16 PERCEPTUAL AND COGNITIVE EFFECTS DUE TO OPERATIONAL FACTORS

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"Non sentient viri fortes in acie vulnera – In the stress of battle brave men do not feel their wounds" – Cicero

Introduction to Stress and Stressors

Modern combat is violent, unpredictable, and cognitively challenging, and accordingly, few would argue against the premise that battlefields are highly stressful. They involve highly mobile operations, destructive weaponry, violent combat, continuous maneuvers, and decentralized command and control. Long hours, acceleration, noise and vibration, altitude effects on the body, and potential mechanical malfunctions are just a few examples of stressors inherent in operating complex military systems. This environment is also where multiple complex decisions must be made, some of which may be life-threatening. Combat is without question a potent, multifaceted stressor that every day involves Warfighters in multiple stressful situations, although these stressors are often accepted by the Warfighter as a standard part of the operational environment with potentially little or no relief in sight. Indeed, modern and future warfare will have a degree of intensity, fluidity, and lethality previously unknown. Yet, despite the advances of technological superiority currently enjoyed by the U.S. and her allied partners, there remains an undeniable human component to combat. The promise of bloodless victories with reliance on high-tech weapons has not replaced the flesh and blood Warfighter on the battlefield. The individual Warfighter remains the characteristic enduring center-point of war. Daily, Warfighters must face hostile combat scenarios involving extreme stressors and perform successfully to survive. Even during relatively calm periods between engagements, Warfighters face stress resulting from sleep deprivation due to sustained or continuous operations, information-overload due to operating complex equipment, emotional strain from exposure to extensive destruction and dead bodies resulting from combat, and anxiety for the welfare of their fellow Warfighters and for family members left back home.

This complex myriad of job stressors puts Warfighters at risk for psychological trauma and medical difficulties ranging from problems of memory and cognition, burnout, substance abuse, and decreased task performance, to severe depression, suicidal tendencies, and Post Traumatic Stress Disorder (PTSD). Unfortunately, Warfighter mental performance directly translates to system performance, combat unit effectiveness, and operational success. Consequently, in military operations, approximately 70% to 85% of all catastrophic mishaps are caused by human error (Wiegmann and Shappell, 2003). Since the research literature and common experience tells us that stressors can affect decision-making and performance on the battlefield, it is imperative that Warfighters, and those who design equipment for their use, be aware of and address these problems. This chapter addresses the human component of the human-machine interface and the effects of operational stressors on the warfighting system operator. It also strives to link operational stress factors to perception, cognition, and human performance errors and their implications for the design of combat systems – including helmet-mounted displays (HMDs). It is incumbent on the research community to address these stresses and strains of combat and to design systems that take degraded operator performance into account.

Notwithstanding, while addressing operational factors, this chapter also recommends countermeasures, leader actions, and design issues for controlling the negative effects of operational stressors. When reading, it is important that you consider the information presented not only from an individual Warfighter's perspective, but also from the perspective of a senior leader employing his units and soldiers as a combat system across the breadth and depth of the battlespace. Designers must understand how their users cope (or fail to cope) with these stressors and how the stress information presented could relate to problems encountered by operators when using their designs.

Psychological stress

Around 1926 an Austrian endocrinologist, Hans Selye, identified what he believed was a consistent pattern of mind-body reactions that he called "the nonspecific response of the body to any demand" (Gabriel, 2006). He later referred to this pattern as the "rate of wear and tear on the body." Selye's definition of stress is necessarily broad, as stress is a broad concept. However, it incorporates two very important points: (1) that stress is a physical or "body" phenomenon and (2) that stress involves some "demand" placed upon an individual. Today we still define stress as the nonspecific physical, psychological, and physiological responses of the body to any demand placed upon it. In popular usage the term *stress* often refers to both the event (technically the "stressor") and to how we react to the event (technically the "stress reaction"). Indeed, stress is a normal reaction to any demand placed on an individual, either physically or mentally.

Operators need stress because it serves as a motivator and an indicator (e.g., increased heart rate, respiration, perspiration) that helps prepare you to respond. Inasmuch, the Yerkes-Dodson Law states that a certain amount of stress is necessary for optimum performance (Figure 16-1). If there is too little stress (astress), operators are under-aroused, bored, and inattentive. Boredom can result in increased risk-taking behaviors and declines in vigilance (a key aspect of attention). On the other hand, if there is too much stress (distress) ability to perform is limited and burnout or overload can be expected. Designers of systems must strive to design for optimal arousal (eustress) and performance such that operators remain engaged and attentive without being overly task saturated.

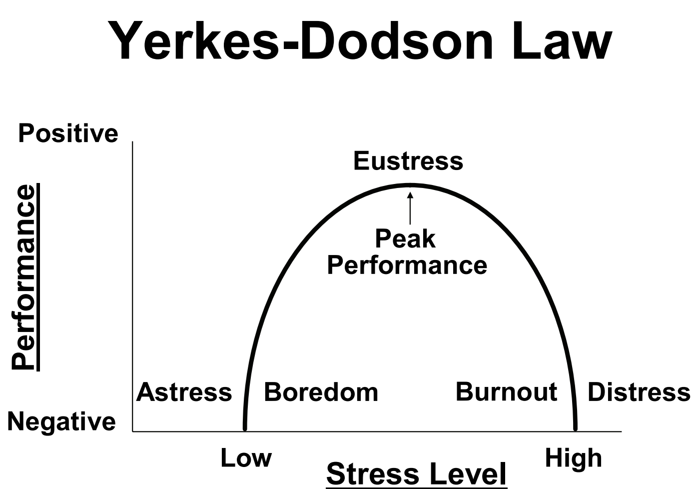

Figure 16-1. Yerkes-Dodson Law.

Additionally, odd as it may seem, some degree of stress response is also critical, in that failure to respond or adapt to stress is considered pathological. Another expression in usage for describing both stressors and stress responses is the General Adaptation Syndrome, a term used to describe the body's short-term and long-term reactions to stress and where the individual terms are described as (Selye, 1946; 1952):

General	– nonspecific response
Adaptation	– places a demand on body to adapt
Syndrome	– no adaptation = pathology

Fortunately humans have developed an inherent set of biological responses to address crisis situations. Generally, psychologists group these stress responses into a three stage process: alarm reaction, resistance, and exhaustion. In the alarm phase the bodily systems are mobilized in response to the event or demand. Therefore, when there is a perceived threat or challenge, a number of immediate, involuntary physiological changes occur – e.g., adrenaline is produced, heart rate and blood pressure increase; the pupils of the eyes dilate for better vision; the lungs take in more oxygen; the bloodstream brings extra oxygen and glucose into circulation for fuel; and digestion stops to allow the body to focus its energy on the muscles; and perspiration (required for evaporative cooling) increases. This adaptive alarm reaction is commonly called the *fight or flight response*, and it prepares the body to deal with (fight) or escape from (flight) the situation. During the resistance phase, the body maintains these efforts to cope with the threat, and eventually, if the threat is sustained, the body fatigues and fails to meet the threat challenges (exhaustion phase). If the stress response is activated too long or often, it can harm the body, causing damage to the immune system, brain, and heart.

Late 20th century psychologists found additional factors can contribute and moderate the stress experience and demonstrated that changes in the level of arousal have not been found to consistently correlate with stress (Lazarus, 1968). Specifically, the same physiological markers found to activate under stress also take place everyday in individuals who would not report being "stressed," but rather being angry, excited, etc. Inasmuch, Lazarus introduced the concept of psychological appraisal. He suggested that a primary appraisal of the event is conducted by the individual to determine the meaning of the event (positive, negative, or neutral). If appraised as negative, the individual then assesses the degree of harmfulness associated with the event. A secondary appraisal is then conducted to determine the availability of coping resources. Stress results when the perceived threat is greater than the perceived coping ability. Stress overload or prolonged stress can produce detrimental responses in individuals with poorly developed or weakened coping ability.

Responses to stress overload generally fall into one of four categories: physical responses, emotional responses, cognitive responses, and behavioral responses. As mentioned, the immediate physical response to a stressful situation involves overall heightened arousal of the body: increased heart rate, increased blood pressure, more rapid breathing, tensing of the muscles, and the release of sugars and fats into circulation to provide fuel for "fight or flight." Stress overload or prolonged stress and its continuous effects on the body may produce long-term physical symptoms such as muscle tension and pain, headaches, high blood pressure, gastrointestinal problems and decreased immunity to infectious diseases (Table 16-1).

Table 16-1.
Physical signs and symptoms of stress.

Immediate	Long-term
Sweaty palms	Sleep problems
Increasing heart rate	Backaches
Trembling	Increasing blood pressure
Shortness of breath	Immune system suppression
Gastrointestinal distress	Fatigue
Muscle tension	Anxiety disorders

Emotional responses to stress overload can range from a keyed-up sense of anxiety and irritability to social withdrawal, hostility, loss of self esteem and depression. *Anhedonia* is a symptom of depression involving an extreme loss of pleasure in activities that were once enjoyable. Persons suffering from stress overload may lose interest in hobbies and other leisure activities and find little happiness in life. If severe enough, depression could lead to suicide, but that topic is outside the scope of this discussion. The reader should only note that suicide can occur in the absence of a history of mental health problems. Extreme stress, like the loss of a loved one (or "dear John" letters in the combat zone), may cause previously healthy people to feel hopeless and consider harming themselves. In combat this could present as suicide by proxy (getting oneself killed intentionally) but may also be masked and appear to be a human error or system failure.

Prolonged stress may affect thinking (i.e., cognition) as well as emotions and behavior. This is a serious issue for Warfighters, as problems with judgment, attention, or concentration pose a great risk to personnel, the mission, and the warfighting system. For example, under high stress conditions, there is a tendency to oversimplify problem solving and ignore important relevant information, taking the "easy way out." This is called the *simplification heuristic*.

Many individuals under high-stress conditions also tend to forget learned procedures and skills and revert to bad habits in a phenomenon called s*tress-related regression*. For example, a student aviator preparing for take-off may forget to turn on the fuel switch and then, realizing the problem and feeling stressed and embarrassed, turn the switch on and risk overheating the engine. This action is clearly contrary to training and represents a kind of regression or failure to utilize prior learning.

Yet another stress-related cognitive error is p*erceptual tunneling*. It is a phenomenon in which an individual or an entire crew under high stress becomes focused on one stimulus, like a warning signal, and neglects to attend to other important tasks or information, such as avoiding and defeating incoming fire. A similar situation may occur when Warfighters realize that they overlooked some aspect critical to mission success, such as missing a radio communication. They may then over-attend to rectifying this problem and become emotionally and mentally fixated on the error and forget other aspects of the operation, missing new information, and further compromising the mission. Beyond affecting memory, judgment and attention, stress can even decrease hand-eye coordination and muscle control.

The behavior responses to stress overload can also affect how we interact with others (e.g., at work, at home, and with friends). For example, explosiveness, social isolation, lateness to work, or a drop in work performance can be signs of stress overload. At times, stress may become so severe that alcohol is used to self-medicate anxiety or depression. Using alcohol as a coping strategy is particularly dangerous, since it impairs judgment and increases impulsivity (see *Smoking and alcohol*). Extreme stress, like the loss of a loved one, may cause previously healthy people to feel hopeless and consider harming themselves or others. This can lead to violence in the home or workplace, and like depression mentioned earlier, can result in suicide.

Psychosocial stressors are those that deal with relationships, career, and finances, as well as the factors that influence these three areas, such as your physical health. Psychosocial stress can be either positive (promotion at work, marriage, birth of a child) or negative life events (divorce or separation, death of a loved one, or illness/injury to self or family). A complete treatment of this subject is outside the scope of this work. The important thing here is to remember that psychological health enhances operator performance, and all aspects of stress have the capability to affect system effectiveness and should be considered in the initial design of a system. Given that consideration, designers must be aware that the typical user of a combat system will not be 100% capable and more likely will be operating in a diminished or degraded capacity.

Capacity to cope

Stresses decrease your capability to function in high stress environments where physical and mental capabilities must be optimal. Figure 16-2 illustrates the compounding effects of stresses, attention problems, environmental stresses, and system problems on one's capacity to cope with normal stresses. Line *A* of the model represents the stresses most within your control. Self-imposed stresses like tobacco or alcohol use, poor sleep management, or self-medicating with over-the-counter (OTC) drugs diminish one's capacity to cope. This decrease in capacity to handle stress is depicted by a dip in line *A*. The more stresses one subjects themselves to, the more the decrease in the capacity to cope. Line *B* of the model depicts environmental and operational stresses beyond the Warfighter's control. For the most part, environmental stresses are based on mission profile, vehicle employed, and time of day. However, unpredictable stresses, like weather or mechanical problems, are also included in environmental stresses. The area between lines *A* and *B* represent the Warfighter's capacity to cope with any unknown stress the system or mission places on them.

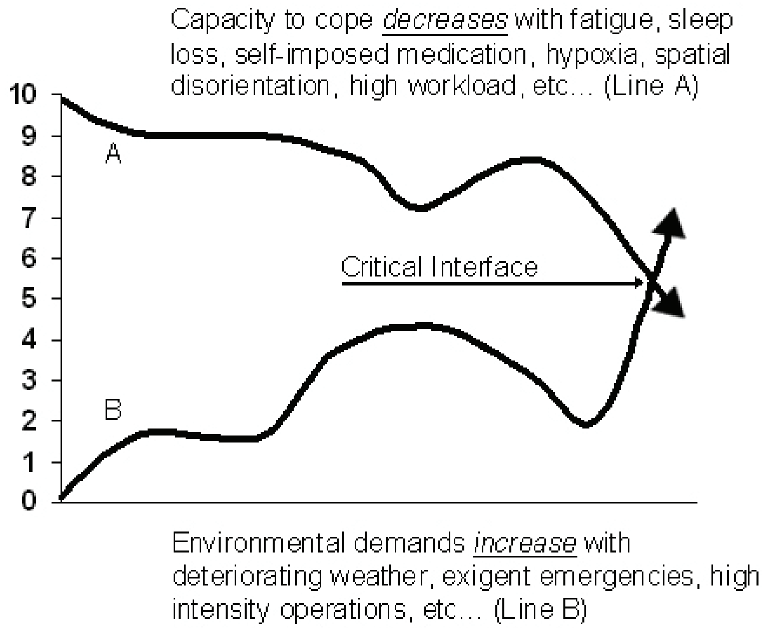

Figure 16-2. Critical interface concept for demands and capacity to cope.

If environmental stresses increase to the point where the capacity to cope and environmental demands intersect (critical interface), the Warfighter loses the capability to effectively cope with the situation increasing the potential for a catastrophic mishap. In most mishaps, there is seldom just one major factor causing the mishap. Many of the operational factors discussed in this chapter decrease one's capacity to cope, but you must remember that few occur in isolation. Instead, mishaps usually occur when many small factors add up to disrupt the Warfighters' capacity to control the system.

Therefore, it is critical to understand the importance of exposure to self-imposed stress. The closer Warfighters are to being 100% capable, the greater their ability to cope with unexpected problems or stresses arising during combat. Although we will discuss each of these concepts in greater detail later in this chapter, it is important to understand that capability decrements from self-imposed stresses result from actions taken by the Warfighters themselves. They can include the use of OTC drugs, caffeine, alcohol or tobacco. Self-imposed stresses also include nutrition, physical condition and life-style. These stresses, as well as circadian rhythm problems, can contribute to fatigue. All of these stresses strain the ability or Warfighters to function at an optimum level. Self-imposed stresses generally decrease performance, impair judgment, and decrease tolerance to other external and operational stresses.

Individual reaction to and performance during stress vary according to four major factors. The first factor is the *degree of mental effort* required by the task to be performed. In general, stress effects performance much less if an individual is engaged in a relatively simple task that is either over-learned (e.g., driving a car) or one that does not involve complex mental skills (like filling sand bags or some other form of manual labor). The *characteristics of* *the situation* in which a task is performed make up the second factor that affects the stress/performance relationship. For example, a student will do much better on a written achievement test if he is working in a quiet, comfortable room as opposed to working in a hot, noisy room. The *biological make-up* of the individual also influences the stress/performance relationship. So, an individual prone to fatiguing easily will not make a good Warfighter, where long hours and night operations are common. The fourth and final factor affecting the stress/performance relationship is one's *personality and mental health*. Individuals prone to obsession, perfectionism, and rigid thinking are less likely to perform well under stress than those persons with more flexible, realistic problem solving and decision making skills. Commonly referred to as Type A and B personalities based on how a person responds to stress. Type A persons (most common in the military) tend to respond to stress with hostility, anger, and greater competitiveness, while Type B persons tend to be easy going and cope well with stress.

Combating stress

Warfighters are competitive by nature; and combat is the ultimate win or lose scenario. Ultimately then, each Warfighter is a successful competitor, as unsuccessful ones tend to select out rather quickly. Arguably, outside of combat such competition is usually a healthy environment in which to function, but it can also be a source of stress. Constantly trying to succeed in a pressure-prone environment, impressing your superiors and outperforming your peers serve as continual sources of stress. Yet, even in peacetime, Warfighters live in a success-oriented and competitive society and are often placed in stressful environments. For example in aviation, it is obvious that an in-flight emergency evokes stress, but a checkride[1] is also a form of stress. Both elicit the same physiological response of fight or flight. Stress is useful if controlled; but a common expression remains true: "If you don't control it, it will control you."

As discussed, stress is necessary and can be both positive and negative. To be an effective Warfighter, each must learn to manage the stresses that are part of the demands of everyday life. However, to begin managing stress, it is necessary to first understand what it is and what it does – how it affects individuals both physically and mentally. Ultimately, each individual must learn to employ effective methods for coping – controlling or relieving stress. Coping techniques can be thought of as falling into one of four categories: avoiding stressors, changing your thinking, learning to relax, and ventilating.

Avoiding stressors is the most powerful technique for managing stress, since it actually prevents one from ever experiencing the full effect of a stressor. Avoiding does not mean running away from stress, however. Foresight and good planning go a long way in helping to avoid unnecessary stress. Prioritizing one's work load effectively will also help to avoid last minute crises. Planning and time management are especially important tasks for leaders, as subordinates will often model their work behavior after the examples set by their chain of command.

Realistic, mission-focused training and an effective physical training (PT) program also help prevent stress overload by providing Warfighters with the knowledge, skills, and physical endurance to perform under stressful conditions such as continuous operations, night operations, and sustained combat. If a Warfighter's comfort in performing mission essential tasks derives solely from garrison training with little realistic combat training, combat conditions and stressors will be new and unanticipated when encountered, and potentially fatal. Finally, paying close attention to communication and team coordination will also help avoid unnecessary stress and prevent mishaps. The stress of military operations can degrade communication, affecting the sound, rate, and content of speech, as well as the operator's ability to comprehend communications. Soldiers under high stress may be less precise in their messages, talk faster, and misinterpret messages more easily. The ability of a squad to work together as a cohesive team is also essential, as a number of accidents have resulted from individual members' feeling that they could not talk openly or disagree with an excessively authoritative leader.

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[1] The *checkride* is a practical test to measure the skills developed throughout flight training. Pass/fail is based on performance against published test standards.

As discussed earlier, *how one thinks about stress* partly defines one's reaction to it, often creating a self-fulfilling prophecy. Pessimism and negativity will produce self-defeating behavior and negative results. Practicing positive self-talk is an important step toward accomplishing one's goals. Keeping a focus on what's going on *right now – today* – also helps prevent stress overload. We can't change the past, and we can only plan for the future; we cannot control the future. Spending time obsessing about past mistakes or worrying about future potential problems is distracting and creates a potential for failing at the task at hand. This is a serious danger for the Warfighter. While in combat, the Soldier's mind must be on warfighting and not on family, career concerns, or other issues past or future. Recognizing the choices one makes in life is also an important strategy for avoiding stress overload. Blaming failures and disappointments on others actually surrenders personal control and makes one's experience of life akin to being strapped down, blindfolded in the back seat of troop transport driven by someone else. It is important to make decisions, take appropriate risks, and accept responsibility for those decisions and risks. It is also important to recognize that sometimes one's decisions and actions will not be successful. When this happens, it is necessary to have the flexibility to accept setbacks and drive on, as opposed to engaging in self-pity or obsessing about repercussions.

Relaxation is an essential, albeit widely underutilized, coping technique. It is impossible to be relaxed and stressed at the same time. Find a relaxation technique that works, and use it regularly. Some examples include: meditation, yoga, self-hypnosis, reading, or pleasurable hobbies (like assembling models or listening to relaxing music).

Ventilation is the fourth and final category of coping techniques. It involves "letting off steam" either interpersonally by talking to someone or physically through exercise. Verbally expressing emotions helps resolve traumas and reduce stress and can be accomplished with a friend, family member, chaplain, or mental health professional. Exercise has long been recognized as a valuable way to "let off steam." Be careful not to overdo it, however, as this may result in injuries and thus more stress.

Fatigue

Fatigue is defined as a state of diminished mental and physical efficiency, i.e., decreased working capacity. Consequently, two types of fatigue often are discussed: mental and physical. Mental fatigue can be caused by continual mental effort and attention on a particular task, as well as by high levels of stress or emotion and exposure to environmental factors such as noise and thermal stress. The level of mental fatigue increases with time on task or exposure. As a result, tasks become more complicated to perform, concentration is reduced, and error rate is increased. Physical fatigue can result from loss of sleep, physical overexertion, medication side effects, thermal stress, and certain health problems.

While both types of fatigue may be, and often are, experienced separately, they more frequently are experienced simultaneously in the battlespace. In fact, in the warfighting environment, it is often difficult to separate the two types with respect to causes and effects. Therefore, the discussion of fatigue will be first discussed here under P*sychological stress* and then continued in the *Physiological stress* section.

We usually think of the negative effects of stress as those effects due to stress overload. Consequently, overload has deservedly received much attention as an important stressor. In overload the demands are such as to exceed the individual's ability to meet them. An example of overload is role conflict. This can be viewed as a situation in which a person finds, in essence, opposing demands being made. An individual often may be asked to work on one assignment when already having some other assignment. That person may have to stop what they are doing at that time to attend to the new task. When the issue concerns merely the sum total of work that must be done irrespective of its difficulty, we talk about quantitative overload. The person has more work than can be done in a given period of time. That person may be fully competent in the work, but time restrictions are what elicit the stress reaction. Quantitative overload could involve working for long hours without appropriate rest periods. When the work is overloading because it requires skills, abilities and knowledge beyond what the person has, then we talk about qualitative overload. The work may demand continuous concentration, innovation and meaningful decision. An important factor contributing to qualitative overload is job complexity. In general, the higher the inherent difficulty of the work, the more stressful the job. In some job situations there is a combination of both quantitative and qualitative overload; this is frequently encountered in Warfighters, particularly new trainees. Remember also, the Yerkes-Dodson Law teaches us that underload can create stress that is problematic.[2] This is a rare occurrence in intense warfighting operations (although, much of day-to-day warfighting consists of sitting around being bored). However, boring or monotonous tasks may result in astress conditions. A job may fail to provide meaningful stimulation or adequate reinforcement. Thus, jobs which involve dehumanizing monotony, no opportunity to use acquired skills and expertise, an absence of any intellectual involvement and repetitive performance provide instances of underload. In these situations boredom results from too high a degree of specialization (being overly qualified or too highly trained for the task). As with many other psychological and physiological problems, Warfighters may not be aware of task underload until they make serious errors. Sleep deprivation, disrupted circadian cycles, or life event stress may all play an additive role in producing even greater fatigue and concomitant performance decrements.

Inasmuch, it is evident that high stress overload or low stress underload both can compromise the Warfighters ability to safely accomplish the mission. Both high and low levels of stress do this by increasing fatigue in the Warfighter. Fatigue has been defined previously as a state of diminished mental and physical efficiency. Fatigue is normally caused by the common day-to-day activities a Warfighter performs. Stress can result in either *acute* or *chronic* fatigue. Acute fatigue is short-term fatigue caused by the normal daily activities of the Warfighter. It is usually remedied with a good night's sleep and rest. Unfortunately, if the Warfighter fails to remedy acute fatigue, then he begins to suffer from chronic fatigue. Chronic fatigue frequently develops gradually over time as is seen during combat deployments. However, problems can also arise when Warfighters fail to gain adequate rest in any situation where short-term fatigue evolves into long-term fatigue. For instance, when he fails to get adequate rest and sleep for several days, he becomes chronically fatigued. Other major causes of chronic fatigue include interrupted or poor sleep patterns, circadian rhythm shifts, illness, successive long missions with minimal recuperation time, and succumbing to self imposed stresses.

Chronic fatigue can lead to motivational exhaustion, commonly referred to as "burnout", and usually results from excessive unmanaged stress. Restorative measures for chronic fatigue are only temporary if stress continues. Signs and symptoms of stress related fatigue in an individual include: concentration and attention are difficult, feelings appear dull and sluggish, general attempts to conserve energy, feel or appear careless, uncoordinated, confused, or irritable. Cognitive effects include: "all or nothing" thinking, failure to focus on the here and now, and too many "musts" and "shoulds." Unfortunately, fatigue is an insidious stressor because Warfighters usually become mentally fatigued before they become physically fatigued. In fact, usually the cognitive deficits are seen by others before the physical signs and symptoms are felt by those affected.

Fatigue has a number of negative effects in the operation of complex systems. One possible result is a change in reaction time. Increases in reaction time occur because of the general decrease in motivation and sluggishness that often accompany fatigue. Decreases in accuracy also may occur, however, when individuals become impulsive and react too quickly and poorly. Fatigue also reduces attention. Fatigued Warfighters may exhibit a tendency to overlook or misplace sequential task elements, like leaving out items on a checklist. They may also become preoccupied with single tasks or elements, like paying too much attention to objects outside the system while on night vision devices, to the exclusion of checking systems and instruments inside their vehicle. Fatigue also impairs memory. Although long-term memory is reasonably well preserved during fatigue, short-term memory and processing capacity are greatly affected. Warfighters may have difficulty recalling operational events, like the location of the objective rally point, and may neglect peripheral tasks, like forgetting to check and ensure proper radio frequencies. Communication is also impaired by fatigue, as Warfighters may become more withdrawn or irritable, less clear in their speech, and more prone to misunderstanding messages. In general,

[2] The condition known as *underload syndrome* is defined as a lack of stimulation (such as a boring job) can result in depression and health problems, e.g., headache, fatigue and recurrent infection.

fatigued Warfighters have little awareness of their impaired performance and may feel physically okay. It is therefore important that other team members monitor each other closely in operations where fatigue is likely. Extreme fatigue can actually lead to hallucinations and problems thinking, causing the individual to appear as if they have a thought disorder or psychosis.

Combat stress, in the past commonly known as *shell shock* or *battle fatigue*, should not be confused with simple fatigue. Remember fatigue is the state of feeling tired, weary, or sleepy that results from prolonged mental or physical work, extended periods of anxiety, exposure to harsh environments, or loss of sleep. Combat stress is a specific military term used to categorize a range of behaviors resulting from the stress of battle that decrease the combatant's fighting efficiency. The most common symptoms are fatigue, slower reaction times, indecision, disconnection from one's surroundings, and inability to prioritize. Combat-stress reaction is generally short-term and can produce a wide range of behaviors, some of which are positive, such as heightened alertness, strength, and endurance, acts of courage and self-sacrifice, and strong personal bonding between soldiers. Combat stress reactions may manifest a broad range of symptoms from normal, common signs experienced by many soldiers such as hyperalertness, irritability, and loss of confidence to less frequently observed warning signs that require immediate attention such as impaired speech or muteness, impaired vision, touch, or hearing, paralysis, or hallucinations. (See Lee et al., 1997; and Solomon, 1993.)

Summary: Psychological stress

A high percentage of military mishaps are caused by user error. Some of the major contributors to human error are self-imposed stresses that decrease the Warfighter's capacity to cope with unforeseen environmental or mission-related stresses. Total prevention of stress and fatigue is impossible, but their effects can be significantly moderated. The major self-imposed stresses are self-medication with OTC drugs, alcohol and tobacco use, hypoglycemia and dehydration. Each of these contributes to fatigue, which is the crucible from which increased susceptibility to stresses such as spatial disorientation, visual illusions, and G-induced loss-of-consciousness arise. Fatigue also is a result of sleep cycle disruption and circadian rhythm shifts caused by transmeridian travel[3] (Meir, 2002). Financial, family, professional and social responsibilities are a few of the peacetime stresses which may confront the Warfighter. External stressors (noise, vibration, cold, heat, etc.) also may lead to negative behaviors associated with self-imposed stress.

Warfighters can strive to minimize self-imposed stresses; however, system designers also must both be aware of these effects and strive to design systems which are tolerant of expected degradations in operator performance. Failure to consider such effect in new designs can result in a less than optimal system at the least and loss of life at the worst. Fortunately, most unnecessary stress can be controlled or avoided with observance of the duty day, rest regulations, adequate recreation, good living quarters, and attention to morale factors. However, generally, the demands of combat are in conflict with the strain caused by internal and external stresses. Recognition, treatment, or better yet, avoidance of stress is essential for maintaining situational awareness, combat effectiveness, and ultimately safety. Resolution of the problems prior to combat is the only way to prevent them from adversely affecting system effectiveness and mission success. If efforts to resolve these stresses are unsuccessful, fault tolerant systems must be developed.

There are many ways to compensate for the effects of stress and fatigue. First, always start a task when well rested, especially when scheduled for extended missions or sustained operations. Warfighters should minimize the use of tobacco and alcohol, and ensure they are well hydrated. Proper diet can also reduce the effects of stress and fatigue. They should avoid high fat, high carbohydrate meals to reduce drowsiness instead placing emphasis on a meal moderately high in protein with moderate carbohydrates. Additionally, they should avoid eating large, filling meals prior to an operation to reduce the chance of drowsiness. It is more beneficial, in this instance, to eat several smaller meals (snacks) rather than a full meal at a single seating.

[3] Transmeridian travel refers to crossing a number of time zones.

The effects of fatigue and stress can be reduced through regular exercise and by staying active. During long convoys or flights, if possible, stop to get up and move around periodically. Internal vehicle lights can be turned up or down to optimize vision. Warfighters should never miss the advantage to take a nap if it can be done safely. When fatigued, it is important for Warfighters to increase their awareness of and cross-check fellow team member activities during critical tasks and functions to offset the potential for increased errors due to fatigue.

Although Warfighters are taught to push themselves to the limits of their abilities, to be tough and effective, it is wrong to think that denial of the effects of stress and fatigue will help accomplish these goals. To a certain extent Warfighters can increase their capacity to cope by eliminating or minimizing exposure to self-imposed stresses. However, stressors such as fatigue are not always controllable in the operational environment. Failing to identify and control for the effects of stress and fatigue in system design will weaken individual soldiers, units, and threaten safety and mission completion. Therefore, awareness of the causes and effects of such stresses is the key to decreasing the negative manifestations, and systems must be designed with the degraded operator in mind. Table 16-2 summarizes necessary Warfighting abilities and the potential effects of various stressors on these abilities.

The following recommendations should be considered in any Warfighter stress-reduction/endurance plan:

- *Place demands into perspective* – Doing well in military training, living comfortably, and being a good parent are all worthwhile aspirations, but they are not life threatening situations. Warfighters cannot control the reflexive physiological process that activates in a crisis situation, but they can control what they perceive as a crisis situation – the key is for them not to overreact.
- *Maintain a healthy diversity* – Entertainment and hobbies provide a healthy balance to life. A healthy balance will make the energy expanded on job and family more effective or meaningful. The military environment, particularly combat, is a demanding one, constantly changing and requiring a total mental and physical commitment from the Warfighter. The Warfighter must maintain focus and not become distracted. Any factor or condition that bothers someone enough to distract from their work is important and must be given adequate attention – but then compartmentalize! Put it away until it can be dealt with properly
- *Eliminate self-imposed stress* – Smoking, excessive drinking of alcohol, self-medicating, poor nutrition and lack of exercise are stressful and make it more difficult to deal with other stresses. Avoiding these behaviors eliminates their effect on the crewmember, minimizing self-imposed stress.
- *Maintain good physical fitness* – Regular, strenuous exercise will help resist the effects of fatigue.
- *Get plenty of natural sleep* – This is the most essential action to take for treating stress and fatigue once it has occurred. Although alcohol is the most widely used sleep aid in the U.S., alcohol-use as such is not appropriate, since it is disruptive to the quality of sleep. Alcohol will put you to sleep quickly, but later in the night you will not sleep as soundly.

Physiological Stress

Psychological stress is neruogenic (originating in the nervous system), is emotional in nature, and requires no physical interaction with the stressor(s). Physiological stress is homeostatic,[4] physical in origin, and similarly to psychological stress manifests itself in autonomic and anatomical changes (e.g., changes in blood pressure and heart rate). The physiological effects of stress occur as a result of certain biological function adjustments that occur in the body which are designed for the body to handle stress efficiently. If this response to the physiological effects of stress is present, then the individual would succumb to the hostility of the situation. The extent of

[4] *Homeostasis* is the ability or tendency of an organism or cell to maintain internal equilibrium by adjusting its physiological processes.

Table 16-2.
Fatigue and stress impact on critical Warfighter abilities.

Necessary (Top Level) Warfighting Abilities	
○ Psychomotor coordination ○ Attention and vigilance ○ Memory	○ Judgment and decision making ○ Prioritization of tasks ○ Effective communication
Stress Effects on Performance	**Fatigue Effects on Performance**
Psychomotor • Decreased tracking abilities	Psychomotor • Tracking not as smooth • Slow and irregular motor inputs
Attention • Perceptual tunneling (decreased peripheral field of attention) • Cognitive tunneling (narrowing salience – e.g., missed radio calls) • Tunneling can be found with both cognitive and emotional stress • Task shedding – entire tasks abandoned	Attention • Perceptual tunneling (reduced audio-visual scan) • Reaction time increases • Errors in timing and accuracy • Vigilance is reduced • Concentration difficult • Lapse or "microsleeps" • Need enhanced stimuli salience ▪ Increased volume ▪ Increased contrast ▪ Increased brightness
Memory • Memory capacity declines (Short-term memory) • Memory strategies compromised ▪ simplification heuristic ▪ speed/accuracy tradeoff • New learning declines • Stress related regression	Memory • Diminished memory • Recall declines • Learning declines
Affect • Group Think more common ▪ More confident in opinions when shared by others ▪ Less confidence in perceptions that contradict the majority ▪ Individual's errors more difficult to identify ▪ Avoids personal responsibility and accountability	Affect • Feel or appear dull and sluggish • General attempt to conserve energy • Feel or appear careless, uncoordinated, confused, or irritable • Cognitive deficits are seen before the physical effects are felt

Table 16-2. (Cont.)
Fatigue and stress impact on critical Warfighter abilities.

Stress Effects on Performance	Fatigue Effects on Performance
Combat Stress • Hyperalertness • Fear, anxiety • Loss of confidence • Impaired senses • Weakness/paralysis • Hallucinations or delusions	Communication • Impaired communication, cooperation, and crew coordination • More fragmented conversations • Misinterpretations

body's physiological response to stress varies across individuals. The physiological stress response can affect a number of organs, including brain, lungs, and heart. Apart from affecting the organs, stress also impacts the functioning of the metabolic system, immune system and cognitive function. Physiological stressors include fatigue, poor physical condition, hunger, disease. For the modern Warfighter, poor physical condition, hunger and disease usually are not of critical concern. However, fatigue is and, in this section, will be further explored via sleep loss and disruption in circadian rhythmicity. Interventions for physical fatigue also will be discussed.

Sleep deprivation

Fatigue is a significant concern for many civilian and military occupations; interest in fatigue and its potentially fatal effects within the truck driving and aviation communities has increased public awareness over the past decade. The fatigue from sleep loss and circadian factors is associated with degradations in response accuracy and speed, the unconscious acceptance of lower standards of performance, impairments in the capacity to integrate information, and narrowing of attention (Perry, 1974). Fatigued pilots tend to decrease their physical activity, withdraw from social interactions, and lose the ability to effectively divide mental resources among different tasks. In general, as sleepiness levels increase, performance becomes less consistent and vigilance deteriorates, cognition slows, short-term memory fails, frontal lobe functioning is impaired, and rapid and involuntary sleep onsets become marked (Bonnet, 1994; Dinges, 1992; Dinges and Kribbs, 1991; Horne, 1988, 1993; Koslowsky and Babkoff, 1992; Naitoh, 1975; Thomas, Sing and Belenky, 1993). Simply remaining awake for 18.5 to 21 hours can produce performance changes similar to those seen with blood alcohol concentrations of 0.05% to 0.08% (Dawson and Reid, 1997). Needless to say, the effects of lengthy duty periods are often compounded by the requirement to work and remain alert at night despite the fact that night duty is associated with a greater overall accident risk than day work (Dinges, 1995; Moore-Ede, 1993). Furthermore, is has been established that extended work shifts (i.e., those longer than 8 hours) are known to reduce the small margin-for-error that already exists in safety-sensitive jobs (Rosa, 1995).

Not only is alertness compromised by on-the-job fatigue, but several studies have found evidence of uncontrollable electroencephalogram (EEG) microsleeps[5] in pilots performing for long durations (Cabon, Coblentz, Mollard, and Fouillot, 1993; Samel, Wegmann, Vejvoda, Drescher, Gundel, Manzeu, and Wenzel, 1997; Rosekind et al., 1994; Wright and McGown, 2001). The presence of these events demonstrates that aircrew members flying today's missions often are suffering from significant cognitive difficulties while on duty

[5] *Microsleeps* are brief, unintended episodes of loss of attention associated with events such as blank stare, head snapping, and prolonged eye closure that may occur when a person is fatigued but trying to stay awake. Microsleep episodes can last from a few seconds to several minutes and often occur when a person's eyes are open.

(Belyavin and Wright, 1987; Ogilvie, Wilkinson, and Allison, 1989; Ogilvie, Simons, Kuderian, MacDonald, and Rustenburg, 1991), and such problems are at the heart of operational safety concerns. Goode (2003) concluded that flights longer than 13 continuous hours were six times more likely than shorter flights to result in fatigue-related mishaps, and a National Transportation Safety Board (NTSB) study of major accidents in domestic air carriers from 1978 through 1990 in part concluded that "…Crews comprising captains and first officers whose time since awakening was above the median for their crew position made more errors overall, and significantly more procedural and tactical decision errors" (NTSB, 1994).

Thus, long flights pose substantial risks for pilots and crews; however, it should be noted that *the duration of the flight itself* is of less importance than *the overall duration of continuous wakefulness*. Evidence of this comes both from the commercial world and from military settings. One study found that 80% of the regional airline pilots admitted to having inadvertently fallen asleep in the cockpit despite the fact that their flights were relatively short (Co et al., 1999). These pilots blamed their fatigue on scheduling issues which led to insufficient sleep (4.6 hours during "stand-up overnight" periods) and lengthy duty cycles (11.2 hours) rather than on prolonged flight durations. Given the nature of most rotary-wing operations, Army pilots may be in similar circumstances. In fact, surveys done on U.S. Army aviators (who typically make relatively short flights) and U.S. Air Force fixed-wing pilots (who sometimes engage in flights as long as 33 hours) reveal that both groups voice the same basic fatigue concerns as a consequence of insufficient sleep even though their routine flight durations differ substantially (Caldwell and Gilreath, 2002; O'Toole, 2004).

The increased sleep pressure from extended duty and the impaired arousal associated with night duty are exacerbated by sleep loss from circadian disruptions (Akerstedt, 1995a). All three factors are common in today's aviation operations. Thus, it is not surprising that the National Aeronautics and Space Administration's (NASA's) Aviation Safety Reporting System (ASRS) routinely receives reports from pilots blaming fatigue, sleep loss, and sleepiness in the cockpit for operational errors such as altitude and course deviations, fuel miscalculations, landings without proper clearances, and landings on incorrect runways (Rosekind et al., 1994). Such mistakes contribute substantially to the estimated 4% to 7% of civil aviation mishaps that are chalked up to fatigue (Kirsch, 1996), the 4% of Army aviation accidents that are considered fatigue related (Caldwell and Gilreath, 2002), and the 8% of Air Force class A mishaps that have been at least in part attributed to aircrew fatigue over the past decades (Caldwell, 2005). However, as disconcerting as these numbers are, a recent consensus report from a panel of experts suggests that the true extent of fatigue-related difficulties may be even greater. Akerstedt (2000) has asserted that fatigue is likely a causative or contributory factor in 10% to 15% of transportation mishaps; that existing statistics underestimate the real size of the problem; and that fatigue represents a greater safety hazard than drug or alcohol intoxication.

Circadian disruptions in alertness and performance

Jet lag

Rapid travel across time zones is not an uncommon occurrence in the modern 24-hour society. Air travel has become the primary mode of transportation to various locations for many people and for many reasons – academics (Takahashi et al., 2002), business, recreation, and participation in athletic and sports activities (Jehue, Street and Zuizenga, 1993; Recht, Lew and Schwartz, 1995; Wright et al., 1983). Many of these trips involve flights across multiple time zones which result in an acute condition known as "jet lag." The symptoms of jet lag have been reported to be caused by the transient internal desynchronization (i.e. mismatch or misalignment) between the internal clock that controls the sleep/wake cycle and the external geophysical clock set by the pervasive light/dark (L/D) cycle. The dissociation between the internal clock and the environmental and work or social obligations ultimately culminates in the impairment of health and productivity (Wisor, 2002). This state of temporal disarray after a change in time zone, before all rhythms return to their original internal phase-angle relationships, has been termed *transient internal desynchronization* (Moore-Ede, Kaas and Herd, 1977) or *transmeridian flight dysrhythmia* or *jet lag* (Dawson and Armstrong, 1996). Almost all individuals who travel these distances are subject to the physiological and psychological symptoms, at least for a few days. Normally, the symptoms of jet lag remit after a few days following the flight, but it may take over a week for some individuals to overcome the symptoms. Age, individual differences, number of time zones crossed, and direction of travel all contribute to the severity of jet lag symptoms (Leger, Badet and de la Giclais, 1993; Klein et al., 1970; Recht et al., 1995).

Some of the physiological symptoms of jet lag include insomnia, daytime somnolence, fatigue, stress, anorexia, nocturia, gastrointestinal discomforts, muscle aches, and head aches, (Haimov and Arendt, 1999; Cho et al., 2000; Cho, 2001). In addition, there are psychological disturbances which include moodiness/depressed mood, apathy, difficulty in concentrating, irritability, malaise, and decrements in both mental and physical performance (Bourgeois-Bougrine et al., 2003; Cabon et al., 2003; Haimov and Arendt, 1999; Minors and Waterhouse, 1988; Petrie, Power and Broadbent, 2004; Recht et al., 1995; Waterhouse et al., 2003). Women also experience delays in ovulation and menstrual dysregulation (Iglesias, Terres and Chavarria, 1980). Chronic or repeated jet lag exposure leads to cognitive decline and temporal atrophy (Cho, 2001).

Jet lag symptoms affect travelers in different ways and to different extents (Minors and Waterhouse, 1998; Waterhouse, Reilly and Atkinson, 1997). While these symptoms may be a minor inconvenience at the start and end of trips for holiday travelers, they may profoundly impair the decision making power of business executives, politicians, pilots, and aircrews. Both the severity and duration of jet lag symptoms are affected by the total numbers of time zones traveled by transmeridian flights as well as the direction of air travel (east or west). Generally, the fewer the number of time zones traveled, the lesser the side effects and discomforts (Aschoff and Wever, 1981). Eastward travelers (who were subjected to a phase advance) require more time to adjust than westward jet travelers (subjected to phase delay). The reason for this difference in adjustment is usually attributed to the ability of the internal body clock to adapt to a longer day than to a shorter day.

To successfully treat the symptoms of jet lag, the circadian rhythms must be retrained to the new time zone and result in minimal or no side effects. Numerous research groups have explored various methods to accomplish this goal, and various scientific and anecdotal observations have been proposed. One proposal states that the adjustment to a new time zone can be effectively accomplished by behavioral interventions; meals and exercise can be altered prior to or during the course of the flight schedule (Minors and Waterhouse, 1988; Winfree, 1987; Woodruff, 1988). However, no consensus has been reached regarding the exact manner to implement these behavioral changes.

Shift lag

Shift work in industrialized countries is very common, with over 27 million people in the U.S. working a shift outside the normal day shift (U.S. Bureau of Labor Statistics, 2004). The incidence of shift work in the military reflects that of the general public. According to a survey of U.S. Army aviation units, approximately 96% of the people surveyed indicated they worked a night shift at some point in their career (Caldwell and Gilreath, 2001). Personnel commonly are rotated to a night shift so that the 24-hour period will be manned at all times. Working night shift (or reverse cycle) presents problems to personnel who must be alert in order to carry out their duties. The initial period of adjustment from days to nights is particularly a problem since work still must be accomplished, but the human body is not capable of changing its internal sleep/wake rhythms quickly. Aviators are responsible for planning missions, flying aircraft, managing flight personnel, and performing a host of other duties while on reverse cycle and are faced with completing the mission even during this adjustment time. Sleepiness and fatigue can lead to dangerous consequences for all concerned. Research indicates that the problems associated with shift work, particularly night shift, include disturbed daytime sleep, and fatigue and sleepiness on the job (Akerstedt and Gillberg, 1982; Akerstedt, 1988; Penn and Bootzin, 1990; Harma, 1995). The reasons for these problems arise from the fact that the human body is programmed to be active during the day and to sleep at night (diurnal). Difficulties occur when one attempts to change these internal rhythms.

The main reason difficulties occur when working at night is due to the body's rhythms of sleep and alertness. Trying to sleep when the body's physiological arousal levels are rising is the main problem associated with daytime sleep. Most research indicates that daytime sleep is approximately 1 to 2 hours shorter than nighttime sleep (Tilley et al., 1982). While a person coming home from the night shift may have no problems initiating sleep, maintaining this sleep as long as desired is difficult at best. Early awakenings, paired with the feeling of non-refreshing sleep, are very common with day sleepers (Akerstedt and Gillberg, 1982). This shortened sleep accumulates during the course of the night shift period, increasing performance problems at night. Studies indicate that after 1 week on night duty, the night worker is functioning at the equivalent of a day worker with 1 night of sleep loss (Tilley et al., 1982).

Trying to stay alert during the time when the body's physiological signals are readied for sleep is a second problem associated with night work. The physiological tendency to sleep at night and to be awake during the day is powerful, with most research indicating that at least a week is needed for the majority of people to change their internal rhythms (Monk, 1990). Some research indicates that even permanent night workers do not adjust completely to night shift (Czeisler et al., 1990). The circadian rhythm is dictated mainly by the light/dark cycle and includes such physiological parameters as temperature, hormone secretions, and heart rate (Minors and Waterhouse, 1990). For example, high body temperature, heart rate, and blood pressure are associated with increased alertness and performance. Decreases in temperature, blood pressure, and cortisol occur in the evening, with a rise in the morning before awakening (Minors and Waterhouse, 1990). These fluctuations in various body rhythms generally occur whether we are asleep or awake. When the body's signals indicate the need for sleep, as occurs at night, the increase in sleepiness leads to decreases in performance.

These performance decrements which occur during night work are due not only to the physiological tendency to sleep during this time in the 24-hour cycle, but also from the accumulated sleep debt which occurs over the course of nights worked. Research indicates that as the number of nights accumulate for consecutive night duties, accidents increase and productivity decreases (Knauth, 1995). A study by Vidacek and associates (1986) found an increase in performance from the first to the third night of the shift, which they interpreted as circadian adjustment, but a decrease in performance occurred by the fifth night, attributable to the accumulated sleep dept. Among strategies which are used to help alleviate some of these problems is improving daytime sleep. Many techniques are suggested which may lead to better daytime sleep (Stone and Turner, 1997).

Sleep loss countermeasures

Unfortunately the scheduling demands posed by today's Warfighter missions (ground or air) are often incompatible with basic human physiological makeup, and this is at the heart of fatigue-related problems in military operations. In aviation, the multiple flight legs, long duty hours, limited time off, early report times, less-than-optimal sleeping conditions, rotating and non-standard work shifts, and jet lag that have become so common throughout modern aviation pose significant challenges for the basic biological capabilities of pilots and crews. Humans simply were not designed to operate effectively on the pressured 24/7 schedules that often define today's flight operations, whether these consist of short-haul commercial flights, long-range transoceanic operations, or around-the-clock military missions.

In order to manage fatigue that stems from acute sleep loss/sleep debt, sustained periods of wakefulness, and circadian factors, a well-planned, science-based, fatigue-management strategy is crucial (Rosekind et al., 1996). Strategies including education, behavioral countermeasures, and pharmacological interventions all have a place in preserving the safety of flight operations in both the fixed-wing and rotary-wing environments.

Education

Education about the dangers of fatigue, the causes of sleepiness while at a designated duty station, and the importance of sleep and proper sleep hygiene is one of the keys to addressing fatigue in operational military contexts. Ultimately, the Warfighters themselves and those scheduling routes and missions must be convinced that sleep and circadian rhythms are important, and that quality off-duty sleep is the best possible protection against on-the-job fatigue. Recent studies have made it clear that as little as 1 to 2 hours of sleep restriction almost immediately degrade vigilance and performance in subsequent duty periods (VanDongen et al., 2003; Belenky et al., 2003). Thus, educational programs must continue to educate leaders and Warfighters on the following points: (1) fatigue is a physiological problem that *cannot* be overcome by motivation, training, or willpower; (2) people *cannot* reliably judge their own level of fatigue-related impairment; (3) there are wide individual differences in fatigue susceptibility that *cannot* be reliably predicted; and (4) there is *no* one-size-fits-all "magic bullet" (other than adequate sleep) that can counter fatigue for every person in every situation. Warfighters and mission schedulers should be advised that it is important to: (1) make adequate off-duty sleep a priority; (2) gain 8 hours of sleep per day either in a consolidated block, or in a series of naps, whenever possible; and (3) adhere to "good sleep habits" to optimize sleep quantity and quality (Caldwell and Caldwell, 2003).

Warfighter-rest strategies

Warfighters can employ a number of strategies to reduce sleep loss. Most of these strategies have been developed within the aviation community but can be applied analogously to ground or vehicular-mounted Warfighters.

On-board sleep

For transport or cargo fixed-wing aviation, one technique for minimizing the impact of sleep loss and continuous duty is the implementation of short out-of-cockpit sleep opportunities (known as "bunk sleeps"). These sleep periods are extremely helpful for sustaining the alertness and performance of long-haul crews. In some fixed-wing military operations, an out-of-cockpit sleep strategy can be implemented in multi-crew aircraft. For B-2 bomber missions, which sometimes last for over 30 continuous hours, one of the pilots may sleep in a cot located behind the seats during low-workload flight phases while the other pilot maintains control of the aircraft. Such on-board sleep should be considered an important aviation fatigue countermeasure for any type of long-range flight operation where an adequate crew compliment is available.

Cockpit naps

Another fixed-wing counter-fatigue strategy related to out-of-cockpit bunk sleep is the cockpit nap. When cockpit naps are implemented, one pilot actually sleeps in his/her cockpit seat (rather than moving to another part of the aircraft) while the other pilot flies the aircraft. Many international airlines now utilize cockpit napping on long flights, and cockpit napping is often authorized for U.S. military flight operations as well. A 1994 NASA study has shown that naps of up to 40 minutes in duration are both safe and effective for long-haul pilots (Rosekind, et al., 1994). However, cockpit napping obviously is not feasible in dual-pilot rotary-wing aircraft, and it is worth noting that cockpit naps are not yet approved for U.S commercial operations.

Controlled rest breaks

Tasks requiring sustained attention, such as monitoring aircraft systems and flight progress, can pose significant problems for already-fatigued personnel (Dinges and Powell, 1988). This is in part why pilots often implement some type of work break strategy (chatting, standing up, walking around, or even simply swapping flight tasks – i.e., flying versus navigating) to help sustain alertness during lengthy duty periods. There is evidence from non-aviation studies that frequent rest breaks can improve physical comfort and reduce eyestrain during prolonged, repetitious tasks (Galinsky et al., 2000). More importantly, Neri et al., (2002) found that simply offering pilots a 10-minute hourly break during a 6-hour simulated night flight significantly reduced pilot sleepiness. Although positive benefits were transient (15 to 20 minutes), they were noteworthy and particularly evident near the time of the circadian trough.

