3 Senses of the Human Body and Measurement of Environmental Factors

3.1 LEARNING GOALS

This chapter will provide the student with knowledge of the human senses and the sensory process for each system. A discussion of tools and techniques to assess the sensory impact is offered to teach the process to evaluate the environment as it relates to the senses. Measurement and management of the occupational conditions on the human senses will also be addressed.

3.2 KEY TOPICS

An introduction to human sensory functions and measurement of the level of sensory capability is the focus of this chapter. Guidelines used to promote ergonomic design that is compatible with the human senses are covered, as well as a discussion of know occupational risk factors.

3.3 INTRODUCTION AND BACKGROUND

Much of what we know about how smells, sights, tastes, textures, and sounds are processed in the brain is due to the work of Wilder Penfield and colleagues during the mid-twentieth century. By directly stimulating different areas of exposed cortical tissue during neurosurgery, these doctors were able to map the specific areas of the brain that are activated as a result of different types of sense stimulation. While the five senses are critical to the brain's ability to process information about the natural world, recent knowledge affirms that they are vital to mental health, and the loss of one or more of these sensations can lead to physical and emotional distress (http://www.sciencedirect.com.proxy.library.emory.edu/science/journal/00016918, *Acta Psychologica*, April 2001).

According to *Webster's Online Dictionary*, "sensory deprivation" is defined as "a form of psychological torture inflicted by depriving the victim of all sensory input." In fact, depriving human beings of their natural human senses has been officially considered torture since the European Court of Human Rights ruled in 1978 (*Ireland v. United Kingdom*) that the use of deprivation techniques such as wall-standing, hooding, subjection to noise, sleep deprivation, and deprivation of food and drink were inhumane. The media took a great interest in the subject surrounding this landmark case as well. For instance, the prominent 1960s' television show *The Twilight Zone* featured an episode where an astronaut isolates himself in a sensory deprivation room in order to mimic the conditions of being on the moon. "Where is Everybody?", as the first episode of the twilight series was titled, results in the astronaut's mental deterioration as a result of his isolation (http://www.websters-online-dictionary.org).

This episode is an example of a growing concern about the effect of environmental factors, like isolation from others and deprivation of sensory stimulation, on the mind, and more specifically, human task performance. Far from the Industrial Revolution era fixation on working employees for the longest hours at the lowest wages possible, today's businesses and manufacturers are looking for ways to improve the quality of work rather than simply increasing the quantity of mechanical output. For instance, over the last 30 years, millions of dollars have been invested in sleep research, to investigate the amount of sleep necessary for adequate performance, as lack of sleep diminishes sensory alertness and brain awareness. In one such study, three groups of healthy subjects were randomly assigned various lengths of post-lunch naps, and tested in areas of alertness, task performance, and autonomic balance. The results of this study, and others like it, demonstrated the benefits of a short post-lunch nap on overall performance quality, and as a result many businesses are trying to incorporate napping facilities for the use of their employees (*European Journal of Applied Physiology and Occupational Physiology*).

3.4 SENSORY FUNCTIONS

The various systems of the body interact to create sensory functions. The human sensory functions are the means by which information is perceived from the external environment by humans. In the absence of sensory capabilities, the body would be cut off from the world as no knowledge of the external environment could be received. The primary senses in ergonomic study include

- Vision
- Audition
- Cutaneous
- Olfactory
- Gustation

The senses are essentially receptors, constantly receving input from the environment. Sensory functions allow the body to respond to stimuli. Nerves and sensory receptors respond to both internal and external stimuli. These stimuli are received by nerves and receptor cells and are converted into impulses that travel to the brain, where the signals are processed. In addition to the traditionally considered "five senses"—sight, hearing, smell, taste, and touch—humans have senses of motion (kinesthetic sense), heat, cold, pressure, pain, and balance (New World Encyclopedia, 2008).

3.4.1 Vision

Vision is a complicated process that requires numerous components of the human eye and brain to work together. The eye is the primary organ of the visual sense. The

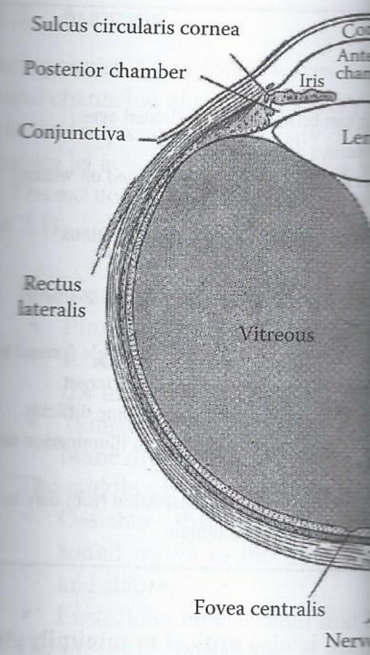

FIGURE 3.1 Eye. (From Gray, H., *Anatom*
Philadelphia, PA, 1918, retrieved September

eye is connected to the brain through th
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network of neurons, electrical impulses
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3.4.1.1 Visual Fatigue

The reliance on the vision as the prima
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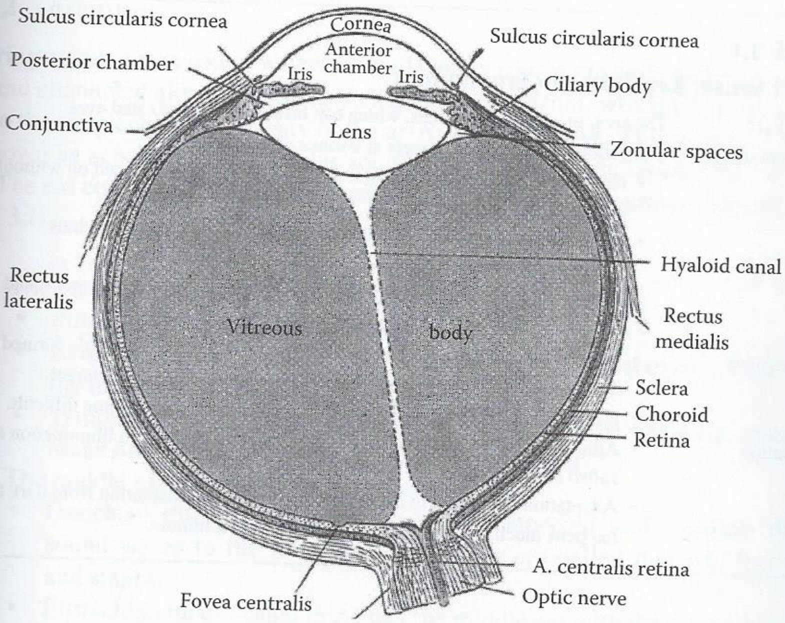

FIGURE 3.1 Eye. (From Gray, H., *Anatomy of the Human Body*, 20th edn., Lea & Febiger, Philadelphia, PA, 1918, retrieved September 9, 2009, from http://www.bartleby.com/107/)

eye is connected to the brain through the optic nerve and is a complex structure that contains a transparent lens. This lens focuses images and light that enter through the pupil onto the retina. The retina is covered with two types of light-sensitive cells known as rods and cones. The cone cells are sensitive to color and are located in the part of the retina called the fovea, where the light is focused by the lens. The rod cells are not sensitive to color, but have greater sensitivity to light than the cone cells. These cells are located around the fovea and are responsible for peripheral vision and night vision. After the photoreceptors collect the light and send the signals to a network of neurons, electrical impulses are generated and subsequently transmitted to the brain through the optic nerve (Figure 3.1; Table 3.1).

3.4.1.1 Visual Fatigue

The reliance on the vision as the primary sensory mode can lead to overuse in the occupational environment, especially in tasks that utilize any type of video display terminals. "Visual fatigue" is the term used to describe conditions experienced by individuals when the visual sense is stressed due to incompatibility of the occupational environment with the visual system. The effects of visual fatigue may include loss of productivity, decline in quality, increased human error, increased accident rate, visual complaints, and long-term discomfort (Grandjean, 1997). To minimize visual fatigue, the occupational environment and task requirements should be designed with consideration of visual capabilities, limitations as well as lighting

TABLE 3.3
Speech Intensity Table

Description	Typical Intensity of Source, dB(A?)	Distance	Message Characteristic
Soft whisper		3–6 in.	Secret communication
Audible whisper	44–69	8–20 in.	Confidential or personal
Normal voice	50–75	20–60 in.	—
Loud voice	56–81	5–8 ft	Nonpersonal, intermediate group
Very loud voice	62–87	To 20 ft	Group address
Shouting	68–93	Upper limit	Hailing or emergency communication

Source: Woodson, W.E., Tillman, B., and Tillman, P. *Human Factors Design Handbook*, 2nd edn., McGraw-Hill, Inc., New York.

In an occupational environment many factors impact the quality and consistency of hearing, including the individual's hearing ability, background noise, competing auditory signals, and environmental factors. The level (or intensity) of the auditory message, as well as the factors listed earlier, should be taken into consideration when designing the distance from which the message should be transmitted. Table 3.3 shows typical speech intensity levels for common communication (Woodson, 1992).

The application of sound auditory guidelines and principles can be effective in reducing negative effects of excessive noise. Although individual perceptions of noise may vary, excessive noise levels that exceed the Occupational Safety and Health Administration (OSHA) guidelines can significantly impact task performance. Table 3.4 provides a summary of some conditions that can result from exposure to excessive noise levels (Woodson, 1992).

3.4.2.2 Noise-Induced Hearing Loss

Noise is any acoustic phenomenon that annoys the listener, making noise a psychological and subjective issue. Noise at safe levels can be annoying and distracting but will not physically affect hearing. However, when an individual is exposed to harmful noise—sounds that are too loud or loud sounds that last a long time—the sensitive structures in the inner ear can be temporarily or permanently damaged, resulting in noise-induced hearing loss (NIHL). Additionally high noise levels can adversely impact task performance. Table 3.3 provides a summary of the impact various sound levels on performance (Woodson, 1992). The small, sensory hair cells convert sound energy into electrical signals that travel to the brain. Once damaged, the sensory hair cells cannot grow back.

Risk factors for NIHL are found in both the occupational and recreational environments. NIHL is completely preventable given good care of the hearing sense. All individuals should understand the hazards of noise and follow safe hearing practices in everyday life. To protect hearing in the occupational environment consider the guidelines provided in Table 3.5.

TABLE 3.4
Noise Effects on Performance

Noise Level, dB	
150	Reduced visual acuity, chest-wall vi "gagging" sensation.
120	Loss of equilibrium.
110	Chronic fatigue and digestive disord
105	Reduced visual acuity, stereoscopic hearing loss when exposure contin
100	Serious reduction in alertness. Atten usually not affected. Temporary he region 600–1200 Hz. Most people maximum duration they will accep
95	Considered to be the upper acceptan environment to be noisy. Temporar 1200 Hz. Speech will be extremely though they may be talking directl
90	At least half of the people in any giv noisy, even though they expected a the range of 300–1200 Hz occurs. The annoyance factor is high, and pupils dilate, the blood pressure in decrease). Listening to a radio is in duration that most people will acce
85	The upper acceptance level (noise e considered the upper comfort level be expected, especially where deci
80	Conversation is difficult (i.e., people is difficult to think clearly after ab increase in metabolic rage. Strong level in confined spaces, and 8 h is
75	Too noisy for adequate telephone c 2 ft apart. Most people will still ju
70	The upper level for normal conver distance of 6 ft people will have and shipboard personnel who are this noise level, unprotected telep level is 68 dB).
65	The acceptance level when people personal conversation is acceptabl experience difficulty sleeping.
60	The upper limit for spaces used fo activities. Most people will rate th conditions.

