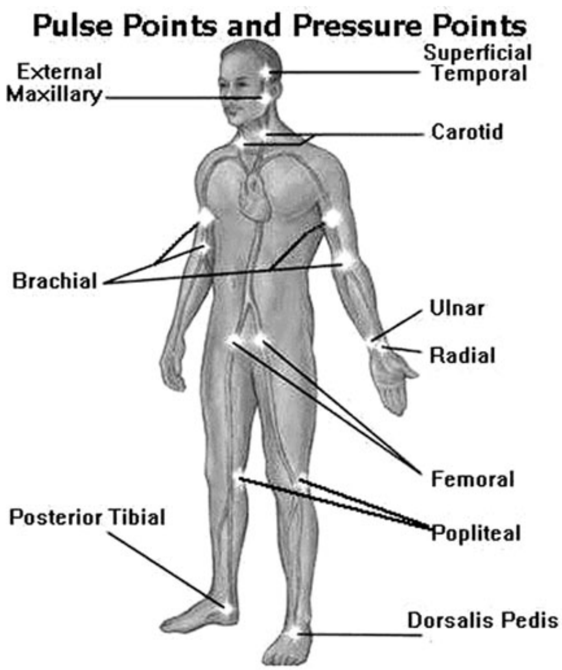

Figure 4–1. Pulse points.

Pulse

Pulse is the rhythmic expansion and contraction of the arterial wall in response to ventricular contractions and changes in blood flow. Your arteries are elastic structures; they expand when there is an increase in blood flow and contract when the flow returns to normal. You can feel this action at any point where an artery lies close to the skin surface. The best points to feel this is where there is a bone directly beneath the artery. These sites are called *pulse points*. The radial and carotid arteries are the most commonly checked pulse points. As we discuss the pulse points, refer to figure 4–1.

Radial pulse

The radial artery is most commonly used for routine pulse checks. It lies along the radius on the inside of the wrist. Place two fingers over the artery and count the pulsations for 15, 30, or 60 seconds to check the radial pulse. Do not press too hard or use your thumb; otherwise you will feel your own pulse.

Carotid pulse

The carotid artery is preferred for pulse checks in emergency situations because it is easily accessible and is very strong. You should be able to feel the carotid pulse even when stroke volume is low. Gently place the same two fingers in the area between the trachea and the neck muscle (*sternocleidomastoid*) on either side of the neck to locate the pulse. Again, count the beats for 15, 30, or 60 seconds. Be extra careful not to place your thumb on the trachea; doing so may cause an obstruction of the reactor's airway. A person's pulse can be characterized by its rate, volume, and rhythm.

Pulse rate

The normal pulse rate for adults is between 60 and 80 beats per minute. The range for children is 80 to 100 beats per minute, and the range for infants may be 100 to 120 beats per minute or faster. Some elderly persons or athletes may have a slightly slower pulse rate, while females may have a faster heart rate.

Pulse volume

Pulse volume is an indication of the strength of the heart muscle. The pulse normally feels full and strong. Abnormal pulse volumes are described as either weak and thready or strong and bounding. Record any perceived abnormal pulses and pressures to better inform medical personnel of the reactor's condition. A weak and thready pulse may be caused by shock or blood loss. A bounding pulse is usually associated with conditions such as exercise and strong emotions

Pulse rhythm

A third characteristic is pulse rhythm or regularity of the heartbeat. The normal pulse has a steady, unbroken rhythm. Abnormal or irregular rhythms are characterized by hesitations between beats or spurts of rapid heartbeats followed by periods of normal rhythm. Understanding theses characteristics will help in your ability to assess the reactor's overall condition.

Again, try to describe all characteristics when you document and report pulse. For example, record "pulse 72, strong and regular." Proper documentation provides the medical team with a much better picture of the patient's condition.

Respiration

Respiration, or breathing, brings oxygen into the body and eliminates carbon dioxide. The anatomy and physiology behind respiration was presented in unit 1 of this volume. Therefore, it is not necessary to explore that aspect again. Like the pulse, respirations have certain characteristics. These characteristics are quality, rate, and depth.