Optimum crew work-rest scheduling

Since scheduling factors are often cited as the number one contributor to Warfighter fatigue, the development and implementation of more "human centered" work routines should be considered paramount for promoting on-the-job alertness. Unfortunately, crew scheduling practices in aviation have yet to incorporate the advanced knowledge of fatigue, sleep, and circadian rhythms that has been gained over the past 20 years. Concerted efforts must be made to develop schedules that recognize 1) sleep as being essential for optimum functioning, 2) breaks as being important for preserving sustained attention, and 3) recovery periods during each work cycle as being necessary to ensure full recovery from fatiguing work conditions (Dinges et al., 1996). In addition, crew schedules should include weekly rather than monthly recovery days to ensure recuperation from cumulative fatigue/sleep debt. Furthermore, scheduling practices must take into account the facts that: (1) circadian factors influence both sleep and performance; (2) homeostatic factors (continuous wakefulness) are similarly important; and (3) under certain conditions these two factors can interact to create sudden and dangerous lapses in vigilance. Also, it must be recognized that training, professionalism, motivation, and increased monetary incentives will have little impact on the basic physiological nature of circadian and homeostatic determinants of operator alertness. Finally, it is important to note that flight crews are made up of *individuals* who are differentially affected by sleep disruptions, long duty periods, circadian rhythms, and other potentially problematic factors. Thus, "one-size-fits-all" scheduling practices are almost certainly inadequate.

Sleep-promoting compounds

Sleep is often difficult to obtain, whether due to physical location (too noisy, hot, or uncomfortable), time of day (shift lag or jet lag), or physiological factors (too much excitement, apprehension, or anxiety). When the opportunity for sleep is available but is prevented by various circumstances, the limited use of sleep aids may be an appropriate solution. The U.S. military allows the use of *temazepam*, *zolpidem*, or *zaleplon* to help sleep under some situations. These hypnotics (sleep-inducing medications) can optimize the quality of crew rest in circumstances where there is an opportunity for sleep, but the situation creates difficulty in obtaining restful sleep. The choice of which compound is best for each circumstance must take several factors into account, including time of day, half-life of the compound, length of the sleep period, and the probability of an earlier-than-expected awakening, which may risk more sleep inertia effects. In addition to possible prescription hypnotics as countermeasures, "natural" substances such as melatonin are also available to personnel. While not approved for pilots, it will be included in the overview of potential countermeasures to insomnia.

Temazepam

Temazepam (Restoril®) (15 to 30 milligram [mg]) has been recommended in military aviation populations in Great Britain since the 1980's (Nicholson et al., 1986; Nicholson, Roth, and Stone, 1985; Nicholson and Stone, 1982). Most studies are mixed in whether next-day performance is affected by nighttime administration of temazepam. Roth and associates (1979) found that 30 mg of temazepam did not affect next-day alertness or performance. These findings were supported by other research (Mattila et al., 1984; Wesnes and Warburton, 1984; 1986). Wesnes and Warburton (1986) found that daytime administration of 10 mg and 20 mg of the soft capsule temazepam did not affect nighttime performance. Porcu and associates (1997) supported these findings.

However, given the long half-life of this medication, temazepam may best be used for optimizing 8-hour sleep periods that are out-of-phase with the body's circadian cycle. Under these circumstances, sleep is often easy to initiate, but difficult to maintain due to the circadian rise in alertness. The longer half-life of temazepam is desirable because the sleep *maintenance* and not sleep *initiation* is usually the problem. In addition, the pharmacokinetic disposition of temazepam is affected by the time of administration, with a faster absorption and shorter half-life and distribution after daytime administration as compared to nighttime administration (Muller et al., 1987). Research shows that temazepam facilitates daytime sleep and in studies involving simulated night operations, has been shown to improve nighttime performance by optimizing daytime sleep (Caldwell et al., 2003; Nicholson, Stone, and Pascoe, 1980; Porcú et al., 1997).

Thus, temazepam appears to be a good choice for maximizing the restorative value of daytime sleep opportunities. However, caution should be exercised prior to using temazepam in certain operational settings since the compound does have a relatively long half-life. Although residual effects were not reported in a military study in which personnel were able to gain suitable sleep before reporting for duty (Bricknell, 1991), nor in some other situations in which 30-40 mg of temazepam were given prior to a full sleep opportunity (Roth et al., 1979; Wesnes and Warburton, 1984), residual post-dose drowsiness has been reported elsewhere. Paul et al. (2004) observed that drowsiness was noticeable within 1.25 and 4.25 hours of a midmorning 15-mg dose. They also noted that psychomotor performance was impaired within 2.25 hours post dose (plasma levels were still elevated at 7 hours post dose). These data emphasize that there is certainly a possibility of sleep inertia hangover effects from temazepam's long half-life; however, the potential for this drawback must be weighed against the potential for impairment from sleep truncation in the event that temazepam therapy is withheld. Along these lines, it should be noted that Roehrs and associates (2003) found that just 2 hours of sleep loss produces the same level of sedative effect as the consumption of 0.54 grams/kilogram (g/kg) of ethanol (the equivalent of two to three 12-ounce bottles of beer), whereas the effects of 4 hours of sleep loss are similar to those of 1.0 g/kg of ethanol (five to six 12-ounce beers).

The same qualities that make temazepam desirable for maintaining the daytime sleep of shift workers make it a good choice for temporarily augmenting the nighttime sleep of personnel who are deployed westward across as many as nine time zones (Nicholson, 1990; Stone and Turner, 1997). Upon arrival at their destination, these travelers are essentially facing the same sleep/wake problems as the night worker. Namely, they are able to fall asleep quickly since their local bedtime in the new time zone is much later than the one established by their circadian clock (from the origination time zone); however, they generally are unable to sleep through the night. Based on a readjustment rate of 1.5 days per time zone crossed (Klein et al., 1970), it could take up to a week for adjustment to the new time zone to occur. Until this adjustment is accomplished, temazepam can support adequate sleep maintenance despite conflicting circadian signals, and the obvious benefit will be less performance-degrading sleep restriction. While the problem with daytime alertness due to circadian disruptions will not be alleviated, the daytime drowsiness associated with increased homeostatic sleep pressure (from sleep restriction) will be attenuated.

Thus, temazepam is a good choice when a prolonged hypnotic effect is desired as long as there is relative certainty that the hypnotic-induced sleep period will not be unexpectedly truncated. This compound is especially useful for promoting optimal sleep in personnel suffering from premature awakenings due to shift lag or jet lag since the hypnotic effect helps to overcome circadian factors that can disrupt sleep immediately following a time zone or schedule change. However, temazepam should not be used longer than is necessary to facilitate adjustment to the new schedule. Depending on the circumstances, temazepam therapy probably should be discontinued after three to seven days either to prevent problems associated with tolerance or dependence (in the case of night workers) or because adaptation to the new time zone should be nearly complete (in the case of travelers or deployed personnel) (Nicholson, 1990). When discontinuing temazepam after several continuous days of therapy, it is recommended that the dosage be gradually reduced for two to three days prior to complete discontinuation in order to minimize the possibility of rebound insomnia (Roth and Roehrs, 1991; U.S. National Library of Medicine and the National Institutes of Health, 2004).

Zolpidem

Zolpidem (Ambien®) (5 mg to 10 mg) may be the optimal choice for sleep periods less than 8 hours. This compound is especially useful for promoting short- to moderate-length sleep durations (of 4 to 7 hours) when these shorter sleep opportunities occur at times that are not naturally conducive to sleep. Just like daytime sleep in general, daytime naps are typically difficult to maintain (Costa, 1997; Lavie, 1986; Tilley et al., 1982), especially in non-sleep-deprived individuals. Furthermore, unless the naps are placed early in the morning or shortly after noon, they can be extremely difficult to initiate without some type of pharmacological assistance (Gillberg, 1984). Zolpidem is a good choice for facilitating such naps because its relatively short half-life of 2.5 hours provides short-term sleep promotion while minimizing the possibility of post-nap hangovers. Thus, it is feasible to take advantage of a nap without significantly lengthening the post-nap time needed to ensure that any drug effects have dissipated (Caldwell and Caldwell, 1998). However, as with temazepam, there should be a reasonable degree of certainty that there will not be an early interruption of the sleep period followed by an immediate demand for performance.

The efficacy of zolpidem as a nighttime sleep promoter has been clearly demonstrated in clinical trials (with up to one year of administration) in normal, elderly, and psychiatric patient populations with insomnia (Blois, Gaillard, Attali, and Coqueline, 1993). Rebound insomnia, tolerance (treatment over 6 to 12 months), withdrawal symptoms, and drug interactions are absent, and the dependence/abuse potential is low (Bartholini, 1988). Overall, zolpidem is a clinically safe and useful hypnotic drug (Palminteri and Narbonne, 1988; Sanger et al., 1987).

Zolpidem may also be helpful for promoting the sleep of personnel who have traveled eastward across three to nine time zones (Suhner et al., 2001). Unlike westward travelers who experience sleep *maintenance* difficulties, eastward-bound personnel suffer from sleep *initiation* problems. For example, a 6-hour time zone change in the eastward direction creates difficulty with initiating sleep because a local bedtime of 2300 translates to a body clock time of only 1700, and it has been well established that such early sleep initiation is problematic (Nicholson et al., 1986; Stone and Turner, 1997; Waterhouse et al., 1997). Thus, eastward travelers need something that will facilitate early sleep onset and suitable sleep maintenance until the normal circadian-driven sleep phase takes over; however, they do not need a compound with a long half life. This is because, in this example, any residual drug effect would only exacerbate the difficulty associated with awakening at a local time of 0700 that corresponds to an origination time (or body-clock time) of only 0100 in the morning. As stated above, sleep difficulties are only part of the jet-lag syndrome, but alleviating sleep restriction or sleep disruption will help to attenuate the alertness and performance problems associated with jet lag.

Thus, zolpidem is a good compound for facilitating naps of moderate durations (4 to 7 hours), even when these naps occur under less-than-optimal circumstance or at the "wrong" circadian time. Zolpidem is also appropriate for treating sleep-onset difficulties in eastward travelers. However, as is the case with any hypnotic, this medication normally should be used only when necessary, i.e., prior to circadian adaptation to a new work or sleep schedule. More chronic zolpidem administration may be essential for promoting naps that occur under uncomfortable conditions or naps that are "out of phase" since, by definition, these generally are difficult to initiate and maintain, but zolpidem probably should not be used for more than seven days to counter insomnia from jet lag. After this time, most of the adjustment to the new time zone should be accomplished (Stone and Turner, 1997; Waterhouse et al., 1997).

Zaleplon

Zaleplon (Sonata®) (5 mg to 10 mg) may be the best choice for initiating very short naps (1 to 2 hours) during a period of otherwise sustained wakefulness. Clinical trials of the hypnotic efficacy of zaleplon have shown improvement in sleep initiation, particularly with the 20-mg dose (Chagan and Cicero, 1999; Elie, Ruther, Farr, Emilien, and Salinas, 1999; Fry et al., 2000). In people diagnosed with primary insomnia, the latency to sleep onset decreased significantly compared to placebo (Chagan and Cicero, 1999). After zaleplon exerts its initial effects, the drug is subsequently (and quickly) eliminated in time for more natural physiological mechanisms to take over and maintain the remainder of the sleep period. There is evidence that there are no hangover problems as early as 6 to 7 hours later (Chagan and Cicero, 1999). Studies indicate that next-day performance is not affected by administration of zaleplon as soon as 4 hours before awakening (Mitler, 2000). Another study concluded that 10 mg of zaleplon may be taken up to 5 hours before driving with little risk of serious impairment (Vermeeren, Danjou and O'Hanlon, 1998). Another study found that 10 mg of zaleplon administered 1.25 and 8.25 hours before testing produced no serious impairment of behavioral performance, memory, or psychomotor performance at either time period (Troy et al., 2000). Other studies have not shown any residual effects in doses as high as 20 mg. Daytime mood and anxiety were not affected when zaleplon was given at bedtime, and residual sedation was not found 5 to 6.5 hours after administration of 10 mg (Forbes and Berkahn, 1999). Paul et al. (2004) found that 10 mg zaleplon increased drowsiness for 2 to 5 hours after dosing, with plasma drug levels equal to placebo by 5 hours post-dose. These authors recommend zaleplon for times when an individual may have to awaken no earlier than 3 hours after drug ingestion. Overall, 10 mg of zaleplon does not affect performance if given at least 5 hours prior to testing.

Thus, zaleplon (10 mg) is a good hypnotic for promoting short naps (2 to 4 hours) which would otherwise be difficult to initiate and maintain. In addition, as was the case with zolpidem, zaleplon can be considered useful for the treatment of sleep-onset insomnia in eastward travelers who are experiencing mild cases of jet lag. For instance, those who have transitioned eastward only 3 to 4 time zones can use this short-acting drug to initiate and maintain what the body believes to be an early sleep period. As with any hypnotic, the course of treatment should be kept as short as is reasonably possible to minimize drug tolerance and drug dependence (Nicholson, 1990). However, a study comparing 10mg zaleplon to 10mg zolpidem found that insomniac patients preferred zolpidem over zaleplon based on sleep initiation and sleep quality (Allain et al., 2003), an important point for physician's who are trying to determine which of these compounds to use.

Melatonin

Melatonin (N-acetyl-5-methoxytryptamine) is considered a chronobiotic in humans (Armstrong, 1999; Claustrat, Kayumov and Pandi-Perumal, 2002; Dawson and Armstrong, 1996; Lewy et al., 1992; Lewy et al., 1998; Pevet et al., 2002; Sack et al., 1996; Short and Armstrong, 1984; Simpson, 1980). The term *chronobiotics* refers to a chemical substance that is capable of therapeutically re-entraining short-term dissociated or long-term desynchronized circadian rhythms, or prophylactically preventing their disruption following an environmental insult (Armstrong, 2000). Melatonin is a potent synchronizer of the locomotor activity rhythms in non-human animals (Armstrong et al., 1988) as well as in humans (Kunz and Bes, 2001). Melatonin has a direct action on the central circadian pacemaker, the suprachiasmatic nucleus (SCN), to modulate its activity and influence circadian rhythms (Reppert et al., 1988; Weaver and Reppert, 1996).

The effects of exogenous melatonin in humans are generally attributed to the ability of this neurohormone to re-entrain the underlying circadian pacemaker (Pandi-Perumal et al., 2002). Properly timed melatonin administration shifts circadian rhythms, facilitates re-entrainment to a novel light/dark (L/D) cycle and alters the metabolic activity of the SCN (Reiter, 2003). Melatonin phase shifts the endogenous rhythm of core body temperature (cBT) and its own endogenous rhythms, as well as the sleep/wake cycle (Arendt et al., 1997). The beneficial effects of melatonin in alleviating the symptoms of jet lag have been extensively explored by various investigators (Arendt, 1999; Arendt and Marks, 1982; Arendt et al., 1995; Atkinson et al., 2003; Cardinali et al., 2002; Lino et al., 1993; Oxenkrug and Requintina, 2003; Parry, 2002; Petrie et al., 1989; Skene et al., 1988; for review, Herxheimer and Petrie, 2002). While the hypnotic properties of melatonin also have been demonstrated in some studies (Cajochen, Krauchi and Wirz-Justice, 2003; Stone et al., 2000), the current school of thought on the mechanism of melatonin is not as a direct hypnotic, but as a soporific agent (Reiter, 2003). It has been postulated that melatonin induces sleepiness by opening the sleep gate and exerts a slight reduction in body temperature that promotes sleep

(Gilbert, Van Den Heuvel and Dawson, 1999; Kennaway and Wright, 2002). Thus, the therapeutic benefit of melatonin for jet lag is a consequence of increasing sleep propensity by inducing an acute suppression of cBT and through a synchronizing effect on the circadian clock mechanisms (chronobiotic effect) (Arendt et al., 1995; 1997; Cardinali et al., 2002). The direction in which melatonin phase-shifts the circadian clock depends on its time of administration (Lewy et al., 1992; Reiter, 2003).

Since melatonin is considered a dietary supplement (nutraceutical), it is not regulated by the FDA as a drug in the U.S. However, the consumption of melatonin is high and caution should be observed in the uncontrolled use of melatonin. Its effects during pregnancy, potential interactions with other pharmaceuticals, long-term usage, purity of the chemical preparation, toxicity and many other considerations remain to be addressed (Arendt and Deacon, 1997; Guardiola-Lemaitre, 1997).

General precautions for hypnotic therapy

Sleep promoting compounds can be useful for promoting sleep in operational contexts where there are problems with sleep initiation or sleep maintenance. However, it should be noted that, like all medications, there are both benefits and risks associated with the use of these compounds. These should be considered by the prescribing flight surgeon, the aviation safety officer, and the individual pilot before the decision to utilize hypnotic therapy is finalized (U.S. military pilots are never *required* to use hypnotics of any type). A hypnotic of any type should not be used if a person is on-call and may be awakened for immediate duty at any time. Although temazepam, zolpidem, and zaleplon are widely recognized as being both safe and effective, personnel should be cautioned about potential side effects and instructed to bring these to the attention of the unit flight surgeon. Potential problems may include morning hangover which may cause detrimental effects on performance, dizziness and amnesia that may be associated with awakenings that are forced before the drug has been eliminated, and various idiosyncratic effects (Balter and Uhlenhuth, 1992; Menkes, 2000; Nicholson, 1990; Roth and Roehrs, 1991). If any difficulties occur, it may be necessary to discontinue the specific compound or to abandon hypnotic therapy altogether. However, it is likely that significant side effects can be reduced or eliminated by using an alternate compound or by modifying dosages or dose intervals (Nicholson, 1990). For these reasons, military personnel are required to experience a test dose of the hypnotic of interest under medical supervision before using the medication during operational situations. Even after the test dose yields favorable results and it is clear that operationally-important side effects are absent, hypnotics should be used with particular caution when the aim is to aid in advancing or delaying circadian rhythms in response to time-zone shifts (Nicholson, 1990; Stone and Turner, 1997; Waterhouse et al., 1997). Reviews by Waterhouse and associates (1997), Nicholson (1990), and Stone and Turner (1997) offer detailed information on this rather complex issue. While melatonin is available over the counter, it is not authorized for use in military pilots.

Alertness-enhancing compounds

For those situations in which, despite everyone's best intentions, adequate sleep opportunities are simply nonexistent, stimulants (or alertness-enhancing drugs) will help to stave off the deleterious effects of fatigue (prescription stimulants are an option only for military pilots). Unavoidable manpower constraints, hostile environmental circumstances, extremely high workloads, and unexpected enemy attacks all may require a postponement of sleep until a break in the operational tempo permits rest and recuperation. Although stimulants should not be viewed as a substitute for proper staffing or adequate work/rest cycles, they can be life saving in circumstances in which sleep deprivation is unavoidable (Cornum, Caldwell and Cornum, 1997). Stimulants are effective and easy to use, and because their feasibility is not dependent upon environmental manipulations or scheduling modifications, their usefulness, especially for short-term applications, can be significant (Caldwell and Caldwell, 2005). Caffeine, modafinil, and dextroamphetamine are approved for certain aviation operations by the

U.S. Air Force, and both caffeine and dextroamphetamine are approved for limited use by the U.S. Army and Navy.[6]

Caffeine

Caffeine is a good choice for situations where medical oversight is limited or not available. This is because caffeine is not a controlled substance, and prescriptions are not required. Also, since caffeine is already in widespread use and is generally viewed as quite safe, there is little concern that there will be adverse physiological consequences associated with its ingestion. Caffeine is available in a number of forms (i.e., tablets, candy, gum, food, and beverages). An 8-ounce cup of drip-brewed coffee contains an average of 135 mg of caffeine, an 8-ounce cup of brewed tea contains approximately 50 mg of caffeine, and a 12-ounce cola drink contains an average of 44 mg caffeine, ranging from 23 to 58 mg, depending on the drink. An 8-ounce cup of Starbucks™ contains 250 mg of caffeine (Center for Science in the Public Interest, 1996).

Although caffeine can produce some minor side effects (Committee on Military Nutrition Research, 2002; Serafin, 1996), in general, these are inconsequential in comparison to the improvements in reaction time and cognitive performance, the improved mood, and the reduction of sleepiness in fatigued subjects (Bonnet et al., 1995; Committee on Military Nutrition Research, 2002; Lieberman et al., 1987; Wyatt et al., 2004). Militarily-focused studies at the Walter Reed Army Institute of Research (WRAIR) (Silver Spring, MD) have shown that 600 mg single-dose caffeine is beneficial for sustaining the performance and alertness of sleep-deprived personnel kept awake for over 50 continuous hours (Wesensten et al., 2002). Other researchers have found that 150 mg to 300 mg bolus doses of caffeine are sufficient to increase performance over placebo when the sleep deprivation period is short, for example less than 24 hours (Penetar et al., 1993).

Despite these and other positive findings, wholesale dependence on caffeine to mitigate the effects of sleep deprivation in the military operational aviation environment is controversial since the effects of tolerance have not been adequately studied (Wyatt et al., 2004). Over 80% of adults in the U.S. daily consume behaviorally active doses of caffeine (Griffiths and Mumford, 1995), and it is possible that acute caffeine administration in operational contexts may not effectively alert severely fatigued individuals. Nonetheless, caffeine should be considered a “first line” approach to pharmacologically-based alertness enhancement because caffeine has been shown to exert a number of positive effects. No medical oversight of caffeine use is required as long as the caffeine comes in the form of coffee, soft drinks, chocolate, or other standard foods and beverages.

Modafinil

Although modafinil (Provigil®) (100-200 mg) is a relatively new alertness-enhancing substance, there is substantial evidence that it is useful for sustaining performance during continuous or sustained military operations (Lagarde and Batejat, 1995). These authors found that the drug reduced episodes of microsleeps and attenuated decrements in reaction time, math, memory-search, spatial-processing, grammatical-reasoning, letter-memory, and tracking tasks. Wesensten et al. (2004; 2002) found 200 mg to 400 mg modafinil to be effective for restoring the performance and alertness of sleep-deprived non-pilots in a typical research setting, however, it was concluded that neither modafinil nor dextroamphetamine (20 mg) offered greater efficacy than a 600-mg dose of caffeine.[7] In active-duty military pilots, Caldwell et al., (2000a) found that 200 mg of modafinil every 4 hours

[6] Note that such approvals are generally “Service-wide” rather than location specific. For instance, U.S. Air Force policy authorizes the use of modafinil for dual-seat bomber missions longer than 12 hours in duration, and authorizes dextroamphetamine on a wider basis for similar circumstances. Although individual units or bases can choose not to utilize these compounds, they are not permitted to authorize the use of medications that have not been officially sanctioned by the U.S. Air Force, Army, or Navy without obtaining a waiver from higher headquarters.

[7] Note that high-dose caffeine should be used judiciously in pilots because adverse reactions such as nausea and vomiting sometimes occur.

maintained flight performance and basic cognition at near-well-rested levels despite 40 hours of continuous wakefulness. However, there were reports of nausea and vertigo that were attributed to the large cumulative dose (600 mg within a 24-hour period). A more recent study with U.S. Air Force F-117 pilots indicated that 100-mg doses of modafinil administered every 5 hours sustained flight control accuracy to within 27% of baseline levels, whereas performance under the no-treatment condition degraded by over 82% during the latter part of a 37-hour period of continuous wakefulness (Caldwell et al., 2004). Similar beneficial effects were seen on measures of alertness and cognitive performance. Furthermore, the lower dose (in comparison to those used in the Caldwell et al., 2000 study) produced these positive effects without causing the side effects noted in the earlier study.

The frequency of adverse side effects with modafinil is low, drug tolerance seems nonexistent even after weeks of continuous use, and the abuse liability is limited (Cephalon, 1998). As a result, modafinil is easier to dispense compared to dextroamphetamine which will be discussed shortly. Another advantage of modafinil is that it appears to have a relatively small adverse effect on recovery sleep even when given fairly close to the time of sleep onset (Buguet et al., 1995). Thus, modafinil may be an optimal choice for use in sustained military operations in which there is a moderate possibility that a short break in the operational tempo could provide an unexpected sleep opportunity. Initial concerns that modafinil caused overconfidence in sleep-deprived people (Baranski and Pigeau, 1997) have not been substantiated by more recent research (Baranski et al., 2002). Nonetheless, modafinil has not been as widely assessed as caffeine and amphetamine in normal, sleep-deprived people engaged in real-world tasks (Akerstedt and Ficca, 1997); work with clinical populations suggests that modafinil is less effective than amphetamine (Mitler and Aldrich, 2000); and some believe that there is insufficient information available concerning modafinil's long-term safety and efficacy (Banerjee, Bitiello and Grustein, 2004). However, for short-term fatigue management, modafinil should be considered a possible option because of its alertness-enhancing capacity and its favorable side-effect profile. Future military policies may make modafinil more widely available in the aviation setting, but pilots will first need to "pass" a ground test for adverse effects and sign an informed consent agreement for using modafinil for an "off label" indication (i.e., none of the prescription alertness-enhancers have been explicitly approved for keeping sleep-deprived but otherwise normal people awake).

Amphetamine

The effects of dextroamphetamine (Dexedrine®, 5 mg to 20 mg) have been well-researched. In comparison to caffeine, amphetamine appears to offer a more consistent and prolonged alerting effect (Mitler and Aldrich, 2000; Weiss and Laties, 1962), and in comparison to modafinil, some reports suggest it is more efficacious (Lagarde and Betejat, 1995; Mitler and Aldrich, 2000). However, there is some disagreement on this point as three other reports have suggested that dextroamphetamine is equivalent to modafinil for sustaining the performance of sleep-deprived normal individuals in sleep-deprivation periods of up to 40 hours (Caldwell, 2001; Pigeau et al., 1995; Wesensten et al., 2004). Real-world operational comparisons of dextroamphetamine to caffeine or modafinil are currently nonexistent due to the difficulties of conducting such studies under warfare conditions. Consequently, simulator-based studies continue to be the best alternative and are still ongoing (e.g., Estrada et al., 2008)

Although dextroamphetamine can produce side effects such as palpitations, tachycardia, elevated blood pressure, restlessness, euphoria, and dryness of mouth (Physician's Desk Reference, 2009), the properly-controlled administration of this compound remains a viable strategy for the sustainment of combat performance in select military aviation operations where sleep is difficult or impossible to obtain. The U.S. Navy's guide for Flight Surgeon's and the U.S. Army's guide for leaders both discuss policy-based guidance for the use of dextroamphetamine in sustained and continuous flight operations (U.S. Army Aeromedical Research Laboratory, 1996; U.S. Navy Aerospace Medical Research Laboratory, 2001), and the U.S. Air Force has authorized the use of dextroamphetamine in certain types of lengthy (i.e., 12 or more hours) bomber and fighter flight missions.

In a study conducted at the Walter Reed Army Institute of Research (Newhouse et al., 1989) a 20-mg dose of dextramphetamine produced marked improvements in mathematical ability, a gradual improvement in logical-reasoning, better performance on choice reaction-time, and an increase in alertness in non-pilots who were sleep deprived for 48 hours. A 10-mg dose produced similar effects, but they were fewer and shorter in duration. In two studies conducted on pilots at the Army's Aeromedical Research Laboratory (Caldwell, Caldwell and Crowley, 1997; Caldwell et al., 1995), repeated 10-mg doses of dextroamphetamine maintained flight performance, an array of cognitive skills, and alertness indicators close to well-rested levels despite 40 hours of continuous wakefulness. These results were later confirmed in an in-flight study with 40 hours of sleep loss (Caldwell and Caldwell, 1997) and in a follow-on simulator study in which the sleep-deprivation period was extended to 64 hours (Caldwell et al., 2000b). Data from actual field environments have further established amphetamine's capacity for reducing the impact of fatigue (McKenzie and Elliot, 1965; Tyler, 1947; Winfield, 1941), and there are reports of beneficial amphetamine effects in combat situations such as Viet Nam (Cornum, Caldwell and Cornum, 1997), the 1986 Air Force strike on Libya (Senechal, 1988), Operation Desert Shield/Storm (Cornum, Cornum and Storm, 1995; Emonson and Vanderbeek, 1995), and Operation Iraqi Freedom (Kenagy et al., 2004). To date, no major side effects or other problems have been reported from the medical use of dextroamphetamine in several military settings (referenced above), and concerns about "judgment impairments" are to some extent negated by reports that amphetamine decreasing risk-taking behavior and the sleep-loss-induced liberal response bias often seen on cognitive tests in sleep-deprived subjects (Newhouse, et al., 1989; Shappel, Neri and DeJohn, 1992) without impairing the ability of such subjects to self-evaluate their own performance (Baranski and Pigeau, 1997).

Thus, dextroamphetamine is a viable counter-fatigue medication useful for military aviation missions in which significant fatigue is a risk factor; however, amphetamine should only be used under proper medical supervision since this medication possesses significant abuse potential. As with modafinil, the use of dextroamphetamine to counter the effects of fatigue in healthy individuals requires an informed-consent agreement for off-label use as well as a suitable ground test to rule out idiosyncratic reactions.

Summary: Physiological stress

Fatigue (the most uncontrollable physiological stressor) is a known risk factor in the operational environment, and it warrants treatment with scientifically-validated fatigue countermeasures. Since a large percentage of operator fatigue stems from insufficient sleep, the best countermeasure would be to avoid sleep deprivation by: (1) ensuring adequate manpower levels to properly staff all work periods; (2) consider scheduling of naps or taking advantage of opportunities for naps; and (3) establishing work/rest schedules that enable personnel to gain sufficient restorative sleep in their off-duty hours. However, if real-world demands disrupt or prevent sleep, and behavioral or administrative counter-fatigue strategies are found to be insufficient or impractical, pharmacological adjuncts can help to safely sustain alertness.

In the event that sleep opportunities are available but compromised due to operational factors that prevent the onset and maintenance of restful sleep, the hypnotics temazepam, zolpidem, and zaleplon should be considered. Temazepam is best for maintaining sleep for relatively long periods during the night or for optimizing daytime sleep, while zolpidem and zaleplon are better for promoting an earlier-than-usual sleep onset or for inducing and maintaining short naps. Also, as discussed earlier, these compounds can help to minimize sleep disruptions associated with circadian factors (jet lag and shift lag). In this regard, the choice of compound depends on when the new sleep opportunity is offered and the probability that the sleep period will be unexpectedly truncated. An effort should be made to balance the need to improve sleep with the need to avoid residual effects, taking into account the effects of sleep restriction versus any residual effects which may occur from medication-induced sleep.

The duration of prescription sleep medication therapy should be kept as short as possible, usually for only a few days, to help with jet lag symptoms, or intermittently to help with shift lag symptoms. While the modern hypnotics are much safer and shorter acting than the hypnotics of years past, caution is still needed with prolonged use of any hypnotic. Continued use of hypnotics for several weeks or months may lead to tolerance or dependence, but the extent of these problems remains an issue of debate (Menkes, 2000; Roth and Roehrs, 1991). In addition, sudden withdrawal after several weeks of therapy may lead to rebound insomnia (Menkes, 2000; Nicholson, 1990).

When considering the use of medications for aid in operational contexts, the following points should be kept in mind: (1) drugs are not a substitute for good work/rest scheduling; (2) sleep-promoting and alertness-enhancing compounds should not be administered to personnel indiscriminately or in the absence of proper medical oversight; and (3) with regard to situations devoid of sleep opportunities, there has not been a drug of any description that has been found capable of indefinitely postponing the basic physiological need for 8 hours of restful daily sleep. However, clearly there are circumstances that warrant the operational use of pharmacological fatigue countermeasures, and in these situations, properly-administered, appropriately-supervised medication therapies can enhance both the safety and effectiveness of military aviation personnel.

It is well known that sleep deprivation affects performance, whether the deprivation is due to long work hours or to shortened sleep length due to changes in work schedule or time zone. A pilot’s task in flying the aircraft requires divided attention and vigilance, both of which are affected by long work hours and lack of adequate rest. When the pilot requires the aid of an HMD while flying the aircraft, additional complexity is added to the task, thereby potentially lowering performance even further (Brown, 2004). Therefore, risk of in flight performance errors increase with the combination of sleep deprivation and wearing HMDs, and the pilot and crew should be aware of this increased risk. Countermeasures to decrease the impact of sleepiness on performance will be useful when HMDs or any other complicating factors are added to the equation, however, there is no research to indicate which countermeasures will address the added risk of flying with HMDs specifically. Thus, a pilot’s best strategy will be to recognize the potential for fatigue-related dangers and take general steps to ensure optimal alertness given the circumstances of the mission.

Self-Imposed (Internal) Stressors

Use of approved over-the-counter and prescription medications

Warfighters, as a subsection of the general population, are overall in better physical condition than the general public. This is a consequence of fairly stringent medical selection criteria that all prospective Soldiers are required to meet prior to induction in an all volunteer force as well as mandatory physical training and a strongly encouraged regimen of extramural exercise and recreational sports. However, even when battlespace-related injuries are discounted, Warfighters, like all civilians, face disease and other physical maladies. Consequently, Warfighters can be expected to need both prescription and OTC medications. In addition, as with their civilian counterparts, Warfighters will use other legal substances believed to be health or performance enhancers.

Approved medications

The effects and concerns of medication use (both prescription and OTC) on human operational performance are important for the Warfighter. This is also true in the HMD environment. Although the entire Warfighter community currently has access to HMD technology and often employs it, the aviation community certainly has the most experience. Consequently, the Aerospace Medicine community (i.e., Flight Surgeons) has a greater depth of knowledge and experience on the effects that medications may have in both the general flight environment and the HMD flight environment than do the corresponding ground-based Surgeons. All branches of the military services have published specific guidance for Flight Surgeons regarding the use of medications in the flight environment. However, and of note, our ground-based counterparts do not have any in-depth nor published guidance documents that indicate when a Warfighter placed on specific medications should be restricted from various occupational activities – to include the use of HMDs – but instead mainly rely on past experience and the art of medicine. It should be noted that in the current Middle Eastern theater of operations, the Army has stated that approximately 12% of the combat forces in Iraq and 17% in Afghanistan are taking prescription antidepressants and or "sleeping pills" in order to cope with harsh operational demands – both of which would adversely affect not only physical performance but also to a greater extent the individual Warfighter's performance with HMDs (Thompson, 2008). Although the vast majority of the discussion that follows will be Aviation Medicine-centric, most is applicable to ground HMD use for all of the Warfighter force.

The use of medications by the Warfighter in any situation is of concern because these products contain a number of chemical compounds that may have negative physical performance effects and neurological (cognitive, perceptual and sensory) effects on the human body. Additionally, an underlying condition also may significantly affect these parameters. For the HMD user (both aviators and ground forces), this fact must be further emphasized due to the very unique perceptual environment that an HMD presents to the user and the often complex cognitive processes that our Warfighters must use to interpret what is being presented to them on the HMD as compared to what their actual four-dimensional (4-D) environment is. The ability to know where you are in an operationally harsh and complex battlespace is paramount to individual Warfighter survival and mission accomplishment.

Whenever an aircrew member presents with a medical condition requiring an OTC or a prescription medication, a Flight Surgeon must evaluate the condition and the proposed course of drug therapy to determine if that aircrew member can continue to fly. In the U.S. Department of Defense (DOD), all three services have different regulations and guidance regarding the treatment of aircrews, what medications they can take, which ones are waiverable for flight, and what processes they must go through to return to the crew member to aviation duty. In general, any medication "grounds" an aircrew member, even if it is a waiverable medication. An aircrew member on a waiverable drug is usually returned to flight status only after an observation period. Drugs for aircrew members must be prescribed by, or with the knowledge of, a Flight Surgeon. Almost any medication can impair a person's ability to fly an aircraft but, more importantly, the condition being treated is often more of a factor in "grounding" a pilot or aircrew member than the drug itself. For example, amoxicillin is a relatively benign drug used commonly for otitis media (middle ear infection). The drug is quite safe, but the middle ear infection may impair the ability to fly. The pilot can fly when the condition resolves, even though he or she may have several more days to complete the course of antibiotics. Conversely, many conditions are fairly benign, but the medications required for treatment can significantly impair cognition, judgment or the sensorium such that safe flight or the optimal use of HMDs would be severely and negatively affected.

As to each individual service, the Army has AR 40-501 (Department of the Army, 2008) that determines medical standards of fitness and AR 40-8, *Temporary Flying Restrictions Due to Exogenous Factors Affecting Aircrew Efficiency* (Department of the Army, 2007). They also have published numerous Aeromedical Policy Letters (APLs) that address medication waivers (Department of the Army, 2006). The medication policy letters break medications down into 5 classes: (1) OTC medications; (2) no waiver action required or information only; (3) chronic use; (4) chronic use requiring waiver; and (5) mandatory disqualifying medications. All of these APLS are web accessible (Department of the Army, 2006).

The Air Force has Air Force Instruction 48-123 which covers use of medications in Air Force aircrew members (Department of the Air Force, 2006). This extensive instruction governs medications, medical conditions, medical standards, etc. affecting aircrew members as well as special duty operators, missile crews, ground controllers, and so forth. Medications may be: (1) approved for use without medical consultation; (2) approved for use by a flight surgeon without removal from flying duty; (3) require a waiver (specifies level of the command structure that waiver must come from), or 4) not waiverable. Medications listed as not waiverable may be approved or granted a waiver after physiological testing at the U.S. Air Force School of Aerospace Medicine, Brooks AFB, Ohio. They also have a waiver guide similar to the Army APLs and again these are internet accessible (U.S. Air Force School of Aerospace Medicine, 2008).

The U.S. Navy has Navy Instruction 3710 (NATOPS General Flight and Operating Instructions) (Department of the Navy, 2001), which includes information governing Navy aircrew members that is similar to AR 40-8 and AR 40-501. Also available on the web is the Naval Operational Medicine Institute (NOMI) guidance regarding medical conditions and medications in Navy aviators (Naval Aerospace Medical Institute, 2007a; 2007b). The guidance and list of waiverable medications is a bit longer than the Army's list. As a final consideration for our civilian aviation HMD users, the Federal Aviation Administration (FAA) also provides some guidance on medical conditions and medication use which is again web available (FAA, 2008).

In treating an aviator, the Flight Surgeon's view regarding medication use is that any aircrew member should be evaluated for restriction from flying duties when initiating any medication and also be advised of potential side effects. Additionally when we place an individual on a medication, we consider: (1) Is the medication compatible with flight duty and, more importantly, is the underlying medical condition compatible with flight duty; (2) is the medication effective and essential to treatment; and (3) is the individual free of aeromedically significant side effects after a reasonable observation period. Since medication side effects are very hard to predict and they occur with irregularity and often differently in any given individual, Flight Surgeons are quite cautious in prescribing patterns. They are especially cautious prescribing medications whose side effects relate to central nervous, cardiac, ophthalmologic, and labyrinthine systems. Finally they also consider the unique environmental considerations present in the aviation environment, i.e., G-forces, hypoxia, pressure changes, noise, heat, cold, acute and chronic fatigue; and how these effect the medication or the underlying medical condition. Since flight surgeons determine suitability for flight duty, they are inherently determining suitability for HMD use (Batchelor, 2006; Orford and Silberman, 2008).

For example, in prescribing practices, U.S. Army flight surgeons rely on the guidance provided by the Commander, U.S. Army Aeromedical Center, Fort Rucker, AL, who has reviewed and classified a wide range of medications for use in the aviation environment. Medications are designated Class 1, 2A, 2B, 3 and 4. Medications not discussed in the APL are currently incompatible with the aviation environment or little information of its safe use in the aviation environment exists. New medications are reviewed constantly and waiver requests are considered on a case-by-case basis but often take a great deal of time to process (Department of the Army, 2006). The following is a brief discussion of the Army model of medication classification for aviation; however the other services do a similar system of classification.

- **Class 1 Medications:** These are OTC medications that may be used without a waiver. Occasional and infrequent use of these OTCs does not pose a risk to aviation safety nor does it violate the intent of AR 40-8. Generally OTCs are approved for acute non-disqualifying conditions and do not require a waiver. They may be used in accordance with standard prescribing practices. Note however, that OTC medications are frequently combination medications, with one or more components contra-indicated for safety of flight. Many OTC medications do not provide a listing of ingredients on the package and often give quite sketchy information on side effects. Also of note is that aircrew members require constant alertness requiring full use of all senses and reasoning powers. Many OTC medications as well as most prescribed medications cause sedation, blurred vision, disruptions of vestibular function, etc. Often the condition for which the medication is used is mild; however, it can produce very subtle effects which may also be detrimental in both the flight and the HMD environment. Just as with the subtle deterioration of cognitive ability that occurs with hypoxia and alcohol intoxication, medication effects may not be appreciated by the individual taking the medicine. These effects may have disastrous results in situations requiring full alertness and rapid reflexes. Of a final note is that all OTCs should only be used infrequently and for short periods of time. The list of approved army OTCs is found in Table 16-3 (Since medications are constantly being reviewed, the reader is directed to refer to the APLs for all other classes of medications on the web) (Department of the Army, 2006).

Table 16-3.
Class 1 Medications
(Department of the Army, 2006)

Type	Comments
Antacids	Tums, Rolaids, Mylanta, Maalox, Gaviscon, etc.®
Antihistamines	Loratidine - Short term use by individual aircrew is authorized but the aircrew member must report use of this medication to the Flight Surgeon as soon as possible. The Flight Surgeon must also be concerned not only with the use of this medication but also the underlying problem that the individual is self- treating (e.g. allergic rhinitis) and the aeromedical implications of the diagnosis.
Artificial Tears	Saline or other lubricating solution only. Visine or other vasoconstrictor agents are prohibited for aviation duty.
Aspirin/Acetaminophen	When used infrequently or in low dosage.
Cough Syrup/ Cough Lozenges:	Many OTC cough syrups contain sedating alcohol, antihistamines or Dextromethorphan (DM) and are prohibited for aviation duty.
Decongestant	Pseudoephedrine - When used for mild nasal congestion in the presence of normal ventilation of the sinuses, and middle ears (normal valsalva).
Pepto Bismol	If used for minor diarrhea conditions and free of side effects for 24 hours.
Multiple Vitamins	When used in normal supplemental doses. Mega-dose prescriptions or individual vitamin preparations are prohibited.
Nasal Sprays	Saline nasal sprays are acceptable without restriction. Phenylephrine HCL may be used for a maximum of 3 days. Long-acting nasal sprays (oxymetazoline) are restricted to no more than 3 days. Recurrent need for nasal sprays must be evaluated by the flight surgeon. Use requires the aircrew member to be free of side effects.
Psyllium Mucilloid	When used to treat occasional constipation or as a fiber source for dietary reasons. Long term use (over 1 week) must be coordinated with the flight surgeon due to possible side effects such as esophageal/bowel obstructions.
Throat Lozenges	Acceptable provided the lozenge contains no prohibited medication. Benzocaine (or similar analgesic) containing throat spray or lozenge is acceptable. Long term use (more than 3 days) must be approved by the local flight surgeon.

- **Class 2A medications:** These are medications which are available by prescription only, have proven to be quite safe in the aviation environment. These medications, when dispensed and their usage monitored by Flight Surgeons, have been quite effective in returning aviators more rapidly to their respective flying positions. While generally safe, one still must take into consideration the underlying medical condition and the ever present possibility of side effects. Note that occasionally the underlying health condition dictating the need for the medication may require a waiver; and if the medication is required on a frequent or maintenance basis, a waiver may also be needed (Department of the Army, 2006).
- **Class 2B medications:** This classification of drugs requires a prescription and must be used under the supervision of the flight surgeon. Unlike Class 2A, they are often employed for chronic long term use and more likely to be used for underlying medical conditions which require a waiver. They also have greater potential for side effects, so all must have a period of observation of at least 24 hours (Department of the Army, 2006).
- **Class 3 medications:** These medications are generally given for treatment of underlying conditions which require a waiver, may have significant side effects, or require significant evaluations as follow-up for safe use. Specific requirements are given under each drug or drug category listed below. Other

requirements as dictated by the underlying medical condition also may be added at the discretion of the Consultant, Aeromedical Activity (Department of the Army, 2006).

- **Class 4 medications:** These medications are strictly contraindicated in the aviation environment due to significant side effects. The underlying cause or need for use of these medications may result in a permanent disqualification or require a waiver for return to flying duty. Generally, a period of continuous grounding is mandatory from the initiation of therapy through cessation of these drugs plus a specified time period to rid the drug completely from the body (usually at least three half lives). Continuous use of these medications is incompatible with continuation of aviation status (Department of the Army, 2006).

In conclusion, the use of medications by the Warfighter is of great concern, first because the underlying condition may significantly affect cognitive, sensory and physical performance and second because of the multiple influences that medications have on these performance parameters. Again, it cannot be overemphasized that for the HMD user who has a unique view of his environment and the 4-D battlespace surrounding him, any decrement in his ability to interpret where he is in an operationally harsh combat scenario is critical to his survival and mission accomplishment.

Dietary supplements

In both Western and Eastern cultures, before the advent of modern pharmacology, individuals relied on naturally occurring substances (e.g., plants, minerals and animal parts) as healing agents. While some of these substances are the basis of many modern drugs, sometimes the cure was worse than the ailment.

2000 B.C.	“Here, eat this root.”
A.D. 1000	“That root is heathen. Here, say this prayer.”
A.D. 1850	“That prayer is superstition. Here, Drink this potion.”
A.D. 1940	“That potion is snake oil. Here, swallow this pill.”
A.D. 1985	“That pill is ineffective. Here, take this antibiotic.”
A.D. 2000	“That antibiotic doesn't work. Here, eat this root.”

-- *Anonymous*

In between are a host of substances that have developed a wide following along side modern drugs as remedies and as dietary *supplements* that are believed to promote health or enhance performance.

As with the use of prescription and OTC medications, the effects and concerns of the use of dietary supplements on Warfighter physical, cognitive and perceptual performance in the HMD environment is another important issue. Dietary supplements include vitamins, minerals, proteins, botanicals/herbs, amino acids, metabolites (including ergogenics) and extracts. In a recent survey, it was noted that the annual sales of dietary supplements in the United States was approaching $16 billion. Additionally, on average, 1,000 new products are developed each year. Although manufacturers are restricted from claiming that using their products leads to therapeutic benefits, surveys show that many people take supplements for purposes such as treating colds or alleviating depression. Surprisingly, the majority of consumers don’t believe these products are definitely safe nor work as promised, but still continue to use them (Institute of Medicine, 2004).

Unlike prescription medications, which are highly regulated by the FDA, dietary supplements are regulated under the auspices of the Dietary Supplement Health and Education Act (DSHEA). This act was passed in 1994 and states that dietary supplements are to be regulated like foods instead of drugs, meaning that they are considered safe unless proven otherwise and are not required to be clinically tested before they reach the market. It is up to the U.S. Food and Drug Administration (FDA) to determine whether a particular substance on the market is harmful, based upon information available in the public domain. Thus, it is fairly obvious that the use of dietary supplements is largely unregulated in both the U.S. military and civilian populations (De Smet, 2002; U.S. Congress, 1994). Many dietary supplements are ineffective, and some have been found to be dangerous (Gardner et al., 2007; Lonn, 2003; Noonan and Noonan, 2006; Solomon et al., 2003; U.S. Federal Register, 2004). To illustrate, Table 16-4 shows a few of the more commonly consumed dietary supplements and their purported benefits contrasted with many of their reported problems. In addition, Table 16-5 provides a list of supplements classed with regard to their well-documented side/toxic effects. Both Tables were compiled from information available in the Physician's Desk Reference (PDR) for Herbal Medicines (PDRHealth, 2007). Finally, due consideration must be given to the fact that some dietary supplements interact with prescribed medications (Scott and Elmer, 2002; Wilson et al., 2006).

As a large organization with a focus on health protection and readiness, the DOD is dedicated to maintaining the health and well-being of the armed forces; these responsibilities include policy development and education regarding dietary supplements. Additionally, the military has the responsibility to train and maintain its members at an optimal readiness posture as well as a mission performance standard. As such, DOD has the responsibility of guiding its service members to make appropriate decisions that best enhances their health, including nutrition.

Unfortunately, as with all sectors of the U.S. population, the use of dietary supplements to promote health has become increasingly popular among members of the military. The prevalence of use among service members has been well documented in a number of reports. For example, in one study, a dietary supplement survey was administered to 2,215 males (mean age, 25 years; range, 18 to 47 years) entering U.S. Army Special Forces and Ranger training schools. Eighty-five percent of the men reported past or present use of a supplement, 64% reported current use, and 35% reported daily use (Arsenault and Kennedy, 1999). In another study, a U.S. Army Special Forces unit was studied to determine characteristics of supplement users and found that most Warfighters (87%) reported current supplement use (Bovill, Tharion and Lieberman, 2003).

Supplements available to service members range from those that might impart beneficial effects to health and performance with negligible side effects to others that have uncertain benefits and might be potentially harmful to health and performance. Furthermore, the military, cognizant of the potential benefits of dietary supplements, is conducting research on some promising supplements. However, there are no service wide military policies (e.g., education or regulations) to guide commanders in management practices for safe use of dietary supplements. With this in mind, the Committee on Military Nutrition Research (CMNR) convened an add hoc working group – the Committee on Dietary Supplement Use by Military Personnel to assist in the assessment of the effects that dietary supplements, whether beneficial or detrimental, might have on different military service members and for some subpopulations facing heightened risks (e.g., Special Forces, Rangers, aviators). They were also asked to review the patterns of dietary supplement use among military personnel (Tables 16-6 and 16-7) (Lieberman, 2008), to recommend a framework to identify the need for active management of dietary supplement use by military personnel, and to develop a systematic approach to monitor adverse health effects. The committee was further tasked with selecting a subset of dietary supplements and, by examining published reviews of the scientific evidence, identifying those that are beneficial or warrant concern. This group has recently published an extensive guide regarding their initial findings of the use of supplements by the military along with the requirements for continued monitoring and research (Institute of Medicine, *in press*).

As with our earlier discussion of medications, the use of dietary supplements by the Warfighter in any situation is of concern because these products contain substances that may have a variety of effects that are not adequately documented. With the HMD user (both aviators and ground forces), this fact must be emphasized due to the very unique perceptual environment that an HMD presents to the user and the complex cognitive processes that Warfighters must use to interpret what is being presented on the HMD as compared to what actual 4-D environment. Undoubtedly, some dietary supplements have clear benefits, some have uncertain benefits, and

Table 16-4.
Common Supplements: Issues and Problems
(PDRHealth, 2007)

Supplement	Purported Benefits	Reported Problems/Issues
Echinacea	Purported benefit is stimulation of cellular immune system Commonly used for fevers, colds, bronchitis and "tendency towards infection"	Long term use not recommended due to unknown effect on immune system with chronic use Not for use in immune system/autoimmune diseases (Multiple Sclerosis, RA, Lupus, etc) or in those with documented allergies to plants in the *Asteraceae/Compositae* family (ragweed, chrysanthemums, marigolds, and daises).
Saw Palmetto	Used primarily as treatment for Benign Prostatic Hypertrophy (BPH). Fairly good evidence that it relieves symptoms in mild BPH (decreased nocturia, hesitancy, post-void dribbling and improved stream).	No change in objective parameters such as prostate size or PSA levels. May cause Gastro- intestinal upset similar to the side effects of radiation therapy.
Creatine	Used as body building supple-ment. Research is conflicting, and there are mixed results in literature. May have mild benefit for less conditioned weight lifters.	No documented benefit in endurance activities. Weight gain of 1to 3 Kg. Questionable true muscle growth – since discontinuation results in loss of weight and muscle size. Heavy use may lead to cramps, nausea, diarrhea, dehydration. Risks of long term use unknown. A decrease in endogenous creatine production has been noted. Case reports of heat casualties with use.
Ephedra	Stimulant found in <u>many</u> body building/weight loss supplements that are advertised to improve endurance.	Reported deaths/disabilities in healthy, young individuals due to use. Possibility exists for sudden incapacitation due to stroke, and heart attack. Banned by the FDA.
DHEA and Androstenedione	Precursor of androgens (testosterone) and estrogen. The so called "Fountain of Youth". Believed effects are anabolic secondary to steroid conversion and possible osteoblast stimulation as well as promotion of protein anabolism.	Banned by NCAA, NFL, IOC. Side effects like anabolic steroids. Many effects are reversible after discontinuation. However, <u>irreversible</u> virilization and gynecomastia has been noted. May potentially increase the risk of hepatic, uterine and prostate CA. Possible <u>positive</u> effect on HDL and total cholesterol.

others are unsafe, especially if taken in combination with medication or in certain work environments. The short term effects of some of these preparations are dangerous and use can result in incapacitation. The long term effects of many of these unregulated preparations are unclear and have not been studied to any degree in the HMD environment. The bottom line is that many of the supplements contain a number of chemicals that can have negative overall health effects, physical performance effects, and neurological (cognitive, perceptual and sensory) effects on the human body, and this can greatly impact an HMD Warfighter's ability to know where he is in an operationally harsh and complex battlespace, which is vital to his survival and mission accomplishment. Again, flight surgeons, under the auspices of various regulations and published guidance (e.g., AR 40-8 and the APLS for

Table 16-5.
Supplements classes by side/toxic effects.
(PDRHealth, 2007)

Supplement Class	Examples
Herbals causing increased bleeding time	Ginseng , Gingko, Garlic, Feverfew
Plants with sedative properties	Hops, Valerian Root, St. John's Wort, Hemlock, Opium Poppy, Passion Flower, Skullcap Mushroom, Wild Lettuce, Wolf's Bane
Hallucinogenic plants	Peyote, California Poppy, Kava-kava, Mandrake, Nutmeg Periwinkle, Thorn apple, Yohimbe Bark
Cardiac active plants	Ma Huang (Ephedra) , Foxglove (Digitalis) both Yellow and Purple, Squill/White Squill, Broom, Lilly of the Valley Pheasant's Eye
Liver toxic plants	Germander, Comfrey, Chapparal, Life Root

the US Army) (Department of the Army, 2006; 2007) can attempt to strictly regulate what the aircrew HMD user's are allowed to consume, but ground based surgeons generally do not have that same guidance when dealing with their HMD Warfighters.