TABLE 3.4
Noise Effects on Performance

Noise Level, dB	Effects
150	Reduced visual acuity, chest-wall vibration, changes in respiratory rhythm, and a "gagging" sensation.
120	Loss of equilibrium.
110	Chronic fatigue and digestive disorders.
105	Reduced visual acuity, stereoscopic acuity, and near-point accommodation and permanent hearing loss when exposure continues over a long period (months).
100	Serious reduction in alertness. Attention lapses occur, although attention duration is usually not affected. Temporary hearing loss occurs if no protection is provided in the region 600–1200 Hz. Most people will consider this level unacceptable, and 8 h is the maximum duration they will accept.
95	Considered to be the upper acceptance level for occupied areas where people expect the environment to be noisy. Temporary hearing loss often occurs in the range of 300–1200 Hz. Speech will be extremely difficult, and people will be required to shout, even though they may be talking directly into a listener's ear.
90	At least half of the people in any given group will judge the environment as being too noisy, even though they expected a noisy environment. Some temporary hearing loss in the range of 300–1200 Hz occurs. Skill errors and mental decrements will be frequent. The annoyance factor is high, and certain physiological changes often occur (e.g., the pupils dilate, the blood pressure increases, and the stroke volume of the heart may decrease). Listening to a radio is impossible without good earphones. The maximum duration that most people will accept is 8 h.
85	The upper acceptance level (noise expected) in the range of 150–1200 Hz. This is considered the upper comfort level, although some cognitive performance decrement can be expected, especially where decision making is necessary.
80	Conversation is difficult (i.e., people have to converse in a loud voice less than 1 ft apart). It is difficult to think clearly after about 1 h. There may be some stomach contraction and an increase in metabolic rage. Strong complaints can be expected from those exposed to this level in confined spaces, and 8 h is the maximum.
75	Too noisy for adequate telephone conversation. A raised voice is required for conversants 2 ft apart. Most people will still judge the environment as being too noisy.
70	The upper level for normal conversation, even when conversants are close together (at a distance of 6 ft people will have to shout). Although persons such as industrial workers and shipboard personnel who are used to working in a noisy environment will accept this noise level, unprotected telephone conversation will be difficult (upper phone level is 68 dB).
65	The acceptance level when people expect a generally noisy environment. Intermittent personal conversation is acceptable. About half of the people in a given population will experience difficulty sleeping.
60	The upper limit for spaces used for dining, social conversation, and sedentary recreational activities. Most people will rate the environment as "good" for general daytime living conditions.

(continued)

TABLE 3.4 (continued)
Noise Effects on Performance

Noise Level, dB	Effects
55	The upper acceptance level for spaces where quiet is expected (150–2400 Hz). People will have to raise their voices slightly to converse over distances greater than 8 ft. This level of noise will awaken about half of a given population about half of the time. It is still annoying to people who are especially sensitive to noise.
50	Acceptable to most people where quiet is expected. About 25% will be awakened or delayed in falling asleep. Normal conversation is possible at distances up to 8 ft.
40	Very acceptable to all. The recommended upper level for quiet living spaces, although a few people may still have sleep problems.
30	Necessary for specialized listening tasks (e.g., threshold signal detection).
<30	Introduces additional problems; that is, low-level intermittent sounds become disturbing. Some people have difficulty getting used to the extreme quiet, and a few may become psychologically disturbed.

Source: Woodson, W.E., Tillman, B., and Tillman, P. *Human Factors Design Handbook*, 2nd edn., McGraw-Hill, Inc., New York.

NIHL is a commonly occurring condition in many occupations. Strategies to reduce the risk of occupational NIHL include the following:

- *Reduce or avoid the generation of the sound by designing machine parts to minimize noise production.*
- Impede the transmission of noise by using barriers, encapsulating noise source, and using sound absorbing surfaces.

The nature of the noise source may require adapting standard procedures or creating unique approaches for reducing the impact of noise. A combination of engineering controls, administrative controls, and personal protective equipment should be used to address hazardous noise and reduce the likelihood of NIHL (Box 3.2).

3.4.2.3 Current Technology: iPods and MP3(4) Impact on Hearing

The rapid development of digital technology has resulted in new kinds of portable music players, including MP3 players such as iPods, in which sound quality is no longer distorted at higher volumes. Because they are equipped with improved headphones, sound-leakage is minimal, allowing these devices to be used at high volume levels in most environments without disturbing others. As a result, the conditions for higher sound levels and longer exposure times are created, both of which are known to increase the risk of hearing damage. MP3 players, thus, may be the most important risk factor for music-induced hearing loss in young people (Vogle, 2008).

TABLE 3.5
Upper Noise Level Limits

Sound Level, dBA	Type of Activity	Communication Equipment	Office Application
108	Maximum design limit for AMC equipment (hearing protection required)	No direct communication	Not recommended
100	Armored vehicles (hearing protection required)	Electrically aided communication satisfactory with attenuating helmet or headset; limited shouted communication possible with difficulty	Not recommended
90	Material that is beyond the state of the art of meeting 85 dBA (hearing protection required)	Shouted communication possible at short distances (1–2 ft)	Not recommended
85	Acceptable level for unprotected hearing for 8 hr exposures	Shouted communication possible at several feet (3–4 ft); telephone use difficult	Not recommended
75	Maintenance shops, garages, and keypunch areas	Occasional telephone use and occasional direct communication at up to 5 ft is acceptable	Not recommended
65	Operation centers, mobile command and communication centers, computer rooms, word processing centers, kitchens, and laundries	Frequent telephone use and frequent direct communication at up to 5 ft is acceptable	Business machine offices
55	Drafting rooms, laboratories, and conferences with two or three people	No difficulty with telephone use and occasional direct communication at up to 15 ft	Shop offices and general secretarial areas
45	Libraries, conference rooms, command and control centers, theatres, and sleeping areas	No difficulty with direct communication	General offices
35	Recording studios and large conference rooms	Areas requiring unusually extreme quiet	Executive offices

Source: Woodson, W.E., Tillman, B., and Tillman, P. *Human Factors Design Handbook*, 2nd edn., McGraw-Hill, Inc., New York.

Given the international popularity of portable music devices, exposure to unsafe sound levels has increased dramatically, and millions of adolescents and young adults are experiencing short-term hearing loss and are potentially at risk of permanent hearing loss through listening to their favorite music. Music-induced hearing loss may be evolving into a significant social and public health problem. Increasing

BOX 3.2 OLFACTORY JOBS

- Culinarian (cook, chef)
- Enologist (wine maker/taster)
- Perfumer
- Quality assurance (food and beverage companies)
- Safety inspector (chemical/hazard, smoke detection)
- Law enforcement (drug and alcohol detection)
- Medical workers
- Firefighters (gas/chemical leaks, smoke detection)

numbers of adolescents and young adults already show related symptoms, such as distortion, tinnitus, hyperacusis, and threshold shifts.

3.4.3 Olfaction

Olfaction involves the sense of smell, and the major organ associated with this sense is the nose. In the upper part of the human nostril, several million smell-reacting sensors comprise the olfactory epithelium, which is responsible for the detection of smell (Figure 3.2). These smell receptors are connected to the olfactory nerve and transmit the sensations to the brain (Myers, 2004). These receptors allow the human to detect as many as 10,000 different smells. However, this is small compared to olfactory capabilities of dogs. Dogs have a sense of smell that is thousands of times more sensitive than humans, as they have 25 times more olfactory receptors than humans (Correa, 2005).

The sense of smell has physiological impacts that stimulate the nervous system, and psychological and psychogenic impacts that effect one's attitude, mood, and ability to perform. The sale of candles, air fresheners, and other fragrances has grown substantially in recent years. The multibillion dollar a year aromatherapy industry is built on the olfactory sense (Figure 3.3) (Demand Studios, 2009).

Several techniques are used to describe and distinguish odor qualities including those developed by Fanger (1988). These two measures are the olf (from the Latin word *olfactus* = olfactory sense) and the decipol (from the Latin "pollution" = pollution) (Konz, 1997). One olf is the emission rate of air pollutants from a standard person in an office or nonindustrial environment. Likewise, one decipol is the pollution caused by 1 olf ventilated by 10 L/s of unpolluted air (Konz, 1997). Table 3.6 shows typical odor perception for sample olf values.

Seven classes of smell are widely recognized: ethereal, camphoraceous, musky, floral, minty, pungent, and putrid. The Henning's Smell Prism (Iowa State University, 2004) presents six odors at the corners of a prism allowing better visualization of combinations of scents that produce complex odors. The Henning's Smell Prism classifies odors as follows (Figure 3.4):

- Fragrant
- Putrid

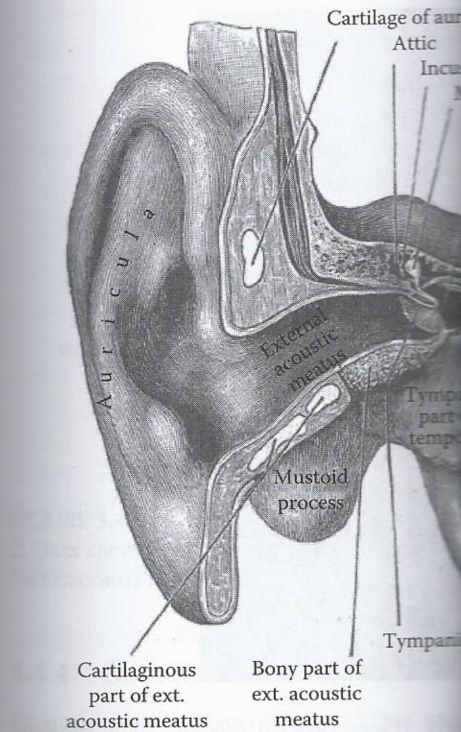

FIGURE 3.2 Ear. (From Gray, H., *Anatomy*
Philadelphia, PA, 1918, retrieved September 9,

- Ethereal
- Spicy
- Resinous
- Burned

While the classes of odors previously de
mary classes of stimulants, most odors a
ing two or more olfactory receptors. The i
can pose challenges to categorizing odors
olfactory sense is the sensory function mo
Dr. Jay Gofried at University College Lon
than clumping together the sights, sounds
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through just one of our sensory channels"

Different scents have also been associat
A 2007 German study showed that partici
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better on a quiz related to the material they