Quality

This characteristic refers to the amount of effort, pain, symmetry, and type of noises involved in breathing. Normal breathing should be effortless, automatic, and relaxed. Breathing is abnormal if it is labored (difficult) or painful. Abnormal breathing is called *dyspnea*. Any type of noise indicates some sort of respiratory obstruction. Abnormal sounds from chamber trainees may indicate any of the following: asthma, emphysema, pulmonary edema, pneumonia, and so forth. Record any obvious abnormal breathing sounds.

Rate

A single respiration consists of one inspiration and one expiration. The respiration rate is the number of breaths a person takes per minute. Adults normally breathe at a rate of 12 to 20 respirations per minute. This figure varies according to the individual's emotional activity, physical activity, and physical condition. Respiratory rates are usually above normal during periods of stress or physical activity. On the other hand, an individual in good physical condition has a below-normal respiratory rate during periods of routine activity. Age also affects the respiratory rate.

An abnormal rate may be either lower or higher than the norm. It is not uncommon to see cases of increased rate during episodes of hyperventilation or hypoxia. *Apnea* is the total absence of respirations. Often, it is the result of hyperventilation and should last only until the carbon dioxide level increases to its normal level.

Depth

This is the volume of air that moves in and out with each respiration. If a reactor is breathing normally, you should see about one inch of chest expansion and feel a steady airflow against the back of your hand. Just like rate, depth is most often dictated by the activity level. Depth also plays a role in hypo/hyperventilation and if left unchecked, it eventually corrects itself. Many times, both rate and depth are the result of an individual's emotional response to a given situation.

You may find it difficult to obtain an accurate count of a reactor's respirations unless the reactor is unaware of your task. If the reactor becomes aware that you are counting respirations, he or she may unconsciously try to alter the results, and you will obtain an inaccurate count. One approach is to count the respirations either just before or just after you check the pulse.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

225. Handling emergency reactions

1. List the problems that always necessitate immediate removal of a reactor from the chamber.

2. What is syncope?

3. What is the treatment for a pneumothorax in the chamber?

4. What procedure should you follow with the remainder of the students after one has been removed from the chamber?

5. What procedures should the lock observer follow with a student reactor descending to ground level?

6. When should you stop taking vital signs?

7. What is the general rule when dealing with unconscious reactors?

8. When should an unconscious reactor be placed on a portable oxygen assembly?

9. When is the portable assembly replaced, and when is 100 percent oxygen use discontinued?

10. What should be done if a reactor's vital signs fail?

226. Checking vital signs

1. What is systolic pressure?

2. What is diastolic pressure?

3. What is the normal blood pressure for adults?

4. What is the most common sight for measuring blood pressure?

5. How should the blood pressure cuff be placed on a person's arm?

6. Define *pulse*.

7. Define *pulse points*.

8. What arteries are most commonly used for checking a person's pulse?

9. Why is the carotid artery preferred for use during emergency situations?

10. What is the normal pulse rate for an adult?

11. What are the three characteristics of respiration?

12. Define the characteristic of quality.

13. What is the normal rate of breathing for an adult?

14. Define the characteristic of depth.

Answers to Self-Test Questions

222

1. Slow venting of expanding gas.
2. Have the student move his or her head and/or jaws from side to side or pinch off the nostrils and swallow.
3. Ear and sinus problems.
4. You should instruct the chamber operator to give the level-off signal as soon as you detect the problem.
5. The “TEST MASK” setting of the regulator.
6. Explain the procedure to the student. Have the student take a mouthful of water, insert the tip of the bag into the nostril of the affected side, pinch closed the nose, make a signal to allow the student to swallow the water, and squeeze the bag as the student’s Adam’s apple rises.
7. Malformed sinus ducts or swollen ducts due to an upper respiratory infection.
8. They should be checked by either the APO or a flight surgeon prior to the flight.
9. Start at the bottom of the right side of the rib cage, massage downward towards the left leg.
10. Transfer the student to the lock for descent to ground level.
11. Level the chamber and determine which tooth is causing the problem.
12. A maxillary sinus block (referring pain to the upper teeth).