Nutrition

Self-imposed stresses such as fatigue and hypoglycemia are reduced by taking proper care of your body. Certain life-style factors that contribute directly to health and well-being also result in decreased stress effects and optimal performance. Two tools that can be used effectively to increase combat performance and increase resistance to fatigue are a proper healthy diet incorporated with a well-rounded exercise program that includes both aerobic and anaerobic exercise.

In order for the human body to function, it must have fuel to burn, specifically the sugar glucose. Glucose liberated during the digestion process enters the blood stream and is transported to the organs and tissues needing it. If there is apparent excess to the body's needs, it is stored as glycogen in the liver itself. The nervous system in general, i.e. the brain, nerves and especially the retina in the back of the eye, are all highly -dependent on blood sugar levels to function. When glucose levels in the blood fall below levels adequate to supply these tissues, the liver converts glycogen to glucose and releases it into the blood stream. Hypoglycemia results when the glycogen stores in the liver are depleted and there is not enough glucose in the blood stream. Hypoglycemia means "low blood sugar" and has a variety of causes. The most common cause is skipping meals or eating foods that are predominantly simple sugars. Other causes of hypoglycemia are high protein/low carbohydrate diets and diets where a Warfighter does not eat for extended periods of time (fasts or starvation diets).

Short-term symptoms of hypoglycemia are shakiness, decreased mental ability, physical weakness, irritability, fatigue and sleepiness. These symptoms arise within 4 to 6 hours after the last meal. However, if the meal consisted primarily of complex carbohydrates, like pasta, potatoes, or whole wheat breads, hypoglycemia does not occur as quickly. If the last meal consisted of simple carbohydrates, like those found in candy and soft drinks, then hypoglycemia occurs much more quickly because of the rapid digestion and rapid metabolism of the simple sugars. Complex carbohydrates, proteins and fat require more time for digestion and utilization. Their glucose is slowly released into the blood and stored in the liver over a period of time, avoiding erratic shifts in metabolism. Simple carbohydrates are absorbed into the blood quickly, causing the blood sugar level to rise dramatically. As the blood sugar rises, the brain senses there is too much glucose in the blood and signals the pancreas to release insulin into the blood stream which acts to remove glucose from the blood and take it to the liver. Unfortunately,

Table 16-6.
Supplement use in the Army-wide survey exercise frequency.
(Institute of Medicine, in press)

	Total N	At Least Once/ Week	1-2 Supplements/ Week	3-4 Supplements /Week	5 + Supplements /Week	Multi-vitamin Use	Sport Drinks Use	Protein Amino Acid Mix Use	Money Spent per Month
Sex									
Male	553	58%	31%	12%	15%	32%	19%	14%	$58
Female	63	71%	37%	20%	14%	37%	20%	10%	$58
Age									
≤20	70	57%	28%	9%	20%	24%	17%	9%	$56
21-29	283	59%	28%	10%	15%	26%	21%	13%	$47
30-39	143	69%	35%	17%	15%	44%	19%	18%	$67
≥40	133	63%	40%	19%	10%	43%	16%	13%	$67
Education									
High School or GED	194	52%	27%	8%	14%	21%	14%	12%	$46
Some College/Associate Degree	289	64%	32%	12%	16%	33%	20%	14%	$71
Bachelor Degree	107	78%	40%	24%	13%	52%	25%	17%	$53
Graduate Degree	39	72%	40%	39%	8%	41%	23%	15%	$25
Occupation									
Combat Arms[a]	219	57%	33%	10%	15%	29%	19%	16%	$64
Combat Support[b]	214	61%	31%	16%	15%	36%	21%	16%	$51
Combat Service Support[c]	192	60%	32%	15%	13%	33%	19%	10%	$59
Rank									
E1-E4	298	53%	30%	9%	15%	24%	21%	12%	$59
E5-E9	195	61%	31%	16%	15%	39%	14%	16%	$67
WO1-WO5	100	67%	36%	18%	13%	43%	15%	13%	$48
O1-O3	31	88%	47%	22%	19%	50%	38%	22%	$32
O4-O6	5	60%	20%	40%	0%	40%	40%	0%	$40
Exercise – Aerobic									
None	28	52%	28%	3%	21%	35%	14%	7%	$31
≤4 days a week	234	66%	38%	17%	12%	40%	21%	16%	$48
≥5 days a week	361	56%	29%	12%	15%	28%	19%	13%	$66
Exercise – Strength									
None	176	45%	28%	9%	8%	19%	14%	4%	$73
≤2 days a week	141	62%	34%	16%	13%	36%	28%	10%	$46
≥3 days a week	306	67%	34%	14%	19%	40%	19%	22%	$55

[a] Infantry, armor, field artillery, air defense, special forces, aviation
[b] Engineer, chemical, military intelligence, military police, signal, civil affairs
[c] Ordinance, quartermaster, transportation, legal, medical, finance, chaplain

Table 16-7.
Supplement use and exercise frequency among survey populations.
(Institute of Medicine, in press)

	Army Wide		Army War College		Ranger	Special Forces
	Male	Female	Male	Female	Male	Male
Use Supplements at least once a week	58%	71%	72%	82%	82%	66%
Use 1-2 different supplements per week	31%	37%	29%	36%	45%	41%
Use 3-4 different supplements per week	12%	20%	14%	6%	19%	14%
Use 5+ different supplements per week	15%	14%	12%	23%	15%	7%
Multivitamin Use	32%	37%	39%	52%	23%	32%
Sport Drinks Use	19%	20%	10%	0%	41%	36%
Protein/Amino Acid Mixture Use	14%	10%	3%	0%	18%	17%
Creatine Use	5.2%	0%	2%	0%	19%	16%
Exercise Frequency						
Aerobic Exercise >3 times / week	91%	90%	75%	N/A	98%	96%
Aerobic Exercise >5 times / week	60%	50%	N/A	N/A	N/A	65%
Strength Training >3 times / week	50%	31%	34%	N/A	45%	36%

if the blood sugar levels are high, insulin removes most of the sugar, leaving a blood sugar level that is lower than before the candy was eaten.

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

To prevent hypoglycemia Warfighters must eat regularly. When meals are missed, snacks of complex carbohydrates are more beneficial than candy and soft drinks. Some snacks designed to keep the amount of sugar in the blood at a constant level include bagels, pretzels, fig or fruit bars, granola bars, yogurt, milk, fresh fruits and vegetables. The bottom line on nutrition and combat is to eat sensible meals containing complex carbohydrates low in fat, at regular intervals. If accustomed to eating three meals a day, then try not to skip a meal since the glycogen stores in the liver may become depleted. Avoid fad diets or high protein/low carbohydrate diets designed to build bulk. Furthermore, protein is an inefficient source of energy and is primarily used to build muscle and bone. Carbohydrates, however, are efficient sources of energy and are easily converted to glucose.

Diet pills should not be relied upon to maintain weight. They often contain the same medications found in decongestants (discussed in the medications section of this chapter). They are stimulants with unwanted side effects including nervousness, tremors, increased blood pressure and heart rate, dehydration due to increased sweating, and sleep disturbances. There is a significant synergistic effect when diet pills are used in conjunction with caffeine. This effect includes a marked increase in blood pressure and increased dehydration. Weight loss can be accomplished without diet pills; a sensible diet and a regular exercise program is a much healthier and safer alternative for losing weight.

Dehydration

Dehydration, like hypoglycemia, is a major contributor to fatigue. There are varying degrees of dehydration, with different symptoms. Unfortunately, most people are constantly in a slightly dehydrated condition. When dehydration is combined with the combat environment, fatigue onset is quicker. Also, in the aviation environment, dehydrated aviations are at a higher risk of experiencing decompression sickness, spatial disorientation, visual illusions, airsickness, and loss of situational awareness.

The first common indication of dehydration is a sensation of thirst. At this point, the Warfighter is about 2% dehydrated or about 1.5 quarts (1.6 liters) low on water. If combined with the diuretic effects of caffeinated drinks (coffee, colas) Warfighters can quickly become 3% or more dehydrated. At a dehydration level of 3%, they may experience sleepiness, nausea, mental impairment, and mental and physical fatigue. After a night of drinking alcoholic beverages, the 3% dehydration level is reached more quickly because of the diuretic effects of alcohol. In addition to mental impairment, dehydration decreases your ability to do high intensity physical work. The best method to prevent the problems of dehydration, obviously, is to drink plenty of water before, during and after each operation. If water is unappealing or unpalatable, drinks that are low in sugar, nonalcoholic, and decaffeinated can be substituted. Many Soldiers prefer “sports drinks” like Gatorade®. These drinks are marginally helpful, but some contain higher amounts of salt than the body normally needs. In addition, some of the drinks are heavily sugared. Usually, Warfighters won’t lose enough salts or electrolytes during normal activity to warrant the use of these types of drinks. However, if they prefer sports drinks to water, then its recommended they drink whatever they like best providing it is not alcoholic, caffeinated or heavily sugared. Staying hydrated before, during and after exertion has a pronounced positive effect on how well you perform combat related duties.

Smoking and alcohol

There are two very commonly used drugs not discussed in the preceding section, *Smoking and alcohol*. The acts of imbibing of these drugs, smoking and drinking, are very prevalent in both the civilian and military communities. Tobacco products are primarily used as stimulants; alcohol is a central nervous system (CNS) suppressant. For historical and social reasons, the use of these drugs are not prohibited or severely limited, although many occupations and especially the aviation community does place some time-related restrictions on the use of alcohol prior to the associated vocational activity. In the discussions to follow, it will be shown that these drugs do have a significant influence on Warfighter performance, especially on visual and cognitive performance. Long-term health effects also have been associated with their use.

Tobacco

First, the effects and concerns of the use of tobacco products on Warfighter physical, cognitive and perceptual performance and specifically their impact in the HMD environment is discussed. Tobacco comes from the plant Nicotinia Tabacum that has in it the drug *nicotine*. Nicotine is a poisonous alkaloid contained in the leaves, roots and seeds of tobacco plants. It is used as an insecticide as well as in some medications, primarily and ironically in smoking cessation medications.

Historically, the military has had a reputation as an environment in which tobacco use is accepted and common. As with the civilian community, military personnel use all forms of tobacco, to include cigarettes, cigars, pipes and smokeless tobacco. Overall in the U.S. DOD population, the prevalence of tobacco use has been reported as 51% in 1980, 53% in 1982, and 47% in 1987 (Edwards, Sanders and Price, 1988). However, when Edwards, Sanders and Price (1988) investigated the impact of smoking on U.S. Army aviation initial-entry rotary-wing (IERW) training flight school performance, they reported only 15% as smokers. In recent years, the DOD has increased efforts to lower tobacco use by members of the Armed Forces, and the rate has declined. Nevertheless, in a recent 2005 survey it again was found that tobacco use remained moderately high among military personnel (Figure 16-3) (Department of Defense, 2005).

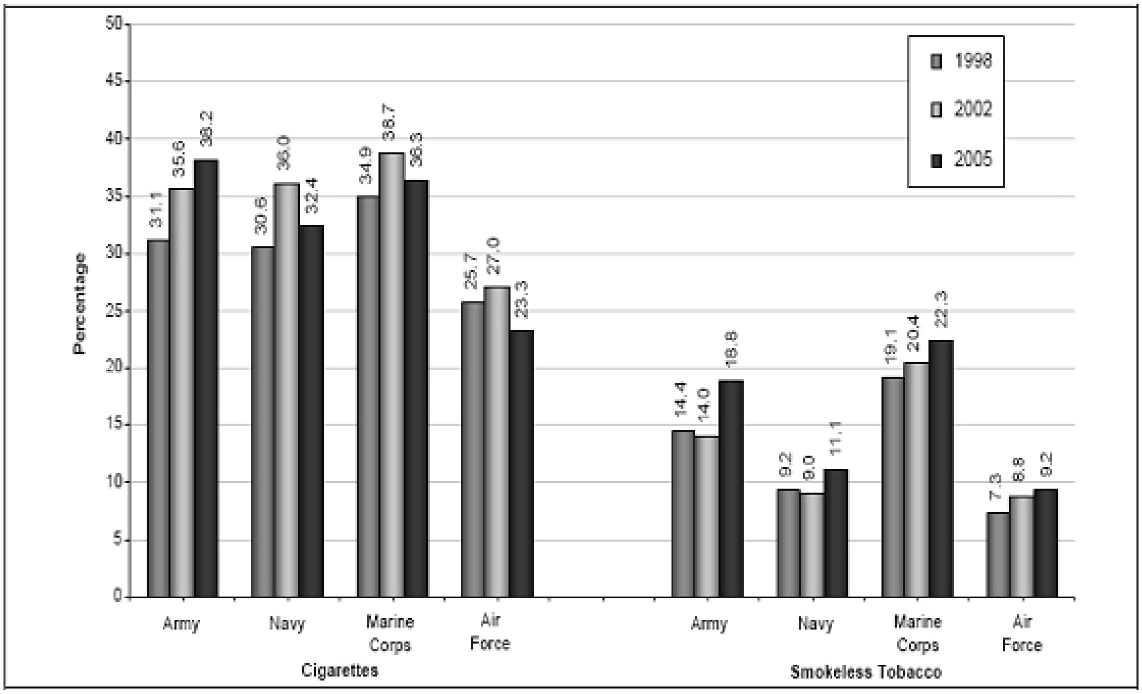

Figure 16-3. Service comparisons in the prevalence of any cigarette use and smokeless tobacco use, past 30 days, 1998-2006 (Department of Defense, 2005).

This high rate of tobacco use is of concern to the DOD for the following reasons:

- Smoking-related illnesses take a toll on the physical readiness of the Armed Forces. Thousands of studies have demonstrated an association between the use of tobacco and negative health outcomes, such as cardiovascular diseases, various cancers, and pulmonary disease (Haddock et al., 1998).
- The use of tobacco also has been associated with negative performance outcomes, such as higher absenteeism, diminished motor and perceptual skills, and poorer endurance (Chisick, Poindexter and York, 1998).
- There is a financial concern. Each year, the DOD spends an estimated $875 million on smoking-related health care and productivity loss (Conway, 1998).
- There is a concern that most of the individuals currently serving in the Armed Forces will eventually return to civilian life, and the DOD has an obligation to return veterans to the civilian sector in the healthiest condition possible (Chisick, Poindexter and York, 1998).

The use of tobacco products by the Warfighter in any situation is of concern because these products contain nicotine and a number of other chemicals that have negative overall health effects, physical performance effects, and neurological (cognitive, perceptual and sensory) effects on the human body.

With the HMD user (both aviators and ground forces), this fact must be further emphasized due to the very unique perceptual environment that an HMD presents to the user and the often complex cognitive processes that Warfighters must use to interpret what is being presented to them on the HMD as compared to their actual 4-D environment.

Overall health effects

From the DOD standpoint, having the healthiest Warfighter population is of utmost importance and holding on to these highly-trained individuals is paramount. Cigarette smoking has been declared as hazardous to health by numerous world health organizations, due to its contributions to hypertension and chronic lung disorders such as bronchitis and emphysema. Tobacco contains at least 28 known carcinogens (cancer-causing agents). The most harmful carcinogens in tobacco are the tobacco-specific nitrosamines. They are formed during the growing, curing, fermenting, and aging of tobacco. Other cancer-causing substances in smokeless tobacco include N-nitrosamino acids, volatile N-nitrosamines, benzo(a)pyrene, volatile aldehydes, formaldehyde, acetaldehyde, crotonaldehyde, hydrazine, arsenic, nickel, cadmium, benzopyrene, and polonium-210. All tobacco, including smokeless tobacco, contains nicotine, which is an addictive substance (National Cancer Institute, 2008).

Tobacco is one of the strongest cancer-causing agents. Tobacco use is associated with a number of different cancers, including lung cancer, as well as with chronic lung diseases and cardiovascular diseases. Lung cancer is the leading cause of cancer death among both men and women in the United States, with 90% of lung cancer deaths among men and approximately 80% of lung cancer deaths among women attributed to smoking. Cigarette smoking remains the leading preventable cause of death in the United States, causing an estimated 438,000 deaths – or about one out of every five deaths each year (National Cancer Institute, 2008).

Tobacco users also increase their risk for cancer of the oral cavity. Oral cancer can include cancer of the lip, tongue, cheeks, gums, and the floor and roof of the mouth. People who use oral snuff for a long time have a much greater risk for cancer of the cheek and gum than people who do not use smokeless tobacco.

The possible increased risk for other types of cancer from smokeless tobacco is being studied. Possible increased risks for heart disease, diabetes, and reproductive problems are being studied (Centers for Disease Control and Prevention, 2004; National Cancer Institute, 2008).

Physical performance effects

Warfighters need to be in top physical condition to be able to survive the harsh operational environments that they operate. Several studies have shown that smoking is associated with impaired cardiovascular fitness and reduced heart rate response to exercise. Chronic smoking is found to affect young male smokers' cardiovascular fitness, impairing the efficiency and decreasing the capacity of their circulatory system. It is not known whether these associations are present in adolescence or whether they change over time. But moderate to heavy smoking (≥10 grams of tobacco per day)[8] has been shown to reduce cardiovascular fitness and heart rate response to exercise in young otherwise healthy smokers (Bernaards et al., 2003; Papathanasiou et al., 2007).

Sensory, perceptual and cognitive effects

From an HMD Warfighter perspective, the ability to think clearly, see well, and react quickly and appropriately are the key requirements to survival and the successful execution of the mission. As a stimulant, nicotine has been found to improve performance on attention and memory tasks. Clinical studies using nicotine skin patches have demonstrated the efficacy of nicotine in treating cognitive impairments associated with Alzheimer's disease, schizophrenia, and attention-deficit/hyperactivity disorder (ADHD) (Levin et al., 2006; Levin and Rezvani, 2002; Rezvani and Levin, 2001). Experimental animal studies have demonstrated the persistence of nicotine-induced working memory improvement with chronic exposure, in addition to the efficacy of a variety of nicotinic agonists. Nicotine has also been shown in a variety of studies in humans and experimental animals to improve cognitive function. Nicotinic treatments are being developed as therapeutic treatments for cognitive dysfunction. Several studies have found that transdermal nicotine significantly improves attentional function in people with

[8] Approximately 14 to 20 cigarettes.

Alzheimer's disease, schizophrenia or Attention Deficit Hyperactivity Disorder (ADHD) as well as normal nonsmoking adults.

Nicotine studies also have been conducted on smooth pursuit eye movements and have showed that nicotine administered by patch improved antisaccade performance and smooth pursuit eye movements. Nicotine also induces loss of anticipatory saccadic eye movements; provides for improved acceleration of eye movements during smooth pursuit initiation; and improves pursuit gain during the maintenance phase (steady-state velocity). However, nicotine does not appear to modify peak predictive pursuit. Thus, Nicotine appears to improve visual attention (Kumari, 2003).

Nicotine is known to improve performance on tests involving sustained attention and recent research suggests that nicotine may also improve performance on tests involving the strategic allocation of attention and working memory. Nicotine improves visual search performance by speeding up search time and enabling a better focus of attention on task-relevant items. This appears to reflect more efficient inhibition of eye movements towards task irrelevant stimuli, and better active maintenance of task goals. When the task is novel, and therefore more difficult, nicotine lessens the need to refixate previously seen letters, suggesting an improvement in working memory (Zingler, 2007).

A few studies have shown that nicotine may improve the ability of humans to focus on auditory information and filter out background noise (Baldeweg et al., 2006; Harkrider et al., 2001). In one study, nonsmokers received nicotine transdermally and their auditory processing was measured. These measurements indicated that nicotine in these nonsmokers appeared to improve the transmission of information in the midbrain and cortex. These areas are believed to involve processing of auditory information related to alertness to changes in the environment and also to the screening of sensory input (Harkrider and Champlin, 2000). On the other hand, clinical studies also have suggested that cigarette smoking is associated with hearing loss, a common condition affecting older adults. One study showed smokers were 1.69 times as likely to have a hearing loss as nonsmokers (Cruickshanks et al., 1998). Two other studies showed that smoking was associated with increased odds of having high frequency hearing loss in a dose-response manner (Mizoue et al., 2003; Nakanishi et al., 2000).

Nicotine has well-known, unpleasant side effects, e.g., transient dizziness, nausea, and nicotine-induced nystagmus (NIN). Motion stimulation increases nicotine-induced dizziness and nausea, but does not significantly influence NIN or postural imbalance. The view is that all measured adverse effects reflect dose-dependent nicotine-induced vestibular dysfunction. Additional motion stimulation aggravates dizziness and nausea, i.e., nicotine increases sensitivity to motion sickness (Zingler, 2007).

Of even greater concern are the effects that smoking tobacco has on night vision. Early studies showed a significant decrease in scotopic dark adaptation with smoking, which was attributed to the hypoxic effects of carbon monoxide (CO). Later studies found that smoking seemingly improved night visual performance on some psychophysical tests. This improvement was presumed to be a result of the stimulant effect of nicotine. More recent studies have reported that smokers have reduced mesopic vision when compared with nonsmokers (Miller and Tredici, 2002).

Although the literature is somewhat confusing,[9] smoking is discouraged in aviation for several reasons, which include:

- There is some evidence that it may degrade mesopic and night vision.
- Although many night flights are low level, the hypoxic effect of CO is additive with altitudinal hypoxia. Cigarette smoke contains a minute amount of carbon monoxide. Just three cigarettes smoked at sea level will raise the physiological altitude to between 5,000 and 8,000 feet (ft) (1500 and 2400 meters [m]). The effect of altitudinal hypoxia on night vision is primarily one of an elevation of the rod and cone threshold. Although decreased cone function is clearly demonstrated by the loss of color

[9] In that the comparison with pure nicotine drug administration via e.g. skin patch vs. cigarette smoking confounds the meta-analysis.

vision at hypoxic altitudes, the decrement in central visual acuity is usually insignificant. However, scotopic (night) vision at altitude can be significantly reduced. Scotopic vision has been reported to decrease by 5% at 3,500 ft (1,050 m), 20% at 10,000 ft (3,050 m), and 35% at 13,000 ft (4,000 m), if supplemental oxygen is not provided. Thus, the use of oxygen, even at low pressure altitudes, can be very important at night (Miller and Tredici, 2002).

- Smoke is a significant irritant for aircrew who wear contact lenses or for those with dry eyes.
- Smoke forms filmy deposits on windscreens, visors, and spectacles and HMDs that can degrade contrast at night.
- The effects of smoking withdrawal during long missions may be dangerous.
- The chronic long-term effects of smoking are hazardous to overall health.

When any Warfighter is required to fly or to rapidly ascend to elevations greater than 10,000 ft (3,050 m) (common elevations found in areas of current conflict such as the mountains along the Afghanistan and Pakistan border as well as those in northern Iraq), it has been noted that they will experience substantial impairment in cognitive performance. Because of their CO load, Warfighters who smoke are already at a physiologic altitude of between 5,000 and 8,000 ft (1500 to 2400 m) above sea level (ASL) thus only compounding the issue and placing them at even a higher physiologic altitude. For example studies have shown that activities requiring decisions, strategies, and memory retention are more vulnerable than automatically performed activities, complex tasks are affected more than simple tasks, and tasks that are not already well learned at sea level will be difficult to learn or perform, especially during initial exposure to altitude. Also, initial exposure to high altitude will likely also adversely affect mood, balance, reaction time, and manual dexterity of fine and complex motor tasks (Banderet and Burse, 1988; Banderet and Shukitt-Hale, 2002; Crowley et al., 1992). For individuals who are already at artificially high physiologic altitudes because of smoking, all these issues are compounded.

With acclimatization, acquired while living at the same altitude or via staging at moderate altitudes, the large cognitive impairments are typically eliminated within one to two days. This has been shown in a number of studies. For example, the large impairment in cognitive function (represented by a code substitution task) that occurs at least during the first few hours for unacclimatized sea-level residents who ascended to 14,000 ft (4,300 m) was eliminated in about 12 hours (Figure 16-4). Also note that there was no cognitive impairment for mountain-area residents who had lived for >21 months at 7,000 ft (2,100 m) prior to their ascent to 14,000 ft (Cymerman et al., 2005; 2006a; 2006b). Unfortunately all of these studies were done on non-smokers and little is known as to if the smoker would be able to acclimatize as quickly.

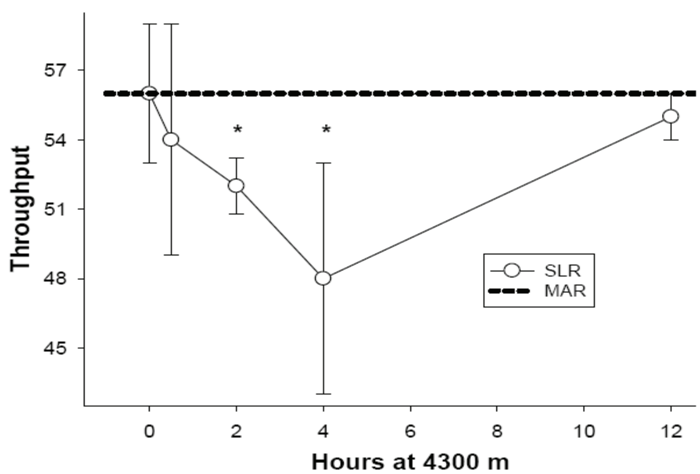

Figure 16-4.Cognitive impairment at altitude (Cymerman et al., 2007).

In 1988, Edwards, Sanders and Price (1988) conducted a study comparing flight school performance in groups of nonsmoking and smoking Army aviation students. The study's intent was to determine whether the effect of smoking enhances or decrements initial flight training performance. Academic and in-flight grades for five phases of IERW classes between January 1984 and November 1986 were extracted from U.S. Army Aviation Community of Excellence, Fort Rucker, AL, (formerly U.S. Army Aviation Center) records and compared to the student's responses to behavior activities on the auxiliary questionnaire portion of the Aviator Epidemiologic Data Register, a comprehensive database collected yearly on every Army aviator by the joint effort of the U.S. Army Aeromedical Research Laboratory (Fort Rucker, AL) and the U.S. Army Aeromedical Activity (Fort Rucker, AL). There were 2,025 student aviators with data sufficiently complete, with the average age of 24.5 years, and with a rank and sex distribution as follows: 96.3% males, 3.7% females; 53.2% commissioned officers, 46.7% warrant officers. Using strict criteria defining smokers and nonsmokers for this study, a 15:85 ratio of smokers to nonsmokers was found (recent quitters and those who smoke less than one pack/day were not included in the analysis). While recognizing that a number of controlled medical studies had determined that smoking is detrimental to overall health, no evidence of a statistically significant relationship was found between smoking behavior and flight school performance.

While not current, the results of a 1986 literature review conducted by the U. S. Army Medical Research and Development Command regarding research into smoking as it related to soldier performance is worth examining (Dyer, 1986)). Research on smoking and other nicotine effects was included in the review. The research reviewed was related to position disclosure in combat; the effects of smoking on physical work capacity and endurance; the effects of smoking on perceptual processes; the effects of smoking on arousal and ability to deal with stress, pain, and fear; smoking-induced hormonal changes; the effects of tobacco deprivation; smoking-disease relationships and their effects on productivity and absenteeism; smoking and abuse of other substances, delinquency, and accidents; and associations between smoking and other factors of potential relevance to soldier performance. Among the main findings, the review disclosed detrimental effects of smoking on physical performance of soldiers, particularly soldiers with several years of tobacco exposure. The review also identified nicotine-related improved performance on vigilance and rapid information processing tasks, including tasks that may be relevant to some soldier tasks. It also showed an abundance of negative behaviors that are correlated with smoking such as drug abuse, delinquency and driving accidents. Research in many areas critical to soldier performance, such as the effects of smoking on dark adaptation and the effects of smoking on testosterone production, showed contradictory results, which the authors argued required additional research for resolution.

In conclusion, the use of tobacco products by the Warfighter is highly discouraged due to detrimental affects on overall health, physical performance and to a greater extent because of the multiple influences that nicotine and CO have on visual perception. Again, it cannot be overemphasized that for the HMD user who has a unique view of his environment and the 4-D battlespace surrounding him, any decrement in his ability to interpret where he is in an operationally harsh combat scenario is critical to his survival and mission accomplishment.

Alcohol

> *Aircrew will not perform aviation duties for a minimum of 12 hours after the last drink consumed and until no residual effects remain -* Army Regulation 40-8 (Department of the Army, 2007*).*

The effects and concerns of the use of alcohol products on Warfighter physical, cognitive and perceptual performance in the HMD environment is an important issue. Alcohol use is fairly ubiquitous in American society, with an estimated 80% of adults imbibing in beer, wine or spirits with a per capita consumption of approximately 25 gallons per year (Orford and Silberman, 2008). It should not be surprising that Warfighters also consume alcohol. In a recent 2005 survey, it was found that alcohol use remains fairly high among military personnel (Table 16-8) (Department of Defense, 2005).

Table 16-8.
Estimates of average daily ounces of ethanol, among entire population and drinkers, by military service. (Department of Defense. 2005)

	Service				
Population	**Army**	**Navy**	**Marine Corps**	**Air Force**	**Total DoD**
Entire Population, per Year	1.9 (0.2)[a,b]	1.4 (0.2)[b,c,d]	1.9 (0.1)[a,b]	0.7 (0.1)[a,c,d]	1.4 (0.1)
Drinkers Only, per Year	2.4 (0.3)[a,b]	1.8 (0.2)[b,c,d]	2.3 (0.1)[a,b]	1.0 (0.1)[a,c,d]	1.8 (0.1)
Drinkers Only, per Drinking Day	8.7 (0.7)[a,b]	6.6 (0.3)[b,c,d]	8.9 (0.4)[a,b]	4.5 (0.4)[a,c,d]	7.0 (0.3)

Note: Table entries for average daily ounces of ethanol are average values among military personnel by Service. The standard error of each estimate is presented in parentheses. Pairwise significance tests were conducted between all possible Service combinations (e.g., Army vs. Navy, Navy vs. Marine Corps). Differences that were statistically significant are indicated.

[a]Estimate is significantly different from the Navy at the 95% confidence level.

[b]Estimate is significantly different from the Air Force at the 95% confidence level.

[c]Estimate is significantly different from the Army at the 95% confidence level.

[d]Estimate is significantly different from the Marine Corps at the 95% confidence level.

Source: DoD Survey of Health Related Behaviors Among Active Duty Military Personnel, 2005 (Average Daily Ounces of Ethanol, Q18-Q26 and Q32-Q34).

Twenty-one percent of service members admit to drinking heavily – a statistic the U.S. military hasn't managed to lower in 20 years. Additionally, young Warfighters between 18 and 25 tend to engage in heavy drinking more than their civilian peers. Binge drinking (now more commonly referred to in the scientific literature as heavy episodic drinking) is also at higher levels than for the civilian population (16.6%). The 2005 estimate of binge drinking, defined as five or more alcoholic drinks within a 2-hour period at least once in the past 30 days, is 44.5% for the military. This estimate is not significantly different from the 2002 estimate (41.8%). It should be noted, however, that the rate of binge drinking among college populations (44.8% in 2001) is very similar to the military rate (Wechsler et al., 2002).

Overall health effects

From the DOD standpoint, healthy Warfighters are tantamount to mission success. Retaining these highly trained individuals is a requisite for an all volunteer force. An extensive body of data shows associations between long-term, heavy alcohol intake and a variety of adverse health outcomes, including coronary heart disease, diabetes, cirrhosis, various cancers, hypertension, congestive heart failure, stroke, dementia, Raynaud's phenomenon, and all-causes mortality. Additionally, binge drinking, even among otherwise light drinkers, increases cardiovascular events and mortality. However, light to moderate alcohol consumption (up to 1 drink daily for women and 1 or 2 drinks daily for men) is associated with cardioprotective benefits, whereas increasingly excessive consumption results in proportional worsening of outcomes (O'Keefe, Bybee and Lavie, 2007). Additionally, moderate alcohol consumption, up to 2 drinks per day, has been shown to be significantly protective for ischemic stroke after adjustment for cardiac disease, hypertension, diabetes, current smoking, body mass index, and education (Sacco et al., 1999). Ethanol itself, rather than specific components of various alcoholic beverages, appears to be the major factor in conferring health benefits, providing that the individual is a moderate drinker (O'Keefe, Bybee and Lavie, 2007).

Physical performance effects

Warfighters need to be in top physical condition to be able to survive the harsh operational environments that they encounter. The effects of ethanol vary and can depend on the extent of its consumption and environmental context. Acutely, ethanol consumption is not consistent with operating machinery or firing weapon systems – this would only be exacerbated in an HMD environment where the Warfighter must use his full cognitive and perceptual capabilities to determine his actual position in the 4-D battlespace. This being the case, the DOD prohibits the consumption of alcohol while on duty and during any deployment. Additionally, the various services have strict guidelines for aircrew that restrict them from operating any aircraft for at least 12 hours after consuming ethanol (i.e., Army regulation 40-8 [Department of the Army, 2007]), which is informally known as the "12 hours bottle to throttle" rule. In actuality, the formal regulation states that aircrew will not operate aircraft for 12 hours after consumption and without after-effects, since the effects of a hangover can greatly affect performance. The latter has been well documented in a number of studies. One example is an alcohol study done on military pilots that documented that 14 hours after consuming the alcohol, pilot performance was worse in the hangover condition on virtually all measures (Yesavage and Leirer, 1986). In another example, a study demonstrated that alcohol use among athletes revealed that alcohol has a causative effect in sports-related injuries, with an injury incidence of 54.8% in drinkers, compared with 23.5% (less than half) of non-drinkers. Researchers believe that this is due to the hangover effect of alcohol consumption, which has been shown to reduce athletic performance by 11.4% (O'Brien and Lyons, 2000).

In addition to its acute effects, ethanol can impede physical performance when its consumption is of a chronically abusive nature, i.e., alcoholism. It has been known for some time that individuals diagnosed with alcohol dependence have displayed various degrees of muscle damage and weakness (Martin and Peters, 1985). However other studies have demonstrated that at low doses, the acute effects of ingestion of ethanol on the response to submaximal and maximal exercise resulted in heart rates at rest and during submaximal exercise were higher after ingestion of ethanol, but there was no effect on stroke volume and the circulatory response, oxygen uptake and pulmonary ventilation to maximal work was not affected by ethanol. These findings are in agreement with data from animal experiments suggesting that ethanol in blood concentrations below 200 mg/100 ml has no significant depressive effect on performance of the normal heart (Blomqvist et al., 1970). Table 16-9 provides a comprehensive listing of some of the more commonly documented acute effects on motor skills, strength and power, and aerobic performance (The University Health Center, 2008).

Sensory, perceptual and cognitive effects

From an HMD Warfighter perspective, the ability to think clearly, see well, and react quickly and appropriately are the key requirements to survival and the successful execution of the mission. From a cognitive standpoint, heavy alcohol drinking is acknowledged by a substantial percentage of young adults in the military population, despite the known cognitive demands associated with their endeavors and the cognitive impairments associated with alcohol usage. Researchers have assessed the acute effects of ethanol (0.6 g/kg) on the acquisition of both semantic and figural and noted that ethanol significantly impaired memory acquisition in both domains (Acheson and Swartzwelder, 1998).

Yet another study examined the effects of ethanol on several complex operant behaviors in rats as a human model. Tasks included: temporal response differentiation (TRD) to assess timing behavior; differential reinforcement of low response rates (DRL) to assess timing and response inhibition; incremental repeated acquisition (IRA) to assess learning; conditioned position responding (CPR) to assess auditory, visual, and position discrimination; and progressive ratio (PR) to assess motivation. Ethanol was found to reduce accuracy or percent task completed for the TRD, DRL, and CPR tasks. This experiment demonstrated that ethanol selectively impairs performance on cognitive-behavioral tasks and that these effects can occur at doses that do not affect the subjects' ability to respond (Popke, Allen and Paule, 2000).

Table 16-9.
Acute effects on motor skills, strength and power, and aerobic performance.
(The University Health Center, 2008)

Physical Performance	Ethanol Effects
Motor skills	Low amounts of alcohol (0.02-0.05 grams/deciliter) result in • decreased hand tremors • slowed reaction time • decreased hand-eye coordination Moderate amounts of alcohol (0.06-0.10 grams/deciliter) result in • further slowed reaction time • decreased hand-eye coordination • decreased accuracy and balance • impaired tracking, visual search, recognition and response skills
Strength, power, and short-term performances	Alcohol will not improve muscular work capacity and results in • a decrease in overall performance levels • slowed running and cycling times • weakening of the pumping force of the heart • impaired temperature regulation during exercise • decreased grip strength, decreased jump height, and decreased 200- and 400-m run performance • faster fatigue during high-intensity exercise
Aerobic performance	Adequate hydration is crucial to optimal aerobic performance. The diuretic property of alcohol can result in • dehydration and significantly reduced aerobic performance • impaired 800- and 1500-m run times • increased health risks during prolonged exercise in hot environments

As far as vision, ethanol has been repeatedly shown to cause significant visual perceptual issues and should be of great concern for all HMD Warfighters. For example:

- Consuming alcohol can have short-term negative affects on vision. For a low blood alcohol level, visual performance is less affected by the visual changes than by alteration in brain functions (Quintyn et al., 1999).
- At higher concentrations, such as when the legal blood-alcohol level is reached and surpassed, depth perception and night vision are affected. It becomes impossible to accurately judge how far away objects are when depth perception deteriorates. Vision becomes blurred or doubled since eye muscles lose their precision causing them to be unable to focus on the same object. Alcohol also affects night vision by keeping the pupils from adapting from darkness to light. Alcohol consumption also produces tunnel vision and can make night blindness worse (Department of Transport South Africa, 2007).
- Contrast sensitivity can be reduced, which can prevent an individual from detecting obstacles within the field-of-view (FOV) for some situations. A reduction in contrast sensitivity, when combined with changes in ocular-motor control and attention deficits, also degrades performance (Pearson and Timney, 1998).

- Studies have illustrated that motion parallax (the ability to recover depth from retinal motion generated by observer translation) is important for visual depth perception. Thresholds in a motion parallax task are significantly increased by acute ethanol intoxication (Nawrot, Nordenstrom and Olson, 2004).
- Also there is a higher incidence of blue-yellow color blindness (tritanopia) found when ethanol is consumed. Individuals showed poorer color discrimination in all spectra but with significantly more errors in the blue-yellow versus the red-green color range ($p < 0.005$, $p < 0.01$). Thus, ethanol appears to act as a toxin to inner retinal layers, which could account for the higher incidence of tritanopia found among alcoholics (Russell et al., 1980).

In regards to auditory perception, numerous studies have shown that the acute ingestion of ethanol can cause auditory distraction on visual forced choice reaction time. This suggests that the attention-capturing effects of the deviant sounds were suppressed by ethanol, thus demonstrating a detrimental effect of ethanol on involuntary attention (Teo and Ferguson, 1986).

Additionally, the effects of ethanol on the evoked response potentials evoked by auditory stimuli are to decrease stimulus attention, and stimulus categorization (Jaaskelainen et al., 1996). Finally ethanol has been noted to specifically blunt lower frequencies affecting the mostly 1000 Hertz (Hz), which is the most crucial frequency for speech discrimination (Upile et al., 2007).

In conclusion, the use of ethanol-containing products by the Warfighter is highly discouraged due to detrimental affects on overall health, physical performance and to a greater extent because of the multiple influences that ethanol has on cognition, vision and auditory perception. With the HMD Warfighter this fact must be further emphasized due to the very unique perceptual environment that an HMD presents to the user and the often complex cognitive, visual and auditory processes that our Warfighters must use to interpret what is being presented to them on the HMD as compared to what their actual 4-D environment is. The ability to know where you are in an operationally harsh and complex battlespace is paramount to individual Warfighter survival and mission accomplishment.

Environment (External) Stressors

> Key concept: Normal physiology in abnormal environments will cause HMD related performance impediments unless these environmental effects are identified, considered and mitigated in HMD design.

This section seeks to address the environmental factors that directly or indirectly affect human performance and will thus affect the human-machine interface associated with HMDs. Generally these factors are characteristics of the aviation environment that require unique countermeasure development versus being under the direct control of the Warfighter. Exceptions to this rule are usually related to lessening the impact of a particular environmental stressor as in the example of smoking and hypoxia noted in the text above. Thus, it becomes incumbent upon the HMD designers to be cognizant of these environmental stressors and understand how the Warfighter will perform when exposed to these conditions.

Thermal stress

Hot and cold environments have been shown to have adverse effects on human sensation, perception, and cognition. There is a wealth of scientific information and analysis of human performance measures with respect to physiological and psychological changes that occur as a result of exposure to heat or cold. However, some of the greatest challenges to human performance when operating in climates outside the body's thermoneutral zone are those that result from issues that at first would appear mundane. For example, the sweat that soaks through the helmet liner of a helicopter pilot flying in the Iraqi desert at 120°F (49°C) can make it extremely difficult to keep NVGs positioned correctly for more than about ten minutes at a time before the helmet begins to shift. Similarly, the wearing of a balaclava[10] to keep one's head warm in the mountains of Afghanistan will necessarily change the way that a combat helmet fits. As a result, displays that do not have a wide range of adjustment in multiple planes may not allow for a full FOV. Furthermore, changes in ambient temperature that might arise in going from a heated (or cooled) ready room to a chilled (or sun-baked) cockpit can lead to decreased resolution due to condensation. This section presents information on the ways in which humans respond to thermal stress. While the preponderance of the available scientific knowledge focuses on objective measures of physiological or psychological performance, the reader is encouraged to consider the practical design implications for HMDs that result from operation in both static and dynamic thermal environments.

Overview of human thermoregulation

Human beings are homeotherms – meaning that circadian and seasonal variation in core temperature is maintained within a relatively narrow range about 99°F (37°C) with normal fluctuations being less than 0.6°F (1°C) (Stocks et al., 2004; Wright et al., 2002). In contrast, the temperature of the skin can vary significantly depending upon environmental conditions; this is especially true for the nose, the ears, and the extremities. Human thermoregulation is a complex process that occurs at multiple levels. The thermoregulatory system is comprised of four main components: (1) thermoreceptors located throughout the body; (2) neural pathways mediating information to and from the central nervous system (CNS); (3) the controlling system within the CNS; and (4) the thermoeffector system, which includes autonomic and behavioral responses (Pozos and Danzl, 2001). While humans can survive in a wide range of thermal conditions, the thermoneutral zone (TNZ) for a naked resting body, which is the range of ambient temperature in which thermoregulation is achieved without changes in metabolic heat production or evaporative heat loss, is relatively narrow and falls between 83°F to 86°F (28°C to 30°C) (Faerevk et al., 2001). Within the TNZ, thermal balance is maintained primarily by regulation of skin blood flow (Wright et al., 2002). Once thermal regulatory action goes beyond minor postural or vasomotor control, thermal stress is experienced.

Thermoreception and thermal comfort

The body's core temperature must be maintained at a high level within a very narrow range for human survival, and both core and peripheral temperature sensing systems are required to maintain homeostasis (Stocks et al., 2004). Thermosensitive nerve endings, or thermoreceptors, are located in different areas of the skin and muscle, and throughout the deeper parts of the body to include arteries, internal organs, and the CNS. The peripheral sensors located in the skin and muscles provide the first line of physiological information. These thermoreceptors are either "warm" or "cold" types according to their responses to external stimuli. The determinants affecting the activation of thermoreceptors and the subsequent thermal sensation are: (1) the number of receptors in a specific region, (2) the intensity of the stimulus, (3) the individual's adaptation to temperature, (4) the rate of temperature change, and (5) the size of the area stimulated. Thermal sensation and comfort are related to the thermal state of the body. Skin temperature is a major determinant of thermal comfort; however, the influence of local sensation varies for different parts of the body (Simmons et al., 2008). For example, local cooling of the hands and feet may produce a whole-body sensation of cold that is not related to average skin temperature. It has been suggested that overall thermal sensation and comfort follow the warmest local sensation in a warm environment and the coldest in a cool environment. It must be emphasized, however, that skin temperature cannot be used as a surrogate for

[10] A balaclava is a form of headgear covering the whole head, exposing only the face and often only the eyes.

core body temperature due to the centrally mediated physiological responses to thermal stress (Pozos and Danzl, 2001).

Thermoregulation and the CNS

The CNS controls all physiological and behavioral responses to thermal stress. The extreme complexity of the thermoregulatory system necessitates that only a cursory overview will be presented. Incoming signals from the periphery and the deep sensors are processed at multiple levels within the CNS to include the spinal cord. The hypothalamus, an area within the brain, is considered to be the body's thermostat (Pozos and Danzl, 2001). At present, it is not clear which variables (i.e., core temperature, temperature change, body heat content, or rate of heat outflow) are regulated. Furthermore, the establishment of a "set-point" is not well understood; however, it is believed that this point may change temporarily due to factors such as acclimatization, hydration, or fever (Sawka and Pandolf, 2001). Changes detected by the hypothalamus can trigger efferent pathways of the thermoregulatory system through parallel processes of behavioral and physiological responses. Examples of thermally oriented behavioral responses can include the donning or doffing of clothing, seeking shelter, or modifying activity levels. Nearly all physiological systems respond in some way to thermal stress. The systems that are most immediately activated include the cardiovascular system, the musculoskeletal system, and the neuro-endocrine system (Pozos and Danzl, 2001).

Thermal balance

Thermal stress is the nonspecific response of a subject to temperatures that fall outside of the TNZ. The basis of all human thermal stress lies in an energy balance equation which satisfies the continuity requirement for energy exchanged between the body and its surroundings which can be summarized as follows (Parsons, 2003):

$$S = (M - W) - (C + R + E + K) \qquad \text{Equation 16-1}$$

where S = storage of body heat, M = metabolic energy transformation, W = work, C = convective heat transfer, R = radiant heat exchange, E = evaporative heat loss, and K = conductive heat transfer. The maintenance of core temperature requires the continuous elimination of metabolic heat in addition to the compensation for any environmental heat gain or loss. The environmental factors that affect the thermal balance equation are ambient temperature, radiant temperature, air (or water) movement, and humidity. Together with metabolic heat production and clothing, these variables can be used to define human thermal environments (Figure 16-5).

Heat production and loss

At increased activity levels, heat generated from metabolic energy transformation and utilization moves from the core to the skin via tissue conduction and circulatory convection. It must then be dissipated to the environment. Within the TNZ, the body makes minor adjustments via cutaneous vasomotor dilation (to dissipate heat) or constriction (to conserve heat) in order to maintain thermal homeostasis (Faerevik et al., 2001). The body experiences thermal stress when vasomotor control alone cannot maintain thermal balance. To compensate, the thermoregulatory control center in the hypothalamus initiates both physiological and behavioral changes. The primary physiological defense against heat stress is the secretion of sweat. Each liter of evaporated sweat removes 580 kilocalories of heat, and sweat rates may approach two liters per hour during strenuous work in hot environments (Finnoff, 2008). However, high ambient humidity, clothing, and other protective gear can impede the evaporation of sweat thereby negating the potential for heat loss while simultaneously exacerbating dehydration. Additionally, clothing can trap heat and hinder other methods of heat exchange (e.g., radiation, convection, conduction) between the body and the environment.

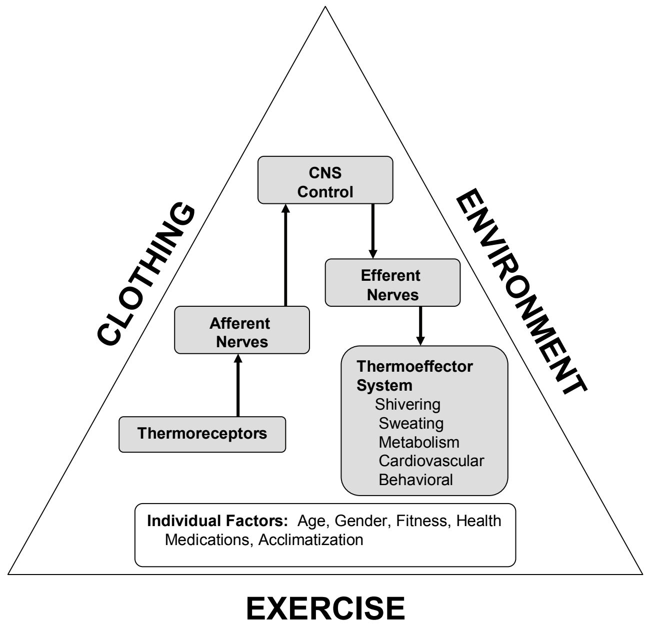

Figure 16-5. Factors affecting thermal balance (Parsons, 2003).

Responses to cold

Vasoconstriction of the superficial blood vessels is an efficient means of reducing heat loss to the environment (Enander and Hygge, 1990). The shell of cooled tissue which includes skin, inactive muscle, and subcutaneous fat provides a layer of insulation for the internal organs. Skin temperatures of the peripheral areas are reduced while the excess blood that is shunted to the inner parts of the body leads to compensatory changes in the cardiovascular system (Stocks et al., 2004). If cooling continues, the hypothalamus sends efferent signals that lead to the involuntary contractile activity of skeletal muscles, or shivering. This increases the metabolic production of heat two to four times above basal levels (Stocks et al., 2004). Simultaneously, behavioral responses to cold are initiated. As with hot environments, excessive or inappropriate clothing may trap heat and lead to sweating which can lead to decreased insulation and enhanced heat loss.

Thermal tolerance

Physiological tolerance to hot or cold environments is a function of both severity and duration of exposure. The core temperature provides the most reliable indicator to predict physical impairment in an environment outside the body's TNZ (Sawka and Pandolf, 2001). Core temperature will continue to rise if evaporative cooling is unable to compensate for the heat gained either from increased metabolic activity or from the environment itself. Humans are better suited to compensate for heat stress, and they are able to tolerate heat stress to a greater extent than cold stress before incapacitation ensues. Heat exhaustion is inevitable when the core temperature goes above 104°F (40°C) (Gonzalez-Alonso et al., 1999). In a cold, dry environment more than one half of heat loss occurs through radiation. Absent appropriate behavioral responses to cold, the minor increase in heat production derived from shivering is often inadequate, and is unsustainable for more than a few hours (Stocks et al., 2004). From a clinical perspective, hypothermia begins as the core temperature falls to 95°F (35°C) or below. There are many common factors that can contribute to the development of uncompensable heat or cold stress. In addition to the more obvious risk factors such as temperature, wind, and humidity, they can include lack of fitness, dehydration, fatigue, and a history of a previous heat or cold injury. One factor that can lead to increased thermal tolerance is acclimatization.