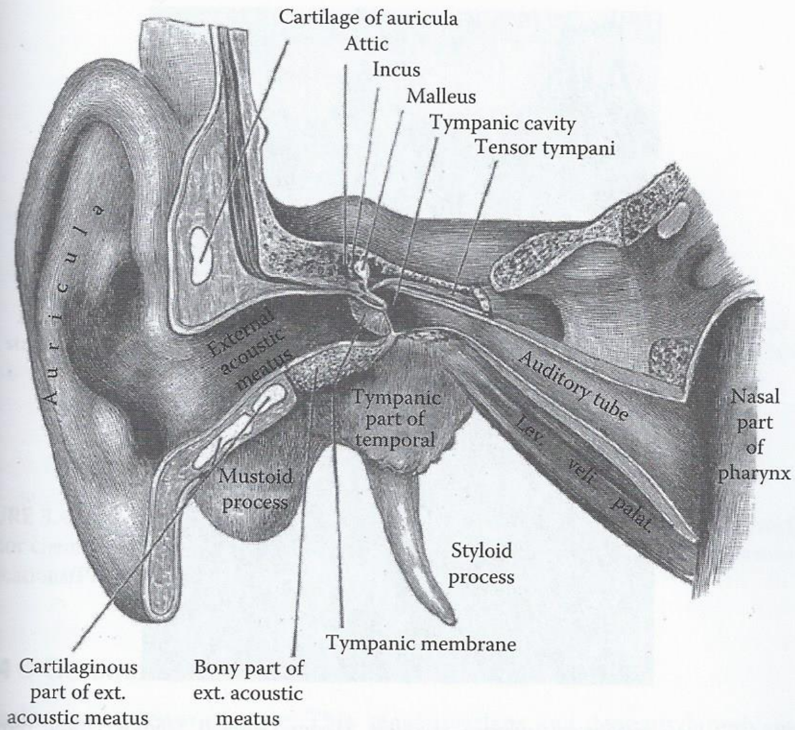

FIGURE 3.2 Ear. (From Gray, H., *Anatomy of the Human Body*, 20th edn., Lea & Febiger, Philadelphia, PA, 1918, retrieved September 9, 2009, from http://www.bartleby.com/107/)

- Ethereal
- Spicy
- Resinous
- Burned

While the classes of odors previously described are recognized as the seven primary classes of stimulants, most odors are considered complex odors encompassing two or more olfactory receptors. The intensity of the odor is another factor that can pose challenges to categorizing odors. Psychological studies have indicated the olfactory sense is the sensory function most strongly associated with memory recall. Dr. Jay Gofried at University College London states "Our study suggests that, rather than clumping together the sights, sounds, and smells of a memory into one bit of the brain, the memory is distributed across different areas and can be re-awakened through just one of our sensory channels" (Gottfried et al., 2004).

Different scents have also been associated with performance in a number of areas. A 2007 German study showed that participants who smelled a rose scent while learning and then again while experiencing Rapid Eye Movement (REM) sleep performed better on a quiz related to the material they had learned the previous day (Hitti, 2007).

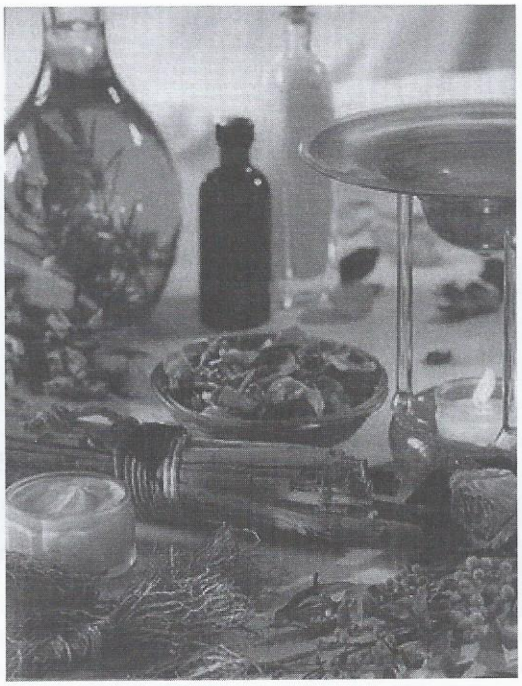

FIGURE 3.3 Aromatherapy industry products. (From Demand Studios, 2009, retrieved September 9, 2009, from http://cdn-write.demandstudios.com/upload/3000/200/00/0/33200.jpg)

TABLE 3.6
Odor Perception

Olf Value	Source
0–5	Per square meter of materials in the office
1	Sedentary person, 1 met
5	Active person, 4 met
6	Smoker, average
11	Active person, 6 met
25	Smoker, when smoking

The inhaling of peppermint vapor has been proven to improve an athlete's speed, strength, and endurance and substantially decrease fatigue (Raudenbush, 2001). The emerging field of aromachology, or the study of aromas and how they affect human behavior and performance, is providing promising possibilities in areas as diverse as athletic performance and improved memory.

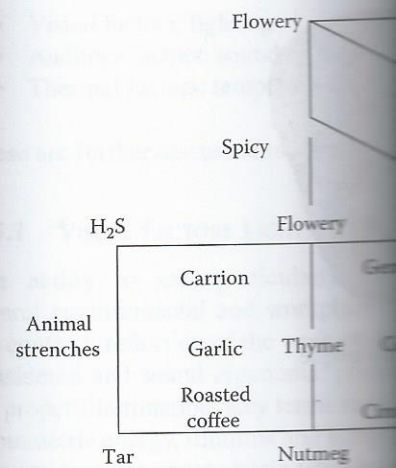

FIGURE 3.4 Henning's smell prism. (Fr
2: Odor chemistry, 2004, retrieved January 2
Publications/PM1963B.pdf)

3.4.4 Gustation

Gustation is the sense of taste. This s
senses of smell and tactation. In other
the tongue engages impact the percept
When considering the sense of taste a
are used to assess the type of taste w
are located primarily on the human to
near the pharynx. They are able to dete
sour. The taste buds are continuously
every 2 weeks. Different parts of the
tastes, such as the tip of the tongue, w
Margolskee, 2001).

Given the strong dependence on the
is perceived as taste actually comes fro
perceive only bitter, salty, sweet, and so
food that provide most of the taste sen
odor molecules travel through the passag
receptors cells at the top of the nasal cav
the bridge of the nose. This information
perceived taste of the food.

Gustation is not used extensively i
are certain occupations that benefit fr
rely on the olfactory sense include w
(Figure 3.5).

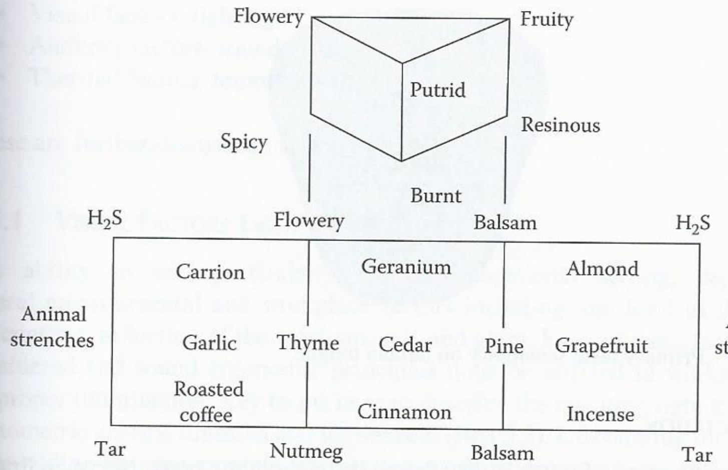

FIGURE 3.4 Henning's smell prism. (From Iowa State University, The science of smell part 2: Odor chemistry, 2004, retrieved January 23, 2011, from http://www.extension.iastate.edu/Publications/PM1963B.pdf)

3.4.4 Gustation

Gustation is the sense of taste. This sense overlaps and depends largely on the senses of smell and tactation. In other words, the smell and texture of objects that the tongue engages impact the perception and degree of favorability of the item. When considering the sense of taste alone, the receptors for taste or taste buds are used to assess the type of taste within substances. Nearly 10,000 taste buds are located primarily on the human tongue but also on the roof of the mouth and near the pharynx. They are able to detect four basic tastes: salty, sweet, bitter, and sour. The taste buds are continuously replaced and are renewed approximately every 2 weeks. Different parts of the tongue are more prone to detect certain tastes, such as the tip of the tongue, which is most sensitive to sweets (Smith and Margolskee, 2001).

Given the strong dependence on the olfactory sense, approximately 75% of what is perceived as taste actually comes from the sense of smell. Taste buds allow us to perceive only bitter, salty, sweet, and sour flavors, but it is the odor molecules from food that provide most of the taste sensation. When food is placed in the mouth, odor molecules travel through the passage between the nose and mouth to olfactory receptors cells at the top of the nasal cavity located just beneath the brain and behind the bridge of the nose. This information is interpreted as a contributing aspect of the perceived taste of the food.

Gustation is not used extensively in the occupational environment, but there are certain occupations that benefit from one's sense of taste. Occupations that rely on the olfactory sense include wine tasters, food critics, and food samplers (Figure 3.5).

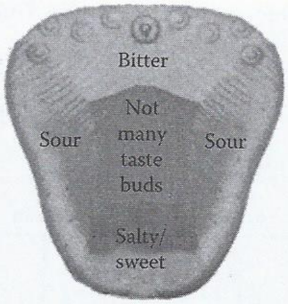

FIGURE 3.5 Primary taste sensitivity on human tongue.

3.4.5 Tactation

Tactation, or the sense of touch is distributed throughout the body. Nerve endings in the skin and other parts of the body transmit sensations to the brain. Some parts of the body have a larger number of nerve endings and, therefore, are more sensitive. Four kinds of touch sensations can be identified: thermal (cold or heat and moisture), pressure, electronic stimulation, and pain.

Sensory capabilities located in the skin are referred to as cutaneous and comprise the tactation sense. The four categories of cutaneous senses include

- Mechanoreceptors that sense tactation, that is, contact touch and pressure
- Thermoreceptors that sense warmth or cold relative to each other and the body's neutral temperature
- Electroreceptors that respond to electrical stimulation of the skin (theoretical, but not a proven factor)
- Nocireceptors that sense pain

These receptors work individually and together to sense the level of tactation to the body.

3.5 ENVIRONMENTAL FACTORS IN ERGONOMICS

The environmental factors that influence the task performance and comfort of workers in the occupational environment can be classified in one or more of the following broad categories (Box 3.3):

BOX 3.3 KEY TERMS

- *Photometric energy*—radiant energy modified by the luminous efficiency of the standard observer.
- *Illuminance*—the amount of light falling on a surface (lx)
- *Luminance*—the amount of light energy reflected (or emitted from a surface)

- Visual factors: lighting
- Auditory factors: sound levels
- Thermal factors: temperature and humidity

These are further discussed in the following sections.

3.5.1 Visual Factors Light Levels

The ability to see, particularly in an occupational setting, depends upon several environmental and workplace factors including: the level of illumination, the contrast, reflection of the work surface, and glare. Each of these factors must be considered and sound ergonomic principles must be utilized in workplace design for proper illumination. Key terms used to describe the resulting light levels include photometric energy, illumina and luminance. (Box 3.3). Discounting the importance of providing an appropriately illuminated work environment can result in OSHA fines, poor quality, reduced output, worker fatigue, job dissatisfaction, and increased risk of injury and subsequent liability. Discussions in the following sections rely on OSHA, the American Illuminating Engineering Society, and Woodson (1992).