223

1. How to administer supplemental oxygen; check oxygen equipment; monitor breathing; and descend the aircraft/chamber.
2. Addition of positive pressure to aid recovery.
3. Decreased oxygen-blood saturation may increase both rate and depth of breathing.
4. Muscle spasms, unconsciousness for as long as 30 seconds, and ceasing of respiration.
5. Decreased vision, mental confusion, dizziness, and nausea.
6. By checking equipment before a flight and monitoring it during the flight.
7. Contaminated oxygen system.

224

1. Learn to read their eyes and observe their behavior (e.g., a trainee placing his or her fingers near the external ear canal, indicating ear pain).
2. By watching the flow indicator on an oxygen regulator for an increased breathing rate.
3. Remove the reactor from the chamber and refer him or her to the flight surgeon.
4. Patience and understanding.
5. Have the trainee sit inside the chamber with the door open and practice breathing with the oxygen mask on.
6. The valve sticks and gives the trainee a feeling of suffocation.
7. They have difficulty breathing due to a lack of experience with pressure breathing.

8. Remove the student from the chamber and refer him or her to the flight surgeon.

225

1. Collapse, extreme pain, syncope, air gas embolism, pneumothorax, pneumomediastinum, and all types of decompression sickness.
2. Loss of consciousness.
3. Immediate descent to ground level.
4. Continue the training profile, but check them thoroughly and take time to calm their fears and anxieties.
5. Monitor and record pulse and respiratory rate; record all pertinent signs and symptoms; and attempt to alleviate the reactor's anxiety, pain, and discomfort.
6. Stop taking the reactor's vital signs when told to stop by the flight surgeon.
7. Assume the worst until you determine otherwise.
8. When he or she regains consciousness.
9. When oxygen is applied in the recovery room. Discontinue oxygen only on orders of the flight surgeon.
10. Perform CPR until the flight surgeon arrives.

226

1. Level of pressure in the arteries during contraction of the left ventricle, representing the highest level of arterial pressure.
2. Level of pressure in the arteries during relaxation of the heart, representing the minimum level of arterial pressure.
3. 120/80.
4. Brachial artery.
5. Wrap it snugly around the upper arm once the pulse is located, centering the bladder over the brachial artery. You should be able to get only two fingers under the cuff when it is properly placed. Position the cuff so the lower edge is one to two inches above the elbow.
6. The rhythmic expansion and contraction of the arterial wall in response to ventricular contractions and changes in blood flow.
7. Point where a bone lies directly beneath an artery.
8. Radial and carotid.
9. It's easily accessible and very strong.
10. 60 to 80 beats per minute (bpm).
11. Quality, rate, and depth.
12. The amount of effort, pain, symmetry, type of noises involved in breathing.
13. 12 to 20 respirations per minute.
14. The volume of air that moves in and out with each respiration.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

Do not return your answer sheet to the Extension Course Program (A4L).

56. (222) For treatment of mild abdominal pain during a chamber flight, do not have the
    a. student stand up and lean backwards.
    b. chamber operator level the chamber.
    c. student massage the abdomen from right to left.
    d. student stand and place a foot on the chamber seat and lean forward.

57. (222) What is the medical term for tooth pain?
    a. Sinusitis.
    b. Barosinusitis.
    c. Barodontalgia.
    d. Dentilmyalgia.

58. (222) Pain in the upper teeth during ascent on a chamber flight may be the result of what type of problem?
    a. Bilateral ear block.
    b. Frontal sinus block.
    c. Maxillary sinus block.
    d. Decompression sickness.

59. (223) At altitudes above FL 400, what does a crew member suffering from hypoxia need to breathe to reestablish
    a sea-level equivalence in oxygen-blood saturation?
    a. Ambient air only.
    b. 100 percent oxygen only.
    c. 100 percent oxygen under positive pressure.
    d. A mix of ambient air and 100 percent oxygen.

60. (223) As normal alveolar oxygen tension is restored, there may be a momentary increase in the severity of hypoxia symptoms which is referred to as
    a. oxygen paradox.
    b. oxygen toxicity.
    c. hyperventilation.
    d. hypemic hypoxia.

61. (223) What is the most common cause of hypoxia incidents?
    a. Faulty equipment.
    b. Faulty instruction.
    c. Contaminated oxygen.
    d. Poor oxygen discipline.