Acclimatization

Acclimatization occurs when prolonged or repeated exposures to an environmental condition lead to significant physiological changes. Heat acclimatization has been shown to greatly improve physical performance, and it leads to greater tolerance for heat exposure (Sawka and Pandolf, 2001). The adaptive changes include increased sweating and earlier onset of sweating, decreased loss of electrolytes through sweat, decreased heart rate, and lower core temperatures. It is theorized that acclimatization to heat changes the thermoregulatory “set point” within the hypothalamus. The majority of the improvement is experienced within the first week of exposure with complete acclimatization by two weeks (Sawka and Pandolf, 2001). The benefits of acclimatization can be partially nullified by fatigue and dehydration, and it is suspected that they are lost shortly after periodic exposure is ended. On the other hand, physiological adaptation to cold is difficult to prove in part due to the behavioral responses invoked by exposure to a cold environment, such as avoidance (Enander and Hygge, 1990). Any adaptation that may occur after repeated exposure to cold is suspected to be relatively minor as compared to those benefits afforded by heat acclimatization.

Clothing and microclimate systems

Protection from environmental extremes can be provided by specialized clothing and systems that can be worn to modify the environment immediately adjacent to the body. Unfortunately, many of the advances in fabrics capable of wicking moisture from the body, thus facilitating heat loss through evaporation, are incompatible with the work environment. More often than not, clothing limits the heat exchange with the surroundings by increasing insulation and inhibiting evaporative heat loss. This can lead to a hot, humid microclimate next to the skin. Even in a cold environment, additional layers of protective clothing may cause significant heat stress, especially when the individual is exposed to a wide range of ambient temperatures over the course of a single duty period. Faerevik et al. (2001) were able to show that standard issue protective clothing worn by aircrew actually shifted the TNZ from to 83°F to 88°F (28°C to 31°C) to a lower range of 50°F to 58°F (10°C to 14°C), and that the clothing hindered evaporative cooling at 65°F (18°C) yet was not sufficiently insulated to prevent shivering at 32°F (0°C). However, their study did not include the wear of protective armor which further inhibits the evaporation of sweat and increases the metabolic cost of physical work. Warfighters operating in uniforms and gear such as shown in Figure 16-6 are at increased risk of uncompensable heat stress especially when exposed to high ambient temperatures. In some cases, the only solution may be the use of an active thermal control system which heats or cools the microclimate within the clothing. Ventilated suits can distribute air over the skin to facilitate evaporation; whereas, liquid cooled garments consisting of interwoven tubing transfer body heat to an external sink through convection.

Immersion

Water is a potent heat sink with a cooling power that far exceeds that of air at the same temperature. Cold water immersion is capable of causing a substantial convective heat loss which can rapidly overcome the body’s ability to maintain its core temperature and subsequently lead to uncompensable hypothermia. The rate of heat loss is a function of the water temperature, the water current, metabolic rate, and the body’s subcutaneous fat content. Shivering offers much less protection in the water due to increased convective loss with movement (Stocks et al., 2004). In general, the greatest performance decrements can be expected to occur in individuals immersed in cold water or those who remain wet and are exposed to cold air (Hoffman, 2001). Therefore, special consideration must be given to the thermal protection utilized in underwater operations.

Figure 16-6. Typical uniform of a U.S. Army Soldier in Iraq circa 2008.

Psychological aspects of performance under thermal stress

Thermal stress is also capable of inducing changes in psychological performance measures. In fact, some researchers believe that changes in psychological measures will often precede critical changes in physiological status (Johnson and Kobrick, 2001). Thus, monitoring certain aspects of behavior can give an early warning of uncompensable thermal stress. Some of the measures used to assess psychological performance include sensory tasks such as vision or hearing, perceptual tasks which require interpretation of environmental changes such as target discrimination, and cognitive tasks that require reasoning or mathematical calculations. A possible explanation for observed decrements in performance under thermal stress is that changes in temperature somehow limit human attention leading to a narrowing of focus in sensory, perceptual, and cognitive abilities thereby forcing task prioritization of finite mental capabilities (Hancock, 1986).

Unfortunately, this field of research is replete with many conflicting reports of the effects of thermal stress on performance (Pilcher et al., 2002). This is likely a result of the diversity in experimental conditions used, the specific performance tasks measured, the severity of the thermal stress, and the duration of the exposure found between studies. Human behavior is influenced by several factors to include the environment, the person, the task, and the situation; and within these are many sub-variables as illustrated in Figure 16-7 (Johnson and Kobrick, 2001).

Thus variations in tasks, conditions, and performance measures can lead to dissimilar outcomes. For example, the simple concept of standardizing the quantification of ambient temperature can become complex quickly when variables such as air velocity, relative humidity, and radiant heat are considered. Furthermore, establishing a relevant measure of the thermal stress induced can be problematic (Enander and Hygge, 1990). Taking the results of multiple studies of the effects of thermal stress on psychological measures, one can conclude that performance is negatively affected by exposure to either heat or cold especially when there is dynamic change in the core body temperature (Hancock, 1986; Pilcher et al., 2002; Wright et al., 2002).

Psychological performance changes in the heat and cold

There are many more studies that have examined the effects of *increased* temperatures on human psychological performance in contrast to the fewer that have studied the effects of *decreased* temperatures. This is probably due to the increased likelihood of exposure to heat stress either in the workplace or through increased body temperature as a result of exercise. As previously mentioned, the results are often difficult to compare. Measures of sensation have found that tactile discrimination is greatest in moderate temperatures (Johnson and Kobrick, 2001), but sensitivity decreases as temperature decreases with measurable impairment at hand skin temperatures

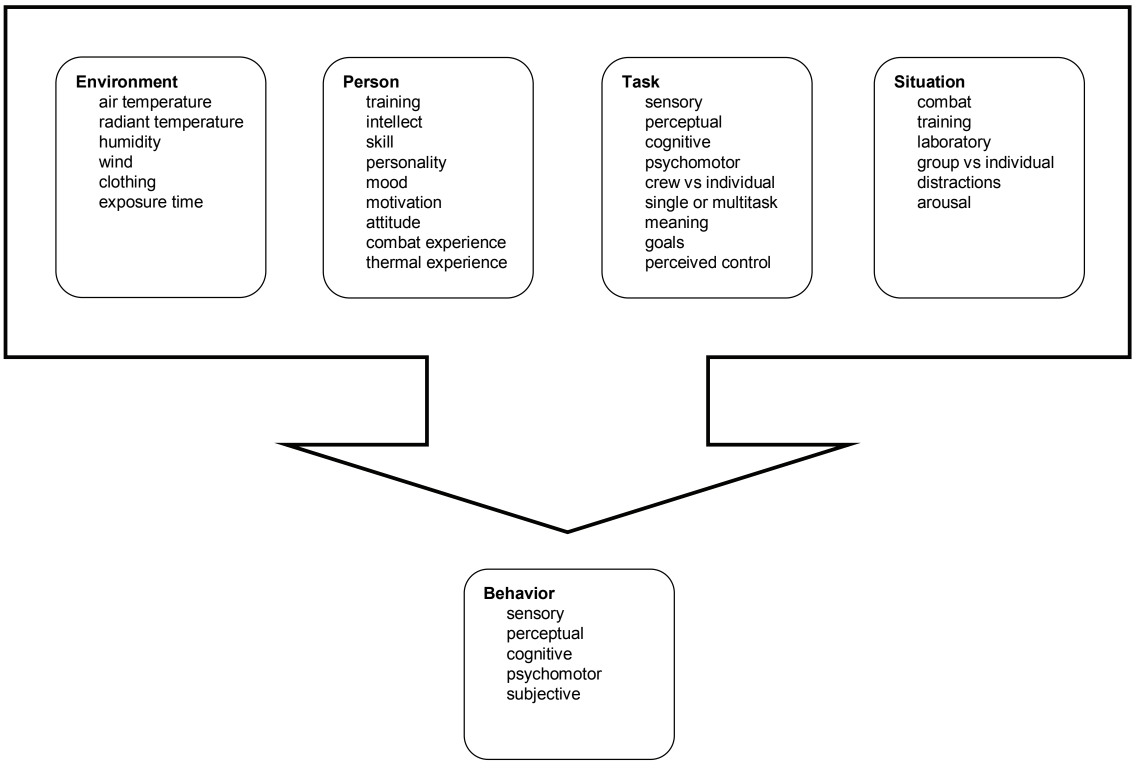

Figure 16-7. Basic psychological model in which behavior is a function of the environment, the person, the task, and the situation (Johnson and Kobrick, 2001).

below 68°F (20°C) (Enander and Hygge, 1990; Hoffman, 2001). The effects of heat on visual acuity and contrast sensitivity were indeterminate (Johnson and Kobrick, 2001); however, there is a valid concern that heat can indirectly interfere with vision through sweat dripping in the eyes and by shifting head gear when the hair, scalp, and helmet interface become wet.

Perception is often measured by subject response times to either visual or auditory stimuli. Higher core body temperatures tend to produce faster response times but lead to more mistakes (Simmons et al., 2008). Mild static hyperthermia improves performance in simple reaction time as long as the body is able to compensate for the thermal stress; whereas, complex reaction times become slower (Enander and Hygge, 1990; Grether, 1973; Hancock, 1986;). Similarly, cold exposure increases the error rate in complex reaction tasks (Enander and Hygge, 1990; Thomas et al., 1989).

There are a wide variety of measures of cognitive functioning which may include target tracking, vigilance, and memory tasks. Vigilance is a complex behavior that consists of attention, alertness, cognition, judgment, and decision making. Visual and auditory vigilance tasks are impaired at elevated ambient temperatures (Johnson and Kobrick, 2001). Psychomotor performance tasks such as tracking, and cognitive functions that require some type of judgment or reasoning are impaired above 85°F (30°C) wet bulb globe temperature (WBGT) (Grether, 1973; Johnson and Kobrick, 2001). Similarly, visual motor tracking is significantly impaired by exposure to temperatures below 10°F (12°C); however, the exposure time does not appear to have a significant effect until the core body temperature begins to drop (Giesbrecht et al., 1993; Hoffman, 2001). In studies of cold water immersion, the speed of complex mental tasks is reduced by one-half at core body temperature below 95°F (35°C), and memory registration is reduced by almost three quarters of what would have been retained under normal physiological conditions (Coleshaw et al., 1983).

Interestingly, physiological adaptation to a controlled environment, or acclimation, does not improve cognitive performance in the heat (Curely and Hawkins, 1983). Nor does acclimation improve the disruption to sleep patterns and sleep effectiveness that is seen during exposure to hot conditions (Johnson and Kobrick, 2001). While acclimation does not appear to be helpful, studies of differential body cooling indicate that head cooling[11] can modulate the detrimental effects of elevated skin and core body temperatures on comfort and alertness (Nunneley et al., 1982; Simmons et al., 2008). This suggests that psychological performance has some correlation with subjective assessments of comfort in both hot and cold environments (Hoffman, 2001; Nunneley et al., 1982).

Conclusions on thermal stress

Thermal stress will compromise cognition, but the level of deterioration is dependent upon the severity of the stress, the resultant core temperature, and the complexity of the task (Giesbrecht et al., 1993; Simmons, 2008; Tikuisis and Keefe, 2007). In hot environments, performance is degraded when thermal homeostasis is disturbed; that is, performance suffers when there is a dynamic change in core body temperature (Hancock, 1986). It is not solely the ambient temperature that affects performance, but the combination of ambient temperature and exposure time that is sufficient to change the core body temperature (Johnson and Kobrick, 2001). In hot and cold environments, cognitive performance decrements will occur when thermal stress becomes uncompensable (Giesbrecht et al., 1993; Simmons et al., 2008).

Many psychological performance measures follow an inverted U-shaped distribution with decreased performance at both higher and lower ambient temperatures (Hoffman, 2001; Pilcher et al., 2002). The nearer the ambient temperature is to the body's TNZ, the less effect it has on performance in both hot and cold environments (Figure 16-8). The range of optimal temperatures may vary by specific task as different types of brain function appear to have different zones of thermal sensitivity with respect to performance (Pilcher et al., 2002; Wright et al., 2002). In general, simple behavioral performance measures show some improvement when core body temperature is statically elevated within a compensable zone; however, the more complex the task the more likely it will deteriorate with exposure to heat or cold (Enander and Hygge, 1990; Wright, 2002).

Implications for HMD design

The head represents only 10% of body surface area, but its potential for heat transfer is amplified because of the extensive vasculature. HMDs that heat the head will tend to increase core body temperature; whereas, HMDs that incorporate some type of cooling device can reduce both thermal discomfort and core temperature thereby improving psychological performance (Nunneley et al., 1982; Simmons et al., 2008). The design of any equipment intended for use in even moderately hot or cold temperatures should take into account the expected

[11] Recent work also has been directed to heat extraction via the hands (e.g., Grahn, Cao and Heller, 2005).

performance decrement in many sensory, perceptual, and cognitive tasks with the understanding that complex tasks, to include vigilance, will suffer impairment to a greater extent.

Of a more practical nature, designers should be cognizant of the indirect effects of hot and cold environments upon human sensation, perception, and cognition. Military uniforms and equipment impose added heat load due to the decreased effectiveness of evaporative cooling as illustrated in Figure 16-6.

HMDs that restrict airflow to the head can exacerbate thermal stress and lead to increased unevaporated sweat that can either drip into the eyes and reduce vision or cause the helmet to shift out of position on the head. In cold environments, users of HMDs can be expected to wear additional clothing to include some type of thermal protection for the head and face as illustrated in Figure 16-9.

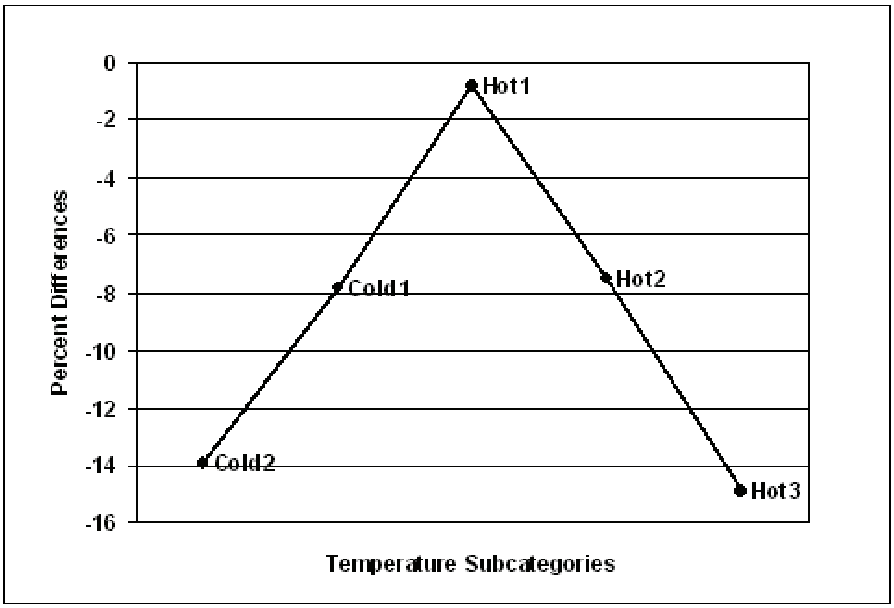

Figure 16-8. Mean percent difference in performance between the neutral temperature groups and the five temperature subcategories. Cold2 = <50°F (10°C); Cold1 = 50°F to 64.9°F (10°C to 18.3°C); Hot1 = 70°F to 79.9°F (21.1°C to 26.6°C) WBGT: Hot2 = 80°F to 89.9°F (26.7°C to 32.2°C) WBGT; Hot3 = 90°F (32.3°C) or greater WBGT (Pilcher et al., 2002).

Figure 16-9. Cold weather gear worn to protect the head and face.

These additional layers necessitate a wide range of image adjustment in order to maximize FOV. Furthermore, gloves worn in both cold and hot environments can restrict manual dexterity and limit tactile sensitivity. Thus, tasks that require fine motor control with the fingers may require additional lighting to allow for visual monitoring in dark or low light conditions. For all military purposes, HMD controls should be designed for operational use with gloves on, and metal surfaces should be coated with rubber to decrease heat conductivity (see later section on *User adjustments* in this chapter).

Thermal stress is a major environmental concern for military operations. Any additional equipment intended to be worn by the Warfighter must be designed and evaluated to minimize (or if possible to reduce) the thermal load.

Altitude threats and hypoxia

"The higher, the fewer…"
-unknown RAF Apprentice
Halton, Buckinghamshire, UK

Warfighter-interface designers must be cognizant of operating environments in order to help foresee and potentially mitigate performance decrements that may Warfighters may incur at high operational altitudes. In the past, when discussing altitude issues and human factors, platform specific categories were reasonable to consider. We still have those full time operators that can be divided into orbital, suborbital, high altitude reconnaissance, fast jet, transport and rotary wing; each with over water and over land caveats. Threats associated with changes in altitude are routinely encountered by pilots and aircrew but are also increasingly experienced by dismounted Warfighters in mountainous operations. In aviation, these dangers exist in both pressurized and unpressurized cabins – especially since a pressurized cabin can become unpressurized in an emergency situation.

However, as we discuss altitude as an operationally relevant factor, the reader should keep in mind that with increasing integration of ground, naval and air assets and the development of joint warfighting doctrine, a single combatant may find himself in multiple environments in quick succession as he executes a mission. Consider a hypothetical example of a 12-hour ingress flight at 50,000 ft and a high altitude parachuting to water at sea level near the objective. After reaching the coast, the Warfighter is required to make an overland trek to 14,000 ft (4,300 m) to reach the mission site. Recovery occurs via helicopter over a 20,000 ft (6,100 m) mountain range and via transport aircraft standing by at a friendly neighboring base. Can HMD devices be designed to be compatible with the wide range of altitude extremes that this Warfighter will experience?

In general, humans live in a gaseous envelope with a set mixture of nitrogen (78%), oxygen (21%), inert gases (1%), carbon dioxide (0.03%), and water vapor (varies) known colloquially as "air." The percentages of these components remain stable as one ascends through the troposphere,[12] but the barometric pressure decreases with distance above the Earth's surface, in an approximately exponential manner, meaning that the partial pressure of available oxygen decrease as well (Dalton's Gas Law).[13] This can lead to both hypoxia and decompression related problems like trapped gas disorders, barotraumas (Boyle's Gas Law)[14] and decompression illness (Henry's Gas Law).[15] Other physical properties that change predictably include temperature (about 2°C per 1000 ft) (Figure 16-10), decreasing humidity, increasing ionization and radiation exposure. HMD designers also should have a

[12] The *troposphere* is the lowest level of the Earth's atmosphere and is considered to extend from the surface of the Earth to an average height of 7 miles (11 kilometers).

[13] Dalton's law (also called Dalton's law of partial pressures) states that the total pressure exerted by a gaseous mixture is equal to the sum of the partial pressures of each individual component in the mixture.

[14] Boyle's law describes the inversely proportional relationship between the absolute pressure and volume of a gas, if the temperature is kept constant within a closed system.

[15] Henry's law states that at a constant temperature, the amount of a given gas dissolved in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid.

general understanding of altitude countermeasures so as to help minimize conflict and interaction with these life support devices.

Hypoxia

Hypoxia can be defined as the lack of adequate tissue oxygen available to support the body's normal metabolism. In healthy individuals, this is usually due to a lack of adequate inspired oxygen and can eventually lead to in-

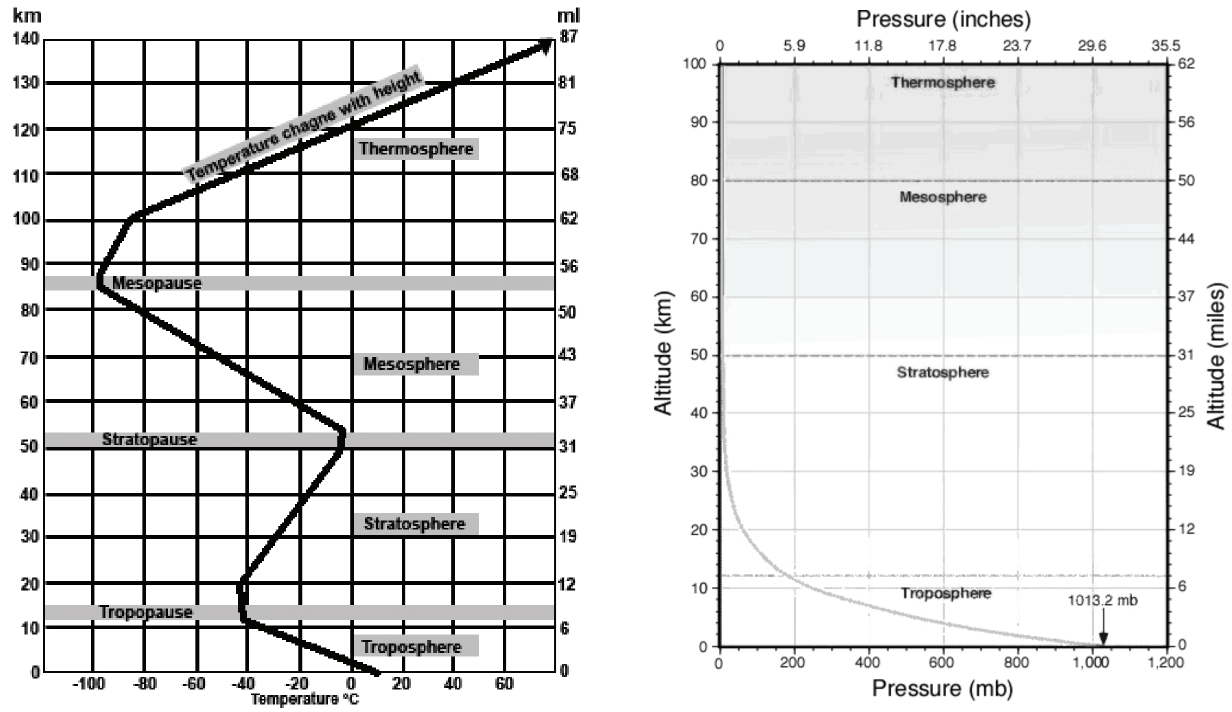

Figure 16-10. Atmospheric temperature (left) and pressure (right) changes as a function of altitude

sufficient energy production, cell dysfunction and, if left unchecked, cell death. It should be noted that the neurologic system is most sensitive to hypoxia, and that even though the brain comprises less than 5% of bodyweight it consumes almost 20% of the oxygen acquired by the circulatory system. This means that higher cognitive functions, as well as vision, are more acutely affected by lack of oxygen. Furthermore, because the brain is affected directly and the symptoms can develop insidiously, the untrained Warfighter is usually unable to detect that he is becoming hypoxic. To further complicate the early detection of hypoxia, individuals vary widely in their initial hypoxia symptom complexes making physiology training in altitude chambers very important for any Warfighters, especially pilots and aircrew, who routinely may operate at high altitudes. Traditionally, extended exposure to cabin altitudes above 10,000 to 12,500 ft (3,050 to 3,800 m) have required supplemental oxygen but recently subtle operationally and physiologically significant effects of hypoxia have been noted at lower altitudes as well (Smith, 2005). Finally, the overall physiologic state of the Warfighter influences the onset of hypoxic symptoms since other factors like alcohol, smoking, general health and life stressors can lower the individual resilience.

Physiologists recognize four types of hypoxia which are categorized based on the cause for the lack of oxygen available to cellular metabolism (Dehart and Davis, 2002). *Hypemic hypoxia* occurs when the body's ability to transport the available oxygen is impaired and may occur due to lack of adequate red blood cells (i.e., bleeding, genetic abnormalities), carbon monoxide poisoning or other chemical poisoning (i.e. sulfa drugs, nitrites). This is analogous to a delivery company not having enough trucks on the road due to fleet shortages or maintenance. In *stagnant hypoxia*, there is a reduction in either regional or whole body blood flow, thereby lessening the delivery of oxygen to tissue. Stagnant hypoxia occurs in heart failure, excessive G-forces, blood clots, tourniquets or strokes. In this case, the delivery company has adequate trucks on the road, but they are stuck in traffic jams or waiting on road construction. *Histotoxic hypoxia* refers to the tissue's inability to accept oxygen that is offered by the circulatory system. It can be caused by metabolic toxins like alcohol, cyanide and some narcotics. By analogy, the delivery company has brought the package to your house, but no one is there to sign for it or accept it, so it goes back on the truck to attempt redelivery the next day.

Hypoxic hypoxia is the most familiar to the aviation community and refers to a lack of available oxygen in the inspired air. As humans ascend into lower atmospheric pressure, the partial pressure of oxygen also decreases meaning that, on a per breath basis, less oxygen molecules are available for the lungs to transfer into the blood stream. For instance, the pressure at 18,000 ft (5,500 m) is only half the normal ground level 760 mm of Hg, so only about half as much oxygen is available to the lungs. Fortunately, due to the design of hemoglobin, the oxygen carrying proteins in red blood cells, there is actually only a 75% to 80% decrease in available oxygen in the blood stream. The non-linear relationship between oxygen saturation and ambient oxygen tension is illustrated in the oxygen dissociation curve (Figure 16-11). Other than altitude, other causes of *hypoxic hypoxia* include asthma, drowning and respiratory arrest. Unlike the previous examples, the delivery company finally has everything in order – enough trucks, clear roads and customers ready to accept packages – but the distribution center has gone on strike leaving partially or completely empty trucks to drive the routes.

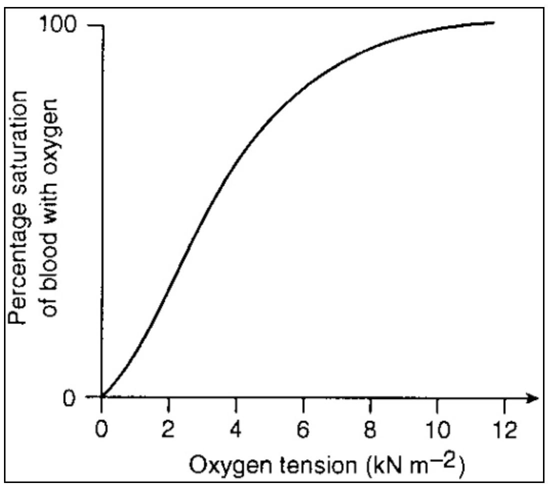

Figure 16-11. Oxygen dissociation curve.

What are the effects of hypoxia? As stated earlier, decrements in higher cognitive functions and visual effects are the most important and obviously observable consequences. Although the exact symptom complexes vary by individual and have an insidious onset, there are generally accepted decrements in functioning that have been divided into four stages: Indifferent, compensatory, disturbance and critical (Table 16-10). Time of useful consciousness (TUC) is defined as the amount of time an individual is able to perform efficiently in a hypoxic environment; after which, the individual is no longer capable of taking proper corrective and protective action. More importantly, it should not be viewed as the time to loss of consciousness.

In studies looking for cognitive deficits, participants exhibited disturbances of memory functions and delayed recall but graphic and semantic memory showed less frequent errors. Simple arithmetical errors, perseveration, impaired visual-motor coordination (jerkiness, illegible writing and poor reproduction of geometric figures) and thought blockage with an inability to complete written tasks were also described. Neuromuscular symptoms of tremor or twitching were noted and later subjects lapsed into a semi-conscious state, mentally switched off and became unresponsive, with eyes open and head upright. Also reported was a feeling of being unable to execute commands, or feelings of euphoria or carelessness, which cast doubt on the ability of these individuals to respond to an emergency (Ernsting, Nicholson and Rainford, 1999; Westerman, 2004).

Table 16-10.
Generalized Hypoxic Symptoms by Stage and Altitude
(Adapted from Reinhart, 1992)

<table>
<tr><th>Altitude (ft)</th><th>Indifferent Stage
O_2 Sat: 90-98%
TUC: unlimited</th><th>Compensatory Stage
O_2 Sat: 80-90%
TUC: >30 min</th><th>Disturbance Stage
O_2 Sat: 70-80%
TUC: 20-30 min</th><th>Critical Stage
O_2 Sat: <70%
TUC: 4-10 min</th></tr>
<tr><td>25000</td><td></td><td></td><td></td><td rowspan="2">Circulatory Failure
Convulsions
Death</td></tr>
<tr><td>20000</td><td></td><td></td><td rowspan="2">Impaired speech
Impaired muscle control
Impaired coordination
Worsening flight control
Impaired visual acuity</td></tr>
<tr><td>15000</td><td></td><td rowspan="2">Drowsiness
Poor judgment
Impaired efficiency
Decreased coordination
Impaired color vision</td><td rowspan="2"></td></tr>
<tr><td>10000</td><td></td><td></td></tr>
<tr><td>5000</td><td>Decreased night vision</td><td></td><td></td><td></td></tr>
</table>

Example of actual cognitive degradation and euphoric indifference experienced by the author during physiologic training: “Once ascent in the hypobaric chamber had been completed, every other student was asked to remove their oxygen mask long enough to develop their distinct hypoxia symptoms. After several minutes of performing cognitive tasks on a clipboard, I stopped and stared straight ahead. When the instructor ordered me to replace my mask, I fully and cheerfully acknowledged the instruction but did not execute the activity. After three requests, the fully oxygenated student next to me was asked to replace my mask and set it to 100% oxygen allowing me to regain full control of my mental facilities.”

Of importance to HMD display design engineers is that decreases in night vision occur at relatively low altitudes during the indifferent stage and that mild hypoxia also impairs some color vision at lower light levels (Connolly et al., 2008). In fact, some research has shown that dark adaptation occurs more rapidly at ground level when supplemental oxygen is supplied to the subject suggesting that some of the tissue in our eyes may normally be somewhat hypoxic (Wangsa-Wirawan and Linsenmeier, 2003). Lower oxygen availability in the cabin air also directly affects the corneas since they get most of their oxygen via diffusion rather than via the blood supply. This becomes even more critical when the ergonomics of an HMD, as in the AH-64 Apache helicopter, requires the use of corrective contact lenses rather than spectacles. Later stages of hypoxia also can lead to visual convergence issues and diplopia, which may of import when considering HMD placement and focal ranges.

Potentially compounding weight and center-of-gravity issues, hypoxia can lead to early and potentially painful neck muscle fatigue over time. This becomes especially acute in higher G-environments and for aircrew that have higher metabolic demands for oxygen due to movement around the cabin or frequent head motion (Smith, 2006).

Consider medical personnel attending to patients en route, loadmasters aboard cargo helicopter or disembarking rescue/recovery personnel that will return to the aircraft after significant exertion.

As discussed earlier, other stressors also affect the overall effect of hypoxic hypoxia. For instance, carbon monoxide, a major component of tobacco smoke, has a 20 times greater affinity for blood than oxygen; given a choice between carbon monoxide and oxygen, the red blood cell will choose the carbon monoxide. This compounds the hypoxic hypoxia with hypemic hypoxia, accelerating symptom development. Some researchers estimate that a regular smoker has a physiologic altitude of 3,000 to 8,000 ft (900 to 2450 m)[16] while at sea level, and he/she will usually display a higher red blood cell count as a result of the chronic hypoxia.

The link between longer mission durations in modern military operations, with its associated extended relative immobility and potential hypoxia, and potentially fatal blood clot formation is the subject of continuing debate. According to some research, prolonged civilian air travel may increase blood levels of clotting factors, particularly among individuals with risk factors for blood clotting disorders. However, it remains unclear whether the reduced cabin pressure and oxygen tension in an unpressurized or partially pressurized aircraft interior creates an increased risk compared to extended immobility on the ground (Toff et al., 2006). From an ergonomic standpoint, however, it would be reasonable to allow aircrew some mobility in their seats and design HMDs that would not further impede the ability to move around, thereby lessening the chance of clot formation.

High altitude illness bears mentioning when discussing altitude effects, but rarely occurs in aircrew. There is however the potential that high-altitude illness may occur if a base station for flight operations is established at altitudes greater than 6000 to 8000 ft (1800 to 2450 m). This syndrome is made up of several symptom complexes including fluid build-up in the lungs called high altitude pulmonary edema (HAPE), brain swelling called high altitude cerebral edema (HACE), retinal hemorrhages, and extremity swelling. High altitude illness generally occurs 1 to 4 days after arrival and there is a tendency for previously acclimatized personnel returning to altitude to fall victim more frequently. The rate of ascent, the altitude attained, the amount of physical activity at high altitude, colder temperatures and individual susceptibility contribute to the incidence and severity of this condition (Hackett, Rennie and Levine, 1976).

Dysbarism

Dysbarism or barotrauma refers to medical problems that arise from the pressure differences between areas of the body and the environment and is a particular concern for aircrew and divers. All involve gases trapped in an enclosed area where pressure cannot equalize during ascent or descent causing pain. This can involve actual air spaces that have become blocked off, referred to as "trapped gas disorders," or be due to the introduction of bubbles in spaces where there should be none, as would be the case is decompression illnesses.

Trapped gas disorders are directly related to Boyle's law (as the pressure increases, the volume decreases and vice versa). As atmospheric pressure decreases, this volume change in trapped gas-filled spaces and organs within your body accounts for the distortion and damage to surrounding tissues leading to pain and occasionally bleeding. Examples can include external ear squeeze, middle ear squeeze, inner ear barotraumas, sinus squeeze, tooth squeeze and gastric squeeze. Rapid decompression at altitude can lead to pulmonary barotrauma (pulmonary over-pressurization syndrome, or burst lung) if aircrew fail to expel air from the lungs during the event. Externally attached devices, depending on their fit and design, have been known to cause problems as well, e.g., mask squeeze and G-suit squeeze, and should be considered in the development of HMDs.

In decompression illness, gas (mostly nitrogen) that was previously dissolved in solution within body fluids forms bubbles inside tissue causing severe pain and neurologic disorders (if the bubbles form in the brain). This process, also known as the "bends" is usually a risk for divers and is explained by Henry's law (more gas will be dissolved in a liquid when the gas is pressurized) interacting with the drop in water pressure when surfacing too

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[16] Throughout this chapter, several different altitude equivalents are given to describe the effects of a number of cigarettes smoked within a certain periods of time. As these values are quoted from different sources, they are subject to variation.

quickly or stay at depth too long. However, it can also be a threat to personnel going to lower atmospheric pressure, resulting in a similar phenomenon.

Other altitude effects

Space borne radiation particles and those ionized particles generated by the collision of these particles with atoms in our atmosphere are collectively referred to as galactic cosmic radiation. In general, our atmosphere combined with the Earth's magnetic field adequately protects us from cosmic radiation, but in certain flight regimes and during disturbances in the Sun's atmosphere, an increased exposure to these charged particles can occur. At higher altitudes there are higher levels of cosmic radiation and aircraft flying at altitudes of 30,000 to 40,000 ft (9,100 to 12,200 m) receive about 100 times greater exposure the ground. The Earth's magnetic field deflects many radiation particles that would otherwise enter the atmosphere and this shielding is most effective at the equator but diminishes at higher latitudes. At the poles, cosmic radiation is about twice as high as at the equator since the magnetic field is essentially nonexistent at the poles. Occasionally, unpredictable solar particle events (SPE), which are ejections of a large mount of charged particles, can lead to sudden increases in radiation levels in the atmosphere. The sun also protects us from cosmic radiation since its heliosphere extends well beyond Neptune and the solar winds intercept many potentially harmful particles. This protection does, however, vary slightly with the 11-year solar cycle; when the sun is at solar max with the greatest number of sunspots, it affords the greatest protection (Friedberg et al., 2000).

Currently, there is no conclusive evidence that ionizing radiation results in significant adverse health effects on long-haul civilian aircrew. However, based on exposure risks and internationally adopted standards, pregnant crewmembers are the only personnel that are at greater risk and these risks are to the fetus only (Chee, Braby and Conroy, 2000). On the other hand, flying higher and lengthier military missions (i.e., reconnaissance, global-reach strategic bombing) might expose aircrew to damaging radiation. Of interest to the HMD developer community is that this exposure potential suggests that the devices must be tested against ionizing radiation failure modes and may require additional hardening for this type of interference.

Lower temperatures at higher altitudes present an obvious thermoregulatory problem for aircrew. At 30,000 ft (9,100 m), for example, the ambient temperature is in the region of -40°C (-40°F). Generally, this is mitigated by having enclosed cockpits with adequate heating systems but in some cases the cabin may not be conditioned or flights may occur in winter conditions. The HMD designer should be aware of this potential hazard and consider effects of vapor precipitation on displays as well as discomfort that could be associated with cold surfaces touching the head.

Also associated with flight into colder and thinner atmosphere is a drop in relative humidity. Although there is no evidence that significant physiologic effects occur due to extended exposure to dry air, substantial subjective complaints of thirst, due to dry mucous membranes, and eye irritation, due to decreased tear film, do occur. In particular, contact lens wearers suffer in these environments and may even lose their lenses or develop corneal ulceration (Dennis, Apsey and Ivan. 1993). This has implications for the design of HMDs that would not allow spectacle use as discussed earlier.

Countermeasures integration

Obviously the various threats that are described here will require some type of countermeasure to lessen the impact of the effect on aircrew and help assure mission success with no loss of life. The mitigation of these threats can take various forms: changes in training, tactics, mission planning, aircraft design and capability and additional life support equipment. Device manufacturers should consider especially the use of oxygen delivery systems and aircrew equipment intended for climatic control. As mention previously in the section on temperature extremes (see *Thermal stress*), this type of integration is key to being able to maintain a useful fit of the device.

An audio device or display that cannot be properly fitted around an oxygen delivery system is equally problematic. As an example, the U.S. Army has recently developed novel oxygen delivery systems like the Portable Helicopter Oxygen Delivery System (PHODS) which utilizes a nasal canulla on a single arm from the helmet (Figure 16-12). As other devices are added to the helmet, minute displacements may cause improper oxygen delivery and lead to subtle hypoxic decrements. More familiar systems of oxygen delivery, each presenting unique human factors issues, include very simple pipe stem systems, various on-demand mask systems and positive pressure systems. Positive pressure systems are more frequently seen in unpressurized fast jet cockpits and usually used above 32,000 ft. It is beyond this altitude that breathing even 100% oxygen is not adequate to properly oxygenate the body due to the low atmospheric pressure and the system begins delivery of oxygen under pressure to avoid arterial desaturation (Ohshund 1991). This type of system must obviously fit very snugly to the face and should not be interfered with by any additional display devices.

Figure 16-12. PHODS device installed on Gentex HGU-56/P US Army helicopter helmet.

Noise

Noise in an acoustical form[17] is defined as any unpleasant or unwanted sound that is unintentionally added to a desired sound. Noise generally is thought of as an auditory problem, e.g., noise can block, distort, or produce a change in the meaning of a communication (see Chapter 13, *Auditory Conflicts and Illusions*). However, noise exposure can have a range of auditory and non-auditory consequences, producing both physiological and psychological effects. At low levels, noise is a distracter and can degrade performance; at high levels, noise can produce temporary and long-term hearing loss. Generally, problems due to noise include hearing loss, stress, high blood pressure, sleep loss and fatigue, distraction, and lost productivity. Considerable effort has been undertaken to develop and provide noise protection to the Warfighter operating in the military environment. However, protective devices often are considered by individuals to be detrimental to the tasks at hand and are not employed as frequently or as effectively as is needed to prevent physiological damage.

Characteristics of auditory noise

Noise is sound, albeit undesirable sound. Noise is a series of changes in sound pressure levels that are created by a source, transmitted via some medium (usually air), and collected and interpreted by the auditory system. Therefore, noise can be defined by all of the general characteristics of a sound wave: frequency, phase, amplitude,

[17] The term noise is often categorized as audio or electronic. Audio noise is used in the music industry to describe unwanted sounds encountered in audio, recording and broadcast systems. Electronic noise refers to unwanted additions to signals in electronic circuits; shot and thermal noise are two of the most common types.

and wave velocity. The response of the human auditory system to the presence of noise will depend on these characteristics (see Chapter 9, *Auditory Function*). Like other sounds, noise is generally complex, consisting of a combination of frequencies.

It is not just the intensity that determines whether noise is hazardous. The duration of exposure is also important. The terms *steady-state* and *impulse* often are used to characterize the duration of sound and hence noise. Steady state noise has negligible fluctuations of level within the period of observation; it is continuous, by definition lasts more then one second, and includes such sources as vacuum cleaners, hair dryers, electrical power generators, lawn mowers and idling engines**.** Impulse noise is very intense and of short duration, usually less than a second. Examples include backfires from motor vehicles, sonic booms and weapons fire. Impulse noise is more difficult to characterize than steady-state noise (Hamernik and Hsueh, 1991).

Noise levels are measured in decibels (dB), a logarithmic unit of measurement that expresses the magnitude of a physical quantity (e.g., sound intensity) relative to a reference level. As the dB expresses a ratio of two quantities with the same unit, it is a dimensionless unit.[18] A normal conversation is at approximately 65 dB SPL;[19] shouting typically can be around 80 dB. To take into account the fact that the human ear has different sensitivities to different frequencies, the intensity of noise is usually measured in A-weighted decibels (dB(A)).[20] The hazard threshold for steady-state noise is 85 dB(A) – the sound of some power lawn mowers – and for impulse noise, 140 dB(P)[21] – the sound made by some machine guns. The noise level for discomfort is 120 dB(A) – the sound of a jet airplane on takeoff, as heard by someone 164 ft (50 m) away. Pain may occur when sounds are louder than 130 dB(A) – the sound of a live rock music concert (Rash, 2006).

Environmental noise

Noise is ubiquitous, with an almost limitless number of natural and artificial sources. The Warfighter can expect to encounter constant and high levels of noise; this is especially true in and around both ground and air military vehicles. In addition, while combat may increase the frequency and intensity of noise exposures, training activities produce equally dangerous noise environments. Paakkonen and Lehtomaki (2005) report that noise episodes in combat and training exercises reaching a peak level of 180 dB. Average noise exposure levels for military exercises were measured outside the ear at approximately 95 to 97 dB and in the ear canal at 82 to 85 dB. Peak levels of 110 to 120 dB for military trainers were measured in the ear canal during the use of small-bore weapons.

The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), maintains a list of noise levels for common U.S. Army equipment on its web site (U.S. Army Center for Health Promotion and Preventive Medicine, 2008). Steady-state noise for selected vehicles, aircraft and power equipment are presented in Table 16-11; impulse noise values for selected armament and munitions are presented in Table 16-12. (Note: Impulse noise levels are measured in a "peak"-related decibel form known as dB(P)).

While not the nosiest military vehicles, helicopters do present the most complex noise environments. Noise spectra for helicopters are comprised of aerodynamically-induced noise from the main and tail rotor assemblies, main gearbox and various transmission chains (Rainford and Gradwell, 2006). In addition to the steady-state noise produced by the engines, mechanical components and airflow, there is impulse noise, commonly called blade slap, caused by the blade-vortex interaction (Schmitz, 1995; Widnall, 1971).

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[18] The decibel (dB) is one-tenth of a bel (B). The dB is used in a variety science and engineering disciplines.

[19] Sound pressure level (SPL) is the term most often used in measuring the magnitude of sound. It is a relative quantity in that it is the ratio between the actual sound pressure and a fixed reference pressure.

[20] A-weighting began with the work of Fletcher and Munson (1933) that resulted in a set of equal-loudness contours corrected for the normal sensitivity profile of human hearing.

[21] Decibel Peak dB(P) is used for peak sound level equal to 20 times the common logarithm of the ratio of the highest instantaneous sound pressure to a reference pressure of 20 micropascals. It is used in the measurement of impulse noise.

Table 16-11.
Measured steady-state noise levels for selected U.S. Army Equipment.
(U.S. Army Center for Health Promotion and Preventive Medicine, 2008)

Model	Name/Condition	Location	Speed km/hr(mph)	Sound Level dB(A)
M996, M997	HMMWV* mini and maxi ambulance, at two-thirds payload	Patient areas	up to 88(55)	Less than 85
M113A3 family	Armored personnel carrier A3 version		Idle 16(10) 32(20) 48(30) 63(40)	85-92 106 109 114 118
M1A2, M1, M1A1	Abrams tank	In vehicle	Idle 16(10) 48(30) 63(40)	93 108 114 117
M2A2	Bradley fighting vehicle	In vehicle	Idle 16(10) 32(20) 61(38)	74-95 110 115 115
MEP-802A	5 kW Tactical quiet generator	Operator panel	Rated load	80
CH-47D	Chinook helicopter	Cockpit	Cruise speed	102.5
UH-60A	Black Hawk helicopter	Pilot Copilot	Cruise speed	106 106
OH-58D	Kiowa helicopter	Right seat Left seat	Cruise speed	101.6 100.3
AH-64	Apache helicopter	Pilot Copilot	Cruise speed	104 101.3

** High Mobility Multi-wheeled Vehicles (HMMWV)*

An interesting paradox with engine-driven vehicles is that sounds can be perceived as both noise and important information simultaneously. For example, aircraft pilots can tell much about the operating conditions of engines by their sounds. Pilots learn to identify specific engine problems by the change in their sounds.

Naval ships face a common high-noise problem due to the need to conduct operations in closely confined areas. The U.S. Navy Center, Norfolk, VA, reports that older ships were not designed using the noise reduction techniques employed on modern ships. Even for newer ships, a number of high-noise areas cannot be avoided. On aircraft carrier flight decks, flight operations are confined to a 4.5-acre (18,200 m^2) area as compared to land-based flight operations that are normally conducted on 10,000 acres (40.5 square kilometers). Noise levels on the flight deck can exceed 145 dB(A). Noise sources on the flight deck include aircraft engines, catapults, and arresting gear equipment. Below the flight deck is the gallery deck in which approximately 1400 sailors live and work. The high noise levels directly above adversely impact most of the gallery deck. Gallery deck noise levels, often in excess of 100 dB(A), can have the effect of reducing cognitive skill levels and cause miscommunication problems, both frequently identified as causes of fatal accidents (U.S. Navy Safety Center, 2008).

Aside from aircraft-related noise, all ships have noise associated with the ship propulsion, i.e., ship propeller excitation on the ship structure. The excited structure then re-radiates as airborne noise. Ventilation systems are often a significant source of shipboard noise. Because of space constraints, air ducts used aboard ships are often very small and have sharp curves and bends. This results in air moving through the ducts at very high velocities, causing noise and vibration in the ventilation system. Fans can also project noise throughout the ventilation system if they are poorly mounted, not properly isolated from air ducts, or are the wrong size. Finally, noise may be generated at the air duct outlets that distribute air in the work environment if proper design parameters are not followed. Poor ship design can provide transmission paths (e.g., through ventilation ducts) for noise to travel from the noisy machinery spaces to berthing accommodations and workspaces (U.S. Navy Safety Center, 2008).

Table 16-12.
Measured impulse noise levels for selected U.S. Army Armament and munitions.
(U.S. Army Center for Health Promotion and Preventive Medicine, 2008)

Model	Name	Location	Sound Level dB(P)
M16A2	5.56-mm rifle	Shooter	157
M9	9-mm pistol	Shooter	157
M2	0.50 caliber machine gun fired from a HMMWV*	Gunner	153
M26	Grenade	At 50 ft	164.3
M72A3	Light antitank weapon (LAW)	Gunner	182
M109A5/6	Paladin, 155mm self propelled howitzer firing M4A2 zone 7 charge	In fighting compartment, hatches open except driver's	166.1
M29A1	81 mm mortar, M374A3 round with charge 4	1 m from the muzzle, 0.9 m above ground, 135° azimuth	178.8

* *High Mobility Multi-wheeled Vehicles (HMMWV)*

Physiological effects of noise

Noise can produce a host of physiological effects, such as headache, fatigue, nausea and insomnia. The major physiological effect of noise exposure is hearing loss. Noise-induced hearing loss (NIHL) can be either temporary or permanent. A temporary hearing loss is a brief shift in the auditory threshold that occurs after a relatively short exposure to excessive noise (more than 90 dB). Fortunately, for such loss, normal hearing recovers fairly quickly after the noise stops. However, if the noise level is sufficient to damage the tiny hairs in the cochlea – the part of the inner ear that is responsible for transforming sound waves into the electrical signals that go to the brain – the threshold shift can be irreversible, resulting in permanent partial or total hearing loss (Rash, 2006). Research has determined that individuals exposed to steady state sound levels of 85 dB(A) for an 8-hour period or longer are in danger of losing their hearing. Likewise, exposure to impulse noises of 140 dB(P) can result in hearing loss (U.S. Army Center for Health Promotion and Preventive Medicine, 2008).

In a review of noise-induced health effects, Soames-Job and Hatfield (2000) cite the following studies and findings:

- Occupational studies having demonstrated that noise exposure contributes to hearing loss (Morata, 1999; Ward, 1993), and may have a detrimental impact on cardiovascular health (Talbott et al., 1996).

- Noise has also been found to impair performance both in occupational (Smith, 1989) and educational settings (Haines et al., 1998; Hygge, Evans and Bulinger, 1998).
- Community surveys demonstrate negative reactions (Fields, 1994; Hatfield and Job, 1998; Job, 1988) and sleep disturbance (Griefahn, 1992; Griefahn et al., 1998; Ohrstrom, Bjorkman and Rylander, 1990; Pearsons et al., 1995) resulting from noise exposure.
- Noise associated with entertainment (e.g. loud music) has been found to have deleterious effects on hearing (Axelsson and Prasher, 1999).
- The effects of aircraft noise on children's blood pressure are uncertain (Cohen et al., 1980; Morrell et al., 1998).
- Although suggestive of a greater prevalence of psychiatric illness amongst residents of high noise areas, the evidence is inconclusive (Abey-Wickrama et al., 1969; Jenkins, Tarnopolsky and Hand, 1981; Kryter, 1990).

In a study of audiometric data of 54,057 Navy enlisted personnel in the Navy and Marine Corps Hearing Conservation Program database from 1995 to 1999, Bohnker at al. (2002) compared threshold shift patterns with historical literature. The data suggest that 82% of the population did not display significant threshold shift (STS) on the *annual* and *termination* audiograms, which increased to 94% after the follow-up examinations. Compared with historical data, STS rates were significantly lower for the most junior enlisted personnel (E1-E3) but not significantly different for more senior enlisted personnel. STS rates were found not to appear to correlate with expected high- and low-noise exposure Navy enlisted occupations.

Performance effects of noise

Hygge (2003) states that a number of studies on the effects of noise on cognition and human performance report the general finding that the task being performed has to be complex and cognitively demanding in order to be negatively affected by noise (e.g., Smith, 1989; 1992). Tasks that are simple and repetitive are unaffected by noise, and if the task is boring, simple enough, or well learned, that noise may even improve performance. Thus, a search for noise sensitive tasks must focus on tasks having a moderate or greater level of complexity and are demanding on cognitive resources. He also states that noise effects on cognition is a fairly covered area in psychological noise research, citing a number of studies that have compared the relative impacts on attention, reading, memory and learning (Cohen et al., 1986; Evans and Hygge, 2002; Evans and Lepore, 1993).

Many of the recent studies on the performance effects of noise have been conducted on children and are based on exposure to aircraft and traffic noise. One reason for this is that groups of children (mostly school age) serve as convenient and less confounded samples. While children are known to have a greater susceptibility and hence show a greater response to noise, findings of these studies often are extrapolated to adults. A representative study (Stansfeld et al., 2005) reported a linear association between exposure to (external) aircraft noise and impaired reading comprehension and recognition memory, and between exposure to road traffic noise and episodic memory (in terms of information and conceptual recall). Results also showed non-linear and linear associations between aircraft and road traffic noise, respectively; annoyance also showed a linear association with road traffic noise. Neither aircraft noise nor road traffic noise was found to have affected sustained attention, self-reported health, or mental health.

In studies involving adults, high background noise levels (>90 dB(A)) typically are found to reduce the quality of performance. A number of studies have demonstrated that noise hinders performance on cognitive tasks involving vigilance, decision-making, and memory (Broadbent, 1971; Salas, Driskell, and Hughes, 1996; Smith, 1989). However, these studies typically involved artificially-generated noises in artificial settings, and exposure was usually short-term (i.e., hours). However, in an investigation of the effects of background noise over a 70-hour period on cognitive performance of astronauts on the International Space Station showed "little to no effect of noise on reasoning, perceptual decision-making, memory vigilance, mood, or subjective indices of fatigue" (Smith et al., 2003).