3.5.1.1 Illumination

Light is defined as any radiation capable of causing a visual sensation. Objects are detected by the human eye in one of two methods, either by emitting a source of light, known as radiance, or by reflecting light, known as irradiance. Both radiance and irradiance are measured in watts per square meter (W/m^2). Illumination is the measure of the stream of light falling on a surface. This light may come from the sun, lamps, or any other bright source. Illumination is measured in lux or foot candle (fc) and is the light density per square foot.

$$1\ \text{lx} = 1\ \text{lumen per square meter} = 0.1\ \text{fc}$$

3.5.1.2 Engineering Procedures in the Design of the Environment for Proper Vision

Proper vision requires sufficient quantity and quality of illumination. Special requirements on visibility (especially with the diminished visual acuity of the elderly) require care in the arrangement and delivery of illumination. Color vision especially requires sufficient light. If an object or environment is well illuminated (above 0.1 lx), the human eye uses photopic vision for sensing the image. Proper color perception occurs under photopic conditions. Vision at illumination levels between 0.1 and 0.01 lx is known as mesopic. In mesopic, brighter areas appear in color, but darker areas are seen in shades of gray. If illuminance falls between 0.1 and 0.01 lx, both cones and rods respond creating a mesopic condition. In light conditions below 0.01 lx, vision is limited to scotopic vision, in which only shades of gray, black, and white can be detected. Table 3.7 provides functional ranges of the visual system and associated capabilities (Gavriel, 1997).

TABLE 3.7
The Functional Ranges of Visual System Capabilities

Name	Dominance Range (cd/m²)	Photoreceptor Active	Wavelength Range (nm)	Capabilities
Photopic	>3	Cones	380–760	Color vision Good detail discrimination
Scotopic	<0.001	Rods	380–760	No color vision Poor detail discrimination
Mesopic	>0.001 and <3	Cones and rods	380–760	Diminished color vision, reduced detail discrimination and a shift in spectral sensitivity as adaptation luminance moves from photopic to scotopic

Source: Gavriel, S. (Ed.): *Handbook of Human Factors and Ergonomics*. 1997. Copyright Wiley-VCH Verlag GmbH & Co. KGaA.

Luminance is the measure of light coming from a surface (a function of the light that is emitted or reflected from the surface of walls, furniture, and other surfaces) and is measured in units of candela per square meter (cd/m^2). The most significant factor in detection of light is the luminance of an object, or the energy reflected or emitted from it. Luminance of an object is determined as a function of incident illuminance and reflectance. Reflectance is an inherent property of an object and is defined as the ratio of the amount of light reflected compared to the amount of light received by an object.

$$\text{Luminance} = \text{Illuminance} \times \text{reflectance} \times \pi^{-1}$$

For example, if a bright table surface has a reflectance of 70% and the incident light has an illumination figure of 400 lx, the luminance of the table will be 70% of $400/\pi = 89\ cd/m^2$ (Figure 3.6).

3.5.1.3 General Rules of Contrast

Vision is affected by contrast as well. Contrast is the difference between the luminance of an object and the luminance of surrounding surfaces, including its shadow. Contrast is calculated as follows:

$$\text{Contrast} = \left[\frac{(L_{max} - L_{min})}{L_{max}}\right] \times 100\%$$

where

L_{max} is the maximum luminance level of surrounding surfaces
L_{min} is the minimum luminance level of surrounding surfaces

FIGURE 3.6 Odor perception. (From Tea
September 9, 2009, from http://www.team

There are general rules that can be us
contrast. These are as follows:

- All of the objects and major sur
- Surfaces in the middle of the visu than 3:1.
- Contrast between the middle fiel not exceed 10:1.
- The working field should be brig edges.
- Avoid excessive contrast to the si
- Light sources should not contrast
- The maximum permissible range is 40:1.

Effective use of contrast can be a useful
ferentiate between task elements. Utiliz
priately contrasted environment.

3.5.1.4 Glare

To avoid unwanted or excessive glare
sources can be used. Direct glare occur
light source such as the headlights of an

FIGURE 3.6 Odor perception. (From Teamwork Photo & Digital, Sekonic, 2009, retrieved September 9, 2009, from http://www.teamworkphoto.com/images/sekonic/758d.jpg)

There are general rules that can be used when designing for appropriate levels of contrast. These are as follows:

- All of the objects and major surfaces in the visual field should be lit.
- Surfaces in the middle of the visual field should not have a contrast of more than 3:1.
- Contrast between the middle field and the edge of the visual field should not exceed 10:1.
- The working field should be brightest in the middle and darker toward the edges.
- Avoid excessive contrast to the sides and below the visual field.
- Light sources should not contrast with their background by more than 20:1.
- The maximum permissible range of contrast between items within a room is 40:1.

Effective use of contrast can be a useful means to communicate information and differentiate between task elements. Utilizing these guidelines will result in an appropriately contrasted environment.

3.5.1.4 Glare

To avoid unwanted or excessive glare, appropriate placement and indirect light sources can be used. Direct glare occurs when light meets the eye directly from a light source such as the headlights of an oncoming car. Direct glare can be reduced by placing high-intensity light sources outside the cone of 60° around the line of sight or by using several low-intensity light sources instead of one intense source.

Indirect glare is reflected from a surface into the eyes such as headlights of a car in your rearview mirror. Altering the angle of the indirect light source can be useful in eliminating indirect glare. Additionally, shields, hoods, and visors can be strategically placed around reflecting surfaces to keep reflected light out of the eye.

3.5.1.5 Sources and Measurement

As previously stated, Illumination, the measure of the stream of light falling on a surface, may come from the sun, lamps, or other bright sources. The level of illumination is measured in lux or foot candle (fc):

$$1 \text{ lx} = 1 \text{ lumen per square meter} = 0.1 \text{ fc}$$

Luminance is the measure of the brightness of a surface, where the perception of brightness of a surface is proportional to its luminance. Luminance is the measure of light coming from a surface (a function of the light that is emitted or reflected from the surface of walls, furniture, and other surfaces) and is measured in units of candela per square meter (cd/m^2).

A comparison of the luminance of various surfaces can be expressed as reflectance, which is the ratio between the total amount of light reflected by a surface compared to the light incident to the surface.

3.5.1.5.1 Light Sources

The type of lighting source used in an environment is dependent upon the lighting requirements, environmental factors, and preferences. The objective in lighting a room or workplace should be to accomplish the following:

- Suitable level of illumination—see Illuminating Engineering Society of North America (IESNA) guidelines for specific lighting design guidelines
- Spatial balance of surface's luminance—avoid sharp changes in luminance levels
- Temporal uniformity of lighting—focusing on bright and dark objects quickly
- Avoidance of glare
- Accommodation to the characteristics of the employee population
- Energy efficiency

The IES guidelines are widely accepted as a resource for designing occupational illumination levels to be compatible with task requirements. A variety of guidelines support task designers in understanding the impact of different levels of illumination on task performance. Table 3.8 provides a summary of these guidelines given the desired "alertness-level" requirements for a task.

TABLE 3.8
American Illuminating Engineering Society Guidelines

Alertness-Level Requirement	Average Light Level, fL
Maximum mental alertness required for highly complex mental task performance	50 and above
Medium mental alertness required for routine manual tasks, leisure reading, and/or stimulating social activity	40
Minimum mental alertness required for nondemanding social intercourse and/or perceptual-motor performance (dining, dressing, personal hygiene, etc.)	30
Rest, mental alertness for minimum interaction with other people (e.g., as in a bar or private dining environment)	15
Sleep	<3

Source: Woodson, W.E., Tillman, B., and Tillman, P. *Human Factors Design Handbook*, 2nd edn., McGraw-Hill, Inc., New York.

Some examples of lighting appropriate for use in occupational environments include filament lamps and fluorescent lights. Filament lamps are relatively rich in red and yellow rays. When used above a workplace they emit heat, and even with a lamp shade, a filament lamp can exceed temperatures of 60°C and can lead to discomfort and headaches. Fluorescent tubes are much more efficient than heated filament and do not produce the same levels of heat. The inside of the tube is covered with a fluorescent substance that converts the ultraviolet rays of the discharge into visible light, the color of which can be controlled by the chemical composition of the fluorescent material.

3.5.1.5.2 Measurement of Illumination

The IESNA has guidelines for lighting requirements and generally the more intense and delicate the work, the more lighting needed. There are several ways to measure light or illumination, and these methods have led to much confusion. The confusion stems from a combination of several sources creating multiple guidelines and the differences between physically described and humanly perceived units. Measurement of the quantity of radiant energy can be made in several ways, but the fundamental types of radiometry energy measurement include the following:

- Total radiant energy emitted from a source, per unit of time (radiant flux, expressed in watts)
- The energy emitted from a point in a given direction (radiant intensity, expressed in watts/steradian)
- The energy arriving at a surface at some distance from a source (irradiance, expressed in W/m^2)
- The energy emitted from or reflected by a unit area of surface in a specified direction (irradiance, expressed in W/m^2)

Although each of these methods of measurement can be used to effectively gauge illumination levels, most light source levels are expressed as radiance.

3.5.2 Noise Levels

Noise is any disturbing or unwanted sound and is among the most pervasive factors impacting the workplace, home, and recreational environments. Noise from occupational machinery, road traffic, construction equipment, manufacturing processes, and landscaping equipment, to name a few, is among the unwanted sounds that are routinely broadcast into the air.

The problem with noise is not only that it is unwanted, but it can also negatively impact human health and well-being. Health problems related to noise include noise induced hearing loss (NIHL), stress, high blood pressure, sleep loss, distraction, and lost productivity, as well as a general reduction in the quality of life.

3.5.2.1 Measuring Noise Levels

Measuring noise levels in the occupational environment is one of the most important aspects of an effective workplace hearing conservation and noise control program (Maxpro Maintenance, 2009). It helps identify work locations with excessive noise levels, employees who may be affected, and where additional noise mitigation methods need to be implemented.

Weighted sound level meters (SLMs) are used to measure noise (Figure 3.7). The weighted scales filter out the sound energy in the lowest and highest frequencies because human sensitivity in these bands is lower. The weighted decibel (db) scale

FIGURE 3.7 Weighted sound levels meters.

is most often used because studies have shown that it is a reliable determinant of noise level. Noise level considers the volume and frequency of the audible stimuli. The equivalent level of sustained noise (continuous sound level) is the summated frequency level.

$$L_{eq} = L_{50} + 0.43(L_1 - L_{50})$$

where

L_{50} is the average noise level
L_1 is the peak noise level

The equivalent level of sustained noise (L_{eq}) expresses the average level of sound energy during a given period of time. The summated frequency level is measured with a sound level indicator and a frequency counter, operating over a given time period. Typically, this time period is equal to a full 8 h work shift. A number of devices are capable of calculating this noise equivalent (L_{eq}), including noise dosimeters, SLMs, and integrated sound level meters (ISLMs). The type of sounds of interest and the source of the noise should be considered when determining how to measure the noise. Useful guidelines for instrument selection can be found in Table 3.9 from the Canadian Centre for Occupational Health Safety (2009).

3.5.2.1.1 *Sound Level Meter*

This device uses a microphone to pick up small, instantaneous variations in air pressure, and converts them into electrical signals. These signals are further processed until a decibel sound level is calculated. This dB level is captured and provided on the readout display. Calibration is required prior to each use and the SLM is commonly used to conduct noise surveys.