62. (224) A common indication of apprehension and claustrophobia during a chamber flight is
    a. mild hypoxia.
    b. severe hypoxia.
    c. mild hyperventilation.
    d. severe hyperventilation.

63. (225) If you suspect a trainee has developed decompression sickness, you should immediately
    a. descend the chamber to 10,000 feet.
    b. have the trainee breathe 100 percent oxygen.
    c. call the flight surgeon for hyperbaric treatment.
    d. follow the procedures to remove emergency reactor.

64. (225) After removing a reactor from the chamber, you should check the reactor's vital signs every
    a. five minutes.
    b. 10 minutes.
    c. 15 minutes.
    d. 20 minutes.

65. (225) Which personnel remain with a chamber reactor until the flight surgeon and his or her team arrives?
    a. Lock observer and crew chief.
    b. Lock observer and lock operator.
    c. Crew chief and aerospace physiologist.
    d. Lock observer and aerospace physiology officer.

66. (226) The difference between systolic and diastolic blood pressure is called
    a. pulse rate.
    b. heart rate.
    c. pulse pressure.
    d. heart pressure.

67. (226) How is blood pressure recorded?
    a. Heart rate over pulse rate.
    b. Pulse pressure over heart rate.
    c. Diastolic pressure over systolic pressure.
    d. Systolic pressure over diastolic pressure.

68. (226) The normal pulse rate per minute for an adult is between
    a. 50 to 80 beats per minutes.
    b. 60 to 80 beats per minutes.
    c. 80 to 100 beats per minutes.
    d. 100 to 120 beats per minutes.

69. (226)
    The quality of respiration is *best* described by the amount of
    a. effort, rate, and depth involved in breathing.
    b. pain, symmetry, and depth involved in breathing.
    c. effort, pain, and depth of noises involved in breathing.
    d. pain, effort, symmetry, and type of noises involved in breathing.

70. (226) Adults normally breathe at a rate of how many respirations per minute?
    a. 6 to 12.
    b. 8 to 16.
    c. 10 to 18.
    d. 12 to 20.

When you complete this course, please complete the student survey on the Internet at this URL: <u>http://www.maxwell.af.mil/au/afiadl/</u>. Click on Student Info and choose 9502 Survey.

Glossary

Abbreviations and Acronyms

ADH	antidiuretic hormone
AF	Air Force
AFI	Air Force Instruction
AFOSH	Air Force Occupational Safety and Health
AGE	air gas embolism
AGL	above ground level
AGSM	anti-G straining maneuver
AP	aerospace physiology
APO	aerospace physiology officer
ATP	adenosine triphosphate
AV	atrioventricular (valve)
BMR	basic metabolic rate
BP	blood pressure
bpm	beats per minute
C	Celsius
CNS	central nervous system
CO_2	carbon dioxide
CO	carbon monoxide
CP	cardiopulmonary
CPR	cardiopulmonary resuscitation
CRU	connector regulator unit
dB	decibel
dBA	a-weighted noise level (decibels)
DCS	decompression sickness
DEA	Drug Enforcement Agency
DNA	deoxyribonucleic acid
EVA	extravehicular activity
F	Fahrenheit
FDA	Federal Drug Administration
FL	flight level
fps	feet per second
G	gravitational forces

GI	gastrointestinal
GL	ground level
Hz	Hertz
IMC	instrument meteorological conditions
IO3	inside observer 3
IV	intravenous
kt	knots
K	Kelvin
lb/in^2	pounds per square inch
mm Hg	millimeters of mercury
mph	miles per hour
mps	meters per second
MSL	mean sea level
N_2	nitrogen
O_2	oxygen
OTC	over the counter
PCO_2	partial pressure of carbon dioxide
PN_2	partial pressure or tension
PNS	peripheral nervous system
PO_2	partial pressure of oxygen
psi	pounds per square inch
P_T	total pressure
RBC	red blood cell
RD	rapid decompression
REM	rapid eye movement
rpm	revolutions per minute
SL	sea level
SPL	sound pressure level
TUC	time of useful consciousness
WBC	white blood cell

Student Notes

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