In a noise study more relevant to the issues of displays, Choi (1983) investigated whether noise intensity and display orientation had any effect on short-term memory task. Results showed that continuous white noise[22] at intensity levels of 30, 85, and 105 dB had no effect on the short-term memory task.

More specifically to HMDs, noise (with the exception of the example of pilots using engine noise to monitor engine performance) is to be attenuated by a helmet to which the HMD is integrated or attached. Therefore, HMD systems are expected to provide an acceptable level of sound (noise) protection.

Noise protection

Warfighters generally wear protective head gear or helmets. Depending on the application, helmets can provide a combination of impact, penetration, sun, windblast and noise protection. Maintaining the necessary hearing protection for the military noise environments, while providing high performance voice communications, is a goal of the HMD designer. Historically, the quality of voice communication has been reduced as noise protection has been emphasized. An example of this is the use of earplugs which block both unwanted sound (noise) and wanted sound (communication voice). Two newer technologies that overcome this problem are the Communication Enhancement and Protection System (CEPS) and active noise reduction (ANR). (See Chapter 5, *Audio Helmet-Mounted Displays*.)

The CEPS is a system designed to control the sound level that arrives at the ear and provide the user with dual radio communications. An expanding foam earplug attenuates ambient sounds that enter the occluded ear canal. The system integrates highly sensitive microphones, rapid response micro-circuitry that inputs the sound to the ear through the miniature earphone of the communications earplug (CEP) that is attached to the expanding foam earplug. The user can control the volume of the signal reaching the ear by contact switches. The device was designed to provide enhanced sound detection capability and localization in "recon" or "watch" modes; enhanced face-to-face communication for night, Mission Oriented Protective Posture (MOPP) or military operations on urban terrain (MOUT) operations; and two-way radio communications in stealth mode. It provides protection for both hazardous impulse and continuous noise environments and rapid cut-off and recovery protection for weapons firing (Gordon and Houtsma, 2008; Mozo and Murphy, 1998).

ANR, first conceived in the 1930s and refined in the 1950s, did not become prevalent in aviation until the 1990s (Tennyson, 2001). In conventional ANR headsets, the frequency and amplitude of the sound inside the headset cavity are measured by a small microphone, and a 180° out-of-phase copy is produced and fed back into the headset. The result is that the two signals superimpose and cancel each other. This out of phase canceling technique is very effective for low frequencies, below 800 Hz, but is generally ineffective for higher frequencies. In some designs, the ANR device actually increases the noise level inside the ear cup in the region of 1000 Hz. Total hearing protection consists of the passive protection provided by the ear cup and the ANR component provided by the electronic system. Studies show ANR does improve speech intelligibility when worn alone, but both hearing protection and speech intelligibility are degraded when worn with ancillary equipment such as spectacles or chemical-biological mask (Gower and Casali, 1994; Mozo and Murphy, 1997).

An interesting challenge for noise protection has been the introduction of inflatable restraints (airbags) into rotary-wing aircraft (Crowley and Dalgard, 2000). In the civilian community, the effectiveness of airbags in reducing deaths in automobile accidents is well known. However, studies have documented incidents of hearing loss associated with airbag deployment (Huelke et al., 1999; Morris and Borja, 1998). The U.S. Army has studied the use of airbags in helicopters as early as 1991 (Alem et al, 1991a; 1991b; Shanahan, Shannon and Bruckart, 1993). A Cockpit Airbag System (CABS) has been developed for the UH-60A/L Black Hawk and OH-58D Kiowa helicopters. To support airbag fielding, the U.S. Army Aeromedical Research Laboratory, Fort Rucker,

[22] White noise is defined as random noise that has uniform power spectral density at every frequency in the range of interest.

AL, has conducted tests to determine the risks to crewmembers and passengers associated with exposure to high impulse noise levels expected during an inadvertent system deployment (Brozoski et al., 2000). A series of 21 airbag deployment tests were conducted in a static UH-60A helicopter. Peak sound pressure levels ranged from 134 dB to 161 dB. Levels at pilot, copilot, and gunner stations exceeded 140 dB during all 21 deployments. Levels in the passenger compartment exceeded 140 dB during 9 of the 21 deployments. Army policy requires the aircrew in the UH-60 helicopter to wear helmets that provide hearing protection or a combination of helmet and earplugs. Passengers are required to wear protective earplugs or muffs or a combination of muffs and earplugs. This level of hearing protection also meets the requirements for protection against high impulse noise levels created by the deployment of airbags. Therefore, if the required hearing protective devices are worn, the potential of inadvertent deployment of the CABS in the UH-60 helicopter has been determined not to pose an additional risk to the hearing of crew and passengers (Ahroon, Gordon and Brozoski, 2002).

The noise protection provided to many Warfighters is a given, as the need to wear a helmet is integral to the Warfighter's mission. However, many military personnel perform tasks in high-noise work environments where helmets, with their inherent protection,[23] are not employed. In these situations, less sophisticated but equally effective hearing protection devices are made available (e.g., earplugs and earmuffs). For these individuals, the command structure must institute and enforce a policy of requiring effective use of such hearing protection devices. However, Abel (2008) has documented user concerns of hearing protection interfering with detection and localization of auditory target warnings and perception of orders. In addition, users frequently complain that devices were often incompatible with other gear and difficult to fit.

Vibration

Modern-day work is more mechanized than in the past (Kjellberg, 1990). This is equally true in both civilian and military environments. A consequence of this mechanization is increased human exposure to *vibration*. For the moment, vibration will be defined as a *to and fro* motion about a point of equilibrium. For a discussion of human exposure, vibration can be categorized as either *localized* or *whole body* (Mansfield, 2005)

Localized vibration, also referred to as hand-arm vibration (HAV), is most associated with the use of various types of vibrating pneumatic, electrical, hydraulic, and gasoline powered hand-tools. However, such hand or hand-arm transmitted localized vibration can be equally associated with more mundane and common actions, e.g., holding onto a steering wheel. As is obvious from the name, HAV is coupled almost exclusively via the hand-arm combination.

Whole-body vibration (WBV) affects the whole of the exposed individual – all parts from head to toe. Most WBV is related to riding in vehicles, e.g., trucks, buses, and fork-lifts in the civilian community; and tanks, helicopters, personnel-carriers, and boats in the military community. WBV is transmitted via seats, backrests, or through the floor, coupling through the buttocks, back or feet.

Human effects due to vibration depend on whether the exposure is acute (i.e., having a rapid onset and short duration) or prolonged and usually are grouped into three categories: physiological effects (including the very common occurrence of motion sickness), psychological effects, and performance effects.

In the civilian world, WBV has been studied extensively by researchers in the field of occupational medicine. While strong correlations between WBV and long-term physiological consequences have been established, it has been difficult to separate these effects from those associated with straining during heavy lifting and poor posture (Cardinale and Pope, 2003; Hulshof and Veldhuizen van Zanten, 1987; Seidel and Heidel, 1986). Low-back pain is a common complaint after exposure to WBV and has been shown to be a major cause of disability in the population under the age of 45 years and has been linked to WBV exposure encountered in some industrial

[23] Noise protection in aviation flight helmets has been a long-pursued development goal. However, most U.S. Army Warfighters wear the Army Combat Helmet (ACH), which has no added hearing protection.

settings (Cardinale and Pope, 2003). Additional suspected health effects due to prolonged exposure include hemorrhoids, hernias, digestive disorders, and urinary problems (Hedge, 2008).

In the military environment, low-back pain has been a long-standing health problem for helicopter pilots and ground-vehicle drivers exposed to prolonged WBV. Seat design, sitting posture and vehicular vibration are often identified as high-risk factors (Bongers et al., 1990; Ensign et al., 2000; Pelham et al., 2005; Wasserman, 2003). Vibration has been a problem in aviation ever since aircraft were fitted with engines (Lam, 2003). As reciprocating engines became commonplace, multiple nodes of vibration developed in the airframes, with intensity and effects varying by location. In helicopters, however, vibration is aircraft-wide, affecting all crewmembers. As in the civilian industrial community, while the medical impact of vibration has not been proven, it generally is accepted that there is a distinct relationship between the presence of vibration and the chronic low back pain often experienced by helicopter pilots and military vehicle drivers.

In addition to physiological effects, vibration can lead to psychological effects such as discomfort and annoyance. Lam (2003) has emphasized that while vibration causes chronic and acute fatigue in operational aircrew and leads to chronic back pain, its significant effects on operational performance must not be overlooked. For example, the utility of sights and vision-enhancing devices (e.g., HMDs) is degraded in the presence of severe vibration.

The physics of vibration

Before expanding the various effects of vibration on the human in detail, it is necessary to improve on the initial superficial definition of vibration as a “to and fro motion” about a point of equilibrium. This will be accomplished using a more rigorous description of vibration from the point-of-view of physics. In physics, the phenomenon of vibration is a subset of oscillatory motion. Oscillations can be several types, e.g., electrical, electromagnetic, mechanical, electro-mechanical, optical, biological, and chemical. The term *vibration* usually is reserved for mechanical oscillations, i.e., to describe a mechanical movement that oscillates about a fixed point (Figure 16-13). Classical examples include a tuning fork, playground swing, oscillating spring, and simple pendulum. Within the context of this chapter’s discussion of adverse operational factors in the military environment, examples include helicopters and motorized vehicles. As a mechanical form of oscillations, vibrations are propagated via a mechanical coupling.

In the example of Figure 16-13, imagine that a piece of colored chalk is attached to the oscillating mass and the chalk is in contact with a long sheet of paper being pulled along as the mass goes through its oscillation. The result will be a simple waveform like that shown in Figure 16-14. As the mass on the spring moves through its up and down motion, the chalk will trace multiple complete motion paths or *cycles*. The number of cycles per unit time defines the *frequency* of the vibration. The standard unit for expressing frequency is the Hertz (Hz), defined as one cycle per second (cps).

Along with frequency and amplitude, a third characteristic is needed to fully define a waveform – *acceleration*. The speed of a vibrating object varies from zero to a maximum during each cycle. It moves fastest as it passes through its stationary position towards its maximum displacement (amplitude). It slows down as it approaches the full amplitude, where it momentarily stops and then moves in the opposite direction passing again through the equilibrium position toward the other maximum displacement position. Speed is expressed in units of distance per unit time (e.g., meters per second [m/s] or feet per second [ft/s]). Acceleration is a measure of how quickly the vibrating object’s speed changes with time. Acceleration is expressed in units of meters per second per second (or meters per second squared [m/s^2]). The magnitude of the acceleration changes from zero (at the equilibrium point) to a maximum (at full amplitude) during each cycle; it increases as the vibrating object moves further from its normal equilibrium position.

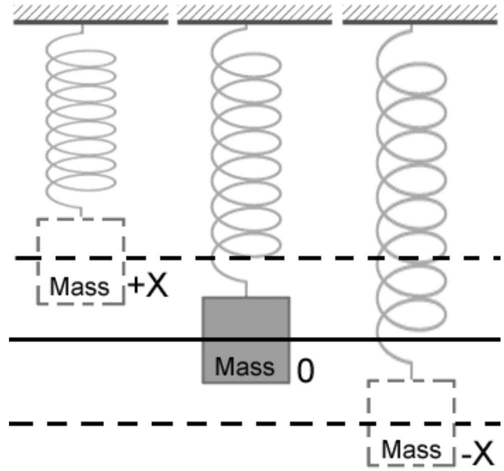

Figure 16-13. Vibration as oscillation about a fixed point, as demonstrated by an oscillating spring.

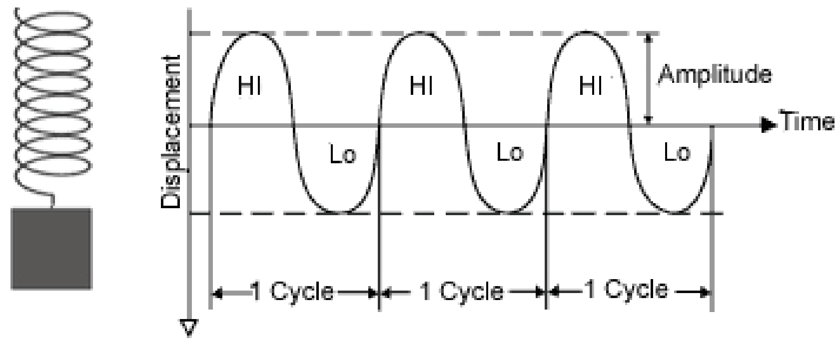

Figure 16-14. The waveform resulting from the motion of a mass attached to an oscillating spring.

Acceleration is the characteristic most frequently used to quantify vibration levels[24] and is measured via a sensor/transducer known as an accelerometer. The piezoelectric accelerometer is the most popular class of these devices; other types are based on piezoresistive, capacitive, and servo transducer technologies.

The vibration waveform presented above is a simple one with only one frequency and amplitude present. It is said to be sinusoidal (i.e., having the form of a sine wave). In the real world, most vibrations are complex, consisting of multiple frequencies and amplitudes.

Complex waveforms (vibrations) are the result of several forcing frequencies occurring at the same time (Figure 16-15). In this case, the resulting vibration will be a summation of the vibration at each frequency. Under these conditions the resulting waveform of the vibration will not be a sinusoid, and may be very complex.

Before leaving the physics discussion of vibration, one special topic stills needs to be introduced – *resonance*. Nearly all objects, when hit or struck, will vibrate, and tend to vibrate at one or more particular frequencies, which depend on the composition of the object, its size, structure, weight and shape. These frequencies of natural vibration are called the *resonant frequencies*. A vibrating object in contact with a second object transfers the maximum amount of energy to the second object when the first object vibrates at the second object's resonant frequencies. At these frequencies, even small oscillating driving forces can produce large amplitude vibrations,

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[24] Vibration magnitude is generally measured in terms of the acceleration of the oscillations, rather than the velocity or displacement between peak-to-peak movements. The preferred International System (S.I.) unit for vibration acceleration magnitude is meters-per-second-per-second (m/s^2), and measurements are often expressed as root-mean-squared (rms) values rather than peak values.

because the system stores vibration energy. This phenomenon is called resonance. The resonant frequency of the human body is approximately 4 to 5 Hz.

A classic aviation example of resonance is ground resonance with helicopters having fully-articulated rotor systems. When a helicopter is resting on the ground with its rotor spinning, a condition called ground resonance can develop. This is a destructive harmonic vibration caused by a dynamic reaction of the rotor blades to the lateral motion of the helicopter. The helicopter can be destroyed by this resonance in periods as short as minutes.

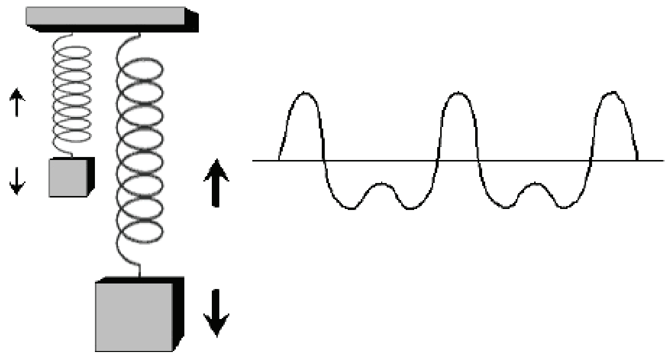

Figure 16-15. A complex waveform resulting from the summation of two sources at two different frequencies and amplitudes.

Human WBV generally occurs in three axes: fore-to-aft (x-axis), lateral (y-axis) and vertical (z-axis). Rotational vibration about the x-, y- and z-axes (called roll, pitch and yaw, respectively) may also occur (Nakashima and Cheung, 2006). The vibration frequency range that is considered important for health, comfort and perception is 0.5 to 80 Hz (International Organization for Standardization-ISO, 1997).[25] Human WBV resonance occurs in the vertical (up-down) direction at frequencies from 4 to 8 Hz. In the lateral and fore-to-aft directions, WBV resonance occurs at 1 to 2 Hz. It is at these resonant frequencies that humans are most vulnerable. The occupational vibration standards attempt to define and compensate for these potentially hazardous human resonant frequencies (Wasserman, 2003).

Physiological effects of noise

The physiological (i.e., health) effects of HAV and WBV are distinctly different, as might be expected based on differing vibration exposure patterns and pathways into the human body (Wasserman, 2003). For this discussion, we will focus on the effects of WBV, and readers are directed to both classical and modern treatises on HAV and its effects (Hamilton, 1918; Pelmear and Wasswerman, 1998; Wasserman, Taylor and Behrens, 1982).

A considerable body of scientific literature exists on the effects of human exposure to WBV. It has been shown that these effects can be either short-term or long-term. Short-term effects include annoyance, discomfort, fatigue, motion sickness, a temporary shift in hearing threshold, reduced motor control, and impaired vision. In addition, although cause and effect has not been proven, long-term and repeated exposure to WBV has been linked to chronic back pain. The degrees to which these effects are manifested depend largely on the characteristics of the vibration and include the frequency, magnitude and duration of exposure; other factors include posture and seating station design (where applicable).

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[25] The range of frequencies that is most often associated with whole-body vibration is still a point of conjecture. While the 1997 ISO standard cites 0.5 to 80 Hz, Griffin (1990) uses an approximate range of 0.5 to 100 Hz.

Discomfort

Discomfort and fatigue are the lesser of the physiological effects of WBV. Vibration factors impacting these effects include exposure duration, magnitude, and frequency. Intermittent and random vibration can have a wakening effect, but continuous exposure can lead to increased fatigue or drowsiness. A few studies have shown a possible link between long-term exposure to low-frequency (3 Hz) vibration and fatigue (Mabbott et al., 2001). As not enough data have been collected to establish meaningful exposure limits, ISO 2631-1 (1997) states, "There is no conclusive evidence to support a universal time dependence of vibration effects on comfort."

Nakashima (2004) suggests that "it is intuitive that an increase in vibration magnitude will lead to increased discomfort." However, the same magnitude of vibration will not produce the same level of discomfort at all frequencies. Studies of the combined effects of vibration magnitude and frequency on discomfort have found that the growth in sensation, ψ, with increasing vibration magnitude, Φ, has been found to agree approximately with Stevens' Power Law, given by

$$\psi = kn\,\Phi$$ Equation 16-2[26]

where k is a constant that depends on the system of units, and n is a frequency dependent growth function.

As stated previously, vibration is an ever-present condition in the aviation community – for the pilot, aircrew and ground crew. Aircraft ground and maintenance crew are exposed to noise levels that are sufficient to induce WBV (Smith, 2002). Whether on the ground or in the air, for frequencies between 100 and 1,000 Hz, a 120 dB noise signal will cause tissue vibration. Below 100 Hz, the airborne vibration can cause movement in the body cavities and air-filled or gas-filled spaces; this can induce symptoms such as nausea, coughing, headache and fatigue (cited in Smith, 2002).

Auditory effects

Research into the effects of WBV on auditory functions is sparse, most being retrospective studies that may identify associations but not cause and effect. The reason for this is that such studies would expose human subjects to unacceptable vibration levels. However, Nakashima (2004) does present a summary of the limited research to investigate temporary hearing loss, or temporary threshold shift, due to vibration:

- Early studies by Temkin (1927), Pinter (1973), and Pyykko et al. (1981) suggested that low-frequency hearing loss was intensified in workers who were exposed to both noise and vibration (cited by Hamernik, Ahroon and Davis, 1989; Nakashima, 2004).
- Okada et al. (1972) studied the effect of noise and vibration, both separately and in combination. They found that 5 Hz vibration with an acceleration of 5 m/s^2 produced a threshold shift of more than 7 dB at 1 kHz and 4 kHz after a 1-hour exposure. The 5-Hz vibration is significant because it is approximately equal to the resonance frequency of the human body. Other vibration frequencies (2, 10 and 20 Hz) caused smaller amounts of threshold shift. A greater threshold shift was reported for exposure to vibration in combination with noise than for exposure to noise alone.
- Hamernik et al. (1989), upon a review of the literature, hypothesized that vibration "may potentiate the effects of noise and may thus increase the risk of hearing loss in a variety of exposure situations." However, studies reviewed that involved humans were limited to low levels of exposure and the

[26] This equation is derived from the more conventional form of Stevens' Power Law (1975) expressed as $\psi = k\Phi^B$, *where* ψ is the magnitude of the sensation, Φ is the intensity of the stimulus, B is a characteristic of any given stimulation continuum and indicates how rapidly the magnitude of the sensation (ψ) grows as the stimulus intensity (Φ) increases, and k is a proportionality constant that depends on the type of stimulus and units used.

reported effects measured were relatively small. Animal studies reviewed also shown an enhanced noise-induced hearing loss in the presence of vibration, but the scope of these studies were limited. They reported their own animal studies in which chinchilla were tested using a 30-Hz/3G root-mean-square (rms) and a 20-Hz/1.3-G rms cage vibration separately and in combination with continuous noise (a 95-dB, 0.5-kHz octave band) and impact noise (113--, 119-, or 125-dB peak SPL) exposure paradigms. All exposures had a 5-day duration. Temporary and permanent threshold shifts were measured using evoked potentials, and sensory cell loss was measured using surface preparation histology. The results obtained from some of the noise/vibration paradigms showed that such exposures can alter some of the dependent measures of hearing. This effect was found to be statistically significant only for the stronger vibration exposure conditions and was evident primarily in the extent of the outer hair cell losses and in the shape of the permanent threshold shift (PTS) audiogram.

- Other studies have also reported temporary threshold shift after prolonged exposure to 5-Hz vibration, which is at the resonance frequency of the human body (see review by Griffin, 1990).

Back pain

One of the most commonly reported physiological effects of WBV is back pain. Back pain is a common complaint for industrial vehicle operators and passengers as well as for military personnel (in ground vehicles, most fixed-wing aircraft, and rotary-wing aircraft [helicopters]). Teschke et al. (1999) identifies a number of confounding factors in trying to establish cause and effect between vibration and back symptoms: age, physical condition and working posture. It has been suggested that repeated and long-term exposure can lead to serious back problems such as herniated discs or premature degeneration of the spinal vertebrae (in Nakashima (2004). The human spine has a resonance frequency of approximately 5 Hz, and the frequencies at which vibration is most effectively coupled to the spine are 4.5 to 5.5 Hz and 9.4 to 13.1 Hz.

Back pain frequently is reported by helicopter aircrew. The pain is most likely to be felt by the pilot in-flight and has been attributed to both the vibration of the seat and poor posture. Seat cushions are the only devices that mitigate the direct link between the aircraft and the pilot's body. In addition, pilots often must assume a forward-bending posture in order to achieve maximum visibility and precise control, which places increased pressure on the intervertebral disc. Motivated by complaints of fatigue and back pain during increased frequency of extended flight missions (6 to 8+ hours) by pilots flying during Operation Iraqi Freedom and Enduring Freedom, Harrer et al. (2005) investigated WBV exposure for U.S. Navy MH-60S pilots. Pilots were exposed to continuous (WBV. Pilot fatigue is a growing operational concern due to the increased frequency of extended durations of missions (6 to 8^+ hours) in support of Operations Iraqi Freedom and Enduring Freedom. The then current rotary wing seating systems were not optimized for the longer missions and wide range of pilot anthropometric measurements, which is now typical of naval aviation. The current seating systems were designed primarily to meet crashworthiness requirements, not for the wide range of pilot anthropometry or to mitigate WBV. Current Hazard Reports (HAZREP) indicated that pain in both pilots' legs and backs begin 2 to 4 hours into the flight and increase with time. Situational awareness also decreases with an increase in flight duration due to the constant distraction of pilots shifting in their seats while flying to get comfortable. Froom (1987) reported a dose-response relationship between the length of military helicopter flights and back discomfort. He also concluded that this pain is typically dull, over the lower back, and its prevalence and intensity are dependent on the total flight hours of exposure.

The Harrer et al., (2005) study compared the effectiveness of three different seat cushions, the current seat cushion versus two anti-vibration seat cushions (A and B). The three seat cushions were measured for acceleration levels averaged over five-minute intervals using a triaxial seat pad accelerometer. The recordings were completed for several round-trip straight and level flights. A frequency analysis from 0 to 80 Hz was conducted on all acceleration measurements to determine the dominant axis and frequency of the pilots' vibration exposure. The results were then compared to the applicable Threshold Limit Values (TLVs) established by the American

Conference of Governmental Industrial Hygienists (ACGIH) (2005) to determine the MH-60S pilots' permissible exposure time for all three seat cushions.

The results showed that pilots of the MH-60S could operate the helicopter with the current seat cushion for less than 6 hours and the anti-vibration seat cushion B for approximately 8 hours without being overexposed to WBV. The anti-vibration seat cushion A increased the stay-time to approximately 16 hours. Since the average flight during a deployment or mission could last in excess of 8 hours, exposure with the current seat cushion would place the pilots at an unacceptable risk of injury, lack of mission readiness, and possible equipment damage. As helicopters are to be outfitted with auxiliary fuel tanks to accommodate the long-duration missions, this will further extend a pilot's overall sitting (exposure) time. In order to lower the pilots' exposure to WBV and reduce potential safety mishaps, the study recommended that the current MH-60S's be retrofitted with the anti-vibration seat cushion A.

Of course, WBV is not just an aviation problem; it also is a concern in all tactical vehicles. Army Regulation (AR) 40-10, *Health Hazard Assessment Program in Support of the Army Material Acquisition Decision Process* (1991), requires all new tactical vehicles and aircraft to be evaluated for potential WBV health hazards. Moran and Butler (1993) conducted one such evaluation of the U.S. Army's M9161A1 Truck Tractor. The vehicle was tested in bobtail (no trailer), unloaded, and loaded configurations for each of the three test terrains. The results showed that the lowest tolerance levels were experienced on the Belgian block course,[27] with less severe WBV occurring on the cross-country course, followed by the primary terrain course. The results also show the passenger exposure limits were consistently lower than the driver's. The evaluation recommendation for the M916A1, operating in its intended environment, was that WBV be limited to the following passenger exposure limits for each test condition: WBV is not to exceed 17.1 hours in any 24-hour period on the paved surfaces for all configurations. Exposure limits for the cross-country terrain are 5.5, 5.2, and 6.1 hours in any 24-hour period for the bobtail, unloaded, and loaded configurations, respectively. For the Belgian block terrain, WBV in any 24-hour period should not exceed 1 hour for both bobtail and unloaded conditions and 2 hours for the loaded configuration.

The use of HMDs aggravates the effects of vibration on pilots, vehicle drivers and crew. Originally designed for crash and impact protection, helmets in many applications now serve as platforms for mounting displays, chemical protective masks, oxygen systems, and laser and flashblindness protection systems. All of these add-ons increase head-supported weight (HSW), which in turn contributes to increased biomechanical stress/strain on the muscles of the neck that are responsible for controlling head movements (Butler and Alem, 1997).

The impact of helmet/HMD weight can be characterized by the total system mass and change in center-of-mass (CM) (offset) due to the addition of the helmet/HMD to the normal head-neck CM. The helmet/HMD mass and CM combine to create a torque that must be counterbalanced by the muscles in the back of the neck to maintain upright posture. The head, too, creates a torque that attempts to rotate the head, moving the chin downward towards the chest. The torques from the helmet/HMD system and the head combine to create a torque that is larger than the torque due to the head alone. The pivot point through which this torque operates is on top of the cervical spine and is known as the atlanto-occipital (AO) complex (Sobotta, 1990). Figure 16-16 shows the head, the location of the A0 complex on top of the cervical spine, and the locations of the head center-of-mass and the helmet center-of-mass. Force vectors also are shown located at each center-of-mass. These force vectors must be counterbalanced by the muscles in the back of the neck.

The total head-supported mass is not the only factor affecting the stress on the posterior neck muscles. The presence of WBV, as is always true in tactical vehicles and aircraft, can causes the head to pitch up and down (Paddan and Griffin, 1988). This pitching motion causes an involuntary stretch response in the posterior muscles of the neck that further increases the amount of force produced by these muscles. The duration of both training and combat missions requires the posterior muscles of the neck to exert counterbalancing forces for a greater period of time than required under more natural conditions. These factors affect the amount of biomechanical

[27] The Belgian block was an oval cobblestone road approximately ½-mile long with an irregular pattern of 3-inch crests.

stress experienced by the posterior neck muscles and play a role in determining a reasonable head-supported mass limit for Warfighters.

Psychological effects of vibration

Human response to WBV exposure can be psychological as well as physiological. The psychological aspect deals with the level of tolerance, which depends to a great extent on the on the environment and the task being performed (Nakashima, 2004). For example, higher magnitudes of vibration would likely be tolerated, or deemed acceptable, in a mass-transit railroad train rather than in a luxury automobile.

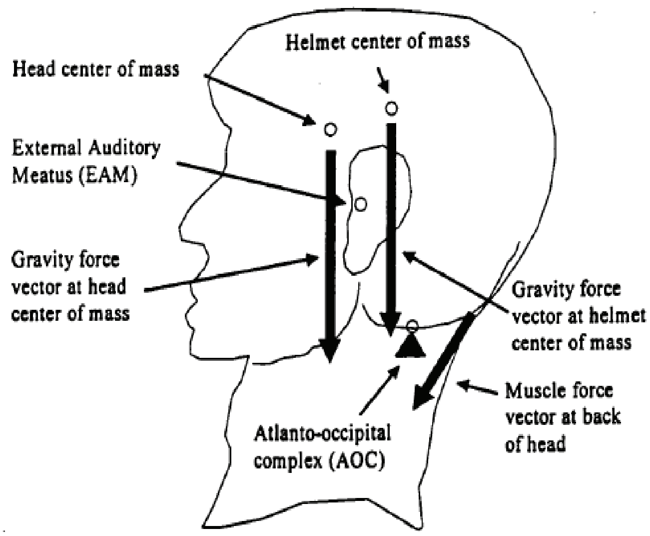

Figure 16-16. Head and neck profile showing the A0 complex, head center of mass, helmet center-of-mass, and force vectors representing the gravity field and the posterior of the neck.

Before the values of a detrimental stimulus become unacceptable to a human from the perspective of degradation in performance or onset of physiological effects, there is a range of levels of the stimulus that may be tolerated but described as *annoying*. Such is the case for short-term or low-amplitude vibrations. It is well known that noise, or unwanted sound, can interfere with speech communication, degrade concentration and interrupt sleep patterns (Nakashima, 2004). However, when the noise is low frequency, a vibration of the body and the surrounding area also may result, which may influence the human perception and acceptance of low-frequency noise. For example, in mechanized environments, the presence of rattle and vibration can increase the level of annoyance (Berglund and Hassmén, 1996; Howarth and Griffin, 1990). Field surveys on the effects of noise and vibration from railway traffic found that residents who were exposed to combined noise and vibration expressed a higher degree of annoyance than those exposed to noise alone (Ohrstrom, 1997; Ohrstrom and Skanberg, 1996).

Performance effects of vibration

If the visual display and its viewer are exposed to vibration that results in an out of-phase oscillation with respect to each other, a blurred image will be seen. Thresholds for this blurring effect depend on the magnitude and frequency of the vibration and can be calculated. In general, the threshold acceleration increases in proportion to the viewing distance and the square of the frequency (Nakashima, 2004). The frequency range of approximately 2 to 20 Hz is associated with such display vibration. Above 20 Hz, the threshold accelerations for blur are rarely encountered (Griffin, 1990). In aircraft, head-up displays and HMDs are collimated by a lens to reduce the image distortion caused by translational vibration. Stabilization systems that move the image on the display can counteract the rotational motion of the head, resulting in greater legibility (Griffin, 1990).

Vibration can affect performance by introducing alignment issues or by interfering with peripheral motor and sensory functions (Kjellberg, 1990). Lewis and Griffin (1976) suggested that interference with kinesthetic feedback mechanisms may be a principal means by which vibration degrades performance in tracking tasks, important in targeting HMDs. While studies have shown that the performance of tasks involving simple reaction time are not significantly affected, vibration has been shown to have a negative affect on more complex cognitive tasks, such as those involving short- and long-term memory. However, the relationships between vibration frequency and magnitude on performance are unclear (Nakashima and Cheung, 2006).

Not surprisingly, as the optics in many HMD designs is frequently levered out from the face, HMDs are particularly susceptible to the effects of WBV (Wells and Haas, 1992). Furness (1981) reported that, at some frequencies, the reading error produced with a panel-mounted display, was present in HMDs at approximately one-tenth of the vibration amplitude. Wells and Griffin (1987a) reported that the number of numerals read correctly from the HMD in a helicopter decreased from 2.4 per second while stationary on the ground to 1.0 per second during in-flight vibration. The reason for the vibration-induced decrement in performance is relative motion between the line-of-sight and the optical axis of the HMD. Rotational oscillation of the head causes vibration of the HMD, but the eyes, under the influence of the vestibular ocular reflex (VOR),[28] remain space-stable (Benson and Barnes, 1978). The VOR, which normally serves to keep images stable on the retina during body movement and vibration, acts to degrade performance with HMDs.

Vibration is also a factor in the use of helmet-mounted sights and head-coupled systems, where head movement is used to direct weapons, sensors, and other systems. Under normal circumstances a person can aim his/her head at a stationary target with pitch and yaw errors as small as 0.1° rms (Wells and Griffin, 1987b). Tracking moving targets with the head is easily learned (Wells and Griffin, 1987c) and, depending on the difficulty of tracking the target motion, can be accomplished successfully. WBV disrupts both head-aiming and head-tracking. With random vibration, aiming at a stationary target is disrupted by the vibration-induced head motion (vibration breakthrough). However, the decrement in head-tracking during vibration is greater than the sum of the decrement caused by tracking and the decrement caused by vibration breakthrough (Wells and Haas, 1992). It is likely that the additional decrement results from attempts to reduce the error between the head-mounted reticule and the target, which is due to lags in the response of the head, result in greater error.

From the perspective of alignment, HMDs require wearers to maintain their eye(s) within the exit pupil(s) of the HMD. Most HMDs have sophisticated and often complex fitting techniques to maintain this alignment. Helmet slippage due to sweat challenges this alignment so does vibration. Smith (2004) conducted a study to characterize cockpit seat and pilot helmet vibration in jet aircraft during aircraft carrier flight operations. Accelerators were used to measure triaxial accelerations at the seat base, seat pan, seat back, and HMD in the F/A-18C (Hornet) jet aircraft. Data were collected during flight operations on two aircraft carriers for a total of 11 catapult launches, 9 touch-and-goes, and 4 arrested landings. Of particular interest was the substantial low frequency seat and helmet vibration observed during the catapult launch. During the stroke period, seat and helmet vertical (Z) accelerations reached 6G and 8G peak-to-peak, respectively, and occurred in the frequency range of 3 to 3.5 Hz. The associated helmet pitch reached peak-to-peak displacements ranging between 9° and 18°. The large helmet rotations were believed to be associated with helmet slippage that can cause partial or complete loss of the projected image on an HMD (vignetting). This is highly undesirable when using the HMD as the primary flight reference. The study recommended that one goal of HMD designers should be "to develop helmet-mounted equipment design guidelines that consider hostile vibratory environments."

Nakashima (2004) in a discussion of cognitive effects of vibration cites two studies. First, Harris and Shoenberger (1980) studied individual and combined effects of noise and vibration on cognition by monitoring

[28] The VOR consists of the constant adjustments of the image in the retina of the eye by the nuclei of the brain stem, which receives information from the eyes, the neck, trunk, cerebellum, and cerebral cortex.

the ability to perform a complex counting task. Twelve male subjects were exposed to 65 or 100 dBA broadband noise, with and without 0.36 rms G-vibration (in the vertical). The vibration was a quasi-random sum-of-sines signal composed of five frequencies: 2.6, 4.1, 6.3, 10 and 16 Hz. The complex counting task involved keeping a simultaneous count of the number of flashes of three lights that flashed at different rates. The study concluded that exposure to broadband noise in combination with a complex vibration signal had a negative effect on the cognitive performance of the subjects, compared to exposure to noise alone.

In the second study, Ljungberg, Neely and Lundstrom (2004) also investigated the effect of combined exposure to WBV and noise on the short-term memory performance. Fifty-four subjects were randomly assigned to low (77 dBA noise and 1.0 m/s^2 vibration), medium (81 dBA noise and 1.6 m/s^2 vibration) or high (86 dBA noise and 2.5 m/s^2 vibration) levels of exposure for duration of 20 minutes. The noise signal was helicopter noise with a dominant 21-Hz component. The memory task involved observing two, four or six letters on a screen for a period of 1, 2 or 3 seconds, after which a probe letter appeared. The subject had to indicate as quickly as possible if the probe was present in the previous list of letters. The subjects stated that it was more difficult to perform the task when exposed to combined noise and vibration, and the high exposure group indicated the highest levels of annoyance. However, no evidence was found for the hypothesis that combined noise and vibration degraded cognitive performance compared to one stimulus on its own. The authors stated that the results were inconsistent with Harris and Shoenberger (1980). Nakashima stated that "the inconsistencies among the results of experimental studies on the effect of combined noise and vibration on cognitive performance are indicative of the complexity of interaction between the two stimuli. There is currently no concrete evidence to support that whole-body vibration exposure has a negative effect on cognition."

Much work has been done in reducing the modes of vibration in modern helicopters. Nonetheless, except for cruise flight, the helicopter cockpit is still a high vibration environment. This is even more so for rear crew stations that do not have the same seat designs as the front cockpit. This vibration affects both the aircraft and the aircrew. The effects of vibration manifest themselves as retinal blur, which degrades visual performance, and as physiological effects, whose resulting degradation is not fully understood (Biberman and Tsou, 1991). Rotary-wing aircraft differ in their vibrational frequencies and amplitudes and these vibrations are triaxial in nature. However, in general they have a frequency range in all axes of 0.5 to 100 Hz. However, specific frequencies of significant amplitude are associated with the revolution rates of the rotor, gears, engines, and other mechanical components (Boff and Lincoln, 1988). The largest amplitude frequency occurs at the main rotor blade frequency multiplied by the number of blades. Other frequencies having significant amplitude include the main rotor frequency (~7 Hz); two, eight, and twelve times the main rotor frequency; tail rotor frequency (~32 Hz); twice the tail rotor frequency; and the tail rotor shaft frequency (~37 Hz). These vibrations are transmitted to the head through the seat and restraint systems (peak transmission, 3 to 8 Hz). They are typically in the vertical and pitch axes and are affected by posture, body size, and add-on masses, such as HMDs. However, the transfer function of these vibrations to the eye is not straightforward. The activity of the vestibulo-ocular reflex stabilizes some of the vibrational transfer, mostly low frequency. However, visual performance degradation still will be present. To further complicate this scenario, the vibrational transfer function to the helmet and HMD is different from that to the eye. While the general influencing factors are the same, e.g., posture, body size, etc, the helmet/HMD mass is also a factor. The result is a very complex frequency and amplitude relationship between the eye and the HMD imagery, which results in relative motion between the imagery and the eye (Wells and Griffin, 1984).

Vibration standards

There are numerous occupational vibration standards used worldwide for both HAV and WBV. The standards have been established to address: human health and comfort, the probability of vibration perception, and the incidence of motion sickness. In the U.S., the occupational standards used for HAV are:

- ANSI S3.34, Human Exposure to Vibration Transmitted to the Hand, Guide for Measurement and Evaluation of. (American National Standards Institute, 1986).[29]
- ACGIH-HAV, Hand-Arm Vibration Standard. (American Conference of Governmental Industrial Hygienists, 2001).
- NIOSH #89-106, Criteria for a Recommended Standard for Occupational Exposure to Hand-Arm Vibration. (National Institute for Occupational Safety and Health, 1989).

For WBV, the standards in the U.S. are:

- ANSI S3.18, Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration. (American National Standards Institute, 2002).
- ACGIH-WBV, Whole-body vibration: TLV physical agents (American Conference of Governmental Industrial Hygienists, 2001).

International standards include:

- ISO 5349 (for HAV), Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration. (International Organization for Standardization, 2001).
- European Union Directive 2002/44/EC (for HAV and WBV) – The minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). (The European Union, 2002).
- ISO 2631-1997 (for WBV) – Mechanical vibration and shock: Evaluation of human exposure to whole-body vibration. (International Organization for Standardization, 1997).

Acceleration

Acceleration is to the aviation system what jolt and vibration are to ground systems, and in the high-G acceleration world of aviation operations, the pilot operator, rather than system design, is the limiting factor in system performance. Modern military aircraft routinely operate in a high-G environment. Additionally, a high sortie[30] rate and sustained operations is the "norm." Therefore, pilots must be in excellent physical and mental condition to perform their duties, both in training and in combat. Acceleration forces on the human body are important to understanding in-flight performance because of their effects on the cardiovascular, pulmonary, and vestibular (orientation) systems. The ability to overcome the effects of acceleration becomes more important as aircraft are designed with greater maneuverability and performance. The ability to combat the adverse effects of G-forces depends directly on one's level of physical condition and ability to reduce negative life stressors.

Before G-forces are discussed in depth, several basic terms are defined below to help the reader understand acceleration and how G-forces are generated.

Physical principles

Speed is the rate of motion (or how far one travels in a certain amount of time), irrespective of direction. An example is flying at 360 knots groundspeed. *Velocity* describes both a rate of motion (speed) and a direction of motion. An example of velocity is 360 knots groundspeed on a heading of 180°. *Acceleration* is a change in velocity per unit time and is generally expressed in feet per second per second (ft/s^2) or meters per second per

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[29] While still used, this standard has been replaced by ANSI S2.70-2006: Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand. (American National Standards Institute, 2006).
[30] Sortie – a mission flown by a military aircraft.

second (m/s^2). Acceleration is produced when either speed or direction (or both) change. One very familiar type of acceleration is that due to gravity. Gravity affects anything on or near the Earth. The acceleration produced by gravity (g) is a constant, 32 ft/s^2 or 9.8 m/s^2. Therefore, a free-falling body will increase its velocity by 32 ft/s or 9.8 m/s for every second it falls. The inertial force resulting from the linear acceleration of gravity acting upon a mass is termed 1G. Therefore, when we discuss G-forces in the flying environment, we are referring to the inertial force resulting from acceleration. Generally, G-forces are dimensionless and expressed as multiples of Earth's gravity, e.g., 5G.

Types of acceleration

There are several types of acceleration. *Linear* acceleration is a change in speed (increase or decrease) without a change in direction. For example, linear acceleration occurs when an aircraft is in a takeoff roll or landing rollout. *Radial* acceleration is a change in direction without a change in speed. When a body moves in a circular path with constant linear speed at each point in its path, it is also being constantly accelerated toward the center of the circle under the action of the force required to constrain it to move in its circular path. This acceleration toward the center of path is called radial acceleration. Radial acceleration occurs when an aircraft pulls out of a dive, pushes over into a dive, or performs an inside or outside turn (and does not change its speed). In these examples, the aircraft's direction changes, but the airspeed remains the same. *Angular* acceleration is a simultaneous change in both speed and direction. Angular acceleration is the most common type of acceleration for aviators and occurs during most aerial maneuvers. For instance, when an aircraft performs a split-S maneuver,[31] the aircraft's speed and direction change simultaneously and the crew experiences angular acceleration.

As an aircraft accelerates in one direction, inertial forces act on the body in the opposite direction of the applied force. The inertial force causes the body to experience a G-force. The following section discusses the types of G-forces a crewmember experiences and the physical factors influencing the effects of G-forces on the body.

Acceleration is experienced primarily across three axes: fore and aft (x-axis), side to side (y-axis) and head to foot (z-axis) (Figure 16-17). The three types of G-forces can be further classified into transverse G, negative G, positive G, and lateral G. By determining the direction of the force and its axis, the type of G can be specified. G-forces can be experienced along other axes as well, but the force applied along the z-axis has the most significant effect on aviator performance. For instance, a force applied from the head towards the feet is a positive Gz force (+Gz) and a force applied from the feet towards the head is a negative Gz force (-Gz). Transverse G-force is the force applied to the front (+Gx) or back (-Gx) of the body. +Gx and -Gx forces are normally encountered during takeoffs, acceleration in level flight, and landing. The maximum transverse G-force tolerable to humans is roughly 15G in the +Gx direction and about 8G in the -Gx direction. Lateral G-forces (the Gy direction) are experienced during spin or roll; however, the effects are negligible. Aircraft are equipped with an accelerometer (G-meter) that monitors G-forces during flight. It displays instantaneous G, maximum positive G, and maximum negative G. The dial also indicates the maximum permissible G-force the aircraft can sustain, both positive and negative.

The maximum tolerance for G acceleration (both in number of G's and time) for each of the different axes at an onset rate of 25G per second (G/s) are (US Navy Aircraft Investigation Handbook, April 1988):

x-axis: 83 +Gx / 0.04 s, 25 -Gx / 2.0 s
y-axis: 9 +Gy / 0.10 s, 9 -Gy / 0.10 s
z-axis: 20 +Gz / 0.10 s, 15 -Gz / 0.10 s

[31] The *split-S* is an air combat maneuver primarily used to disengage from combat. To execute a split-S, the pilot half-rolls his aircraft inverted and executes a descending half-loop, resulting in level flight in the exact opposite direction at a lower altitude.

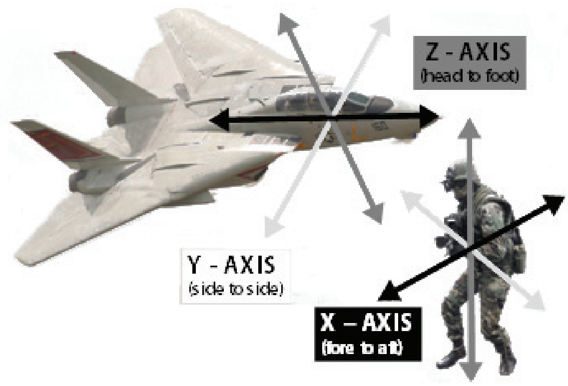

Figure 16-17. Acceleration is a dimensionless parameter and occurs in three axes.

Specific body tolerance is determined by the magnitude of the G-force, the duration of exposure to the G-force and the rate of application (or onset) of those forces. The magnitude of the G-force is the size of the G-force applied to the body. The greater the magnitude of acceleration and accompanying inertial force, the greater the resulting G-force. For instance, a crewmember pulling +6 Gz is being accelerated to six times the gravitational force of the Earth, or 192 ft/s^2. Modern fighter aircraft, like the F-18 and F-16, are capable of exposing the pilot to sustained 8G to 9G. Duration of exposure to the G-Force is another determinate of the effects of the G-force on the body. For example, jumping from a table one meter high results in a decelerate force of about 14G for a fraction of a second, usually with no ill effects. But, being exposed to 14G for over 2 seconds will result in significant physical and physiological effects. Rate of application (or G-onset) directly influences the effect of a G-force. Rate of G-force application is expressed in G per second (G/s). To illustrate the effect of G-onset, imagine dropping a brick on someone's foot versus placing a brick of identical mass on the person's foot. The dropped brick has a greater physical effect on the foot than the brick placed, even though both bricks are identical in mass; the difference is in the rate of acceleration and the resultant inertial force. Acceleration or G-forces along the Z-axis (e.g., accelerated/decelerated turns or maneuvers; positive or negative acceleration) are of special concern in aviation because of the adverse impact on human systems such as the cardiovascular, cerebral, respiratory and visual systems. For example, the average time to a visual symptom (grayout)[32] of +Gz exposure is determined by the rate of G-onset. The slower the onset, the longer the time to grayout in the low to moderate G ranges.

Physical considerations

Several factors or physical considerations (of the operator) determine the effects of G-forces on the body. These factors help explain why certain G-forces have different effects on the body and why the body reacts to certain types of G-forces in different situations. It is important to note that some of these factors are interrelated and have a combined effect on the crewmember.

Previous G-exposure effects G-tolerance. For example, the push-pull effect (PPE) is a phenomena of reduced +Gz tolerance when preceded by exposure to Gz that is less than +1Gz. It is thought that the less than +1Gz exposure causes a cardiovascular relaxation which can affect subsequent +Gz tolerance. A -Gz exposure for a

[32] A grayout (or greyout) is a transient loss of vision characterized by a perceived dimming of light accompanied by a brown hue and a loss of peripheral vision. .It is a precursor to fainting or a blackout and can be caused by hypoxia, a loss of blood pressure or restriction of blood flow to the brain.

duration of less than 2 seconds can significantly affect +Gz tolerance, possibly reducing tolerance by up to 1.5G (dependent upon magnitude and duration of the –Gz exposure). Maneuvers that produce the PPE include dive attacks, extensions, air combat maneuvering guns defense and split-s maneuvers. PPE can reduce G-tolerance by 30% to 40%. However, another aspect of previous G-exposure is the fact that the body can be prompted to prepare for increased G. The G warm-up is a maneuver consists of a very controlled exposure to increased G that prepares the pilot for higher G follow-on maneuvers.

Positive G-force effects G-tolerance. As mentioned earlier, positive G-force is the force applied from the head towards the feet. It is expressed as +Gz. It occurs during turns and dive recoveries and is the G-force most often experienced by crewmembers. Physiological tolerance to positive G is usually indicated by visual symptoms. Blood pooling in the lower extremities usually begins at 1 to 3 +Gz. This decreases head level blood pressure, and at higher +Gz blood flow to the brain ceases (there is generally a 22 mm Hg drop in head level arterial pressure per additional "G"). Initially, the decreased blood pressure results in gray-out of the visual system (between 3 to 4 +Gz). However, the brain has only a 4- to 5-second oxygen reserve and once the oxygen reserve is used, unconsciousness results. The average resting tolerance to +Gz is 5.5G and by 4 to 5 +Gz crewmembers may begin to blackout, with most pilots experiencing gravity-induced loss of consciousness (G-LOC) by 5 to 6 +Gz. With high-G onset rates, unconsciousness can happen without any preceding visual cues, so preventing G-LOC is a blood pressure control game. The pilot must perform an anti-G straining maneuver (AGSM) or unload the Gs immediately. The AGSM sustains blood flow during the critical period of G onset and can provide 3.5 to 4 +Gz of protection provided it is performed correctly. The AGSM is performed by tensing the skeletal muscles (particularly in the lower extremities and the abdomen), cyclic breathing, and exhaling against a closed glottis. The AGSM is started prior to G onset and does not stop until the aircraft returns to 1G flight.

Our bodies are conditioned to live in a positive-G environment; accordingly, we have an increased tolerance to positive G's. However, negative G-forces are not tolerated well by humans, mostly as a result of physical discomfort.[33] A negative G-force is defined as the force being applied from the feet towards the head and is expressed as -Gz. Negative G-force adversely effects G-tolerance; exposures to negative G (between 0 to -1G) for as short as 2 seconds can reduce tolerance by as much as 1.5G during subsequent "pulls" to positive G. Fortunately, -G conditions are seldom experienced in high levels during normal flight. Normally, -Gz is experienced when the nose of the aircraft is lowered during a "pushover" or when experiencing turbulence. In -G maneuvers, the baroreceptors sense the increased blood pressure at the brain level and in response open up the peripheral blood vessels to try to decrease blood pressure with slowing of the heart rate. The physical symptoms of -Gz are a sense of weightlessness, congestion in the head and face, headache, and visual blurring. Blood begins pooling in the head at about 1 -Gz and vision can be affected with as little as 2.5 -Gz. Some flyers have reported a phenomenon called "redout," a reddening of vision during sustained negative Gz flight, however, the causes of redout are not completely understood. The limits of human tolerance (due to physical discomfort) to -Gz begins to appear at - 2.5 to -3Gz , and greater than -3Gz can be physically incapacitating. Currently there is no practical method to counteract the effects of -Gz. Under normal conditions; the only way to combat the effects of -Gz is to reduce aircraft maneuvering and return to a 1-G environment.