3.5.2.1.2 *Integrated Sound Level Meter*

The ISLM is very similar to the dosimeter (see the following text), except the device is handheld rather than worn. The ISLM is designed to perform calculations at a given static location, yielding a single noise reading despite any continuous fluctuations in the environment.

3.5.2.1.3 *Noise Survey*

A noise survey uses sample noise measurements from various locations to identify areas, machines, and equipment that generate harmful noise levels. This is usually done with a SLM. A sketch showing the locations of workers and noisy machines is drawn. Noise level measurements are taken at a representative number of positions around the area and are marked on the sketch. More measurements will yield an increasingly accurate survey and an accompanying noise map.

A noise map can be produced by drawing lines on the sketch between points of equal sound level. Noise survey maps, like that in Figure 3.8, provide very useful information by clearly identifying areas where there are noise hazards. The map is created by connecting points of equal sound level.

TABLE 3.9
Guidelines for Instrument Selection

Type of Measurement	Appropriate Instruments (in Order of Preference)	Result	Comments
Personal noise exposure	1. Dosimeter	Dose or equivalent sound level	Most accurate for personal noise exposures
	2. ISLM	Equivalent sound level	If the worker is mobile, it may be difficult to determine a personal exposure, unless work can be easily divided into defined activities
	3. SLM	dB(A)	If noise levels vary considerably, it is difficult to determine average exposure. Only useful when work can be easily divided into defined activities and noise levels are relatively stable all the time
Noise levels generated by a particular source	1. SLM	dB(A)	Measurement should be taken 1–3 m from source (not directly at the source)
	2. ISLM	Equivalent sound level dB(A)	Particularly useful if noise is highly variable; it can measure equivalent sound level over a short period of time (1 min)
Noise survey	1. SLM	dB(A)	To produce noise map of an area; take measurements on a grid pattern
	2. ISLM	Equivalent sound level dB(A)	For highly variable noise
Impulse noise	1. Impulse SLM	Peak pressure dB(A)	To measure the peak of each impulse

Source: Canadian Centre for Occupational Health Safety, 2009, Retrieved September 9, 2009, from http://www.ccohs.ca/

A standard SLM takes only instantaneous noise measurements. This is sufficient in workplaces with continuous noise levels. But in workplaces with impulse, intermittent, or variable noise levels, the SLM makes it difficult to determine a person's average exposure to noise over a work shift. One solution in such workplaces is a noise dosimeter.

3.5.2.1.4 Noise Dosimeter

A noise dosimeter is a portable sound measuring device for employees who are fairly mobile. A noise dosimeter is usually held in place near the hip, with a miniature microphone attached to the collar, as shown in Figure 3.9. This type of noise measurement is especially useful when the worker is changing locations frequently.

FIGURE 3.8 Sample noise su
Safety, 2009, retrieved Septemb

FIGURE 3.9 Noise dosimeter.
9, 2009, from http://www.works

A noise dosimeter require
Association, 2010):

- *Criterion level:* exposu
- Criterion level is 90 dB
  87 dB(A) for Canadian
- *Exchange rate:* 3 or 5
- *Threshold:* noise level
  late noise dose data.

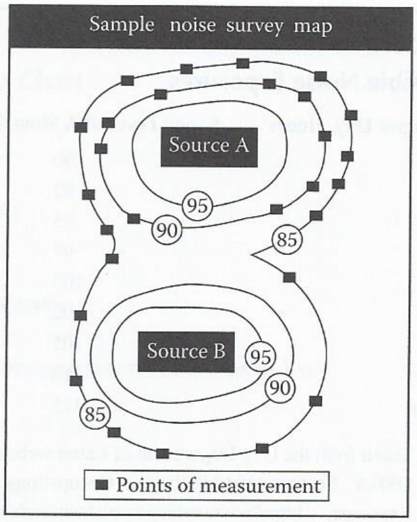

FIGURE 3.8 Sample noise survey map. (From Canadian Centre for Occupational Health Safety, 2009, retrieved September 9, 2009, from http://www.ccohs.ca/)

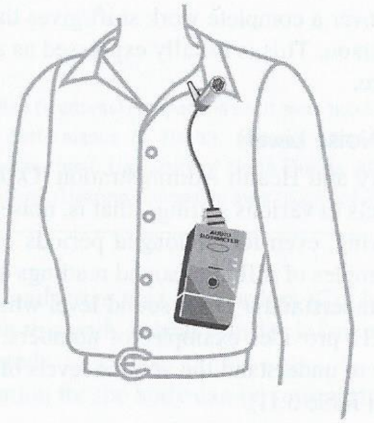

FIGURE 3.9 Noise dosimeter. (From Work Safe Saskatchewan, 2009, retrieved September 9, 2009, from http://www.worksafesask.ca/files/ont_wsib/certmanual/battery.jpg)

A noise dosimeter requires the following setting (Canadian Occupational Health Association, 2010):

- *Criterion level:* exposure limit for 8 h/day 5 days/week.
- Criterion level is 90 dB(A) for many jurisdictions, 85 dB(A) for some, and 87 dB(A) for Canadian federal jurisdictions.
- *Exchange rate:* 3 or 5 dB as specified in the noise regulation.
- *Threshold:* noise level limit below which the dosimeter does not accumulate noise dose data.

TABLE 3.10
Permissible Noise Exposures

Duration per Day, Hours	Sound Level dBA Slow Response
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
1/4 or less	115

Source: Taken from the U.S. Department of Labor website under OSHA Section 1910.95(b)(1), Occupational Noise Exposure, http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9735&P_TEXT_VERSION=FALSE

Wearing the dosimeter over a complete work shift gives the average noise exposure or noise dose for that person. This is usually expressed as a percentage of the maximum permitted exposure.

3.5.2.2 Acceptable Noise Levels

The Occupational Safety and Health Administration (OSHA) publishes guidelines for acceptable noise levels in various settings, that is, noise levels that will not cause long-term harm to hearing, even for prolonged periods of time. Permissible noise exposure times and examples of different sound readings are found in Table 3.10.

It is often easier to understand a given sound level when it is compared to common activities. Table 3.11 provides examples of numbers, collected from a variety of sources that help one to understand the volume levels of various sources and how they affect our hearing (Table 3.11).

3.5.3 Thermal Conditions: Temperature and Humidity

Perceived thermal comfort is a function of environmental conditions and personal factors. The primary environmental factors are airflow (wind), air temperature, air humidity, and radiation from the sun or other radiant sources and nearby surfaces. The personal factors that affect comfort are clothing, level of physical activity, and level of acclimation or adaptation to the environment. Body heat balance then becomes a function of the personal, environmental, and administrative conditions. Table 3.12 provides a summary of the body heat balance factors and the heat balance equation for the body (Eastman Kodak, 1983).

The equation describing body heat balance is given below. Each term (column 1 in Table 3.12) is defined in column 2 of the table, and its major determinants are

TABLE 3.11
Decibel Comparison Chart

Weakest sound heard
Whisper quiet library
Normal conversation (3–5 ft)
Telephone dial tone
City traffic (inside car)
Train whistle at 500 ft, truck traffic
Subway train at 200 ft
Level at which sustained exposure may resu
Power mower at 3 ft
Snowmobile, motorcycle
Power saw at 3 ft
Sandblasting, loud rock concert
Pain begins
Pneumatic riveter at 4 ft
Even short-term exposure can cause perma
recommended exposure with hearing prote
Jet engine at 100 ft, gun blast
Death of hearing tissue
Loudest sound possible

Source: Statistics for the decibel (loudness) c Centre for Human Performance & resources/howtos/loudness.html; Uni unf.edu/anf/adacompliance/Hearing_

identified in column 3. Conductive he the end of the table, since this path of surface is directly contacted.

The heat balance equation for the b

$M \pm C$

The level of humidity in an envir and perceived thermal load of operato in environments where water or exce working conditions. Table 3.13 provi humidity levels and ambient temperat

3.5.3.1 Measurement of Thermal

Due to the variability involved in the p no standard or regulation for workplac there are general guidelines that hav

TABLE 3.11
Decibel Comparison Chart

	Environmental Noise, dB
Weakest sound heard	0
Whisper quiet library	30
Normal conversation (3–5 ft)	60–70
Telephone dial tone	80
City traffic (inside car)	85
Train whistle at 500 ft, truck traffic	90
Subway train at 200 ft	95
Level at which sustained exposure may result in hearing loss	*90–95*
Power mower at 3 ft	107
Snowmobile, motorcycle	100
Power saw at 3 ft	110
Sandblasting, loud rock concert	115
Pain begins	*125*
Pneumatic riveter at 4 ft	125
Even short-term exposure can cause permanent damage—loudest recommended exposure with hearing protection	*140*
Jet engine at 100 ft, gun blast	140
Death of hearing tissue	180
Loudest sound possible	194

Source: Statistics for the decibel (loudness) comparison chart were taken from a study by Chasin, M., Centre for Human Performance & Health, Ontario, Canada, http://www.gcaudio.com/resources/howtos/loudness.html; University of North Florida, ADA Compliance, http://www.unf.edu/anf/adacompliance/Hearing_Campaign.aspx (accessed February, 2011).

identified in column 3. Conductive heat gain or loss (Co) has also been included at the end of the table, since this path of heat transfer is important when a hot or cold surface is directly contacted.

The heat balance equation for the body can be summarized as follows:

$$M \pm C \pm R - E = \pm S.$$

The level of humidity in an environment can significantly impact the comfort and perceived thermal load of operators. High humidity levels are often experienced in environments where water or excessive moisture is present as well as in outside working conditions. Table 3.13 provides a guideline for exposure time in certain humidity levels and ambient temperatures (Eastman Kodak, 1983).

3.5.3.1 Measurement of Thermal Load

Due to the variability involved in the perception of the thermal environment, there is no standard or regulation for workplace temperature in the United States. However, there are general guidelines that have been adopted by occupational health and

TABLE 3.12
Body Heat Balance

Term	Definition	Determinants
M	Metabolic heat gain	Physical workload, or the muscular work done minus the work efficiency
C	Convective heat gain or loss	Air velocity The difference between air temperature and a person's average skin temperature
R	Radiative heat gain or loss	The difference between a person's average skin temperature and the temperature of surfaces in the environment, measured with a globe thermometer or radiometer The amount of skin exposed to the solid surface
E	Evaporative heat loss	The difference between the water vapor pressure of a person's skin and the water vapor pressure, or relative humidity, of the environment; it is indirectly related to workload and the person's sweat rate Air velocity
S	Heat storage in, or loss from, the body	Balance of the aforementioned factors Rectal and skin temperatures Body weight
Co	Conductive heat gain or loss	The area of the conductive surface The difference between the person's skin temperature and the temperature of the surface contacted

Source: Developed from information in Kaman, 1975; Leithead and Lind, 1964; Eastman Kodak, 1986.

safety personnel. A commonly used reference is the threshold limit values (TLV) for heat stress, published by the American Conference of Governmental Industrial Hygienists (ACGIH). Specific to non-office environments, this publication is an excellent source of heat stress exposure literature. The units are expressed as wet bulb globe temperature (WBGT). The WBGT was developed in the late 1950s for the U.S. Marine Corps Recruit Depot on Parris Island in South Carolina (Australian Government website, 2010). Humidity in this region can be extreme and this measurement was developed to assess and minimize the impact on U.S. Marines in this environment.

The WBGT successfully combines temperature, humidity, and solar radiation to help employers estimate the environmental effects on workers. This composite measure resulted from studies following the 1950 fatal heat stroke outbreak at the U.S. Marine Corps Recruitment Depot on Parris Island in South Carolina. Over time, this index has been used in workplaces, as well as sporting events. More specifically, the WBGT is a culmination of the following:

- Dry bulb temperature
- Relative humidity

TABLE 3.13
Recommended Maximum Temp
to High-Heat Environments (up

Exposure Time (min)	Workload[b]	Relative Hu 20%
5	L	63 (14
	M	59 (13
	H	57 (13
15	L	53 (12
	M	52 (12
	H	51 (12
30	L	52 (12
	M	47(11
	H	41 (10
45	L	51 (12
	M	41 (10
	H	36 (97

Source: Adapted from Rodgers and Cord, tion in Bell et al., 1971; Gagge, 1 and Goldman, 1978; Eastman Ko

Note: For 5 min exposure times in high ai mum temperatures are recommend heavy workload).

L	56 (13
M	54 (12
H	52 (12

[a] These temperatures assume the followin ity = 0.1 m/s (20 ft/min); radiant heat = 2 and dry bulb.
[b] Workload abbreviations: L, light, up to 1 240 kcal/h); H, heavy, >230–350 W (>2

- Mean radiant temperature
- Air velocity

The perceived temperature is calcul two equations to calculate the WBGT

WBGT =

where
T_{nw} is the natural wet bulb temper natural air movement

TABLE 3.13
Recommended Maximum Temperatures for Short-Duration Exposures to High-Heat Environments (up to 63°C or 146°F)

		Maximum Ambient Temperature, °C (°F)[a]		
Exposure Time (min)	Workload[b]	Relative Humidity 20%	Relative Humidity 50%	Relative Humidity 80%
5	L	63 (146)	56 (133)	56 (133)
	M	59 (138)	48 (118)	46 (115)
	H	57 (135)	46 (115)	42 (108)
15	L	53 (128)	45 (113)	40 (104)
	M	52 (126)	43 (110)	38 (100)
	H	51 (124)	41 (106)	36 (97)
30	L	52 (126)	44 (112)	39 (102)
	M	47(116)	38 (100)	34 (93)
	H	41 (106)	36 (97)	30 (86)
45	L	51 (124)	43 (110)	38 (100)
	M	41 (106)	36 (97)	31 (88)
	H	36 (97)	32 (90)	27 (81)

Source: Adapted from Rodgers and Corl, 1981, Eastman Kodak Company; based on information in Bell et al., 1971; Gagge, 1973; Hardy, 1970; Leithead and Lind, 1964; Pandolf and Goldman, 1978; Eastman Kodak, 1986.

Note: For 5 min exposure times in high air velocities (2 m/s, or 400 ft/min), the following maxi mum temperatures are recommended (L, light workload; M, moderate workload; H, heavy workload).

L	56 (133)	50 (122)	48 (118)
M	54 (129)	49 (120)	44 (111)
H	52 (126)	48 (118)	42 (103)

[a] These temperatures assume the following conditions: clothing insulation = 0.6 clo; air velocity = 0.1 m/s (20 ft/min); radiant heat = 2°C (3.6°F), which is the difference between the globe and dry bulb.

[b] Workload abbreviations: L, light, up to 140 W (120 kcal/h); M, moderate, >140–230 W (>120–240 kcal/h); H, heavy, >230–350 W (>240–300 kcal/h).

- Mean radiant temperature
- Air velocity

The perceived temperature is calculated with consideration of these factors using two equations to calculate the WBGT:

$$\mathrm{WBGT} = 0.7\,T_{nw} + 0.3\,T_g$$

where

T_{nw} is the natural wet bulb temperature obtained with wetted sensor exposed to natural air movement

T_g is the temperature of center of 6 in. diameter hollow copper sphere painted on the outside with black matte finish (globe thermometer)

For assessing WBGT when solar sources are present, the equation is modified to include this parameter:

$$\text{WBGT} = 0.7\,\text{WB} + 0.2\,\text{GT} + 0.1\,\text{dB}$$

where

WB is the natural wet bulb temperature (temperature of sensor in a wet wick exposed to air current)

GT is the globe temperature (globe temperature of a black sphere)

dB is the dry bulb temperature (dry bulb temperature measured while shielded from radiation)

Although several approaches have been developed, the standard methods and procedures to measure the factors in the WBGT calculation are fairly consistent. A discussion of the equipment is presented in the following section.

3.5.3.2 WBGT Equipment

WBGT instruments are available commercially and require regular maintenance if they are to consistently provide accurate measurements. The WBGT is measured by a three-temperature element device (Figure 3.10):

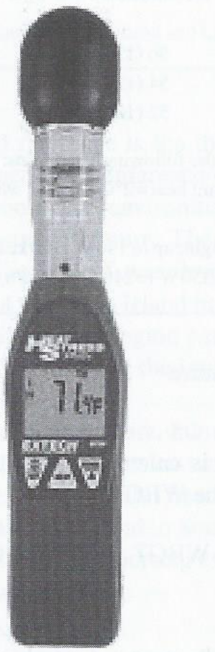

FIGURE 3.10 WBGT measurement equipment.

- The natural wet bulb te wind, humidity, and rad mometer with its bulb w constant reservoir of dist the wick is representative
- The black globe tempera tion and wind. The devi centrally located thermo
- The (shade) air tempera This consists of a radiati weather screen.

The WBGT is not without criti ment has factors that impact th accounted for in this measurem for correction factors with resp specific clothing types can be s or insulation rating associated

3.5.3.3 Other Thermal Ind

The effective temperature (ET) air velocity. This measurement humidity and low radiant heat.

The heat stress index (HSI) but is still unsatisfactory in mea to implement.

Operative temperature takes convection but not humidity an

Oxford index is a weighting 2003). This index is useful to a

TABLE 3.14
WBGT Correction

Clothing Type
Summer lightweight wor
Cotton coveralls
Winter work clothing
Water barrier, permeable

Source: ACGIH, 1992.

[a] Clo: Insulation value exchange by radiation ture between the skin a

- The natural wet bulb temperature (WB) signifies the combined effects of wind, humidity, and radiation. The device consists of an unshielded thermometer with its bulb wrapped in a cotton wick. The wick is fed with a constant reservoir of distilled water. The continuous evaporative cooling of the wick is representative of sweat evaporation.
- The black globe temperature (GT) represents the combined effects of radiation and wind. The device is usually a 150 mm (6 in.) black globe with a centrally located thermometer.
- The (shade) air temperature (dB) is the standard forecast temperature. This consists of a radiation-shielded thermometer—usually contained in a weather screen.

The WBGT is not without criticism as many believe that the occupational environment has factors that impact thermal comfort that are not considered or sufficiently accounted for in this measurement. To address some of these issues, WBGT allows for correction factors with respect to clothing. A summary of correction factors for specific clothing types can be seen in Table 3.14. This table provides the clo, a value or insulation rating associated with the clothing type as described.

3.5.3.3 Other Thermal Indices

The effective temperature (ET) index is a culmination of temperature, humidity, and air velocity. This measurement is regularly used in mines and other places with high humidity and low radiant heat.

The heat stress index (HSI) considers the rate of work and environmental factors but is still unsatisfactory in measuring an individual's heat stress and can be difficult to implement.

Operative temperature takes into account the combined effects of radiation and convection but not humidity and air flow.

Oxford index is a weighting of the wet bulb and dry bulb temperatures (Parsons, 2003). This index is useful to account for the impact of variations on the worker and

TABLE 3.14
WBGT Correction Factors (°C)

Clothing Type	Clo[a] Value	WBGT Correction
Summer lightweight working clothing	0.6	0
Cotton coveralls	1.0	−2
Winter work clothing	1.4	−4
Water barrier, permeable	1.2	−6

Source: ACGIH, 1992.

[a] Clo: Insulation value of clothing. One clo = 5.55 kcal/m2/h of heat exchange by radiation and convection for each °C difference in temperature between the skin and the adjusted dry bulb temperature.

occupational factors related to thermal issues. Table 3.15 provides a summary of thermal strain indices (Bentel and Santee, 1997).

Each of these indices can be utilized to assess key aspects of the thermal environment on the worker. Careful consideration of the thermal environment, as well as economic factors, will impact the selection of the most appropriate approach.

3.5.3.4 Controlling the Thermal Conditions

There are five generally used engineering controls that reduce heat stress including ventilation, air cooling, fans, shielding, and insulation. Additional approaches can be used to reduce physical demands, which indirectly affect heat stress, provided there is a reduction in metabolic effort. Also, as previously discussed, the occupational environment should permit time for personal conditions such as acclimatization and adaptation to occur. Finally, fluid replacement and task design are controls that should be implemented as well.

3.5.3.4.1 Engineering Controls

- *General ventilation*—This method of cooling is provided through a permanent system for large areas such as overhead fan systems, or portable ventilation devices for small areas. General ventilation works by taking cooler air, typically from outside the work area, and distributing it within the environment containing the warmer air.
- *Air treatment/air cooling*—This method removes heat from the air in order to reduce the temperature.
- *Air conditioning*—While this tends to be the most expensive method, air conditioning is very effective. To reduce costs, chillers are often used as a substitute in cool or dry climates to cool the air. This system circulates cold water through coils in the air-conditioning system and distributes this cooled air into the environment to reduce the temperature indoors.
- *Local air cooling*—This method tends to be more effective at cooling smaller, targeted areas. This approach is generally less expensive to set up and can be quickly accomplished with a portable blower and air chiller.
- *Shielding or insulation*—Radiant heat can be reduced through shielding, or interrupting the path between the worker and the heat source. Radiant heat can be reduced through surface modification (i.e., a flat black surface will absorb more heat than a smooth, polished one), insulation, and shielding.

It is also useful to combine these techniques to amplify the reduction efforts to minimize the impact of the heat source.