Physiological effects and symptoms

Prolonged exposure to G-forces affects the body in four principle ways – restricting mobility, affecting the cardiovascular system, stimulating the vestibular system, and reducing visual acuity. A 150-pound crewmember

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[33] Children hanging from upside-down by their feet experiencing only -1 Gz notwithstanding. However, in such situations, they are not being called upon to perform demanding physical or cognitive tasks. Inversion tables and similar devices purport to reduce back pain by creating a -Gz environment. The May Clinic cites no scientific evidence to support this claim and cautions individuals with heart disease, high blood pressure and eye diseases (e.g., glaucoma) to avoid the use of these devices (Mayo Clinic, 2007).

weighs 600 pounds when exposed to +4 Gz. This increase in weight severely restricts mobility and movement in the aircraft. For example, the head weighs about 29 pounds when wearing a typical helmet and oxygen mask. At 4 +Gz, the same head-helmet combination has an effective weigh of approximately 116 pounds. This increased weight can force the unprepared pilot's chin into his chest when a loop is initiated. Combined with other physiological effects of +Gz, decreased mobility interferes with the ability to function at peak levels during high-G flight. Additionally, as +Gz forces increase, blood pressure begins to decrease because of the effects of the G-forces on the cardiovascular system. Each +Gz drops blood pressure 22 mm Hg. The cardiovascular system attempts to compensate for the drop in blood pressure by constricting peripheral blood vessels and increasing the heart rate. This compensation is known as the cardiovascular reflex. Vestibular effects and their symptoms also play a critical role in spatial disorientation and balance. The otoliths are stimulated by gravity and linear acceleration forces to provide you a sense of direction. The semicircular canals respond to angular acceleration to provide another sense of direction. If pilots fail to rely on their instruments and visual cues, acceleration forces can provide stimuli that induce disorientation, motion sickness, vomiting and vertigo. As already mentioned, the visual system is affected by high G-forces. For blood to enter the retina, the cardiovascular system must overcome about 13-18 mm Hg of intraocular pressure. As the G-forces increase and the blood pressure in the brain begins to drop, there is insufficient blood pressure to overcome the intraocular pressure. Therefore, the tissue in the eye that detects light (retina) starts losing its blood supply. As the blood supply is decreased, peripheral vision is affected and pilots experience a dimming, misting, or graying of your vision referred to as grayout or they may experience tunnel vision, where the only vision remaining is in the center of the visual field. As the G-force increases, the blood pressure drops to where it cannot overcome the intraocular pressure and all vision is lost, referred to as black-out. It is important to note that black-out does not mean unconsciousness; however, the blacked-out pilot is in imminent danger of G-LOC.

The effects of G-LOC are described as two phases of incapacitation – absolute and relative. In absolute incapacitation the pilot is actually unconscious for roughly 9 to 21 seconds, with an average time of 15 seconds. During this period the body generally relaxes. However, during the latter stages of absolute incapacitation, pilots may experience marked involuntary skeletal muscle contractions and spasms just before regaining consciousness. These contractions can cause the arms to flail, leave the flight controls, or hit other aircraft controls. The second phase of incapacitation is experienced once the pilot regains consciousness. Unfortunately, there is not an instantaneous return to an alert and functional state. Pilots often experience mental confusion, disorientation, stupor, apathy or memory loss. During this time, they are incapable of consciously flying the aircraft, making decisions, taking action against a threat, or communicating effectively. The time of relative incapacitation usually mirrors that of the absolute incapacitation. Auditory stimulation during this period speeds recovery to alertness, although, dissociation, stupor, and feelings of uneasiness often linger after recovery from G-LOC.

Variability in G-tolerance

G-tolerance changes from day to day and hour to hour based on a number of variables. Understanding the reasons for these variables can help maximize tolerance and minimize the threat of acceleration effects. The following section describes some of the physiological factors and their effects on G-tolerance as well as physical protections against acceleration effects.

The role of self-imposed stress

Crewmembers generally drink less water than they need and are slightly dehydrated most of the time. Dehydration reduces G-tolerance markedly by depleting blood plasma volume. Aircrews must drink plenty of noncaffenated, nonalcoholic fluids (even when not thirsty) prior to (and during) flight. The body suffers a 35% decrease in ability to do anaerobic work and a 20% decrease in ability to do aerobic work if you are 3% dehydrated. Therefore, an AGSM can only be maintained for one-half the time it normally would. For instance, if a pilot can normally pull 9G for 10 seconds, the effects of dehydration would limit him to 9G for 5 seconds. Fatigue also significantly decreases G-tolerance. Crewmembers that are fatigued or are lacking sleep tend to experience lapses in mental function and a lower ability to maintain muscle tension during the AGSM. Mental fatigue slows your response and anticipation of high-G maneuvers. Physical fatigue lowers the capability to maintain adequate muscle strain during the AGSM and also lowers the capability to perform subsequent strains. Warfighting aviators should take maximum advantage of crew rest, stay well rested and maintain good sleep patterns prior to flying. Safe flight demands that pilots perform at peak levels in a high-G environment, however, self-medication with over-the-counter drugs can decrease their performance. Those who require medication should not be flying. They are a danger to themselves and their fellow crewmembers. Therefore, pilots are instructed to not self-medicate, to report to the flight surgeon, and to always obtain qualified medical treatment. Alcohol misuse, and the accompanying hangover, drastically reduces G-tolerance. The reduced G-tolerance is primarily due to alcohol's dehydrating effects. In addition, a hangover clouds mental capability, slows the thinking and decision-making processes, as well as the ability to effectively judge situations. Alcohol-use should be avoided prior to flight. Remember from the previous section that although regulations generally restrict alcohol consumption 12 hours prior to flight or mission planning, some detrimental aftereffects can last as long as 48 to 72 hours. Additionally, alcohol can also contribute to fatigue and hypoglycemia. Food is the fuel used to function in a high-G environment. Missing meals or not taking the time to eat correctly directly affects ones ability to withstand increased G-force. Pilots will not have fuel in their system to maintain high levels of activity for extended periods of time if they do not eat or if they eat improperly prior to flight.

Prevention methods

Sometimes referred to as a G-suit, fast pants, or "speed jeans," these devices consist of a pair of pants-like covers fitting tightly over the leg and lower abdomen (Figure 16-18). Air bladders in the thigh, calf and abdomen areas of the suit are automatically inflated by an anti-G valve on the aircraft. However, the G-suit is not the primary means of G-LOC protection and used by itself, only allows for 1 to 1.5G of protection. Pilots must also rely on the AGSM to protect themselves from G-LOC. G warm-up maneuvers also prepare the pilot for subsequent high-G maneuvers. This maneuver consists of a total of 180° of turn and is used to operationally check G-suits and to practice straining maneuvers up to an amount of G approaching the maximum amount anticipated on that particular flight.

Figure 16-18. G-suit.

Physical conditioning mentioned previously is a method to improve muscle strain during the AGSM. Physical conditioning is also important in decreasing the fatigue levels and increasing stamina required for multiple G maneuvers. Both anaerobic and aerobic physical conditionings are encouraged. The AGSM is essentially an anaerobic maneuver. The muscles used to perform the AGSM rely upon anaerobic energy sources (energy sources not requiring oxygen). Crewmembers flying high performance aircraft are encouraged to develop a weight training program to maximize their muscle strain ability. Weight training is the primary method of anaerobic conditioning and decreases your chances of injury, particularly neck injury during high-G maneuvers. Anaerobic conditioning increases the muscle's ability to contract and sustain the contraction throughout the G stress. Without sufficient anaerobic conditioning, the muscles fatigue quickly, and the AGSM loses its efficiency. However, developing a conditioning program based solely on anaerobic exercise is not complete.

Aerobic conditioning must complement your anaerobic conditioning. Pilots need to be aerobically fit to combat fatigue and recover from multiple G-maneuvers. Aerobic exercise programs require oxygen to produce the necessary energy. Aerobic conditioning increases stamina and resistance to fatigue. (G-LOC typically occurs towards the end of engagements during the fatigue period.) Aerobic conditioning does increase cardiovascular fitness, leading to lower heart rates, lower blood pressure, and faster recovery times from aerobic exercise. Unfortunately, these attributes of aerobic exercise are not entirely beneficial and may lead to problems in the high G environment. Therefore, it is not recommended for fighter aircraft crewmembers to pursue an excessive competitive aerobic exercise program; an aerobic exercise program that does not exceed the equivalent of running twenty miles per week is suggested. Overall, for crewmembers that fly in high performance aircraft, a sound anaerobic training program coupled with a sensible aerobic exercise program will help maximize their G-tolerance. However, exercising prior to high-G flight leaves one in a pre-fatigued state and dehydrated, and is not recommended.

Summary: Acceleration

G-forces are the result of inertial forces acting on the body. G is a dimensionless number expressed as a ratio of a body's acceleration to the force of gravity (32 ft/s^2 or 9.81 m/s^2). The magnitude, duration of exposure, rate of application, direction of force applied and previous G exposure are physical factors influencing the body's physiological response to a G-force. These factors define the G-force and can predict the effect the G-force will affect performance. +Gz is the force of greatest concern since it is regularly encountered in-flight. The effects of +Gz are decreased mobility, visual disturbances like grayout and blackout, and finally G-LOC. Physiological factors will increase or decrease your G tolerance. These factors include your physical condition and self-imposed stresses (fatigue, dehydration, self-medication, alcohol use and nutrition). Staying in shape, avoiding self-imposed stresses, and performing an effective AGSM will help increase G-tolerance and decrease the effects of acceleration on performance.

Ambient lighting

Use of HMDs is not confined to nights only. While pilotage imagery mostly may be employed at night and during other periods low illumination (e.g., dawn, dust and periods of weather-related low visibility), HMD symbology may be employed over the entire 24-hour period.

Since HMDs produce visible energy for viewing of their information, night operation offers little problems. A basic understanding of the human visual system's response to low illumination (scotopic and mesopic vision) is most sufficient for HMD designers and can be reviewed in Chapter 7, *Visual Function*. Nonetheless, there is one potential problem for HMD users during night and low-illumination operation. This problem is associated with chromatic aftereffects and first was raised in the early 1970s (Glick and Moser, 1974). This afterimage phenomenon was reported by U.S. Army aviators using NVGs for night flights. It was initially, and incorrectly, called "brown eye syndrome." The reported visual problem was that aviators experienced only brown and white color vision for a few minutes following NVG flight. Glick and Moser (1974) investigated this report and concluded that the aviator's eyes were adapting to the monochromatic green output of the NVGs. When such adaptation occurs, two phenomena may be experienced. The first is a "positive" afterimage seen when looking at a dark background; this afterimage will be the same color as the adapting color. The second is a "negative" afterimage seen when a lighter background is viewed. In this case, the afterimage will take on the compliment color, which is brown for the NVG green. The final conclusion was that this phenomenon was a normal physiological response and was not a concern. A later investigation (Moffitt, Rogers, and Cicinelli, 1988) looked at the possible confounding which might occur when aviators must view color cockpit displays intermittently during prolonged NVG use. Their findings suggested degraded identification of green and white colors on such displays, requiring increased luminance levels.

For HMD designers the more difficult problem is supplying sufficient luminance in the presence of high ambient lighting conditions, specifically high intensity light sources, which are discussed in the following section.

High intensity light sources

The Warfighter can be exposed to a number of high intensity (bright) light sources. These sources can be natural (e.g., the Sun) or artificial (e.g., lasers, explosions, searchlights, and fires). The effects of such exposure can range from glare, through flashblindness (or dazzle), to retinal burns. For HMD users, lasers have always been a major concern. For example, with NVGs, lasers viewed directly will shut down the image intensifier (I^2) tubes, causing loss of imagery. Such shutdowns of I^2 tubes can result from virtually all high "brightness" sources. Of greater concern with lasers are situations where the laser energy may enter the eyes from the periphery. This can result in flashblindness which is a temporary vision impairment that follows a brief exposure to bright light and interferes with the ability to detect or to identify a target, or even retinal injury (Rash and Manning, 2001). However, while laser exposure is still a concern in the military community, it has yet to become the severe operational hazard, as previously anticipated.

For the Warfighter, glare is the most frequently encountered effect from high intensity light sources; this is especially true for HMD users. Glare can be classified into various types by either its source:

- Direct glare – bright light in the FOV
- Reflected glare – bright light reflected from a surface; and further categorized as:
    - Specular (smooth, polished surfaces)
    - Spread (pebbled, brushed surfaces)
    - Diffuse (flat-painted, matte surfaces)
    - Compound

Or, its effect (Hedge, 2008):

- Discomfort glare – produces discomfort, does not impair vision
- Disability – reduces visual performance
- Blinding – causes temporary blindness

Both direct and reflected glare are of issue with HMD use. Blinding glare tends to be transient and infrequent but has the most severe visual impact. However, disability glare is very common, more frequently degrading visual performance. Disability glare reduces visual performance by reducing image contrast or visually distracting an individual. Usually, but not always, glare is transient, being a serious problem only when it happens during some critical moment – a purposely induced or inadvertent inability to detect or identify an object on the side of the road or ahead while driving at night; a temporary inability to read instruments while flying or targeting an enemy; a reduced capability when using night vision devices. Refractive surgery often exacerbates susceptibility to disability glare, increasing its magnitude and frequency of occurrence. Consequently, this increases risk to personnel in the battlespace.

The study of glare

Glare was described by Goethe in 1810 and Purkinje in 1823. Their explanations portended the neural versus physical (scatter) debate that was clearly framed by Helmholtz in 1852. Cobb, in 1911, was the first to quantify disability glare by developing the concept of *equivalent background* (taken from Vos, 2003). The concept was expanded by Holladay (1926; 1927), Stiles (1929), and Stiles and Crawford (1937). Their work, formally presented at the 1939 Commission Internationale de l'Eclairage (*CIE*) meeting, culminated in a formula that clearly implied that intraocular scatter was the main cause of glare:

$$L_{eq} = 10E_{glare} / \theta^2 \qquad \text{Equation 16-3}$$

where, L_{eq} is the equivalent veiling background in candelas per square meter (cd/m^2), E_{glare} is the illuminance of the glare source at the eye measured in lux, and θ is the angular distance between the line-of-sight and the glare source in degrees. For an extended glare sources this formula is integrated over the angular aperture of the glare source. Subsequent research, carefully controlling pupil size and eye movement, substantiated the proportionality of L_{eq} and E_{glare}. In addition, it was shown that the forward scatter from the cornea, crystalline lens and ocular fundus, taken together, are sufficient to explain L_{eq} (Vos, 2003).

The Holladay-Stiles formula is still widely used and considered a good estimate for glare from sources between 1° and 30°. It should also be noted that this formula was widely used during World War II vision research.

Fry and Alpern (1953) referenced a 1939 observation by Schouten and Ornstein, … " that the depression of brightness still persists when the image of the glare source falls on the optic nerve head," an area without receptors and lateral neural connections. Fry and Alpern found that the course of foveal dark adaptation following a peripheral glare source or a direct veiling illumination followed the same pattern. In addition they showed that increasing the glare angle was equivalent to decreasing the direct veiling illuminance. These studies argued that the brightness of the foveal image of a test object was a consequence of forward light scatter in the eye caused by a peripheral glare source and not lateral neural effects.

Around 1965, the *CIE* asked Vos to head a committee to update the Holladay-Stiles formula. He had recently completed a doctoral dissertation on the mechanisms of glare. In a succession of papers that followed he showed that the cornea, lens and fundus contributed about equally, with some variability, to forward scatter in the normal eye (Vos, 1963; Vos and Boogaard, 1963; Vos and Bouman, 1964). Vos also showed that the three sources of scatter alone could account for the L_{eq} in the Holladay-Stiles formula, putting to rest the physical scatter-neural controversy.

There were other major issues regarding scatter that also had to be solved. One had to do with the question of wavelength. In general it has been found that stray light (scatter) in the eye is independent of wavelength (van den Berg, Ijspeert and de Waard, 1991; Vos, 2003; Wooten and Geri, 1987). However, van den Berg et al. (1991) found a small wavelength-dependent scatter with transmission of light through the ocular wall of subjects with blue eyes. The effect was virtually zero for subjects with dark brown eyes. They concluded that "depending on pigmentation, eye-wall transmittance and fundal reflections do introduce some wavelength dependence." This suggests that most scatter in the eye is Mie[34] scatter, due to intraocular and intracellular particles substantially larger than the wavelengths of visible light (Figure 16-19). This is consistent with scatter produced by most cataracts, lens opacities resulting from hereditary factors, trauma, inflammation, ultraviolet radiation, drugs, or disease (de Waard et al., 1992; Kanski, 2003; Klein, Klein and Linton, 1992; Schneck et al., 1993; Smith, 2002;

[34] Mie scattering described by the German physicist Gustav Mie is based on an analytical solution of Maxwell's equations for the scattering of electromagnetic radiation by spherical particles (1910).

Thomson, 2001). Cataracts are usually whitish, occasionally brunescent, and are made up of fairly large particles. The amount of scatter in the normal eye that is independent of wavelength has also been shown to be related to eye pigmentation, more pigmented eyes generally showing less scatter (van den Berg, Ijspeert and de Waard, 1991; Vos, 2003; Vos and van den Berg, 1999).

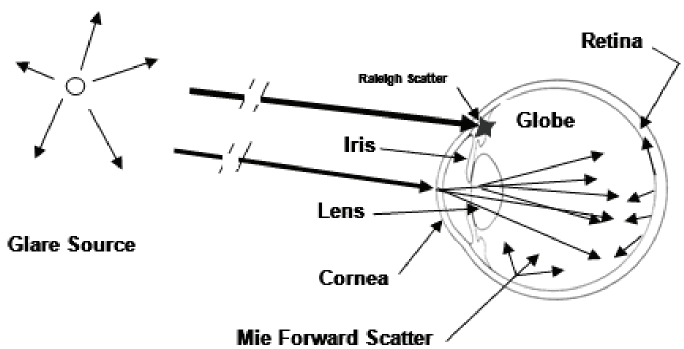

Figure 16-19. The cornea, lens and retina contribute about equally to Mie scatter. There is very little wavelength-dependent scatter, mostly for individuals with little eye pigment.

Another major factor affecting disability glare is age (Ijspeert et al., 1990; Vos, 2003; Vos and van den Berg, 1999). De Waard et al. (1992) found that light scatter increases by a factor of three by age 80. Schieber (1994b, 1995) extensively reviewed the impact of visual aging on driving performance, pointing out that there is not only an increase in glare sensitivity with age, but also an increase in glare recovery time. Swanson (1998) pointed out that scatter increases significantly with age and that as little as one-third of the light reaches the retina in a 65-year-old as in a 25-year-old. Additionally, he pointed out that light scatter in the lens is responsible for a majority of the complaints of disability glare for older adults, often leading to a voluntary cessation of night driving. Haegerstrom-Portnoy et al. (1999) showed that, even though everyone experiences disability glare to some extent, the effect is accelerated after age 65.

The measurement of glare

There have been many attempts, but no universally adopted technique, a gold standard, for measuring disability glare. The technique currently gaining the widest support, particularly in Europe, has adopted the stray light definition of glare and called the problem solved, i.e., glare is the veiling light that results from forward Mie scatter in the eye (van Rijn et al., 2005b). Van Rijn et al. (2005a) stated that:

> "…disability glare is the reduction in visual performance caused by veiling luminance on the retina. It is an effect of intraocular stray light. Measurements of glare and stray light are particularly important for drivers, cataract, and refractive surgery. Glare testing in the elderly may be important in view of the high accident rates in this age group, especially at night. Moreover, glare measurements may predict future decrease of visual acuity."

This would be fine, except that this approach does not, for example, adequately predict the nighttime "glare" experienced by refractive surgery patients when they see the headlights of an oncoming vehicle. Stray light measurement is certainly a major factor in creating glare and works very well for evaluating cataract patients. However, with the advent of refractive surgery, now widely accepted within the military community, other factors have come into play. Van den Berg (1991) questioned the validity of most glare-testing, stating that:

> "…present tests for the stray light type of glare fail on validation research. Also, in clinical use, the reliability of glare testing seems to be questionable. The problem is the absence of a generally accepted reference, a golden standard of glare."

Ghaith et al. (1998) found that disability glare assessment 1, 3, and 6 months refractive surgery techniques of post radial keratotomy (RK) and photorefractive keratectomy (PRK), using measurements from the Brightness Acuity Tester (BAT) and the Multivision Contrast Tester (MCT 8000), did "not accurately reflect patient's subjective assessment of their visual performance in daily life as expressed in a questionnaire." These devices measured high and low contrast visual acuity (VA), which should be affected by veiling glare resulting from forward Mie scatter. In a personal correspondence Barbur (2004) said that visual performance of most refractive surgery patients does not differ significantly from normal subjects having had no surgery. However, he pointed out that there are some significant "outliers" that present with demonstrable vision problems, particularly when under mesopic ambient illumination important to the Warfighter, when a large pupil size favors increased aberrations.

The major visual problems that patients experience are night vision glare, reduced contrast sensitivity, halos and starburst (Bailey et al., 2003; Fan-Paul et al., 2002). These problems are usually reduced a few months after surgery (McLeod, 2001). However, it is not entirely clear whether this is a resolution of the problem, patient adaptation, or simply self-justification, i.e., resolution of cognitive dissonance (Brunette et al., 2000; Chou and Wachler, 2001; Melki, Proano, and Azar, 2003).

The incidence of problems is also unclear and somewhat dependent on the diameter of the ablation zone (Martinez et al., 1998):

> "Depending on the magnitude of the attempted correction and the size of the ablation zone, past PRK studies have reported 15% to 60% of patients complaining of glare, 26% to 78% complaining of halos, and 12% to 45% complaining of difficulty with night vision. As many as one third of patients after PRK have reported to be disappointed with their results, despite good uncorrected visual acuity or even emmetropia. In some studies, up to 10% of patients who underwent PRK with an ablation zone 4.00 mm in diameter considered the problem of halos severe enough to interfere with driving at night."

More recent papers have reported significant reductions in night vision problems with both Laser-Assisted *In Situ* Keratomileusis (LASIK) and PRK (Figure 16-20). This has come with an increase in ablation zone diameter and better ablation techniques. Of 690 questionnaires answered, 55.1% of patients reported an increase in daytime glare and 31.7% reported a decrease in the quality of night vision following surgery (Brunette et al., 2000). In spite of this, they reported that 96.2% said they believed having the surgery was a good choice. Bailey et al. (2003) surveyed 841 patients (returning questionnaires) and found a 117%-increase in reporting starbursts for each 1-mm decrease in ablation diameter. In a report on a single patient Chalita and Krueger (2004) performed wavefront-guided LASIK enhancement surgery after lifting the preexisting flap on a 3-year post-LASIK patient who presented with post-LASIK symptoms of glare, halo and double vision. The retreatment outcome was complete resolution of double image and halos. This outcome coincided with a reduction in both low- and high-order aberrations. Chalita et al. (2004) found a strong correlation between wavefront measurements/aberrations and visual symptoms such as coma, starbursts and glare.

Klein (2001) said that, "Night vision is an embarrassing topic for refractive surgery […] A large percentage of post refractive surgery eyes have large pupils at night that result in disturbing halos." This is particularly true for individuals in their 20s, a prime age for the Warfighter. Currently, there is often a poor correlation between measurements made with current devices to measure post-surgery scatter and visual performance. There is a need for better measurement strategies to evaluate and predict post-refractive surgery vision at night, particularly for young individuals, where virtually all of the vision is under conditions of low illumination with large pupils (Barbur, 2004; Klein, Hoffman and Hickenbotham, 2003; Klein, 2001; Sagawa and Takeichi, 1992).

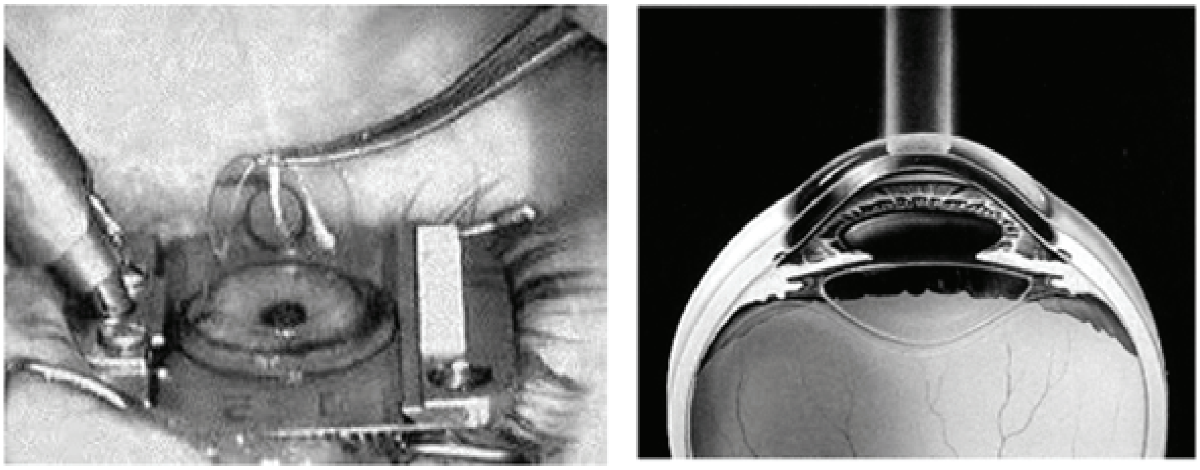

Figure 16-20. LASIK refractive surgery (left) removes a flap from the cornea before laser ablation. After laser ablation the flap is replaced. PRK refractive surgery (right) removes only the top layer of cells (epithelium) from the cornea prior to laser ablation. These cells grow back, from the periphery toward the center. After 6 months the outcome of these surgeries is very similar.

Complexity of the disability glare problem

Vision is a dynamic process. Nowhere is this more obvious than in the long history of efforts to develop a practical definition and measure of disability glare. We all know it when we see it – halos, reduced contrast, starburst patterns that can obscure objects due to oncoming automobile headlights at night. Outwardly it seems simple enough, but definition, quantification and reliable prediction are very difficult. In fact, it is very complex on several levels, the anatomical/structural levels, sensory levels, the physics and environmental levels, and the cognitive and perceptual levels. Disability glare is the overall consequence of a myriad of changing, interactive factors that can increase inter-subject variability and mask retinal image degradation (Chisholm et al., 2003). The factors discussed below are condensed from several sources (Atchison and Smith, 2000; Bron, Tripathi and Tripathi, 1997; Kaufman and Alm, 2002; Korb et al., 2002). All these factors impact susceptibility to disability glare or its measurement.

The anatomy and physiology are themselves very complicated (see Chapter 6, *Basic Anatomy and Physiology of the Human Eye*). The cornea is a multi-layered armature that forms the surface on which the tear layer, the first optical surface, forms and reforms through blinking (Bron, Tripathi and Tripathi, 1997). The tear layer/cornea provides more than two-thirds of the optical power of the eye (Atchison and Smith, 2000). Multiple glands in the lids and around the eye socket form the complex tear layer that has both aqueous and oily components (Bron, Tripathi and Tripathi, 1997; Korb et al., 2002). The power of this aspherical optical surface can and does vary as a function of time. In addition, irregularities in the shape and curvature of the cornea/tear layer can create variations in focus. These variations are called astigmatism and aberrations. The corneal stroma (the central layer of the cornea), scatters about 10% of the visible light striking it.

The crystalline lens is a multi-layered optic just behind the iris/pupil (Bron, Tripathi and Tripathi, 1997). It grows by increased layering throughout life. The crystalline lens is suspended like a trampoline by the zonule fibers. Sphincter muscles attached to the zonule fibers can pull on the lens to change its shape and, therefore, the eye's focus (the process of accommodation). Over the years the lens increases in size and stiffens, losing its ability to change focus/accommodate (presbyopia), as well as some of its clarity (Bron, Tripathi and Tripathi, 1997; Ciuffreda, 1998). Changes in the fibers and proteins of the crystalline lens can produce local areas that scatter light (cataract), sometimes becoming opaque (Hemenger, 1990; Swanson, 1998; Thomson, 2001). Cataracts produce primarily Mie scatter.

Aberrations, caused by shape irregularities of the eye's optical surfaces, are partially counterbalanced by the cornea-lens optical combination (Kelly, Mihashi and Howland, 2004; Artal, Berrio and Guirao, 2002), but this balance can be upset by both age and refractive surgery (Artal, Berrio and Guirao, 2002; Artal et al., 2003). The power of the cornea and the accommodated lens combine with the distance between the lens and the photosensitive retina to determine whether the eye will be emmetropic (requiring no correction to focus an image).

The pigmented iris, between the cornea and the lens, is an aperture stop that reduces intraocular stray light primarily through absorption (Keating, 1988; van den Berg, Ijspeert and de Waard, 1991). The pupil, the physical opening in the iris, can change diameter with changes in illumination, convergence of the two eyes, accommodation, and emotion (Bron, Tripathi and Tripathi, 1997; Ciuffreda, 1998; Lowenstein and Loewenfeld, 1969). In the dark, the pupils of young adults can be well over 7 mm in diameter (Schumer, Bains and Brown, 2000). On-average, they become smaller with age.

Within the eye, between the cornea and the lens is a circulating fluid called the aqueous humor. It provides nutrition and oxygen for the avascular cornea. Posterior to the lens is the vitreous humor, a gel/liquid. With age, this substance begins to have localized areas of different refractive index due to pockets of localized liquefaction. These variations in homogeneity act as local optical surfaces in the main optical pathway of the eye and can cause scatter (Bron, Tripathi and Tripathi, 1997; Smith, 2002).

The multilayered inside-surface of the eye, the retina, is a specialized extension of the brain with some 130 million or more photoreceptors of various kinds (Bron, Tripathi and Tripathi, 1997). The photoreceptors reside in a back layer of the retina behind the retinal nerve cells. Posterior to the photoreceptors is the pigment epithelium, a pigmented layer that helps to reduce stray light in the eye, and the choroid, a highly vascular layer. Complex, laterally interacting neurons lay anterior to the photoreceptors (toward the incoming light), except in the fovea centralis, which is a tiny depression in the retina about 1.5 mm in diameter, where most of the neurons are pushed aside. Most of our sharp vision takes place in this area (Bron, Tripathi and Tripathi, 1997; Schwartz, 1994). The photoreceptor cells of the eye are of two general types. The more densely packed, thinner cells are called cones. They are most concentrated in the fovea and parafovea regions, rapidly diminishing in density peripheral to these areas. They function under brighter lighting conditions, provide our sharpest acuity, and are responsible for the first stage of neural color processing. The larger photoreceptors are called rods. They are absent in the fovea, increase in density peripheral to the fovea and then begin to decrease in density. These cells are very sensitive to light and motion, but provide much poorer acuity. They do process brightness variations, but do not process color information. Photoreceptor cells change their sensitivity and range of sensitivity to light as ambient lighting conditions change – adaptation level. Initially, this process can be very rapid (Boynton, Bush and Enoth, 1954; Bron, Tripathi and Tripathi, 1997; Schwartz, 1994). Cones and rods interact neurally in complex ways. This is particularly important when considering lower illumination levels (Krizaj, 2000; Krizaj and Hawlina, 2002; Stabell and Stabell, 1979, 1998)

As the light environment changes the eye adjusts. Vision, as living, is a dynamic, changing process. When the ambient illumination increases, the eye light adapts; when illumination decreases, the eye dark adapts (Baker, 1949, 1953; Barlow, 1972; Bartlett, 1966, Graham, 1966a-b, Schwartz, 1994). The time course for these processes is also a variable, with the most rapid changes occurring during the first few seconds of an illumination change. These chemical, neural and mechanical changes combine with sensory and perceptual neural processing within the brain to help maintain a relatively stable representation of the world visually (Schwartz, 1994).

The effect of scattered light may be enhanced under conditions of low light adaptation. Intraocular stray light can cause a dark-adapted retina to light-adapt, producing a prolonged reduction in vision after the glare source has been removed. "With pathologically increased dark adaptation the effect can be stronger" (van den Berg, 1991). Steady stimuli, producing scattered light that acts more as an adapting stimulus (altering the state of adaptation), can create a paradoxical increase in contrast sensitivity as ambient light increases at low luminances (Bichao, Yager and Meng, 1995). In general, transient light stimuli are considerably more effective at producing glare and raising thresholds than are steady glare sources (Bichao, Yager and Meng, 1995). Under some conditions there can be a persisting visual after-image (following light stimulation), particularly in a relatively uncluttered FOV (Brown, 1966). This after-image can be a result of retinal or central neural activity (Shinsuke, Kamitani and Nishida, 2001).

In general, cone receptors operate above approximately 3.4 cd/m^2; these brightness levels are photopic. Between about 0.034 to 3.4 cd/m^2, moonlight, vision operates with both rods and cones; these brightness levels are mesopic. Only rods operate at brightness levels below 0.034 cd/m^2; these brightness levels are scotopic. Most of us are using photopic or mesopic vision at night while driving a car. Ultimately, one million neural fibers from each eye are sent to an area of the brain called the lateral geniculate nucleus. From this nucleus on there is a continuing cascade of neural processing within the brain (abstracting and assembling information originating at the retina). This results in a representation of the external world that combines with memory, other senses and emotion, forming a context for behavior appropriate to our biological niche. Glare can interrupt this process.

Intraocular glare results from and combines with many environmental (extraocular) factors. The most obvious are the glare source's color, brightness, temporal characteristics and angle with respect to the observer's line-of-sight (Vos and van den Berg, 1999). But there are many other environmental factors – scratched windshields or windscreens, eyeglasses or goggles, contact lenses, type of contact lenses, fog, rain, snow and ice, time of day, other objects like automobile chrome, flashes at night, use of night vision devices, the context in which glare occurs, and more. Each of these factors or combination of factors can influence the degree and importance of glare (Applegate, 1989; Applegate and Wolf, 1987; de Wit and Coppens, 2003; Elliott, Mitchell, and Whitaker, 1991; Lewis, 1993; Pitts, 1993).

Perceptual and cognitive factors combine with sensory input to play a role in disability glare (Allen et al., 2001; Anderson and Holliday, 1994; Green, 2004; Green and Senders, 2004; Pulling et al., 1980; Schieber, 1994a-b). Issues of target acquisition, recognition and identification depend on contrast sensitivity, context, masking, clutter, and other factors, as well as sensory considerations. A bright headlight may cause a reduction in pupil size, decreasing aberrations of the eye and improving acuity, but the individual may not see an unexpected object due to reduced light gathering ability of the eye and consequent reduced contrast. However, an expected object may be seen under the same conditions.

Disability glare is the combined consequence of a multitude of interacting factors, many of which are nonlinear. And disability glare can be dangerous. It can be dangerous when a Warfighter has only a split second to detect or identify someone or something. It also can be dangerous when a pilot needs to detect or identify another aircraft or is engaged in critical, low-altitude maneuvers. With the advent of refractive surgery and its increasingly wider application in the military, the issue of glare with younger people has become real. Of equal concern is that there is no current gold standard for measuring glare and predicting problems from glare at night.

Ergonomic Issues

The term *ergonomics* refers to the applied science of designing the characteristics of devices that humans use in such a way as to ensure efficient, effective, comfortable and safe use. In this section we will discuss two specific ergonomic issues that are associated with HMD design and use – eyewear and user controls – and then address the global issue of compatibility with a host of components, devices and systems that may be required to be used by Warfighters in combination with their HMD, i.e., system compatibility.

Eyewear

For Warfighters, eyewear includes devices used for vision correction and for eye protection. Therefore, the discussion below is limited to corrective spectacles, sunglasses, ballistic protective goggles, laser protective goggles, and nuclear-biological-chemical (NBC) masks (Figure 16-21). Most of this eyewear is necessary to prevent or reduce injury from dust, wind, shrapnel and debris, laser energy, or the sun. In conflicts involving improvised explosive devices (IEDs), mortars, sand, wind and dust, protective eyewear is essential equipment

(Dawson, 2008). Data from the Iraq conflict shows that 10% of Warfighters injured have injuries to the eye(s). Therefore, it becomes a matter of fact that this eyewear will be used in conjunction with HMDs.

Military Eye Protection System (MEPS)

Sun, Wind, Dust Goggles

Aviator Sunglasses

M-43 NBC Protective Mask

Figure 16-21. Examples of military eyewear.

Although provided with government-issued eyewear, a number of Warfighters elect to purchase their own eyewear products from commercial vendors. Unfortunately, many Warfighters do not possess the knowledge to make selections that meet military requirements. The military has addressed this problem by developing programs that test commercially-available eyewear. One program, the U.S. Army's Military Combat Eye Protection Program (MCEPP)[35] tests commercial protective eyewear to military ballistic and ANSI Z87.1 (American National Standards Institute, 2003) standards. The program maintains an Authorized Protective Eyewear List (APEL), which is available to Warfighters via the Internet at http://peosoldier.army.mil/pmseq/eyewearmessage.asp

Until rather recent designs, an HMD's optics historically has been located very close to the eyes. This close proximity results in a very small distance between the optics and eye(s). This has proven to be an important equipment compatibility issue. The operational requirements of warfare have necessitated that Warfighters be provided with protection against directed energy (e.g., lasers, microwave radiation, etc.) and chemical warfare environments. Protection has been generally in the form of protective spectacles, goggles, or masks. Most of these protective add-on devices must be located between the HMD optics and the eyes. Oxygen masks are an additional requirement for moderate above-sea-level altitudes. Current HMD designs provide little space for incorporation of these additional devices and systems.

In addition, as Warfighters age, they undergo changes in their visual capability. Aviators experience the same sort of refractive error progression as the general population; individuals who are nearsighted or farsighted tend to become more nearsighted or farsighted with age, resulting in increased dependence on glasses or contact lenses. One of the most pronounced effects is the ability to accommodate, i.e., change focus. Human range in accommodation generally decreases with age from a robust 11 diopters at age 20 years to a limiting 2 diopters by

[35] The MCEPP was created by the Program Executive Office (PEO) Soldier, an organization with the U.S. Army whose primary purpose is to develop equipment that can be rapidly fielded.

age 50 years (Records, 1979). As a result, to retain the experience of older aviators, there is a requirement to provide visual correction, and this correction must be useable while wearing HMDs.

HMDs are examples of optical systems. Simply stated, an optical system consists of one or more optical elements. These optical elements include lenses, mirrors, prisms, filters, etc. One of the simplest optical systems is a magnifying glass, which consists of a single lens encased in a ring that may have a handle attached. Beyond the simple magnifier, practically all optical systems contain multiple optical elements. HMD optical systems are generally quite complex and can consist of a dozen or more optical elements.

Exit pupil and eye relief

As optical systems, most HMDs have their optical elements fixed in place within a housing. Furthermore, these systems are designed to be viewed by the human eye. Figure 16-22 shows the optical design of a simple pupil-forming compound microscope and the path of light rays through the system. For ease of discussion, the optical elements are presented only. Light rays passing through the system form an image at the exit pupil. Simply defined, the exit pupil is where the eye must be placed in order to optimally view the image. The exit pupil can be thought of as the area through which all of the image-forming rays pass. [Note: Technically, the exit pupil is a volume in space.] If the eye is placed behind or in front of the exit pupil, the eye will not capture some of the rays. This results in a reduced FOV (Rash et al., 2003).

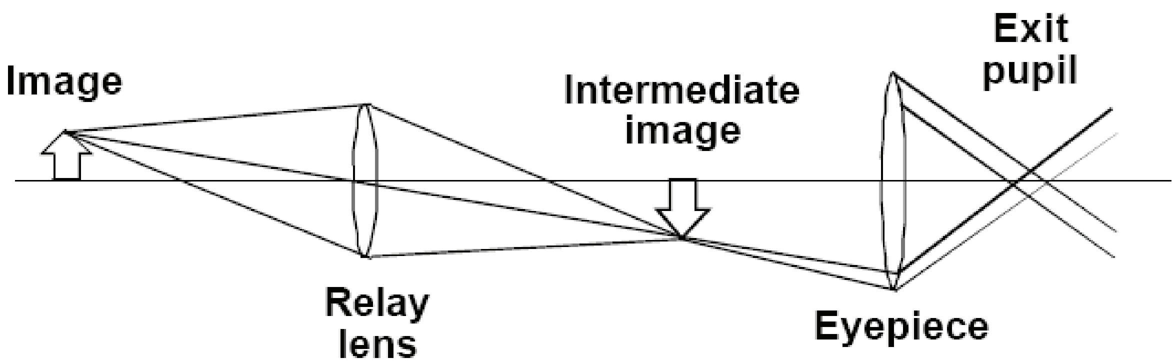

Figure 16-22. The path of light rays through a pupil-forming system.

An important characteristic of the system in Figure 16-22 is the distance along the optical axis between the last optical element and the exit pupil (where the eye would be positioned). This distance is known as the "optical eye relief." Figure 16-23 expands the final element of the system and presents this distance. In addition, it further refines the definition of the optical relief as the distance along the optical axis from the last optical surface to the cornea of the eye. [Note: Often, the entrance pupil of the eye, which is approximately 3 mm behind the surface of the cornea, is used as the reference point in the definition of optical eye relief.] When an optical system is defined, the optical eye relief distance is often cited as an important parameter.

In Figures 16-22 and 16-23, the optical system was depicted as exposed optical elements. But, in practice, one cannot ignore the system housing. Figure 16-24 shows a side cut-away view of the example optical system showing the last optical element as enclosed in the housing. The most noticeable difference when the housing is considered is the extension of the housing beyond the final surface of the last optical element. This difference impacts the available (or usable to the viewer) optical eye relief distance. A new distance requires definition, that of the distance from the plane through the outer edge of the housing to the cornea of the eye. This new distance is often referred to as "physical eye relief." Physical eye relief is, at best, equal to optical eye relief. In practice, physical eye relief almost always is less than optical eye relief.

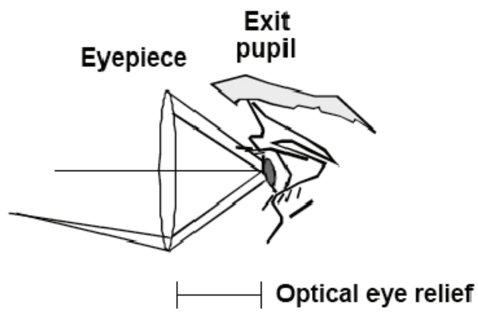

Figure 16-23. Defining the optical eye relief distance as the distance along the optical axis from the last optical surface to the cornea of the eye.

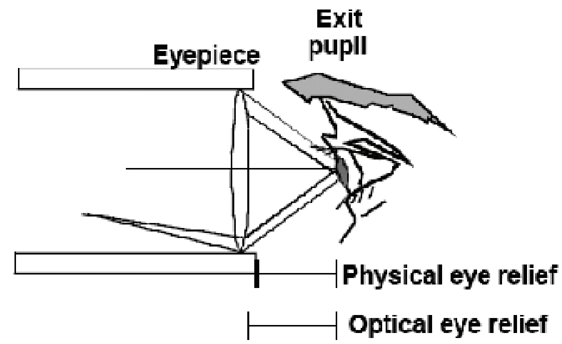

Figure 16-24. A side cut-away view of the example optical system showing the last optical element as enclosed in the housing.

Consider the display unit of the Integrated Helmet and Display System (IHADSS) HMD fielded on the AH-64 Apache helicopter. The IHADSS is a monocular design. Imagery obtained from a nose-mounted thermal sensor is reproduced on a miniature, 1-inch diameter, cathode-ray-tube mounted on the right side of the helmet. The image on the face of the CRT is optically relayed to the pilot's right eye. The relay optics and CRT are referred to as the Helmet Display Unit (HDU) (Figure 16-25). Two optical elements of the HDU should be noted. The first is the objective lens that is positioned almost perpendicular to the pilot's face. This lens is approximately $1^3/_4$ inches in diameter and is mounted as the last element in the HDU housing barrel. The second is the beam splitter mounted on the side of the HDU barrel farthest from the face. The beam splitter, also referred to as the combiner, reflects the IHADSS imagery into the pilot's eye.

Figure 16-25 demonstrates the difference in the concepts of optical and physical eye relief for the IHADSS HMD. The IHADSS design optical eye relief is 10mm. By definition, this distance is the distance along the optical axis from the last optical element (center of the combiner) and the exit pupil. Figure 16-25 shows why the optical relief distance is not a functional (practical) parameter. The center of the combiner is located well back behind the lip of the HDU barrel housing. The HDU barrel and the interaction between the barrel and the wearer's cheekbone limit how close the combiner can be placed in front of the eye. This situation severely reduces the available distance between the pilot's eye and the plane that passes through the closest physical HDU structural element, and it is this distance that defines the physical eye relief.

In summary, *optical* eye relief distance is an optical system design parameter. However, it is a misleading parameter when the optical design is intended for use in systems such as HMDs where intervening devices must be placed between the optical system and the users eye, e.g., corrective spectacles, oxygen masks, nuclear, biological and chemical (NBC) protective mask, etc. A more useful parameter is *physical* eye relief. Physical eye relief distance, usually less than optical eye relief distance, takes into consideration the physical features of the structure and housing of the optical system's elements and these features' impact on reducing the "real" distance available between the optical system "HMD" and the viewer's eye.

Before leaving the description of eye relief, it may be worth addressing why the HMD design cannot simply provide a greater physical eye relief distance. For any HMD design, the two starting parameters that must be decided upon are exit pupil size and eye relief. However, these two parameters have considerable impact on the size of the last optical element in the HMD's eyepiece and the focal length of the system. All of these factors combined have additional impact on packaging size and total head-supported weight, very important parameters for HMD use in the military environment. In conclusion, the designer simply cannot make the eye relief distance as large as may be desired.

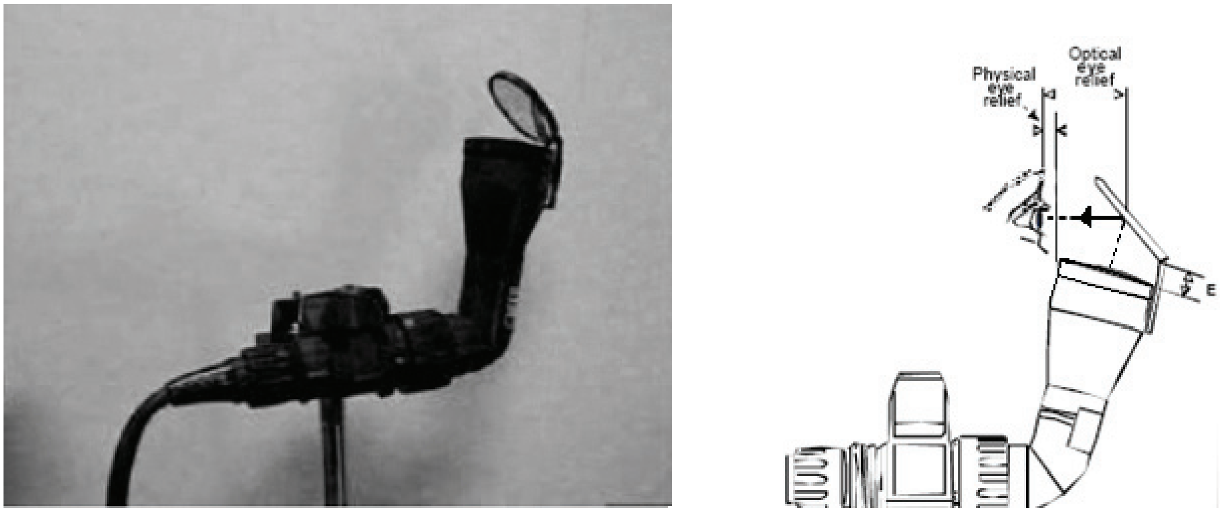

Figure 16-25. The IHADSS HMD helmet display unit.

Vision correction and HMDs

It is estimated that up to one-third of active duty U.S. Army, Navy, and Air Force Warfighters require corrective lenses (Madigan and Bower, 2004).[36] This percentage also is applicable to both the aviation and ground/ship Warfighter communities. Spectacles have been the traditional solution for visual correction. However, they pose complex issues for Warfighters using HMDs. Among these are: discomfort when worn with the helmet, slippage, reduced FOV, and interfering reflections off the lens and frame. Incompatibility with NBC protective masks and some forms of laser eye protection also have been problems.

Spectacles

Spectacle lenses are held in a frame, supported on the nose. Two arms attached to the frame hold the assembly to the head. The distance from the back part of the correcting spectacle lens to the eye's corneal surface is called the vertex distance (Figure 16-26). It ranges from 8 to 18 mm. Lens thickness is usually several millimeters, depending on material, type of glass or plastic, and lens shape, determined largely by the amount of correction required (Benjamin, 1998). Consequently, the front of the lens forms a surface that is some distance from the face, limiting ability to position or place the eye in the exit pupil. This necessitates increasing the required physical eye relief for many optical devices including HMDs (Licina, 1998; Melzer and Moffitt, 1997; Rash and McLean, 1998). If a pilot uses bifocals, the position of the head and eyes are restricted so that the region of the lens having the appropriate power (correction) is centered between the object being viewed and the pupil of the eye. However, in spite of some obvious limitations, eyeglasses work very well in most situations. They are cheap, durable, can be worn for extended periods of time, and are easy to manufacture and maintain. They provide excellent vision and a wide range of vision corrections.

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[36] As would be expected, requirement for visual correction increases with age, e.g., U.S. Air Force normalized, age-related data showed that a fairly constant percentage (over time) of 21- to 40-year-old Air Force pilots wear spectacles, but that almost 50% of ages 41 to 45 years do and approximately 90% of pilots over age 45 years wear spectacles.

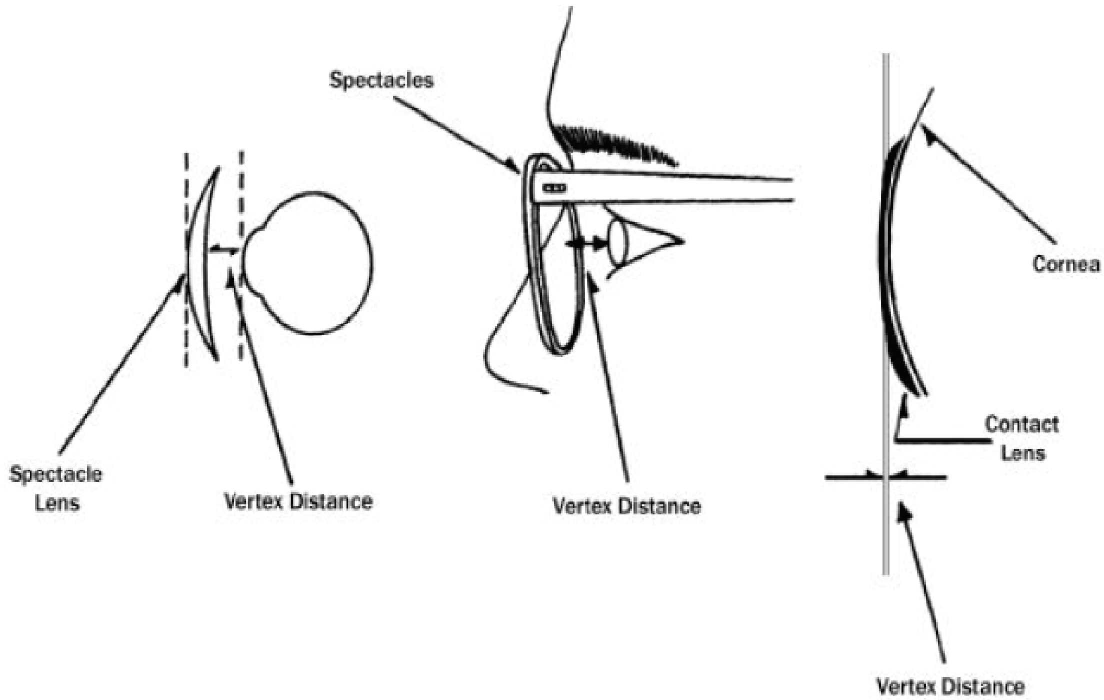

Figure 16-26. Vertex distance for spectacle lenses and contact lenses.

Nonetheless, the problem with spectacles has driven the search for other solutions to refractive error correction for pilots. Eyeglasses "present serious compatibility problems with many advanced optical systems, life support equipment, night vision or laser protective goggles, chemical protective hoods, and other personal protective gear" (Polse, 1990). In addition, there can be problems with perspiration and fogging, G-forces, reflections, seeing in foul weather, and comfort problems/hot spots when worn with helmets.

Contact lenses

To reduce the human factors issues associated with vision correction via spectacles, contact lens (CL) use and refractive surgery techniques have increased in acceptance by all of the military services. Use of CLs would appear to solve many of the problems experienced with spectacles, and, as it turns out, they do. Use of CLs to correct for refractive error solves the eye relief, spectacle comfort and reflection problems. Contact lenses are, simply put, more compatible with current optical devices like HMDs. However, CLs have their own set of problems, making their use less than universal among Warfighters.