3.5.3.4.2 Administrative Controls and Work Practices

Management participation and training are vital to implementing new work practices and promoting a healthy workplace. The following components are listed by NIOSH (1986) as being vital in creating a good heat stress training program:

TABLE 3.15
Thermal Strain Indices

Index	Source(s)	Inputs Indices for Heat Exposure	Comments
Wet bulb globe temperature (WBGT)	ISO 7243 (1989); NIOSH (1986); Yaglou and Minard (1957)	T_a, T_{nwb}, T_g	WBGT requires simple input and calculations. WBGT is not recommended for conditions of high humidity.
Wet globe temperature (WGT)	Botsford (1971)	botsball	The botsball is an instrument consisting of a fabric-covered 60 mm black ball over a dial thermometer. WGT may be read off a scale or converted to WBGT if T_a is known
Heat stress index (HSI)	Belding and Hatch (1955); ISO 7933 (1989)	T_a, T_{wb}, T_{bg} or T_r, V, M	HSI is the ratio of evaporative heat loss required to maintain a constant body temperature to the maximum amount of sweat that can be

TABLE 3.15
Thermal Strain Indices

Index	Source(s)	Inputs	Comments
		Indices for Heat Exposure	
Wet bulb globe temperature (WBGT) Wet globe temperature (WGT)	ISO 7243 (1989); NIOSH (1986); Yaglou and Minard (1957); Botsford (1971)	T_a, T_{nwb}, T_g botsball	WBGT requires simple input and calculations. WBGT is not recommended for conditions of high humidity. The botsball is an instrument consisting of a fabric-covered 60 mm black ball over a dial thermometer. WGT may be read off a scale or converted to WBGT if T_a is known
Heat stress index (HSI)	Belding and Hatch (1955); ISO 7933 (1989)	T_a, T_{wb}, T_{bg} or T_r, V, M	HSI is the ratio of evaporative heat loss required to maintain a constant body temperature to the maximum amount of sweat that can be evaporated under the given climatic conditions. Required sweat rate index (S_r^*), a further development of HSI, is used in ISO 7933
Oxford index (WD)	Leithead and Lind (1964)	T_a, T_{wb}	WD originated from research on men performing rescue tasks in hot underground mines. WD can be used to determine tolerance times
		Indices for Cold Exposure	
Wind chill index (WC)	Siple and Passel (1945)	T_a, V	WCI is an index for the cooling rate of wind and air temperature on bare skin. There is no adjustment for solar radiation, clothing, or activity level
Required clothing insulation (IREQ)	Holmer (1984); ISO TR 11079 (1993)	T_a, T_r, V, $R.H.$, M	Clothing insulation required for survival ($IREQ_{min}$) with a t_{sk} of 30°C and for maintaining thermal equilibrium ($IREQ_{neutral}$) are calculated
		Equivalent Temperature Indices	
Effective temperature (ET)	Houghten and Yaglou (1923)	T_a, T_{wb}, V	ET relates actual conditions to an equivalent, calm, saturated environment. ET overemphasizes effects of humidity in cool and neutral conditions and underemphasizes its effects in warm conditions

(continued)

TABLE 3.15 (continued)
Thermal Strain Indices

Index	Source(s)	Inputs	Comments
"New" effective temperature (ET*)	ASHRAE (1993); Gagge et al. (1971); Gonzalez et al. (1974)	T_a, T_r, V, P_a, i_m, w, M	ET* was developed to replace ET. It includes skin-wettedness (w) and water vapor pressure (P_a) parameters in calculating the temperature of an environment at 50% R.H. that results in equivalent total heat loss from the skin as in the actual environment
Operative temperature (T_o)	Winslow et al. (1937)	T_a, T_{bg} or T_r, V	T_o combines dry heat exchange parameters. There is no adjustment for work rate or effects of humidity on evaporative cooling. Formulas for approximating T_o are provided in ISO 7730 (1993)

Source: Gavriel, S. (Ed.): *Handbook of Human Factors and Ergonomics*, 1997. Copyright Wiley-VCH Verlag GmbH & Co. KGaA.

- Knowledge of the hazards of h
- Recognition of predisposing fa
- Training of employees regard stress
- Awareness of first-aid procedu heat stroke
- Dangers of using drugs, includi environments
- Use of protective clothing and
- Purpose and coverage of enviro and the advantages of worker p

It is also important to observe NIOSH prone to produce heat stress. Table 3. for acclimated workers (NIOSH, 198

Additional administrative controls part of the day, adding breaks at appr ment options throughout task perform ties to further reduce the likelihood f of heat stress are varied and in some c are summarized in see Table 3.17 (NI

The primary issues to consider in gram to manage thermal stress includ

1. Identifying tasks and workers w
2. Establishment of a plan and pro
3. Define process for monitoring
4. Monitoring may include any co
   a. Measuring heart rate

TABLE 3.16
NIOSH Recommended WBGT L for Acclimatized Workers

Hourly Work/Rest Cycle	Light (<230
Continuous work	<30.0
75% work/25% rest	30.6
50% work/50% rest	31.7
25% work/75% rest	32.2
Ceiling limit	38.9

Source: Gavriel, S. (Ed.): *Handbook of* Wiley-VCH Verlag GmbH & Co.

Note: Limits are for a "standard" worker

- Knowledge of the hazards of heat stress
- Recognition of predisposing factors, danger signs, and symptoms
- Training of employees regarding their responsibilities in avoiding heat stress
- Awareness of first-aid procedures for, and the potential health effects of heat stroke
- Dangers of using drugs, including therapeutic ones, and alcohol in hot work environments
- Use of protective clothing and equipment
- Purpose and coverage of environmental and medical surveillance programs and the advantages of worker participation

It is also important to observe NIOSH recommended WBGT limits in environments prone to produce heat stress. Table 3.16 provides exposure guidelines from NIOSH for acclimated workers (NIOSH, 1986).

Additional administrative controls include scheduling outdoor jobs for the cooler part of the day, adding breaks at appropriate intervals, job sharing, and fluid replacement options throughout task performance. This includes worker monitoring activities to further reduce the likelihood for heat stress. Factors affecting the likelihood of heat stress are varied and in some cases cannot be administratively controlled and are summarized in see Table 3.17 (NIOSH, 1986).

The primary issues to consider in the development of a worker monitoring program to manage thermal stress include the following:

1. Identifying tasks and workers with an increased risk of heat stress
2. Establishment of a plan and process to do heat stress monitoring regularly
3. Define process for monitoring
4. Monitoring may include any combination of measures including
   a. Measuring heart rate

TABLE 3.16
NIOSH Recommended WBGT Limits, in °C, for Heat Stress Exposure for Acclimatized Workers

	Workload		
Hourly Work/Rest Cycle	**Light (<230 W)**	**Moderate (230–350 W)**	**Heavy (>350 W)**
Continuous work	<30.0	<26.7	<25.0
75% work/25% rest	30.6	27.8	25.6
50% work/50% rest	31.7	29.4	27.8
25% work/75% rest	32.2	31.1	30.0
Ceiling limit	38.9	36.7	35.0

Source: Gavriel, S. (Ed.): *Handbook of Human Factors and Ergonomics*, 1997. Copyright Wiley-VCH Verlag GmbH & Co. KGaA; NIOSH, 1986.

Note: Limits are for a "standard" worker weighing 70 kg with a 1.8 m^2 body surface area.

TABLE 3.17
Factors Affecting the Occurrence of Heat Stress

Factor	Effect
Hydration state	Hypohydration results in lower sweat production and an increase in core temperature
Acclimatization	Repeated heat exposure leads to earlier onset of sweating, a higher sustained sweat rate, and lower core temperature and heart rate
Age	Sweating mechanism and circulatory system become less responsive with age, and there is high level of skin blood flow, possibly due to impaired thermoregulatory mechanism
Physical fitness	Exercise that increases maximal aerobic capacity improves thermoregulatory responses in the heat
Subcutaneous fat	Subcutaneous fat provides an insulative barrier, reducing transfer of heat from muscles to skin
Gender	Although studies indicate that sweating and vasodilation occur at higher core temperatures in women than men, when controlled for fitness and menstrual phase, gender differences in the follicular phase are questionable. Women in the luteal phase have significantly higher core temperatures, which may impact thermoregulatory responses
Body size	Leaner individuals are at an advantage because they have a larger ratio of surface area to body mass and, thus, greater capacity to dissipate heat
Diet	Regular consumption of a balanced diet serves to replace salt and other electrolytes lost in sweat, maintaining sweating efficiency
Previous heat illness	Previous occurrence of heat stroke increases susceptibility to subsequent heat illness
Drugs and alcohol	Use interferes with the functioning of the central and peripheral nervous system, negatively affecting heat tolerance

Source: Gavriel, S. (Ed.): *Handbook of Human Factors and Ergonomics*, 1997. Copyright Wiley-VCH Verlag GmbH & Co. KGaA.

i. Working heart rate—obtained by counting the radial pulse for 30 s immediately after work has ceased.
ii. Recovery heart rate—obtained by comparing the initial 30 s pulse to a second pulse taken 2.5 min into the rest period.

b. Oral temperature—measured with a clinical thermometer after work but before the employee drinks water. If the oral temperature taken under the tongue exceeds 37.6° C, shorten the next work cycle by one-third.
c. Body water loss—can be measured by weighing workers prior to work, at different intervals during the work shift, and at the conclusion of the work shift.

3.6 VIBRATION AND THE HUMAN BODY

The International Standard (ISO 2631) for evaluation of human exposure to whole-body vibration gives guidelines for how vibration should be measured and assessed.

The ISO 2631 standard entitled "Me
human exposure to whole-body vibr
2631-4, and 2631-5) (Nakashima, 200
is considered for varied ranges and ca
and sensory capabilities. The three r
nomic assessment of vibration are

- Low frequencies (0 to 2 Hz)
- Middle frequencies (2 to 15–20
- High frequencies (greater than

Historically, the occupational safety
concerned with high-frequency vibr
need to be concerned about all type
low and middle frequencies can cau
cases *more* cumulative trauma to th
frequencies.

The human body can amplify the v
from an outside source. We know, f
(muscles, tendons, and bones) can "
the vibration as it moves through the
includes the use of handheld power to
through the arm, and to the upper bod

Human response to vibration depen
amplitude, direction, point of applicati
body size, body posture, body tensio
of exposure to vibration requires the
directions, frequencies, and duration
Analysis, 2010).

Vibration measurement instrumen
vibration including hand-arm, foot-leg
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a single number as a measure of vibr
expressed in meters per second square

The cumulative effects on the bod
tibular problems, and other disorders.
finger disease (Raynaud's syndrome),
syndrome, tendonitis, and various bo
vibration can lead to nausea, impaired
impaired cardiac rhythm, and prematu

The ISO 2631 standard entitled "Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration" consists of four parts (2631-1, 2631-2, 2631-4, and 2631-5) (Nakashima, 2004). The impact of vibration on the human body is considered for varied ranges and can produce numerous outcomes on the physical and sensory capabilities. The three ranges of frequency–classification in the ergonomic assessment of vibration are

- Low frequencies (0 to 2 Hz)
- Middle frequencies (2 to 15–20 Hz)
- High frequencies (greater than 20 Hz)

Historically, the occupational safety and ergonomic communities were much more concerned with high-frequency vibration; however, recent years have revealed a need to be concerned about all types of vibration. It is well documented that the low and middle frequencies can cause at least comparable damage, and in some cases *more* cumulative trauma to the human body than vibrations at the higher frequencies.

The human body can amplify the vibration (in these lower frequencies) that exists from an outside source. We know, for instance, that the musculoskeletal system (muscles, tendons, and bones) can "be a path" for vibration and actually amplify the vibration as it moves through the body. An example of low-frequency vibration includes the use of handheld power tools that transmit the vibration from the hand, through the arm, and to the upper body.

Human response to vibration depends on several factors, including the frequency, amplitude, direction, point of application, time of exposure, clothing and equipment, body size, body posture, body tension, and composition. A complete assessment of exposure to vibration requires the measurement of acceleration in well-defined directions, frequencies, and duration of exposure (WISHA Hand-Arm Vibration Analysis, 2010).

Vibration measurement instruments can be used to measure various types of vibration including hand-arm, foot-leg, or full body impact. A typical vibration measurement system includes an accelerometer, which is a device to sense the vibration, a recorder, a frequency analyzer, a frequency-weighting network, and a display, such as a meter, printer, or recorder. The accelerometer produces an electrical signal in response to the vibration. The size of this signal is proportional to the acceleration applied to it. The frequency analyzer determines the distribution of acceleration in different frequency bands. The frequency-weighting network mimics the human sensitivity to vibration at different frequencies. The use of weighting networks gives a single number as a measure of vibration exposure (i.e., units of vibration) and is expressed in meters per second square (m/s^2).

The cumulative effects on the body are seen in musculoskeletal disorders, vestibular problems, and other disorders. Some of the more common disorders are white finger disease (Raynaud's syndrome), hand-arm vibration syndrome, carpal tunnel syndrome, tendonitis, and various bone and joint disorders. Long-term exposure to vibration can lead to nausea, impaired vision, hyperventilation, high blood pressure, impaired cardiac rhythm, and premature fatigue.

The methods to reduce the exposure or result of vibration on the user should be aggressive, as the conditions that result can be debilitating and long term. Techniques that can be used to mitigate the effects of vibration include source control, path control, and receiver control (Wasserman and Wilden, 2006).

- *Source control* is considered a long-term engineering approach to address the source (tool, equipment, or vehicle) that is emitting the vibration. This should ideally be accomplished at the design stage; however, it is often required in redesign of existing products or task environments. In addition to design changes to reduce vibration intensity, source control can be accomplished with wraps on the tool, regulation of tool speed, or balancing and process redesign.
- *Path control* is accomplished by altering the amount of exposure to the vibration. To reduce the amount of vibration, administrative controls can be applied to alter the task performance process. This can be accomplished by rotating personnel, job sharing, and providing frequent rest breaks throughout the tasks.
- *Receiver control* is designed to reduce the vibration experienced by the operator. To reduce vibration, the receiver control approach isolates tools to reduce the level of vibration that is received or adapts posture to limit exposure. Other means to control vibration received by the operator include modifying the task to allow a reduction in force exertion (i.e., grip, grasp, or push forces) or reducing contact area for task performance. Personal protective equipment, such as padded gloves, can also reduce the impact of the vibration.

3.7 EXPOSURE TO CHEMICALS, RADIATION, AND OTHER SUBSTANCES

Many jobs require employees to be exposed to chemical, biological, radiation, and other types of hazards. Examples of tasks with these risk factors include waste disposal, recycling professions, health-care professions, and first responders. Exposure to hazardous substances can have serious effects on workers' health. Some substances, such as asbestos (which can cause lung cancer and mesothelioma), are now banned or subject to strict control worldwide. Yet many substances that are still widely used can also cause serious health problems, if the risks associated with them are not managed. The impact of these substances can have a wide range of health effects including (OSHA Europa, 2010)

- Acute effects, for example,
  - Poisoning
  - Suffocation
  - Explosion
  - Fire
- Long-term effects, for example,
  - Respiratory diseases (i.e., reactions in the airways and lungs) such as asthma, rhinitis, asbestosis, and silicosis
  - Occupational cancers (i.e., leukemia, lung cancer, mesothelioma, cancer of the nasal cavity)

- Health effects that car
  - Skin diseases
  - Reproductive prob
  - Allergies
- Accumulation in tissu
  - Some substances c
    lead and mercury
  - Some substances c
- Penetration through th

Workers regularly exposed
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Exposure to extreme tem
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3.8 SUMMARY

The human body is a compl
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The senses of the body are ar
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The body responds to str
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Ergoweb® Case Study—S
By Arthur R. Longma

Task Prior to Abatement

This task was performed b
one cleaner/packer). With

- Health effects that can be both acute and long-term, for example,
  - Skin diseases
  - Reproductive problems and birth defects
  - Allergies
- Accumulation in tissues
  - Some substances can accumulate in the body (e.g., heavy metals such as lead and mercury or organic solvents) gradually poisoning the system
  - Some substances can produce long-term health and reproductive issues
- Penetration through the skin and dermal conditions

Workers regularly exposed to liquids, including water, which can break down the skin's natural defense barrier, are most at risk of developing skin problems.

Exposure to extreme temperature, solar radiation, and biological risks also contribute to exposure-related problems. Heavy physical work can also enhance the uptake of dangerous substances.

3.8 SUMMARY

The human body is a complicated and amazing collection of systems and sensory capabilities that permit an infinite number of movements, activities, and functions. The senses of the body are an inherent safety mechanism, which respond to external stimuli and are the gateway to the human. The senses interpret external signals and allow the internal systems to respond. Hazardous conditions may be immediately sensed and workers and management must pay attention to these signals to eliminate acute hazards. Some hazards pose risks that may not be immediately detected. These types of hazards can cause long-term disability and health concerns. These dangers are even more critical for engineers and management to consider in workplace design, as workers may not realize in the short term the long-lasting consequences.

These senses of the body are the pathway for human perception of the outside world.

The body responds to stress from internal and external stimuli. It is important to reduce external stimuli so bodily systems are not overly stressed. This is called "engineering" the problem out of the task design. It is equally important for management and employees to recognize hazards in the workplace that may stress the body beyond acceptable limits and respond to the signals and signs a body exhibits when it is being unduly stressed. Mitigation of risks should always be a priority.

Case Study

Ergoweb® Case Study—Skin Stapler Assembly and Welding Operation
By Arthur R. Longmate and Timothy J. Hayes

Task Prior to Abatement (Description)

This task was performed by a four-man crew (two assemblers, one welder, and one cleaner/packer). With the tote upright on the table, the assembler would reach into the pan each time and get a single component (total five components) for each assembly. Workers needed to reach near the bottom of the tote when the pans were less than half-full. The welding operation involved welding the instrument in an ultrasonic welder and then firing it five times to test staple formation and staple feed in the magazine.

Task Prior to Abatement (Method Which Verified Hazard)

The welding operation steps were:

1. Get one instrument from tray with the left hand
2. Position and insert into welder nest using the same hand
3. Close manual clamp on welder nest with left hand
4. Push and hold welder activation buttons to cycle welder
5. Get instrument from weld nest using right hand
6. Fire instrument once by striking trigger forcefully with palm of left hand
7. Place instrument aside for final cleaning or destroy it if not acceptable
8. Record the defect type on sheet

If the welder station became backed up, one of the assemblers would swing over and assist the welder by performing the test-firing function.

Task Prior to Abatement (Method Which Identified Hazard)

The ergonomic-related medical incidence rate was extremely high in this department. These incidences include various forms of tendinitis and hand/wrist related disorders.

Many employees were placed on medical restrictions.

Ergonomic Risk Factor (Force)

High mechanical force concentrations to the hands and fingers and high hand force is required to dig the parts out.

Ergonomic Risk Factor (Posture)

Longer reach than necessary and difficulty in grasping is required to grasp the parts.

Ergonomic Risk Factor (Repetition)

High repetitive wrist flexion and ulnar deviation is required in order to strike the trigger forcefully with the palm of the left hand five times to fire each instrument for approximately 4000 instruments per day.

Ergonomic Solution (Administrative Controls)

A structured job rotation sequence was established to reduce the exposure to the high repetitive and forceful tasks.

Ergonomic Solution (Engineering Controls)

Assembly stations with adjustable V-stands were provided to tilt up tote pans to the most accessible angle without allowing parts to spill out onto the table.

New, adjustable ergonomic
vided for shorter employees to
increase comfort.

A presence sensing activatio
angle mounting bracket was dev
of the welder in order to reduce
buttons using the thumbs (reduc

A pneumatic clamp was use
to eliminate repetitive striking
ment for welding.

Ergonomic Solution (Benefits

All workers that perform this
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- Productivity has increase
- Employee response to t
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Ergonomic Solution (Metho

There has been a 10%–12% in

New medical problems hav

Comments

Providing a conveyor to a
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although from an ergonomic
clear because of the low weig
to the relatively high cost of t
questionable ergonomic impac

Source: Longmate, A.R. and
1990.

EXERCISES

3.1 Explain an occupational
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3.2 Explain how to minimize
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3.3 Discuss the types of vibra
How can these levels of v

3.4 Why do many older peop

New, adjustable ergonomic chairs were purchased and footrests were provided for shorter employees to reduce the risk of posture related injuries and increase comfort.

A presence sensing activation button system was provided and an adjustable angle mounting bracket was developed to attach the activation buttons to the side of the welder in order to reduce the high repetition and forceful task of activating buttons using the thumbs (reducing the thumb tendinitis).

A pneumatic clamp was used to automatically clamp the instrument in order to eliminate repetitive striking of a manual De-sta-co clamp to retain the instrument for welding.

Ergonomic Solution (Benefits)

All workers that perform this task now have reduced exposure to various forms of tendinitis and other hand/wrist related disorders.

- Productivity has increased up to 10%–12%.
- Employee response to the modifications has been extremely positive and they can perform the task with less risk of injury.

Ergonomic Solution (Method Which Verified Effectiveness)

There has been a 10%–12% increase in productivity.

New medical problems have greatly diminished.

Comments

Providing a conveyor to automatically transport trays of assembled instruments between the assembly and welding workstations is under consideration, although from an ergonomic view, the positive influence of a conveyor is not as clear because of the low weight (about 5 lb) of the full trays of instruments. Due to the relatively high cost of the conveyor (about $8000 per line) and due to the questionable ergonomic impact, justification is in question.

Source: Longmate, A.R. and Hayes, T.J., *Ind. Manage.*, 32(2), 27, March/April 1990.

EXERCISES

3.1 Explain an occupational environment where each of the human senses is utilized for task performance.

3.2 Explain how to minimize overloading of the visual system in a visual inspection task in a manufacturing facility.

3.3 Discuss the types of vibrations impacting workers and the sources of vibration. How can these levels of vibration be determined?

3.4 Why do many older people need higher illumination to see objects clearly?

ERGONOMICS

Foundational Principles, Applications, and Technologies

Pamela McCauley Bush, PhD, CPE

CRC Press
Taylor & Francis Group

Ergonomics and Human Factors

ERGONOMICS
Foundational Principles, Applications, and Technologies

A complete introduction to the field, **Ergonomics: Foundational Principles, Applications, and Technologies** discusses scientific principles, research, applications, and emerging trends in technology. The text covers basic ergonomic principles from research and application perspectives. It includes hands-on laboratory activities to complement classroom instruction and cases studies that demonstrate application of ergonomic knowledge. Using an approach that highlights the physical over the cognitive, the author focuses less on kinesiology principles and more on applied kinesiology in ergonomics.

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- Covers the human senses and the sensory process for each, including tools and techniques for assessing sensory impact
- Explains the functionality, relationship, and elements of the integrated roles of the muscular system and nervous system
- Introduces the study of anthropometrics and the principles that can be used to support anthropometric design, including data collection, calculation of statistics, and identification of appropriate data sources
- Examines the basic ergonomic principles of work place design and evaluation of hand tools
- Discusses the origin, nature, and impact of work-related musculoskeletal disorders (WMSDs) in the global community
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