CLs are formed, circular pieces of bell- or dome-shaped, transparent material that will maintain their shape while being held to the cornea of the eye by fluid attraction forces or the lid (Mandell, 1988). These small pieces of material vary in diameter from a little less than 7 mm to a little greater than 20 mm. A CL surface largely replaces the cornea optically providing refractive correction of the eye. Use of CLs to correct for refractive error solves the eye relief and spectacle comfort and reflection problems. The reason CLs solve the eye relief problem is because they are very thin, tenths of a millimeter, and rest on the cornea. This makes the vertex distance effectively zero (Figure 16-26). From the standpoint of eye relief, a CL on the cornea is virtually indistinguishable from the cornea without a CL. There is no frame used to support CLs, eliminating this source of discomfort and obstruction. The reflection characteristics of an in-place CL are very close to those of the natural, exposed cornea and do not provide any unusual viewing problems. There are two basic types of CLs, hard and soft.

Molded, hard plastic CLs were first made in 1938. Some were made of polymethyl methacrylate, a lens material that is still used, albeit not often. These lenses do not absorb water and are impermeable to oxygen. They rest on a layer of tears between the back surface of the CL and the corneal epithelium (the surface cells on the cornea). The hard CL moves when the wearer blinks, providing a pumping action that forces fresh, oxygenated tear between the cornea and the lens. Today, hard lenses called rigid gas permeable (RGP) CLs are more generally used. They are made from a variety of materials and, as their name suggests, are permeable to oxygen.

A soft, flexible hydrophilic CL was first conceived in Czechoslovakia in the 1950s and introduced in 1968. Since that time, many CL materials have been developed with varying flexibility, durability, water content, and oxygen transmissibility. Although soft CLs also move on the cornea, they tend to move less than hard C's and do not perform a tear pumping action. Consequently, the cornea depends, in part, on soft CL gas permeability to supply it with oxygen. Soft contact lenses have a certain water content that, along with thickness, is related to gas permeability. This is of concern, because hypoxia of the cornea, insufficient oxygen supplied to the tissue, can change its clarity and power. Hydration of the CL is also important in maintaining soft CL shape and directly related to its optical power. Environmental effects can cause changes in CL water content, particularly with hydrogel lenses (Refojo, 1991). These CLs can dehydrate in dry air until they reach equilibrium with tear absorption. If the air is very dry and the individual is in a draft, the water content at equilibrium may be too low, resulting in reduced CL performance and reduced oxygen transmission (O'Neal, 1991; Polse, 1990). Thick CLs with moderate to low water content have a slower rate of evaporation (O'Neal, 1991; Refojo, 1991). Consequently, the U.S. Air Force approved CLs are 58% water content or less.

The advantages of CL use were outlined by Crosley, Braun and Bailey (1974), Tredici and Flynn (1987), and revisited by the *Committee on Vision Commission on Behavioral and Social Sciences and Education National Research Council* (Polse, 1990) and the *Considerations in Contact Lens Use Under Adverse Conditions: Proceedings of a Symposium* (Flattau, 1991). Some of these advantages are: no interference with optical instruments (increased eye relief), increased FOV, no lens fogging, elimination of reflections from spectacle lenses, elimination of some perspiration problems, and use for treatment of specific medical/optical conditions. Tredici and Flynn (1987) went on to list 16 disadvantages, which include: CL intolerance, dislodging (for a variety of reasons, including G-force), increased chance of corneal edema, often poorer visual acuity than with spectacles, added health care burden, and difficulty of lens hygiene and professional care in the field (Table 16-13).

Even though great technical strides have been made in CL materials and design, the military has taken a very conservative stance regarding CL use in aviation, and they have done so for good reasons (Wiley, 1993). Military

Table 16-13.
Rationale for and disadvantage of contact lens use in U.S. Army aviation.
(Adapted from Crosley, Braun and Bailey, 1974; Tredici and Flynn, 1987)

RATIONALE FOR CONTACT LENS USE IN U.S. ARMY AVIATION

1. Increased field-of-vision
2. Good vision in inclement weather outside aircraft
3. No lens fogging
4. Elimination of reflections from spectacle lens
5. No interference with use of optical instruments (reduced physical eye relief)
6. Reduced perspiration problem
7. Compatibility with protective masks
8. Treatment of some medical/optical conditions

Table 16-13. (Cont.)
Rationale for and disadvantage of contact lens use in U.S. Army aviation.
(Adapted from Crosley, Braun and Bailey, 1974; Tredici and Flynn, 1987)

DISADVANTAGES OF CONTACT LENS USE IN U.S. ARMY AVIATION

1. Some individuals cannot tolerate contact lenses (newer materials have improved comfort and accommodation/adaptation)
2. Often poorer visual acuity than with spectacles
3. Lenses can be dislodged (a greater problem with hard contact lenses)
4. Bubbles can form beneath the contact lens at altitude (central vision with hard lenses, peripheral vision with soft contact lenses)
5. High G-forces can dislodge contact lenses, particularly hard lenses (a greater problem with Air Force aviation than Army aviation)
6. More difficult and time-consuming to fit than spectacles (particularly binocular and toric lenses)
7. Added health care burden (increased cost from professional fitting, follow-up, care)
8. Foreign body problems (particularly with hard contact lenses in high-particulate environments, smoke)
9. Lens hygiene and professional care difficult in field
10. Increased corneal infection risk (greatest with extended wear lenses that are necessary in the field)
11. Edema with extended wear and altitude (can reduce visual acuity and comfort)
12. Extended wear can be a problem (corneal edema, increased infection risk, comfort, etc.)
13. Can act as a sink in chemical environment (increasing toxicity, irritation, allergic reactions)
14. Allergic reactions (GPC, increased concentration of environmental allergens)

aviators must be able to perform continuously under very adverse conditions. Flight crews can be exposed to a variety of adverse environmental conditions: chemicals, dust, heat, cold, altitude changes, high and low humidity, G- forces, and adverse weather. The list is lengthy. Further, CLs may have to be cared for under very primitive conditions and worn for extended periods of time. There may not be optometrists or ophthalmologists in a field environment to care for the variety of eye problems that can arise from CL wear. Some of these conditions and some of the more general problems associated with CL wear restricts their use in the military to this day.

There are a number of excellent papers chronicling the history of CL use in military aviation Wiley, 1993; Lattimore, 1991b; Lattimore and Cornum, 1992; Tredici and Flynn, 1987). These papers give extensive reviews of the problems with CL wear in the military. The number of injuries and diseases associated with CL wear is unclear; these problems, although generally rare, include scratches and abrasions, dry eye and infection.

Soft CLs are relatively resistant to minor dust problems. However, scratches and abrasions do occur. CLs can be a barrier to some chemical exposures, but can also absorb chemicals, such as organic solvents, after a short period of exposure (Dennis et al., 1989a; Nilsson and Anderson, 1982). Consequently, chemical exposure can result in a toxic or allergy problem or simply an irritation. Even tearing of a CL can be a serious problem if it occurs at the wrong time in flight when both hands and feet are required to maintain control. As noted by the working group on Contact Lens Use Under Adverse Conditions (Polse, 1990), the cockpit (and the battlespace in general) can be a dusty and polluted environment. Although soft CLs are generally not recommended for highly polluted environments, they do seem acceptable in the cockpit (Lattimore and Cornum, 1992; Polse, 1990; Josephson, 1991; Dennis, 1988; Dennis et al., 1989b; Dennis et al., 1988; Kok-van Aalphen et al., 1985).

As a summary for the use of CLs as a potential solution to the physical eye relief problem in HMD applications, consider the statement from the working group on Contact Lens Use Under Adverse Conditions (Polse, 1990): "…helicopter personnel currently face the greatest spectacle incompatibility problems of any aviators, even as they face the greatest possible stumbling blocks to the successful use of contact lenses." CL use solves the eye relief, reflection and discomfort problems arising from spectacle use with HMDs. However, CLs do not provide a particularly good, general solution to presbyopia or astigmatism, and present new issues of their own, i.e., logistics, hygiene, use under extreme conditions, etc. At best, CLs can be used in situations where spectacles do not work well. At worst, they create more problems than they solve. In any case, they are here, probably to stay. However, refractive surgery is the latest refractive option emerging, and correction may provide an additional solution.

Refractive surgery techniques

Refractive surgery includes any procedure that surgically modifies the optical power of the human eye in order to eliminate or reduce the need for spectacles or contact lenses. In the latter half of the 20th century, the most common use of surgical intervention to change the power of the eye was the use of incisions in the cornea to correct unwanted or induced astigmatism after cataract surgery. The large peripheral corneal incisions needed to extract the cataractous lens often led to significant unequal power of the postoperative eye and a few accurate incisions in the peripheral cornea easily reduced astigmatism with minimal additional intervention. However, it was not until the advent of radial keratotomy (RK) in the 1970s that refractive surgery entered the popular mainstream. Today's arsenal of refractive surgery techniques includes everything from incisions and laser reshaping of the cornea to ocular implants. Although most techniques have been successful in reducing the individual's need for spectacles or contacts, almost all techniques have side effects that to varying degrees may affect visual performance in the operational environment.

Great leaps have been made in the technologies surrounding refractive surgery, and the outcomes have been much more precise, however, there are still problems associated with refractive surgery. Most notably, individuals may experience problems with night vision, the presence of halos or glare at night, increases in dry eye symptoms (especially after PRK or LASIK), and risks associated with surgeries that expose the eye to possible infections or reactions to agents used in the surgery (such as anesthetics). The problems with night vision, halos and glare have been mainly associated with an increase in the aberrations of the eye after refractive surgery. Aberrations due to changes in the shape of the cornea are most pronounced if the refractive correction is high, the ablation zone is small or the pupil is large (Martínez et al., 1998; Oshika et al., 1999). Aberrations are generally minimal when the refractive correction is less than 6.00 diopters of myopia or 4.00 diopters of hyperopia. Most lasers ablate a zone larger than the daylight pupil size; however, in some cases, pupil size under low light conditions may exceed the ablation area and cause visual disturbances. In a normal eye, the aberrations of the anterior surface of the cornea are balanced by opposite aberrations of the remaining refractive surfaces in the eye, including the posterior corneal surface and the crystalline lens. The anterior surface of the cornea is the primary refracting surface of the eye; therefore, modifications at this surface have the greatest effect on the quality of the image formed by the eye. If the aberration balance of the eye is modified, there are various impacts on visual performance ranging from subtle visual disturbances to severe distortions.

A significant amount of work is being done to improve the outcome of refractive surgery. One main technology has contributed towards this effort – the capability to measure the higher order aberrations of the eye. Most refractive surgery technologies have increased the basic aberration level of the eye through the induction of shape changes or a mismatch between the optics of the added components and the optics of the eye. The most promising procedures for reducing the amount of induced higher order aberrations are the corneal refractive surgery procedures or custom implants. Using a scanning spot laser, very precise ablations can be applied to the cornea in either PRK or LASIK. The problem with PRK is that the cornea undergoes a certain amount of unpredictable healing as the epithelium regrows over the corneal surface and the anterior corneal stroma responds to the laser insult. This can result in an undoing of the precise ablations and a reduction in the overall desired effect of the correction. With LASIK, the replacement of the flap over the ablated area is much like putting a thick blanket over a precisely sculpted surface; the end result is not as finely sculpted as anticipated.

The military has been a leader in studying the impact of refractive surgery techniques, especially in terms of performance under highly visually demanding conditions. Navy studies of PRK have been ongoing since 1993 and more recent efforts have been aimed towards evaluation of advanced LASIK technologies (Stanley, Tanzer and Schallhorn, 2008). Air Force efforts to evaluate refractive surgery have concentrated on determination of the effects of altitude, G-forces, and disability glare (Ivan, 2002). Studies show that moderate altitude does not cause PRK and LASIK corneas to undergo the same significant corneal thickening and curvature changes as previously seen with RK (Davidorf, 1997; van de Pol et al., 2000). Army studies have evaluated the impact of both PRK and LASIK on military operations including the helicopter flight environment (Hammond, Madigan and Bower, 2005; van de Pol et al., 2007) . Overall, study results completed by all three services show that PRK and LASIK are effective alternatives to spectacles or CLs in the aviation environment, with the caveat that not all refractive surgery procedures are appropriate for all aviation specialties. This fact is reflected in the differences in specific approved procedures from one service to the other.

User adjustments

One last but very important topic is that of the most direct interface the user has with the HMD, i.e., the controls that provide the user the ability to make adjustments to the display's characteristics. Despite the trend and the various arguments for automatic or self-adapting circuits and systems, the unique environments and situations encountered by the Warfighter, coupled with the potentially severe outcomes, argue for providing the user with the capability to make control inputs for the purpose of optimizing HMD information. Until advances in a number of scientific fields allow what would currently be considered as "futuristic" user-directed inactive control over HMD functions, (see Chapter 19, *The Potential of an Interactive HMD*), such adjustments most likely will be accomplished by hands-on controls.

On HMD devices, both monocular and binocular, there should be mechanical, electronic, or optical adjustment mechanisms available for the user to optimize the attributes of the imagery and selection of displayed information. The mechanical adjustments are used primarily to align the optical axes and exit pupils of the device to the entrance pupils and primary lines of sight of the user, if required by the inherent design. The electronic adjustments may include display brightness, contrast, electronic focus, sizing, sensor sensitivity characteristics (gain and off-set for thermal sensors), etc. The optical adjustments may include the focus adjustments for the eyepieces and sensor objective lens, and magnification selection for targeting and pilotage sensors.

Adjustment control concepts

Before discussing the various control types, there are a few higher order principles for display controls worth reviewing. First is the principle of location compatibility (or the *collocation principle* as described in Wickens and Hollands, 2000). This principle is most closely associated with the human tendency to move or orient toward a source of stimulation within the design environment. A physical interpretation of this principle is to actually position adjustment controls near the stimulus to which they are related, e.g., collocating a radio volume control on the radio itself. Touch screen controls are the ultimate realization of the collocation principle. Unfortunately, this principle is not always possible to implement, and in military vehicles or on the individual Warfighter, where space is at a premium, it is rarely achieved. Automobile designers recently have elected to ignore this principle by placing radio controls on the steering wheel, although ostensibly for safety consideration, i.e., to minimize time spent looking down away from the road.

Wickens and Hollands (1999) suggest that when the collocation principle cannot be adhered to, the consequences may be minimized by employing other compatibility principles, such as *congruence* and *rules*. Congruence is based on the concept that the spatial array of controls should have the same configuration or "be congruent with" the spatial array of the objects (stimuli) being controlled. Figure 16-27 shows the classical stovetop burner example often used to illustrate the collocation and congruent principles of control layout.

When congruence is not achievable, the designer has to fall back on a set of *rules*, a rule being a definite plan used to map controls to stimuli.

The U.S. Air Force has been exploring new spatial arrangement paradigms, along with information modality and temporal organization through the application of adaptive controls for their next-generation crew stations

(Haas et al., 2001). Their goal is to develop and evaluate interface concepts that will enhance overall performance by embedding knowledge of the Warfighter's state inside the interface, enabling the interface to make informed, automated decisions regarding many of the interface's information management display characteristics. These characteristics include information modality, spatial arrangement, and temporal organization. It is hypothesized that by increasing the ability of the interface to adapt to the changing requirements of the Warfighter in real time the interface will provide intuitive information management to the Warfighter.

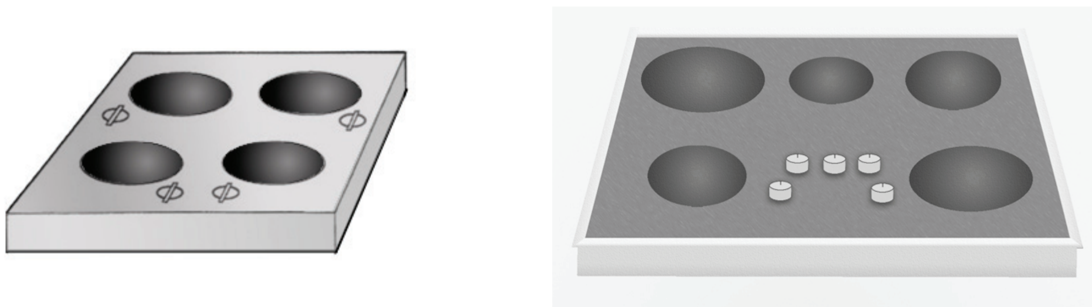

Figure 16-27. Use of stovetop burner arrays to illustrate the collocation (left) and congruent (right) principles of control layout.

A second higher order principle for display controls is *movement compatibility*. The relationship between a control movement and the effect most expected by a user population is known as a *direction-of-motion stereotype*; such a relationship is said to be compatible (Chan and Chan, 2007). Neurocognitive research has reported the strong relationship between movement observation and movement execution (Brass et al., 2000).

As an example, consider the typical *brightness* and *contrast* controls on many displays. These two controls are highly associated with adjustments of image quality and are often adjusted in a back-and-forth manner or clockwise rotational manner, which is typical of many controls (Figure 16-28).

The ISO developed a standard (ISO 9241-410:2008, *Ergonomics of Human-system Interaction – Part 410: Design Criteria for Physical Input Devices*) that specifies criteria based on ergonomics factors for the design of physical input devices for interactive systems, which includes keyboards, mice, pucks, joysticks, trackballs, track pads, tablets and overlays, touch sensitive screens, styli and light pens, and voice- and gesture-controlled devices. It provides guidance on the design of these devices, taking into consideration the capabilities and limitations of users, as well as specific criteria for each type of device.

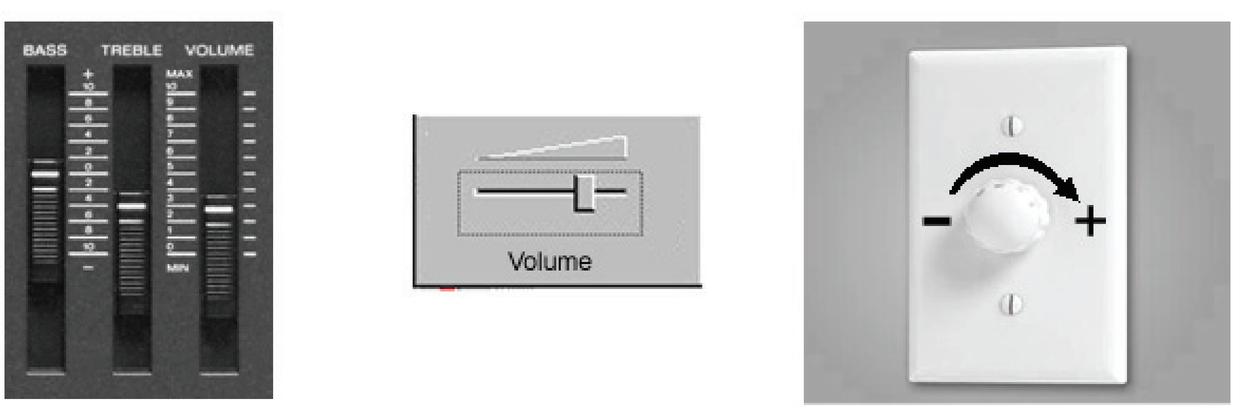

Figure 16-28. Examples of movement compatibility with various control designs: Left – Moving up increases variable, moving down decreases. Middle – Moving right increases variable, moving left decreases. Right – Turning clockwise increases variable, turning counterclockwise decreases.

Control physical design

There are a huge number of human factors and ergonomic issues associated with the physical implementation of input controls. Control device types run a wide gamut that include switches, knobs, handles, wheels, pointers, levers, trackballs, pedals, touch screens and computer mice (Sanders and McCormick, 1993). However, for HMDs, the adjustment input controls are well-defined in function and relatively narrow in selection. In the following sections, design, human factors and ergonomic issues of current HMDs are discussed.

Mechanical adjustments

Except for some early hand-held head-up displays (HUDs) used in helicopter gun ships for rocket and mini-gun alignment, fixed HUDs require no mechanical user adjustments except for seat height. For other HMD types, the mechanical adjustments may include interpupillary distance (IPD), fore-aft, vertical, tilt, roll, yaw, etc. The mechanical adjustment components may range from fine-threaded individual adjustments for one axis or plane to friction locks with ball-joints that include all axes and planes. The mechanical range of adjustments has typically been based on the 1st to 99th percentile male user.

Each potential mechanical misadjustment will affect some visual characteristic, but the adjustments are interrelated (King and Morse, 1992; McLean et al., 1997). For example, with the nonpupil-forming Aviator's Night Vision System (ANVIS), when the fore-aft adjustment is set exactly at the optimum sighting alignment point (OSAP) which is the maximum viewing distance that provides a full FOV, increasing the fore-aft distance from the eye along the optical axis proportionally decreases the ANVIS FOV (Kotulak, 1992; McLean, 1995). From the OSAP, misalignment of the IPD will decrease the FOV in the opposite direction of display movement for each ocular, thereby reducing the binocular FOV, but will not reduce the total horizontal FOV.

Misalignment of the IPD of the NVGs has been blamed for disrupting depth perception (Sheehy and Wilkinson, 1989) and inducing vergence errors (Melzer and Moffitt, 1997). However, when the eyepieces are adjusted to infinity, vergence changes do not occur (McLean et al., 1997).

For a pupil-forming system, when the pupil is moved forward or aft of the eye box that is formed around the exit pupil location along the optical axis, the FOV will be reduced. If the pupil of the eye is moved laterally from the edge of the eye box, the full FOV of the image will be extinguished within the distance of the width of the eye pupil.

For NVGs, the displacements of the right and left oculars together or relative to each other around the roll, tilt, and yaw axes will not displace the viewed image when focused at infinity, since the sensor and display are physically bound together and located near the eye. The individual FOV will be displaced in the direction of movement, but not the image. However, for HMDs with remote sensors, any relative movement between oculars around the axes will displace the images and change the convergence, divergence, or cyclo-rotation to the eyes. For the monocular HDU of the IHADSS, the mechanical adjustments are fore-aft and roll. The combiner can be moved up and down for eye alignment with the optical axis of the HDU, but most of the alignment is obtained with proper helmet fit to keep the combiner at the lowest position to obtain the maximum eye clearance and FOV. Misalignment of the HDU and IHADSS helmet outside a specific value will not allow a proper boresight with the total system.

Activation, adjustment, or movement of any mechanism on the HMD or associated instrumentation must be accomplished by the user through tactile identification and activation through any required personal protective equipment (PPE), e.g., the aviator's flight gloves, as well as, the chemical protective over-glove currently used. Removing gloves for adjustments is not a viable option.

Electronic adjustments

On present night vision imaging systems such as ANVIS, there are no user electronic adjustments provided. The tube amplification and automatic brightness control (ABC) level are set at the factory according to specifications. Since the 2nd and 3rd generation intensifier tubes are basically linear amplifiers with a gamma approaching unity (Allen and Hebb, 1997; Kotulak and Morse, 1994a), the imaged contrast should remain constant for changes in light level and between right and left tubes. A field study at a U.S. Army NVG training facility measured the differences in ANVIS luminance output between the right and left tubes for 20 pairs of ANVIS and found 15% of the sample had luminance differences greater than 0.1 log unit (30%) below the ABC level and none had differences greater than 0.1 log unit above the ABC level (McLean, 1997). The recent AN/PVS-14 monocular night vision device for ground troops has a user adjustable gain control, which may be incorporated in future aviation NVG designs.

For HMDs with remote sensors, both the displays in the HMD and sensor usually have user adjustments for optimization of the image. For the monocular HDU with the IHADSS, the pilot can adjust the contrast and brightness of the CRT display with the aid of a grey scale test pattern. The thermal sensors can be optimized by adjusting the gain and bias levels, where the gain refers to the range of temperatures, and the bias the average or midpoint temperature. The sensor can electronically transmit approximately 30 grey levels, where the HDU can only show about 10 grey levels (Rash, Verona, and Crowley, 1990). This means that scenes containing objects with large temperature differences would either cause loss of details from the saturation of hot objects or no contrast for cooler objects from the background. Thermal sensors are used for both pilotage and target detection. The gain and bias adjustments to optimize the contrast between the trees and sky for pilotage are considerably different than the "hot spot" technique used for the copilot/gunner for target detection. Therefore, the user will desire both manual and automatic sensor adjustment options to obtain specific information for a given scene. Thermal sensors also have an option to electronically reverse the contrast (polarity) from either white hot or black hot to either improve target detection or provide a more natural visual scene for pilotage.

Optical adjustments

For NVGs, the user has both eyepiece and objective lenses to adjust for optimum resolution. The objective lens focus is independent of the eyepiece focus and is similar to the focusing of a camera lens. The eyepiece focus adjusts the spherical lens power to compensate for the user's refractive error (hyperopia or myopia) or induced accommodation. The standard objective lenses for ANVIS and the AN/PVS-5 NVGs adjust from approximately 10 inches (4.0 diopters) to infinity for the AN/PVS-5s and slightly beyond infinity for the ANVIS. This 4-diopter objective lens adjustment range is obtained with approximately a one-third (120-degree) rotational turn of the focusing knob. This means 1 degree of objective lens rotation equates to approximately 0.03 diopters. With the very fast objective lens for ANVIS (f#/1.2), detectable blur was found with as little as 0.05 diopter of objective lens misfocus (McLean, 1996). The latest fielded I^2 version (ANVIS-9) incorporates a fine focus objective lens where two turns (720 degrees rotation) change the focus from infinity to 1 meter (1 diopter). Objective lens focus with the ANVIS-9 or the Air Force 4949 is both more precise and much more stable during flight.

Eyepiece diopter focus: Fixed or adjustable? The most controversial subject for night imaging devices has been the eyepiece focus for I^2 devices and HMDs. Previous literature has suggested that dark focus, instrument myopia, and night myopia could play a significant part in determining the optimum lens power for night vision devices. A study by Kotulak and Morse (1994b) includes an extensive review of this literature. One group of visual scientists (Moffitt, 1991; Task and Gleason, 1993) suggests using fixed focused systems with a diopter value from 0.00 to -1.00 (infinity to 1 meter). Using aviators labeled emmetropic, other researchers have found better visual resolution with user focus adjustable eyepieces than with infinity fixed-focused eyepieces (Kotulak and Morse, 1994a; Task and Gleason, 1993). Using the most plus lens power focusing monocular technique, Kotulak and Morse (1994b) reported that 13 aviator subjects adjusted the eyepiece focus an average of -1.13 diopters (0.63

SD) with a mean difference between right and left eye focus of 0.57 diopters (0.47 SD). Using the same focusing technique with 12 subjects, Task and Gleason (1993) found an average eyepiece setting of -1.05 diopters (0.24 SD) and with a mean difference between right and left eye focus of 0.40 diopter (0.29 SD).

With the HDU monocular system of the IHADSS, Behar et al. (1990) found the average diopter eyepiece setting by 20 Apache pilots was -2.28 diopters, range 0 to -5.25 diopters. The frequently reported symptoms of asthenopia and headaches were attributed to over stimulating accommodation. [This was attributed to the failure of the IHADSS to provide a zero diopter detent or marking on the HDU focus knob.] However, CuQlock-Knopp et al. (1997) found an average diopter setting for a monocular NVG and the biocular AN/PVS-7 for 22 subjects to be 1.47 diopters and -1.54, respectively, with standard deviations of approximately 1 diopter. CuQlock-Knopp et al. (1997) also evaluated the relationship between the value of the eyepiece diopter setting and the reported eyestrain, and found no significant correlations with either the monocular or the biocular NVG.

For the classical HUD that is mounted on the glare shield and used for an aiming device, the crosshair or pipper must be collimated at infinity to retain alignment with small head and eye movements. For the monocular and binocular night imaging devices, the infinity eyepiece focus will result in some nonspectacle wearing users having less than optimum resolution. Several visual scientists (e.g., Task, Gleason, McLean, et al.) believe that some of the so called emmetropic aviators that do not wear corrective lenses are actually low myopes (-0.25 to -0.75 D) (Kotulak and Morse, 1994b) that will show reduced resolution with decreasing light levels which increase the pupil size and blur circle on the retina. The eyepiece lens power that provides most users with the best resolution with NVGs and HMDs appears to be slightly minus power between approximately -0.25 and -0.75 diopters. To ensure that optimum resolution is obtained by the aviation population of all of the nonspectacle wearing and spectacle wearing personnel using night imaging devices, a small range of adjustment would be desired, and better training in focusing procedures, to include a binocular focusing method to control accommodation with vergence. A problem found with some fixed-focused viewing devices such as the "Cats eyes NVGs" has been the ability of the factory to precisely set the eyepiece focus within a 0.12 diopter tolerance. The zero position on the diopter scale of newly received ANVIS was found to vary by up to 1.25 diopters on 10 sets of NVGs. The military specification for the zero scale tolerance for NVGs is 0.50 diopters. This would result in blurred vision for emmetropic users if the errors are on the plus lens power side. With the newer generation of image intensifiers and thermal sensors, resolution has improved to approximately 20/25 (Snellen acuity) for optimum conditions. Therefore, the focus adjustments for both the objective and eyepiece are more critical than with previous night imaging devices. Thus, a small range of user adjustable eyepiece and objective lens focus capability for the image intensifier systems and for the eyepieces of HMDs is recommended.

System integration

An HMD may be considered as a subsystem (i.e., a single component) that is intended to be used in coordination with other subsystems. The concept of *system integration* as used in this chapter is one of integrating the multiple subsystems into one system and ensuring that the subsystems function together as a system (Georgia State University, 2007). System integration issues will vary depending on the user's functional environment.

Equipment compatibility

All HMD designs must be physically and functionally compatible with all existing mission and life support (e.g., survival) equipment. Each military branch identifies a list of equipment with which new subsystems must be compatible. Examples include corrective/protective eyewear, protective masks, oxygen masks, shoulder harnesses, survival vests, flotation equipment and components, body armor, vehicle or aircraft seat armor, and cabin interior structures and systems. The difficulty of achieving HMD-equipment compatibility is demonstrated in Figure 16-29 (left), which shows a frontal view of an Apache aviator wearing a full aviator life-support equipment (ALSE) ensemble with M-43 protective mask. Figure 16-29(right) shows the potential for interior aircraft compatibility problems by depicting an aviator in the Apache front seat with the HMD optics attached.

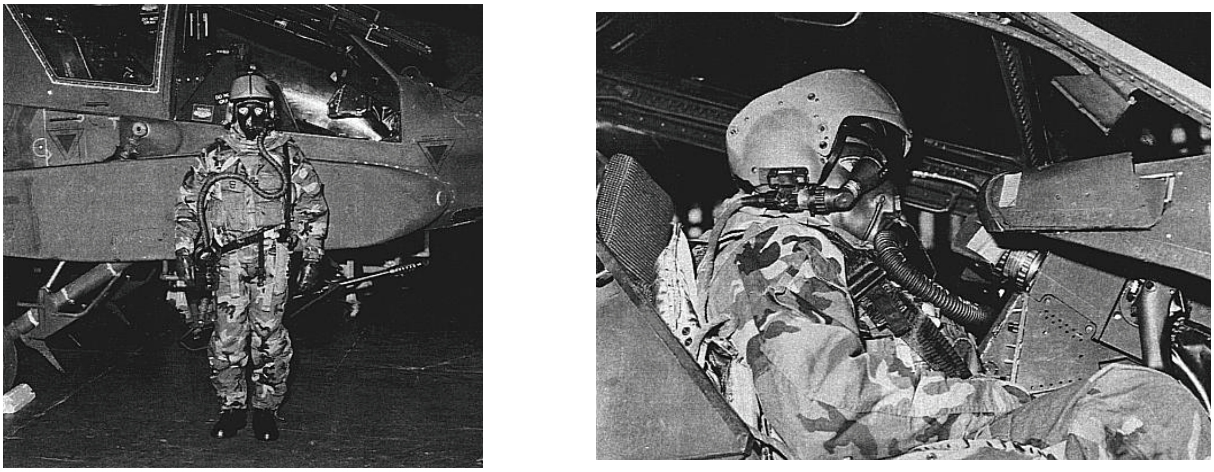

Figure 16-29. A frontal view of an Apache aviator wearing a full, aviator life-support equipment (ALSE) ensemble with M-43 protective mask (left) and in the Apache front seat with the HMD optics attached.

Egress[37]

In enclosed environments (e.g., ground vehicles and aircraft), emergency *egress* is considered one of the most important system integration issues. During pre- and post-crash emergency situations, the HMD user must be able to disengage from some or all components of the HMD system. In most military ground vehicles, fixed- and rotary-wing aircraft, the presence of an HMD adds another level of complexity to the Warfighter escape sequence. For ground vehicles and rotary-wing aircraft, it is essential that a quick-disconnect capability be provided. In addition, in the event that the user is unable to reach the disconnect mechanism or has insufficient time to do so, the HMD cables must be designed to provide a hands-free break-away capability (i.e., allow their breaking away by moderate brute force).

For fixed-wing aircraft, emergency egress typically involves ejection and parachuting. While the requirements for quick disconnect and an alternative hands-free break-away still must be met, this demanding scenario places additional aerodynamic requirements on the initial HMD design in order to prevent injury and HMD/helmet loss during the ejection and parachuting processes, e.g., ejection performance was a major concern during the design of the Joint Helmet-Mounted Cueing System (JHMCS). Barnaba and Kirk (1999) evaluated JHMCS performance parameters during ejection that included structural integrity, facial and head protection, neck tensile loads, ejection seat and crew equipment compatibility, and mechanical functionality.

Summary

The major goal of this chapter is to make HMD designers and users aware of the difficult and demanding environment in which HMDs must operate. Paper designs and laboratory prototypes must take into consideration the multitude of operational factors with which the HMD user must contend. These factors range widely in type and scope. Whether environmental (external) or self-imposed (internal) in nature, they invariably affect human performance. Technology, no matter how great, is only as good as its effectiveness in the hands (or on the heads) of the user in the actual operating environment.

[37] The terms *ingress* and *egress* are defined as entering and exiting, respectively.

References

Abey-Wickrama, I., A'Brook, M.F., Gattoni, F.E.G., and Herridge, C.F. (1969). Mental-hospital admissions and aircraft noise, *Lancet*, 2, 1275-1277.

Acheson, S.K., Stein R.M., and Swartzwelder H.S. (1998). Impairment of semantic and figural memory by acute ethanol: Age-dependent effects, *Alcoholism, Clinical and Experimental Research*, 22(7), 1437-1442.

Ahroon, W.A., Gordon, E., and Brozoski, F.T. (2002). Impulse noise levels of the UH-6OA/L Black Hawk helicopter cockpit air bag system - enhanced lateral air bags. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2002-16.

Akerstedt, T. (1995). Work hours, sleepiness and the underlying mechanisms, *Journal of Sleep Research,* 4(Suppl. 2)*,* 15-22.

Akerstedt, T. (1988). Sleepiness as a consequence of shift work, *Sleep*, 11(1), 17-34.

Akerstedt, T. (2000). Consensus statement: Fatigue and accidents in transport operations, *Journal of Sleep Research, 9,* 395.

Akerstedt, T., and Ficca, G. (1997). Alertness-enhancing drugs as a countermeasure to fatigue in irregular work hours, *Chronobiology International*, 14(2), 145-158.

Alem, N.M., Shanahan, D.F., Barson, J.V., and Muzzy, III, W.H. (1991a). The airbag as a supplement to standard restraint systems in the AH-1 and AH-64 attack helicopters and its role in reducing head strikes of the copilot/gunner, volume I. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 91-6.

Alem, N.M., Shanahan, D.F., Barson, J.V., and Muzzy, III, W.H. (1991b). The airbag as a supplement to standard restraint systems in the AH-1 and AH-64 attack helicopters and its role in reducing head strikes of the copilot/gunner, Volume II. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 91-6a.

Allain, H., Bentue-Ferrer, D., Le Breton, S., Polard, E., and Gandon, J. (2003). Preference of insomniac patients between a single dose of zolpidem 10 mg versus zaleplon 10 mg, *Human Psychopharmacology: Clinical and Experimental,* 18(5), 369-374.

Allen, J.H., and Hebb, R. C. 1997. Determining the gamma of a night vision device. Orlando, FL: Naval Air Warfare Center. Report No. NAWCTSD-TR-95-003.

Allen, M.J., Abrams, B.S., Ginsburg, A.P., and Weintraub, L. (2001). *Forensic Aspects of Vision and Highway Safety*. Tucson, AZ: Lawyers and Judges Publishing Company.

American Conference of Governmental Industrial Hygienists. (2001). ACGIH-HAV, Hand-arm vibration standard. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

American Conference of Governmental Industrial Hygienists. (2001). Whole-body vibration: TLV physical agents. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

American Conference of Governmental Industrial Hygienists (2005). Whole-body vibration. In: *Threshold limit values, TLVs and biological exposure indices for 2005*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

American National Standards Institute. (2002). ANSI S3.18, Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration. American National Standards Institute.

American National Standards Institute. (2003). ANSI Z87.1, Occupational and Educational Personal Eye and Face Protection Devices. American National Standards Institute.

American National Standards Institute. (1986). ANSI S3.34, Human Exposure to Vibration Transmitted to the Hand, Guide for Measurement and Evaluation of. American National Standards Institute.

American National Standards Institute. (2006). ANSI S2.70-2006: Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand. (Revision/replacement of ANSI S3.34-1986)

American Sleep Disorders Association. (1994). *Coping with Shiftwork*. Rochester, MN.

Anderson, S.J., and Holliday, I.E. (1994). Night driving: Effects of glare from vehicle headlights on motion perception, *Ophthalmology and Physiological Optics*, 15, 545-551.
Applegate, R.A. (1989). Disability glare and hydrogel lens wear revisited, *Optometry and Vision Science*, 66(11), 756-759.
Applegate, R.A., and Wolf, M. (1987). Disability glare increased by hydrogel lens wear, *American Journal of Optometry and Physiological Optics*, 64(5), 309-312.
Arendt, J. (1999). Jet-lag and shift work: Therapeutic use of melatonin, *Journal of the Royal Society of Medicine, 92,* 402-5.
Arendt, J., and Deacon, S. (1997). Treatment of circadian rhythm disorders – Melatonin, *Chronobiology International,* 14, 185-204.
Arendt, J., and Marks, V. (1982). Physiological changes underlying jet lag, *British Medical Journal,* 284, 144-46.
Arendt, J., Deacon, S., English, J., Hampton, S., and Morgan, L. (1995). Melatonin and adjustment to phase shift, *Journal of Sleep Research,* 4(Suppl. 2), 74-79.
Arendt, J., Skene, D.J., Middleton, B., Lockley, S.W., and Deacon, S. (1997). Efficacy of melatonin treatment in jet lag, shift work, and blindness, *Journal of Biological Rhythms,* 12, 604-17.
Armstrong, S.M. (1999). Melatonin as a chronobiotic for circadian insomnia: Clinical observations and animal models, *Advanced Experiments in Medical Biology,* 460, 283-297.
Armstrong, S.M, Cassone, V.M., Chesworth, M.J., Redman, J.R., and Short, R.V. (1986). Synchronization of mammalian circadian rhythms by melatonin, *Journal of Neural Transmission*, 21(Suppl.), 375-394.
Artal, P., Berrio, E., and Guirao, A. (2002). Contribution of the cornea and internal surfaces to the change of ocular aberrations with age, *Optical Society of America*, 19(1), 137-143.
Artal, P., Guirao., A, Berrio, E., Piers, P., and Norrby, S. (2003). Optical aberrations and the aging eye, *International Ophthalmology Clinics*, 43(2), 63-77.
Aschoff, J., and Wever, R. (1981). The circadian system of man. In: Aschoff, J. (Ed.), *Handbook of Behavioral Neurobiology, Volume 4, Biological Rhythms*. New York, USA: Plenum Press.
Atkinson, G., Drust, B., Reilly, T., and Waterhouse, J. (2003). The relevance of melatonin to sports medicine and science, *Sports Medicine,* 33, 809-31.
Atchison, D.A., and Smith, G. (2000). *Optics of the Human Eye*. Oxford: Butterworth-Heinemann.
Axelsson, A., and Prasher, D.K. (1999). Tinnitus: A warning signal to teenagers attending discotheques? *Noise and Health,* 2, 1-2.
Bailey, M.D., Mitchell, G.L., Dhaliwal, D.K., Boxer Wachler, B.S., and Zadnik, K. (2003). Patient satisfaction and visual symptoms after laser in situ keratomileusis, *Ophthalmology*, 110(7), 13711378.
Baker, H.D. (1953). The instantaneous threshold and early dark adaptation, *Journal of the Optical Society of America,* 43(9), 798-803.
Baker, H.D. (1949). The course of foveal light adaptation measured by the threshold intensity increment, *Journal of the Optical Society of America*, 39(2), 172-179.
Baldeweg, T., Wong, D., and Stephan, K.E. (2006). Nicotinic modulation of human auditory sensory memory: Evidence from mismatch negativity potentials *International Journal of Psychophysiology*, 59(1), 49-58.
Balter, M.B., and Uhlenhuth, E.H. (1992). New epidemiologic findings about insomnia and its treatment, *Journal of Clinical Psychiatry*, 53(12 Suppl.), 34-39.
Banderet, L., and Burse, R. (1988). Effects of high terrestrial altitude on military performance. In: Gal, R., and Mangelsdorff, D. (Eds.), *Handbook of Military Psychology*. New York: John Wiley and Sons.
Banderet, L., and Shukitt-Hale, B. (2002). Cognitive performance, mood, and neurological status at high terrestrial elevation. In: Lounsbury, D.E., Bellamy, R.F., and Zajtchuk, R. (Eds.), *Medical Aspects of Harsh Environments.* Washington, DC: Office of the Surgeon General, Borden Institute.
Banerjee, D., Vitiello, M.V., and Grunstein, R.R. (2004). Pharmacotherapy for excessive daytime sleepiness, *Sleep Medicine Review,* 8, 339-354.

Barnaba, J.M., and Kirk, W.F. (1999). Evaluation of ejection safety for the Joint Helmet-Mounted Cueing System, *Proceedings of SPIE, Helmet- and Head-Mounted Displays IV*, 3689, 210-219.

Baranski, J.V., Gil, V., McLellan, T.M., Moroz, D., Buguet, A., and Radomski, M. (2002). Effects of modafinil on cognitive performance during 40 hr of sleep deprivation in a warm environment, *Military Psychology*, 14(1), 23-47.

Baranski, J.V., and Pigeau, R.A. (1997). Self-monitoring cognitive performance during sleep deprivation: Effects of modafinil, d-amphetamine, and placebo, *Journal of Sleep Research*, 6, 84-91.

Barbur, J.L (2004). (Personal correspondence).

Barlow, H.B. (1972). Dark and light adaptation: Psychophysics. In: Jameson, D., and Hurvich, L.M. (Eds.), *Visual Psychophysics*. New York: Springer-Verlag.

Bartholini, G. (1988). Growing aspects of hypnotic drugs. In: Sauvanet, J.P., Langer, S.Z., and Morselli, P.L. (Eds.), *Imidazopyridines in Sleep Disorders*. New York: Raven Press. p. 1-9.

Bartlett, N.R. (1966). Dark adaptation and light adaptation (Chapter 8). In: Graham, C.H. (Ed), *Vision and Visual Perception*. New York: John Wiley and Sons.

Batchelor, A.J. (2006). Medication and aircrew. In: Rainford, D.J., and Gradwell, D.P (Eds.), *Ernsting's Aviation Medicine*. London: Hodder Arnold.

Belenky, G., Wesensten, N.J., Thorne, D.R., Thomas, M.L., Sing, H.C., Redmond, D.P., Russo, M.B., and Balkin, T.J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study, *Journal of Sleep Research*, 12(1), 1-12.

Belyavin, A., and Wright, N.A. (1987). Changes in electrical activity of the brain with vigilance, *Electroencephalography and Clinical Neurophysiology,* 66, 137-144.

Benjamin, W.J. (Ed.) (1998). *Borish's Clinical Refraction*. Philadelphia, PA: W.B. Saunders Company.

Benson, A.J., and Barnes, G.R. (1978). Vision during angular oscillation: The dynamic visual and vestibular mechanisms, *Aviation, Space and Environmental Medicine*, 49, 340-345.

Berglund, B., and Hassmén, P. (1996). Sources and effects of low-frequency noise, *Journal of the Acoustical Society of America*, 99(5), 2985-3002.

Bernaards, C.M., Twisk, J.W., van Mechelen, W., Snel, J., and Kemper, H.C. (2003). A longitudinal study on smoking in relationship to fitness and heart rate response, *Medicine and Science in Sports and Exercise*, 35(5), 793-800.

Biberman, L.M., and Tsou, B. (1991). Image display technology and problems with emphasis on airborne systems. Alexandria, VA: Institute for Defense Analysis. IDA Paper P-2448.

Bichao, I.C., Yager, D., and Meng, J. (1995). Disability glare: Effects of temporal characteristics of the glare source and of the visual field location of the test stimulus, *Journal of the Optical Society of America*, A12(10), 2252-2258.

Blois, R., Gaillard, J., Attali, P., and Coqueline, J. (1993). Effect of zolpidem on sleep in healthy subjects: A placebo controlled trial with polysomnographic recordings, *Clinical Therapeutics,* 15(5), 797-809.

Blomqvist, G., Saltin, B., Mitchell, J.E., and Vastagh, G.F. (1970). Acute effects of ethanol ingestion on the response to submaximal and maximal exercise in man, *Circulation*, 42, 463-470.

Boff, K.R., and Lincoln, J.E. (1988). Vibration characteristics of rotary-wing aircraft. *Engineering Data Compendium: Human Perception and Performance*. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory. p. 2072-2136.

Bohnker, B.K., Page, J.C., Rovig, G., Betts, L.S., and Sack, D.M. (2002). Navy Hearing Conservation Program: threshold shifts in enlisted personnel, 1995-1999, *Military Medicine*, 167(1), 48-52.

Bongers, P.M., Hulshof, C.T., Dijkstra, L., Boshuizen, H.C., Groenhout, H.J., and Valken, E. (1990). Back pain and exposure to whole body vibration in helicopter pilots, *Ergonomics*, 33(8),1007-1026.

Bonnet, M.H. (1994). Sleep deprivation. In: Kryger, M.H., Roth, T., and Dement, W.C., (Eds.), *Principles and practice of sleep medicine* (2nd Ed.). Philadelphia: W.B. Saunders Company.

Bonnet, M.H., Gomez, S., Wirth, O., and Arand, D.L. (1995). The use of caffeine versus prophylactic naps in sustained performance, *Sleep*, 18(2), 97-104.

Bourgeois-Bougrine, S., Carbon, P., Gounelle, C., Mollard, R., and Coblentz, A. (2003). Perceived fatigue for short- and long-haul flights: A survey of 739 airline pilots, *Aviation Space and Environmental Medicine,* 74, 1072-77.

Boynton, R.M., Bush, W.R., and Enoch, J.M. (1954). Rapid changes in foveal sensitivity resulting from direct and indirect adapting stimuli, *Journal of the Optical Society of America*, 44(1), 56-60.

Brass, M., Bekkering, H., Wohlschlager, A., and Prinz, W. (2000). Compatibility between observed and executed finger movements: Comparing symbolic, spatial and imitative cues, *Brain and Cognition,* 44(2), 124-143.

Bricknell, M.C.M. (1991). Sleep manipulation prior to airborne exercises, *Journal of the Regimental Army Medical Corps*, 137, 22-26.

Broadbent, D.E. (1971). *Decision and Stress.* New York: Academic Press.

Bron, A.J., Tripathi, R.C., and Tripathi, B.J. (1997). *Wolff's Anatomy of the Eye and Orbit. 8th Edition*. London: Chapman and Hall Medical.

Brown, J.L. (1966). Afterimages. In: Graham, C.H. (Ed.), *Vision and Visual Perception*. New York: John Wiley and Sons, Inc.

Brown, E.L. (2004). The effects of fatigue on position determination and cognitive workload using a visual and 3-dimensional auditory display. Monterey, CA: Naval Postgraduate School.

Brozoski, F.T., Johnson, P.A., Crowley, J.S., and McEntire, B.H. (2000). Effects of inadvertent UH-60 cockpit airbag system deployment on flight control. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2000-15.

Brunette, I, Gresset, J., Boivin, J., Pop, M, Thompson, P, Lafond, G.P., and Makni, H. (2000). Functional outcome and satisfaction after photorefractive keratectomy, *Ophthalmology*, 107(9), 1790-1796.

Buguet, A., Montmayeur, A., Pigeau, R.A., and Naitoh, P. (1995). Modafinil, d-amphetamine, and placebo during 64 hours of sustained mental work. II. Effects on two nights of recovery sleep, *Journal of Sleep Research*, 4, 229-241.

Butler, B.P., and Alem, N.M. (1997). Long duration exposure criteria for head-supported mass. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-34.

Cabon, P., Bourgeois-Bougrine, S., Mollard, R., Coblentz, A., and Speyer, J.J. (2003). Electronic pilot-activity monitor: A counter measure against fatigue on long-haul flights, *Aviation Space and Environmental Medicine,* 74(6 Pt 1), 679-82.

Cabon, P.H., Coblentz, A., Mollard, R., and Fouillot, J.P. (1993). Human vigilance in railway and long-haul flight operations, *Ergonomics,* 36(9), 1019-1033.

Cajochen, C., Krauchi, K., and Wirz-Justice, A. (2003). Role of melatonin in the regulation of human circadian rhythms and sleep, *Journal of Neuroendocrinology,* 15, 432-7.

Caldwell, J.A. (2001). Efficacy of stimulants for fatigue management: The effects of Provigil and Dexedrine on sleep-deprived aviators, *Transportation Research*, F4, 19-37.

Caldwell, J.A. (2005). Fatigue in aviation, *Journal of Travel Medicine and Infectious Disease,* 3(2), 85-96.

Caldwell, J.A., and Caldwell, J.L. (1997). An in-flight investigation of the efficacy of dextroamphetamine for sustaining helicopter pilot performance, *Aviation, Space, and Environmental Medicine*, 68(12), 1073-1080.

Caldwell, J.A., and Caldwell, J.L. (1998). Comparison of the effects of zolpidem-induced prophylactic naps to placebo naps and forced-rest periods in prolonged work schedules, *Sleep,* 21(1), 79-90.

Caldwell, J.A., and Caldwell, J.L. (2005). Stimulants. In: Kushida, C.A. (Ed.), *Sleep Deprivation: Clinical Issues, Pharmacology, and Sleep Loss Effects*. New York: Marcel Dekker, Inc.

Caldwell, J.A., and Caldwell, J.L. (2003). *Fatigue in aviation: A guide to staying awake at the stick*. Burlington, VT: Ashgate Publishing Company.

Caldwell, J.A., Caldwell, J.L., and Crowley, J.S. (1997). Sustaining female helicopter pilot performance with Dexedrine during sustained operations, *International Journal of Aviation Psychology*, 7(1), 15-36.

Caldwell, J.A., Caldwell, J.L., Crowley, J.S., and Jones, H.D. (1995). Sustaining helicopter pilot performance with Dexedrine during periods of sleep deprivation, *Aviation Space and Environmental Medicine*, 66(10), 930-937.

Caldwell, J.A., Caldwell, J.L., Smith, J.K., Alvarado, L., Heintz, T., Mylar, J.T., Mandichak, M., and Schroeder, C. (2004). *The efficacy of modafinil for sustaining alertness and simulator flight performance in F-117 pilots during 37 hours of continuous wakefulness*. Technical. Brooks City-Base, TX: U.S. Air Force Research Laboratory; January. Report No. AFRL-HE-BR-TR-2004-0003.

Caldwell, J.A., Caldwell, J.L., Smythe, N.K., and Hall, K.K. (2000a). A double-blind, placebo-controlled investigation of the efficacy of modafinil for sustaining alertness and performance of aviators: A helicopter simulator study, *Psychopharmacology* (Berlin), 150, 272-282.

Caldwell, J.L., and Gilreath, S.R. (2001). Work and sleep hours of U.S. Army aviation personnel working reverse cycle, *Military Medicine*, 166(2), 159-166.

Caldwell, J.A., and Gilreath, S.R. (2002). A survey of aircrew fatigue in a sample of Army aviation personnel, *Aviation, Space, and Environmental Medicine,* 73, 472-480.

Caldwell, J.L., Prazinko, B.F., Rowe, T., Norman, D., Hall, K.K., and Caldwell, J.A. (2003). Improving daytime sleep with temazepam as a countermeasure for shift lag, *Aviation Space and Environmental Medicine,* 74(2),153-163.

Caldwell, J.A., Smythe, N.K., LeDuc, P.A., and Caldwell, J.L. (2000b). Efficacy of dextroamphetamine for the maintenance of aviator performance during 64 hours of sustained wakefulness, *Aviation Space and Environmental Medicine,* 71(1), 7-18.

Cardinali, D.P., Bortman, G.P., Liotta, G., Albornoz, L.E. ,Cutrera, R.A., Batista, J., and Gallo, P.O. (2002). A multifactorial approach employing melatonin to accelerate resynchronization of sleep- wake cycle after a 12 time-zone westerly transmeridian flight in elite soccer athletes, *Journal of Pineal Research,* 32, 41-46.

Cardinale, M., and Pope, M.H. (2003). The effects of whole-body vibration on humans: Dangerous or advantageous? *Acta Physiologica Hungarica*, 90(3), 195-206.

Center for Science in the Public Interest (1996). *Caffeine: The inside scoop*. In: Nutrition Action Health Letter, Dec. Washington DC: Center for Science in the Public Interest.

Centers for Disease Control and Prevention. (2004). 2004 Surgeon General's report – The health consequences of smoking. Retrieved from: http://www.cdc.gov/ tobacco/data_statistics/sgr/sgr_2004/chapters.htm

Cephalon (1998). *Clinical Investigator's Brochure.* West Chester: Cephalon, Inc.

Chagan, L., and Cicero, L.A. (1999). Zaleplon: A possible advance in the treatment of insomnia, *PandT,* 24(12), 590-599.

Chalita, M.R., and Krueger, R.R. (2004). Correlation of aberrations with visual acuity and symptoms, *Ophthalmology Clinics of North America*, 17, 135-142.

Chalita, M.R., Chavala, S., Xu, M., and Krueger, R.R. (2004). Wavefront analysis in post-LASIK eyes and its correlation with visual symptoms, refraction, and topography, *Ophthalmology*, 111(3), 447-453.

Chan, W.H., and Chan, A.H.S. (2007). Movement compatibility for rotary control and digital display, *Engineering Letters*, 14(1) Retrieved from; http://www.engineeringletters.com/issues_v14/issue_1/EL_14_1_2.pdf)

Chee, P.A., Braby, L.A., and Conroy, T.J. (2000). Potential doses to passengers and crew during supersonic transport, *Health Physics*, 79, 547-553.

Chisholm, C.M., Evans, A.D.B., Harlow, J.A., and Barbur, J.L. (2003). New test to assess pilot's vision following refractive surgery, *Aviation, Space, and Environmental Medicine,* 74(5). 551-559.

Chisick, M.C., Poindexter, F.R., and York, A.K. (1998). *Comparing tobacco use among incoming recruits and military personnel on active duty in the United States*. Tobacco Control, 7, 236-240

Cho, K, (2001), Chronic 'jet lag' produces temporal lobe atrophy and special cognitive deficits, *Natural Neuroscience,* 4, 567-68.

Cho, K., Ennaceur, A., Cole, J.C., and Suh, C.K. (2000). Chronic jet lag produces cognitive deficits, *Journal of Neuroscience,* 20(RC66), 1-5.

Choi, S.H. (1983). The effect of noise and display orientation on cognitive performance. Master's Thesis. Monterey, CA: Naval Postgraduate School.

Chou, B., and Wachler, B.S.B. (2001). The role of pupil size in refractive surgery, *Refractive Source*. Retrieved from: http://www.refractivesource.com/

Ciuffreda, K.J. (1998). Accommodation, the pupil, and presbyopia. Chapter 4. In: Benjamin, W.J. (Ed.), *Borish's Clinical Refraction*. Philadelphia: W. B. Saunders Company.

Claustrat, B., Kayumov, L., and Pandi-Perumal, S.R. (2002). Dual role of melatonin in humans: A hormone and a chronobiotic drug. In: Haldar, C., Singaravel, M., and Maitra, S.K. (Eds.), *Treatise on Pineal Gland and Melatonin* (pp. 543-553). Enfield, NH: Science Publishers, Inc.

Co, E.L., Gregory, K.B., Johnson, J.M., and Rosekind, M.R. (1999). *Crew factors in flight operations XI: A survey of fatigue factors in regional airline operations*. NASA Technical Memorandum No. 1999-208799. Moffett Field, CA: NASA Ames Research Center.

Cobb, P.W. (1911). The influence of illumination of the eye on visual acuity, *American Journal of Physiology*, 29, 76-99.

Cohen, S., Evans, G.W., Krantz, D.S., and Stokols, D. (1986). Physiological, motivational, and cognitive effects of aircraft noise on children: Moving from the laboratory to the field, *American Psychologist,* 35, 231-243.

Cohen, S., Evans, G.W., Stokols, D., and Krantz, D.S. (1980). *Behavior, Health, and Environmental Stress.* New York, NY: Plenum Press.

Coleshaw, S.R., Van Someren, R.N., Wolff, A.H., Davis, H.M., and Keatinge, W.R. (1983). Impaired memory registration and speed of reasoning caused by low body temperature, *Journal of Applied Physiology*, 55, 27-31.

Committee on Military Nutrition Research (2002). *Caffeine for the Sustainment of Mental Task Performance: Formulations for Military Operations*. Washington, DC: National Academy Press.

Connolly, D.M., Barbur, J.L., Hosking, S.L., and Moorhead, I.R (2008). Mild hypoxia impairs chromatic sensitivity in the mesopic range, *Investigative Ophthalmology and Visual Sciences*, 49(2), 820-827.

Conway, T.L. (1998). *Tobacco use and the United States military: A longstanding problem* [Editorial]. Tobacco Control, 7, 219-221.

Cornum, R., Caldwell, J.A., and Cornum, K.G. (1997). Stimulant use in extended flight operations, *Airpower Journal,* 11(1)*,* 53-58.

Cornum, K.G., Cornum, R., and Storm, W. (1995). *Use of psychostimulants in extended flight operations: A Desert Shield experience*. In: Advisory Group for Aerospace Research and Development Conference Proceedings No. 579, Neurological Limitations of Aircraft Operations: Human Performance Implications. Nuilley-sur-Seine, France: NATO Advisory Group for Aerospace Research and Development; p. 371-374.

Costa, G. (1997). The problem: Shiftwork, *Chronobiology International,*14(2), 89-98.

Crosley, J.K., Braun, E.G. and Bailey, R.W. 1974. Soft (hydrophilic) contact lenses in U.S. Army aviation: An investigative study of the Bausch and Lomb Soflens, *American Journal of Optometry and Physiological Optics*, 51(7), 470-477.

Crowley, J.S., and Dalgard, C.L. (Eds.) (2000). Proceedings of the Technical Cooperative Program Workshop: Inflatable restraints in aviation. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2000-21.

Crowley, J.S., Wesensten, N., Kamimori, G., Devine, J., Iwanyk, E., and Balkin, T. (1992). Effect of high terrestrial altitude and supplemental oxygen on human performance and mood, *Aviation Space and Environmental Medicine,* 63, 696-701.

Cruickshanks, K.J., Klein, R., Klein, B.E.K., Wiley, T.L., Nondahl, D.M., and Tweed, T.S. (1998). The epidemiology of hearing loss study, *Journal of the American Medical Association*, 279, 1715-1719.

CuQlock-Knopp, V.G., Sipes, D.E., Torgerson, W., Bender, E., Merritt, J.O., McLean, W., and Myles, K. (1997). Extended use of night vision goggles: An evaluation of comfort for monocular and biocular configurations. Aberdeen Proving Ground, MD: U.S. Army Research Laboratory. Report No. ARL-TR-1427.

Curley, M.D., and Hawkins, R.N. (1983). Cognitive performance during a heat acclimatization regimen, *Aviation, Space, and Environmental Medicine*, 54, 709-713.

Cymerman, A., Fulco, C.S., Muza, S.R., Zupan, M., Kambis, K.W., Elliot, L., Udy, J., and Rock, P.B. (2005). Neurocognitive function in moderate altitude residents (2200 m) exposed for 3 days to 4300 meters (Abstract), *Banff, 10th International Symposium*.

Cymerman, A., Muza, S.R., Beidleman, B.A., Ditzler, D., and Fulco, C.S. (2006a). Postural stability and acute mountain sickness during exposure to 24 hours of simulated altitude (4300 m), *High Altitude Medicine and Biology,* 2, 509-514.

Cymerman, A., Muza, S., Fulco, C., Beidleman, B., Elliott, L., Elliott, S., Tapia, M., Money, A., and Root, E. (2007). Normobaric intermittent hypoxic exposures do not improve psychomotor performance during hypobaric hypoxia, *High Altitude Medicine and Biology*, 7(4), 324.

Cymerman, A., Muza, S. R., Fulco, C. S., Friedlander, A., Zupan, M., and Elliott, L. (2006b). Oculometrics as a measure of altitude acclimatization of moderate-altitude residents compared to sea-level residents (Abstract), *Journal of the Federation of American Societies for Experimental Biology,* 20, A1431.

Czeisler, C.A., Johnson M.P., Duffy, J.F., Brown, E.N., Ronda, J.M., and Kronauer, R.E. (1990). Exposure to bright light and darkness to treat physiologic maladaptation to night work, *The New England Journal of Medicine,* 322(18), 1253-1259.

Dawson, D., and Armstrong, S.M. (1996). Chronobiotics – drugs that shift rhythms, *Pharmacology and Therapeutics,* 69, 15-36.

Dawson, D. (2008). Army offers choices in protective gloves and eyewear. Retrieved 30 October 2008 from: http://peosoldier.army.mil/docs/gloveseyewear08.pdf

Dawson, D., and Reid, K. (1997). Fatigue, alcohol and performance impairment, *Nature,* 388*,* 235.

de Waard, P.W.T., Ijspeert, J.K., van den Berg, T.J.T.P., and de Jong, T.V.M. (1992). Intraocular light scattering in age-related cataracts, *Investigative Ophthalmology and Visual Science*, 33(3), 618-625.

de Wit, G.C., and Coppens, J.E. (2003). Stray light of spectacle lenses compared with stray light in the eye, *Optometry and Vision Science*, 80(5), 395-400.

Dehart, R L, and Davis, J.R. (Eds.) (2002). *Fundamentals of Aerospace Medicine*. Philadelphia: Lipcott Williams and Wilkins.

Dennis, R.J. (1988). Wear of soft contact lenses by tactical aircrew. Considerations in contact lens use under adverse conditions - a symposium. Brooks AFB, TX.

Dennis, R.J., Apsey, D.A., and Ivan, D.J. (1993). Aircrew soft contact lens wear: A survey of USAF eye care professionals, *Aviation Space and Environmental Medicine,* 64, 1044-1047.

Dennis, R.J., Flynn, W. J., Oakley, C. J., and Block, M. G. (1989b). Soft contact lenses: Sink or barrier to chemical warfare agents? Brooks AFB, TX: USAF School of Aerospace Medicine. USAFSAM-TR-89-2.

Dennis, R.J., Woessner, W.M., Miller, R.E., and Gillingham, K.K. (1989a). Effect of fluctuating +G sub z exposure on rigid gas-permeable contact lens wear. Brooks AFB, TX :U.S. Air Force School of Aerospace Medicine Technical Report No. USAFSAM-TR-89-23.

Department of the Air Force. (2006). Air Force Instruction AF48-123, Medical Examinations and Standards. Retrieved 20 September from: http://www.e-publishing.af.mil/index.asp

Department of the Army. (2006). Aeromedical Policy Letters. Retrieved 28 August 2008 from: https://aamaweb.usaama.rucker.amedd.army.mil/AAMAWeb/ policyltrs/Army_APLs_Mar06_v3.pdf

Department of the Army. (2007). Army Regulation AR 40-8, Temporary Flying Restrictions Due to Exogenous Factors Affecting Aircrew Efficiency. Retrieved 1 September 2008 from: http://www.army.mil/ usapa/epubs/pdf/r40_8.pdf

Department of the Army. (1991). Army Regulation AR-40-10. Health hazard assessment program in support of the Army material acquisition decision. Washington, DC: Department of the Army.

Department of the Army. (2008). Army Regulation AR-40-501, Standards of Medical Fitness. Retrieved 10 September 2008 from: http://www.usapa.army.mil/ pdffiles/r40_501.pdf

Department of Defense. (2005). Department of Defense survey of health related behaviors among active duty military personnel; A component of the defense lifestyle assessment program (DLAP). RTI International, December 2006. Retrieved from: http://www.ha.osd.mil/special_reports/ 2005_Health_Behaviors_Survey_1-07.pdf

Department of the Navy. (2001). OPNAV Instruction 3710.7T, NATOPS General Flight and Operating Instructions. http://doni.daps.dla.mil/Directives/03000%20Naval%20Operations%20and%20Readiness/03-700 % 20Flight%20 and%20 Air%20Space%20Support%20Services/3710.7T-1.pdf

Department of Transport South Africa. (2007). Arrive alive…don't drink and drive. Retrieved 10 August 2008 from: http://www.transport.gov.za/projects/arrive/alcohol98.html

Dinges, D.F. (1992). Probing the limits of functional capability: The effects of sleep loss on short-duration tasks. In: Broughton, R.J., and Ogilvie, R.D. (Eds.), *Sleep, arousal, and performance*. Boston, Birkhauser.

Dinges, D.F. (1995). An overview of sleepiness and accidents, *Journal of Sleep Research,* 4(Suppl. 2), 4-14.

Dinges, D.F., Graeber, R.C., Rosekind, M.R., Samel, A., and Wegmann, H.M. (1996). *Principles and guidelines for duty and rest scheduling in commercial aviation*. Moffett Field, CA: NASA Ames Research Center, Report No. 110404.

Dinges, D.F., and Kribbs, N.B. (1991). Performing while sleepy: Effects of experimentally-induced sleepiness. In: Monk, T.H. (Ed.), *Sleep, sleepiness and performance* (pp. 97-128). Chichester: John Wiley and Sons.

Dinges, D.F., and Powell, J.W. (1988). Sleepiness is more than lapsing. *Sleep Research,* 17, 84.

Dyer, F.N. (1986). Smoking and soldier performance. Fort Rucker, AL: U.S. Army Aeromedical research Laboratory. USAARL Report No. 86-13.

Edwards, R.J., Sanders, M.G., and Price, D.R. (1988). Comparison of Army flight school performance in smokers and nonsmokers. Fort Rucker, AL: U.S. Army Aeromedical research Laboratory. USAARL Report No. 88-6.

Elie, R., Ruther, E., Farr, I., Emilien, G., and Salinas, E. (1999). Sleep latency is shortened during 4 weeks of treatment with zaleplon, a novel nonbenzodiazepine hypnotic*, Journal of Clinical Psychiatry,60*(8), 536-544.

Elliott, D.B., Mitchell, S., and Whitaker, D. (1991). Factors affecting light scatter in contact lens wearers, *Optometry and Vision Science*, 68(8), 629-633.

Emonson, D.L., and Vanderbeek, R.D. (1995). The use of amphetamine in U.S. Air Force tactical operations during Desert Shield and Storm, *Aviation Space and Environmental Medicine, 66,* 260-263.

Enander, A.E., and Hygge, S. (1990). Thermal stress and human performance, *Scandinavian Journal of Work, Environment & Health*, 16, 44-50.

Ensign, W., Hodgdonl, J.A., Prusaczyk, W.K., Ahlers, S., and Shapiro, D. (2000). A Survey of self-reported injuries among Special Boat Operators. San Diego, CA: Naval Health Research Center.

Ernsting, J., Nicholson, A.N., and Rainford, D.J.(1999). *Aviation Medicine*. Oxford: Butterworth Heinemann.

Evans, G.W., and Hygge, S. (2003). Noise and performance in children and adults. In: Luxon, L., and Prasher, D., (Eds.), *Noise and Its Effects*. London: Whurr Publishers.

Evans, G.W., and Lepore, S.J. (1993). Nonauditory effects of noise on children: A critical review. *Children's Environments*, 10, 31-51.

Faerevik, H., Markussen, D., Oglaend, G.E., and Reinertsen, R.E. (2001). The thermoneutral zone when wearing aircrew protective clothing, *Journal of Thermal Biology*, 26, 419-425.

Fan-Paul, N.I., Li, J., Miller, J.S., and Florakis, G.J. (2002). Night vision disturbances after corneal refractive surgery, *Survey of Ophthalmology*, 47(6), 533-546.

Federal Aviation Administration. (2008). Guide for Aviation medical Examiners. http://www.faa.gov/ about/office_org/headquarters_offices/avs/offices/aam/ame/guide/media/guide06.pdf

Fields, J.M. (1994). A review of an updated synthesis of noise/annoyance relationships. NASA CR-194950. NASA, Hampton, VA.

Finnoff, J.T. (2008). Environmental effects on brain function, *Current Sports Medicine Reports*, 7, 28-32.

Flattau, P.E. (Ed.) (1991). Considerations in contact lens use under adverse conditions: Proceedings symposium. Washington, DC: National Academy Press.

Forbes, A.J., and Berkahn, C. (1999). Does zaleplon help you sleep and wake refreshed? *Drugs and Therapy Perspectives*, 14(4), 1-4.

Friedberg, W., Copeland, K., Duke, F.E., and O'Brien III, E.B. (2000). Radiation exposure during air travel: Guidance provided by the FAA for air carrier crew, *Health Physics,* 79, 591-595.

Froom, P, Hanegbi, R., Ribak, J., and Gross, M. (1987). Low back pain in an AH-1 Cobra helicopter, *Aviation Space Environmental Medicine,* 58, 315-8.

Fry, G.A., and Alpern, M. (1953). The effect of a peripheral glare source upon the apparent brightness of an object, *Journal of the Optical Society of America*, 43(3), 189-195.

Fry, J., Scharf, M., Mangano, R., and Fujimori, M. (2000). Zaleplon improves sleep without producing rebound effects in outpatients with insomnia*, International Clinical Psychopharmacoly,15*, 141-152.

Furness, T.A. (1981). The effects of whole-body vibration on the perception of the helmet-mounted display, Unpublished Doctoral Thesis, University of South Hampton.

Gabriel, G. (2006). Hans Selye: The discovery of stress. Retrieved on 15 October 2008 from: http://www.brainconnection.com/topics/?main=fa/selye

Galinsky, T.L., Swanson, N.G., Sauter, S.L., Hurrell, J.J., and Schleifer, L.M. (2000). A field study of supplementary rest breaks for data-entry operators, *Ergonomics, 43(5),* 622-638.

Georgia State University. (2007). Systems integration (Course syllabus). Retrieved 24 February 2009 from: http://www2.cis.gsu.edu/cis/program/syllabus/graduate/CIS8020

Ghaith, A.A., Daniel, J., Stulting, R.D., Thompson, K.P., and Lynn, M. (1998). Contrast sensitivity and glare disability after radial keratotomy and photorefractive keratectomy, *Archives of Ophthalmology*, 116(1), 12-18

Giesbrecht, G.G., Arnett, J.L., Vela, E., and Bristow, G.K. (1993). Effect of task complexity on mental performance during immersion hypothermia, *Aviation, Space, and Environmental Medicine*, 64, 206-211.

Gilbert, S.S., Van Den Heuvel, C.J., and Dawson, D. (1999). Daytime melatonin and temazepam in young adult humans: Equivalent effects on sleep latency and body temperature, *Journal of Physiology,* 51, 903-14.

Gillberg, M. (1984). The effects of two alternative timings of a one-hour nap on early morning performance, *Biological Psychology,19*, 45-54.

Glick, D.D., and Moser, C.E. (1974). Afterimages associated with using the AN/PVS-5, night vision goggle. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR 75-1-7-1.

Goethe, J.W. (1810). Zur Farbenlehre I, Tübingen, Ch.8. Deutsch: Taschenb Verlag, 1963.

Gonzalez-Alonso, J., Teller, C., Andersen, S.L., Jensen, F.B., Hyldig, T., and Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat, *Journal of Applied Physiology*, 86, 1032-1039.

Goode, J.H. (2003). Are pilots at risk of accidents due to fatigue? *Journal of Safety Research, 34,* 309-313.

Gordon, E., and Houtsma, A.J.M. (2008). Performance of the Communication Enhancement and Protective System (CEPS) under sustained high and low temperature. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2008-10.

Gower, D.W., and Casali, J.G. (1994). Speech intelligibility and protective effectiveness of selected active noise reduction and conventional communications headsets, *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 36(2), 350-367.

Graham, C.H. (1966a). Some basic terms and methods (Chapter 3). In: Graham, C.H. (Ed.), *Vision and Visual Perception*. New York: John Wiley and Sons, Inc.

Graham, C.H. (1966b). Some fundamental data (Chapter 4). In: Graham, C.H. (Ed.), *Vision and Visual Perception*. New York: John Wiley and Sons, Inc.

Green, M. (2004). *Seeing Pedestrians at Night*. Retrieved from: www.visualexpert.com/Resources/ pedestrians.html

Green, M., and Senders, J. (2004). *Human Error in Road Accidents*. Retrieved from: www.visualexpert.com/ Resources/ roadaccidents.html

Grether, W.F. (1973). Human performance at elevated environmental temperatures, *Aerospace Medicine*, 44, 747-755.

Griefahn, B. (1992). Noise control during the night: Proposals for continuous and intermittent noise, *Acoustics Australia,* 20, 43-47.

Griefahn, B., Deppe, C., Mehnert, P., Moog, R., Mohler, U., and Schumer-Kohrs, A. (1998). Intermittent versus continuous noises. Their influence on sleep latency and motility during the night, *Proceedings of Internoise '98*, Christchurch. (on CD.) Australia: Causal Productions.

Griffin, M.J. (1990). *Handbook of Human Vibration*. London: Academic Press.

Griffiths, R.R., and Mumford, G.K. (1995). *Caffeine - A drug of abuse?* In: Bloom, F.E., Kupfer, D.J., (Eds.). Psychopharmacology: The Fourth Generation of Progress. New York: Raven Press.

Guardiola-Lemaitre, B. (1997). Toxicology of melatonin, *Journal of Biological Rhythms, 12*, 697-706.

Haas, M.W., Nelson, W.T., Repperger, D., Bolia, R., and Zacharias, G. (2001). Applying adaptive control and display characteristics to future Air Force crew stations, *International Journal of Aviation Psychology,* 11(2), 223-235.

Hackett, P.H., Rennie, D., and Levine, H.D. (1976). The incidence, importance, and prophylaxis of acute mountain sickness, *Lancet*, 2(7996), 1149-55.

Haddock, C.K., Klesges, R.C., Talcott, G.W., Lando, H., and Stein, R.J. (1998). Smoking prevalence and risk factors for smoking in a population of United States Air Force basic trainees, *Tobacco Control*, 7, 232- 235.

Haegerstrom-Portnoy, G., Schneck, M.E., and Brabyn, J.A. (1999). Seeing into old age: Vision function beyond acuity, *Optometry and Vision Science*, 76(3), 141-158.

Haimov, I., and Arendt, J. (1999). The prevention and treatment of jet lag, *Sleep Medicine Reviews, 3*, 229-40.

Haines, M.M., Stansfeld, S.A., Job, R.F.S., and Berglund, B. (1998). Chronic aircraft noise exposure and child cognitive performance and stress. In: Carter, N.L., and Job, R.F.S. (Eds.), *Noise Effects, Proceedings of the 7th International Congress on Noise as a Public Health Problem*. Sydney, Australia: Noise Effects '98.

Hamernik, R.P., and Hsueh, K.D. (1991). Impulse noise: Some definitions, physical acoustics and other considerations, *Journal of the Acoustical Society of America*, 90, 189-196.

Hamernik, R.P., Ahroon, W.A., Davis, R.I., and Axelsson, A. (1989). Noise and vibration interactions: Effects on hearing, *Journal of the Acoustical Society of America*, 86(6), 2129-2137.

Hamilton, A. (1918). A Study of Spastic Anemia in the Hands of Stonecutters: The Effect of the Air Hammer on the Hands of Stonecutters. U.S. Dept of Labor Report 236, No. 19.

Hammond, M.D., Madigan, Jr., W.P., and Bower, K.S. (2005). Refractive surgery in the United States Army, 2000–2003, *Ophthalmology*, 112, 184–190.

Hancock, P.A. (1986). Sustained attention under thermal stress, *Psychological Bulletin*, 99, 263-281.

Harkrider, A., and Champlin, C. (2000). Acute effects of nicotine on physiological responses of the auditory systems of nonsmokers, *Acoustical Society of America*, 107(5), 2900.

Harkrider, A.W., Champlin, C.A., and McFadden, D. (2001). Acute effect of nicotine on non-smokers: I. OAEs and ABRs, *Hearing Research*, 160(1-2), 73-88.

Harma, M. (1995). Sleepiness and shift work: Individual differences, *Journal of Sleep Research*, 4(Suppl. 2), 57-61.

Kristin, L., Harrer, K.L., Yniguez, D., Majar, M., Ellenbecker, D., Estrada, N., and Geiger, M. (2005). Whole body vibration for MS-60S pilots, *Proceedings of the Forty Third Annual SAFE Association Symposium*, 303-314.

Harris, C.S., and Shoenberger, R.W. (1980). Combined effects of broadband noise and complex waveform vibration on cognitive performance, *Aviation, Space, and Environmental Medicine*, 51(100), 1-5.

Hatfield, J., and Job, R.F.S. (1998). Evidence of optimism bias regarding the health effects of exposure to noise. In: Carter, N.L., and Job, R.F.S. (Eds.), *Noise Effects, Proceedings of the 7th International Congress on Noise as a Public Health Problem*. Sydney, Australia: Noise Effects '98, p. 251-254.

Hedge, A. (2008). Human vibration. Retrieved 16 August 2008 from: http://ergo.human.cornell.edu/studentdownloads/DEA325pdfs/Human%20Vibration.pdf. Cornell University.

Hedge, A. (2008). Glare and visual performance. Retrieved 16 July 2008 from Cornell University website: http://ergo.human.cornell.edu/studentdownloads/DEA350pdfs/glare.pdf

Helmholtz H. (1852). Ueber Herrn Brewsters Analyse des Sonnenlichtes, *Ann Physik und Chemie,* 86, 501- 523.

Hemenger, R.P. (1990.) Light scatter in cataractous lenses, *Ophthalmological Physiological Optics*, 10, 394-397.

Herxheimer, A., and Petrie, K.J. (2002). Melatonin for the prevention and treatment of jet lag, *Cochrane Database System Reviews, 2*, CD001520.

Hoffman, R.G. (2001). Human psychological performance in cold environments. In: Pandolf, K.B. (Ed.), *Medical Aspects of Harsh Environments*. Washington, DC: Borden Institute.

Holladay, L.L. (1926). The fundamentals of glare and visibility, *Journal of the Optical Society of America,* 12(2), 271-319.

Holladay, L.L. (1927). Action of a light-source in the field of view in lowering visibility, *Journal of the Optical Society of America*, 14(1), 1-15.

Horne, J.A. (1988). Sleep loss and 'divergent' thinking ability, *Sleep,* 11, 528-536.

Horne, J.A. (1993). Human sleep, sleep loss and behaviour: Implications for prefrontal cortex and psychiatric disorder, *British Journal of Psychiatry,* 162, 413-419.

Howarth, H.V.C., and Griffin, M.J., (1990). Subjective response to combined noise and vibration: Summation and interaction effects, *Journal of Sound and Vibration*, 143(3), 443-454.

Huelke, D.F., Moore, J.L., Compton, T.W., Rouhana, S.W., and Kileny, P.R. (1999). Hearing loss and automobile airbag deployments, *Accident Analysis and Prevention*, 31(6), 789-792.

Hulshof, C.T.J., and Veldhuizen van Zanten. (1987). *International Archives of Occupational Environment and Health*, 59, 205-220.

Hygge, S. (2003). Noise exposure and cognitive performance – Children and the elderly as possible risk groups. Retrieved on 18 August 2008 from University of Gavle, Sweden, Laboratory of Applied Psychology web site: http://www.euro.who.int/document/NOH/ paperbyhygge2003.pdf

Hygge, S., Evans, G.W., and Bullinger, M. (1998). The Munich airport noise study- effects of chronic aircraft noise on children's cognition and health. In: Carter, N.L., and Job, R.F.S. (Eds.), *Noise Effects, Proceedings of the 7th International Congress on Noise as a Public Health Problem*. Sydney, Australia: Noise Effects '98. p. 268-274.

Iglesias, R., Terres, A., and Chavarria, A. (1980). Disorders of the menstrual cycle in an airline stewardess, *Aviation Space and Environmental Medicine,* 51, 518-20.

Ijspeert, J.K., De Waard, P.W.T., van den Berg, T.J.T.P., and De Jong, P.T.V.M. (1990). The intraocular stray light function in 129 healthy volunteers; dependence on angle, age and pigmentation, *Vision Research*, 30(5), 699-707.

International Organization for Standardization. (1997). Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration, Part 1: General requirements. ISO 2631-1:1997. *International Organization for Standardization*.

International Organization for Standardization. (2001). ISO 5349 (for HAV), Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration. *International Organization for Standardization*.

Jaaskelainen , I.P., Alho, K., Escera , C., Winkler, I., Sillanaukee, B., and Naatanen, R. (1996). Effects of ethanol and auditory distraction on forced choice reaction time, *Alcohol*, 13(2), 153-156.

Jehue, R., Street, D., and Huizenga, D. (1993). Effect of time zone and game time changes on team performance: National Football League, *Medical Science, Sports, and Exercise,* 25(1), 127-131.

Jenkins, L., Tarnopolsky, A., and Hand, D. (1981). Psychiatric admissions and aircraft noise from London Airport: Four-year, three-hospitals' study, *Psychological Medicine*, 11, 765-782.

Job, R.F.S. (1988). Community response to noise: A review of factors influencing the relationship between noise exposure and reaction, *Journal of the Acoustical Society of America*, 83, 991-1001.

Johnson, R.F., and Kobrick, J.L. (2001). Psychological aspects of military performance in hot environments. In: Pandolf, K.B. (Ed.) *Medical Aspects of Harsh Environments*, Washington, DC: Borden Institute, 135-159.

Josephson, J.E. (1991Ocular occupational health concerns: Considerations for pilots wearing contact lenses. In: Flattau, P.E. (Ed.), Considerations in contact lens use under adverse conditions: Proceedings symposium. Washington, DC: National Academy Press.

Kanski, J.L. (2003). *Clinical Ophthalmology: A Systematic Approach (5th Ed.)*. Philadelphia: Butterworth Heinemann.

Kaufman, P.L., and Alm, A. (Ed.s). (2002). *Adler's Physiology of the Eye: Clinical Application (10th Ed.)*. Philadelphia: C. V. Mosby.

Keating, M.P. (1988). *Geometrical, Physical, and Visual Optics*. Boston: Butterworth-Heinemann.

Kelly, J.E., Mihashi, T., and Howland, H.C. (2004). Compensation of corneal horizontal/vertical astigmatism, lateral coma, and spherical aberration by internal optics of the eye, *Journal of Vision,* 4(4), 262-271.

Kennaway, D.J., and Wright, H. (2002). Melatonin and circadian rhythms, *Current Topics in Medical Chemistry,* 2, 199-209.

Kenagy, D.N., Bird, C.T., Webber, C.M., and Fischer, J.R. (2004). Dextroamphetamine use during B-2 combat missions, *Aviation Space and Environmental Medicine,* 75(5)*,* 381-386.

Kjellberg, A. (1990). Psychological aspects of occupational vibration, *Scandinavian Journal of work, Environment and Health*, 16(Supplement 1), 39-43.

King, J.M., and Morse, S.E. (1992). Interpupillary and vertex distance effects on field-of-view and acuity with ANVIS. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 93-9.

Kirsch, A.D. (1996). Report on the statistical methods employed by the U.S. FAA in its cost benefit analysis of the proposed Flight Crewmember Duty Period Limitations, Flight Time Limitations and Rest Requirements, Docket No. 28081. *Comments of the Air Transport Association of America to FAA notice 95-18, FAA Docket No. 28081*. Appendix D, pp. 1-36.

Klein, B.E.,K., Klein, R., and Linton, K.L.P. (1992). Prevalence of age-related lens opacities in a population, *Ophthalmology*, 99(4), 546-552.

Klein, K.E., Bruner, H., Holtmann, H., Rehme, H., Stolze, J., Steinhoff, W.D., Wegmann, H.M. (1970). Circadian rhythm of pilots' efficiency and effects of multiple time zone travel, *Aerospace Medicine,*41(2), 125-132.

Klein, S.A. (2001). Problems with wavefront aberrations applied to refractive surgery: Developing standards, *Ophthalmic Technologies XI, SPIE Proceedings,* 4245, SPIE: Bellingham, Washington.

Klein, S.A., Hoffmann, S., and Hickenbotham, S.C. (2003). Improved glare (halos and scattered light) measurement for post-LASIK surgery. Vision Processing Laboratory, Vision Science Program UC Berkeley. http://cornea.berkeley.edu/presentations/

Knauth P. (1995). Speed and direction of shift rotation, *Journal of Sleep Research,* 4(Suppl. 2), 41-46.

Kok-van Aalphen, C., van der Linden, J.W., Visser, R., and Bol, A.H. (1985). Protection of the police against tear gas with soft lenses, *Military Medicine*, 8, 451-454.

Korb, D.R., Craig, J., Doughty, M., Guillon, J., Smith, G., and Tomlinson, A. (2002). *The Tear Film: Structure, Function and Clinical Examination*. London: Butterworth-Heinemann.

Koslowsky, M., and Babkoff, H. (1992). Meta-analysis of the relationship between total sleep deprivation and performance, *Chronobiology International,* 9(2), 132-136.

Kotulak, J.C. (1992). In-flight field-of-view with ANVIS. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 93-8.

Kotulak, J.C., and Morse, S.E. (1994a). Factors that determine visual acuity through night vision goggles for emmetrones. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 94-l 6.

Kotulak, J.C., and Morse, S.E. (1994b). Relationship among accommodation, focus and resolution with optical instruments, Journal of the Optical Society of America, II, 71-79.

Krizaj, D. (2000). Mesopic state: Cellular mechanisms involved in pre- and post-synaptic mixing of rod and cone signals, *Microscopy Research and Technique,* 50, 347-359.

Krizaj, D., and Hawlina, M. (2002). Cellular basis for rod-cone interactions in the outer retina, *ZDRAV VESTN*, 71(Supplement II), 137-145.

Kryter, K.D. (1990). Aircraft noise and social factors in psychiatric hospital admission rates: A re-examination of some data, *Psychological Medicine*, 20, 395-411.

Kumari, V., Gray, J.A., Ffytche, D.H., Mitterschiffthaler, M.T., Das, M., Zachariah, E., Vythelingum, G.N., Williams, S.C.R., Simmons, A., and Sharma, T. (2003). Cognitive effects of nicotine in humans: An fMRI study, *NeuroImage*, 19(3), 1002-1013.

Kunz, D., and Bes, F. (2001). Exogenous melatonin in periodic limb movement disorder: An open clinical trial and a hypothesis, *Sleep,* 24, 183-7.

Lagarde, D., and Batejat, D. (1995). Disrupted sleep-wake rhythm and performance: Advantages of modafinil, *Military Psychology,* 7(3)*,* 165-191.

Lam, D.M. (2003). Aviation medicine. In: Kelly, P.W. (Ed.), *Military Preventive Medicine: Mobilization and Deployment*, *Volume I.* Department of the Army. Washington, DC: Office of the Surgeon General.

Lattimore, M.R., and Cornum, R.L.S. (1992). The use of extended wear contact lenses in the aviation environment : An Army wide study. Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 92-35.

Lavie, P. (1986). Ultrashort sleep-waking schedule. III. 'Gates' and 'forbidden zones' for sleep, *Electroencephalography and Clinical Neurophysiology,* 63, 414-425.

Lee, K.A., Vaillant, G.E., Torrey, W.C., and Elder, G.H. (1997). A 50-year prospective study of the psychological sequelae of World War II combat, *Year Book of Psychiatry and Applied Mental Health*, 1997(7), 301-302.

Leger, D., Badet, D., and de la Giclais, B. (1993). The prevalence of jet-lag among 507 traveling businessmen, *Sleep Research,* 22, 409.

Levin, E.D., McClernon, F.J., and Rezvani, A.H. (2006). Nicotinic effects on cognitive function: Behavioral characterization, pharmacological specification, and anatomic localization, *Psychopharmacology (Berlin).*184(3-4), 523-39.

Levin, E.D., and Rezvani, A.H. (2002). Nicotinic treatment for cognitive dysfunction, *Current Drug Targets (CNS Neurological Disorders*), 1(4), 423-31.

Lewy, A.J., Ahmed, S., Jackson, J.M., and Sack, R.L. (1992). Melatonin shifts human circadian rhythms according to a phase-response curve, *Chronobiology International,* 9, 380-92.

Lewy, A.J., Bauer, V.K., Ahmed, S., Thomas, K.H., Cutler, N.L., Singer, C.M., Moffit, M.T., and Sack, R.L. (1998). The human phase response curve (PRC) to melatonin is about 12 hours out of phase with the PRC to light, *Chronobiology International,* 15, 71-83.

Lewis, A.L. (1993). Basic concepts in environmental lighting. Chapter Five. In: Pitts, D.G., and Kleinstein, R.N (Eds.), *Environmental Vision: Interactions of the Eye, Vision, and the Environment*. Boston: Butterworth-Heinemann. p. 137-150.

Lewis, C.H., and Griffin, M.J. (1976). The effects of vibration on manual control performance, *Ergonomics*, 19(2), 203-216.

Licina, J.R. (2000). Human factors engineering (HFE) issues. In: Rash, C.E. (Ed.), *Helmet-Mounted Displays: Design Issues for Rotary-Wing Aircraft. Bellingham*. WA: SPIE Press.

Lieberman, H.R., Wurtman, R.J., Emde, G.G., Roberts, C., and Coviella, I.L.G. (1987). The effects of low doses of caffeine on human performance and mood, *Psychopharmacology (Berlin),* 92, 308-312.

Lino, A., Silvy, S., Condoroelli, L., and Rusconi, A.C. (1993). Melatonin and jet lag: Treatment schedule, *Biological Psychiatry,* 34, 587-88.

Ljungberg, J., Neely, G., and Lundstrom, R. (2004). Cognitive performance and subjective experience during combined exposures to whole-body vibration and noise, *International Archives of Occupational Environmental Health,* 77, 217-211.

Lowenstein, O., and Loewenfeld, I.E. (1969). The pupil. In: Davson, H. (Ed.), *The Eye*. New York: Academic Press. p. 255-337.

Mabbott, N., Foster, G., and McPhee, B. (2001). Heavy vehicle seat vibration and driver fatigue. Report to the Department of Transport and Regional Services, Australian Transport Safety Bureau.

Madigan, W., and Bower, K. (2004). Refractive surgery and protective eyewear in the military, *Ophthalmology*, 111(5), 855-856.

Mandell, R.B. (1988). *Contact Lens Practice.* Springfield, IL: Charles Thomas.

Mansfield, N.J. (2005). *Human Response to Vibration*. Boca Raton, FL: CRC Press.

Martin, F.C., and Peters, T.J. (1985). Assessment in vitro and in vivo of muscle degradation in chronic skeletal muscle myopathy of alcoholism, *Clinical Science (Colch.)*, 68, 693-700.

Martinez, C.E., Applegate, R.A., Klyce, S.D., McDonald, M.B., Medina, J.P., and Howland, H.C. (1998). Effect of pupillary dilation on corneal optical aberrations after photorefractive keratectomy, *Archives of Ophthalmology*, 116, 1053-1062.

Mattila, M.J., Aranko, K., Mattila, M.E., and Strömberg, C. (1984). Objective and subjective assessment of hangover during subacute administration of temazepam and nitrazepam to healthy subjects, *European Journal of Clinical Pharmacology,* 26, 375-380.

McKenzie, R.E., and Elliot, L.L. (1965). Effects of secobarbital and d-amphetamine on performance during a simulated air mission, *Aerospace Medicine,* 36*,* 774-779.

McLean, W.E. (1995). Video method of measuring field-of-view of electro-optical devices versus eye clearance. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 95-30.

McLean, W.E. (1996). ANVIS objective lens depth of field. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 96-17.

McLean, W.E. (1997). An assessment of luminance imbalance with ANVIS at an Army helicopter training airfield. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-21.

McLeod, S.D. (2001). Beyond Snellen acuity, *Archives of Ophthalmology,* 119, 1371-1373.

Meir, R. (2002). Managing transmeridian travel: Guidelines for minimizing the negative impact of international travel, *Strength and Conditioning Journal*, 24(4), 28-34.

Melki, S.A., Proano, C.E., and Azar, D.T. (2003). Optical aberrations after LASIK. In: Azar, D.T., and Koch, D.D. (Eds.) *LASIK Fundamentals, Surgical Techniques, and Complications*. New York: Marcel Dekker. p. 387-402.

Menkes, D.B. (2000). Hypnosedatives and anxiolytics. In: Dukes, M.N.G., and Aronson, J.K (Eds.), *Meyler's Side Effects of Drugs.* Amsterdam: Elsevier Science.

Melzer, J.E., and Moffitt, K. (1997). *Head-Mounted Displays: Designing for the User*. McGraw-Hill, New York, New York.

Miller, II, R.E., and Tredici, T.J. (2002). Night Vision Manual for the Flight Surgeon. Brooks AFB, TX: Armstrong Laboratory. AL-SR-1992-0002.

Minors, D.S., and Waterhouse, J.M. (1990). Circadian rhythms in general. In: Scott, A.J. (Ed.) *Shiftwork: Occupational Medicine: State of the Art Reviews*. Philadelphia, PA: Hanley and Belfus, Inc.

Mitler, M.M. (2000). Nonselective and selective benzodiazepine receptor agonists—where are we today? *Sleep*, 23(Suppl. 1), S39-S47.

Mitler, M.M., and Aldrich, M.S. (2000). *Stimulants: Efficacy and adverse effects*. In: Kryger, M.H., Roth, T., and Dement, W.C. (Eds.). *Principles and Practice of Sleep Medicine* (3rd Ed.). Philadelphia: W.B. Saunders Co.

Minors, D.S., and Waterhouse, J.M. (1988). Avoiding jet lag again, *Nature,* 32, 23-24.

Mizoue, T., Miyamoto, T., and Shimizu, T. (2003). Combined effect of smoking and occupational exposure to noise on hearing loss in steel factory workers, *Occupational and Environmental Medicine*, 60, 56-59.

Moffitt, K. (1991). HDU image focus and visual accommodation. San Jose, CA: Kaiser Electronics. Position paper, dated 7 Oct 1991.

Moffitt, K., Rogers, S. P., and Cicinelli, J. (1988). Chromatic aftereffects associated with a night vision goggle simulation, *Aviation, Space, and Environmental Medicine*, 59(2), 125-128.

Monk, T.H. (1990). The relationship of Chronobiology to sleep schedules and performance demands, *Work and Stress,* 4(3), 227-236.

Moore-Ede, M. (1993). *Aviation Safety and Pilot Error, in Twenty-Four Hour Society*. Reading, MA: Addison-Wesley Publishing Co.

Moore-Ede, M.C., Kaas, D.A., and Herd, J.A. (1977). Transient circadian internal desynchronization after light-dark phase shift in monkeys, *American Journal of Physiology,* 232, R31-R37.

Al W., Moran, A.W, and Butler, B.P. (1993). Whole-body vibration assessment of the M916A1 truck tractor. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 93-34.

Morata, T.C. (1999). Is it still necessary to conduct research on noise-induced hearing loss? *Noise and Health*, 2, 3-6.

Morell, S., Taylor, R., Carter, N.L., Job, R.F.S., and Peploe, P. (1998). Cross-sectional relationship between blood pressure of school children and aircraft noise. In: Carter, N.L., and Job, R.F.S. (Eds.), *Noise Effects. Proceedings of the 7th International on Noise as a Public Health Problem*. Sydney, Australia: Noise Effects Inc. p. 275-279.

Morris, M.S., and Borja, L.P. (1998). Noise levels associated with airbag deployment may result in occupants experiencing irreversible hearing loss, *Trauma*, 44(1), 238-239.

Mozo, B.T., and Murphy, B.A. (1997). The assessment of sound attenuation and speech intelligibility of selected active noise reduction devices and the communications earplug when used with the HGU- 56/P aviator helmet. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-08.

Mozo, B.T., and Murphy, B.A. (1998). Novel communications and hearing protection for helmet systems: Communications Earplug. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 98-23.

Muller, F.O., Van Dyk, M.V., Hundt, H.K.L., Joubert, A.L., Luus, H.G., Groenewoud, G., and Dunbar, G.C. (1987). Pharmacokinetics of temazepam after day-time and night-time oral administration, *European Journal of Clinical Pharmacology,* 33, 211-214.

Naitoh, P. (1975). Sleep deprivation in humans. In: Venables, P.H., and Christie, M.J. (Eds.), *Research in Psychophysiology*. London: John Wiley.

Nakashima, A.M. (2004). The effect of vibration on human performance and health: A review of recent literature. Toronto: Defence Research and Development Canada. Technical Report DRDC TR 2004-089.

Nakashima, A.M., and Cheung, B. (2006). The effects of vibration frequencies on physical, perceptual and cognitive performance. Toronto: Defence Research and Development Canada, Technical Report 2006-218.

Nakanishi, N., Okamoto, M., Nakamura, K., Suzuki, K., and Tatara, K. (2000). Cigarette smoking and risk for hearing impairment: A longitudinal study in Japanese male office workers, *Journal of Occupational and Environmental Medicine*, 42(11), 045-1049.

National Cancer Institute. (2008). Overview of prevention. Retrieved from: http://www.cancer.gov/cancertopics/pdq/prevention/control-of-tobacco-use

National Cancer Institute. (2008). Purpose of PDQ summary. Retrieved from: http://www.cancer.gov/cancertopics/pdq/prevention/lung/HealthProfessional

National Institute for Occupational Safety and Health. (1989). Criteria for a recommended standard for occupational exposure to hand-arm vibration, *National Institute for Occupational Safety and Health*. NIOSH #89-106

National Transportation Safety Board. (1994). *A review of flightcrew-involved, major accidents of U.S. air carriers, 1978 through 1990* (NTSB Safety Study No. SS-94-01). Washington, DC.

Naval Aerospace Medical Institute. (2007a). Waiver Guide: Medications. http://navmedmpte.med.navy.mil/nomi/nami/waiverguidetopics.cfm

Naval Aerospace Medical Institute. (2007b). U.S. Navy Aeromedical Reference and Waiver Guide. http://navmedmpte.med.navy.mil/nomi/nami/WaiverGuideTopics/pdfs/Waiver%20Guide%20-%20Physical%20Standards.pdf

Nawrot, M., Nordenstrom, B., and Olson, A. (2004). Disruption of eye movements by ethanol intoxication affects perception of depth from motion parallax, *Psychological Science*, 15(12), 858-865.

Neri, D.F., Oyung, R.L., Colletti, L.M., Mallis, M.M., Tam, P.Y., and Dinges, D.F. (2002). Controlled activity as a fatigue countermeasure on the flight deck, *Aviation, Space and Environmental Medicine,* 73(7)*,* 654-664.

Newhouse, P.A., Belenky, G., Thomas, M., Thorne, D., Sing, H.C., and Fertig, J. (1989). The effects of d-amphetamine on arousal, cognition, and mood after prolonged total sleep deprivation, *Neuropsychopharmacology,* 2(2)*,* 153-164.

Nicholson, A.N. (1983). Antihistamines and sedation, *Lancet,* 2, 211-12.

Nicholson, A.N. (1990). Hypnotics and occupational medicine, *Journal of Occupational Medicine,*32(4), 335-341.

Nicholson, A.N., Pascoe, P.A., Spencer, M.B., Stone, B.M., Roehrs, T.A., and Roth, T. (1986). Sleep after transmeridian flights, *Lancet,* 2, 1205-1208.

Nicholson, A.N., Roth, T., and Stone, B.M. (1985). Hypnotics and aircrew, *Aviation Space and Environmental Medicine,* 56, 299-303.

Nicholson, A.N., and Stone, B.M. (1982). *Sleep and Wakefulness Handbook for Flight Medical Officers*. Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development.

Nicholson, A.N., Stone, B.M., and Pascoe, P.A. (1980). Efficacy of some benzodiazepines for day-time sleep, *British Journal of Clinical Pharmacology,* 10, 459-463.

Nilsson, S.E., and Anderson, L. (1982). The use of contact lenses in environments with organic solvents, acids or alkali, *Acta Ophthalmologica*, 60(4), 599-608.

Nunneley, S.A., Reader, D.C., and Maldonado, R.J. (1982). Head-temperature effects on physiology, comfort, and performance during hyperthermia, *Aviation, Space, and Environmental Medicine*, 53, 623-628.

O'Brien, C.P., and Lyons, F. (2000). Alcohol and the athlete, *Sports Medicine*, 29(5), 295-300.

Ogilvie, R.D., Simons, I.A., Kuderian, R.H., MacDonald, T., and Rustenburg, J. (1991). Behavioral, event-related potential and EEG/FFT changes at sleep onset, *Psychophysiology,* 28*,* 54-64.

Ogilvie, R.D., Wilkinson, R.T., and Allison, S. (1989). The detection of sleep onset: Behavioral, physiological and subjective convergence, *Sleep,* 12*,* 458-474.

Ohrstrom, E. (1997). Effects of exposure to railway noise – a comparison between areas with and without vibration, *Journal of Sound and Vibration*, 205(4), 550-560.

Ohrstrom, E., Bjorkman, M., and Rylander, R. (1990). Effects of noise during sleep with reference to noise sensitivity and habituation: Studies in laboratory and field, *Environment International,* 16, 477-482.

Ohrstrom, E., and Skanberg, A.B. (1996) A field survey on effects of exposure to noise and vibration from railway traffic, Part I: Annoyance and disturbance effects, *Journal of Sound and Vibration*, 193(1), 39-47.

Ohshund, R.K., Dalton, C.I., Reams, G.C., Rose, J.W., and Oswald, R.E. (Eds.) (1991). *United States Naval Flight Surgeon's Manual*. Pensacola, FL: Naval Aerospace Medical Institute.

Okada, A., Miyake, H., Yamamura, K., Minami, M., 1972. Temporary hearing loss induced by noise and vibration, *Journal Acoustical Society of America*, 51(4), 1240-1248.

O'Keefe, J.H., Bybee , K.A., and Lavie, C.J. (2007). Alcohol and cardiovascular health: The razor-sharp double-edged sword, *Journal of the American College of Cardiology*, 50(11), 1009-1014.

O'Neal, M.R. (1991). Effect of aircraft cabin altitude and humidity on oxygen tension under soft and hard gas-permeable contact lenses. In: Flattau, P.E. (Ed.), *Considerations in Contact Lens Use under Adverse Conditions: Proceedings of a Symposium.* Washington, DC: National Academy Press. Retrieved 1 Oct 2008 from: http://www.nap.edu/catalog/1773.html

Orford, R.R., and Silberman, W.S. (2008). Pilot health and aeromedical certification. In: Davis, J.R., Johnson, R., Fogarty, J.A., and Stepanek, J. (Eds.), *Fundamentals of Aerospace Medicine,* 4th Edition Philadelphia: Lippincott Williams and Wilkins.

Oshika, T., Klyce, S.D., Applegate, R.A., Howland, H.C., and El Danasoury, M.A. (1999). Comparison of corneal wavefront aberrations after photorefractive keratectomy and laser in situ keratomileusis, *American Journal of Ophthalmology,* 127, 1-7.

O'Toole, K.J. (2004). *U.S. Air force aircrew fatigue survey*. Abstracts of the Aerospace Medical Association 75th Annual Scientific Meeting, No. 293, pp. B64, Ankorage, AK. Arlington, VA: Aerospace Medical Association.

Oxenkrug, G.F., and Requintina, P.J. (2003). Melatonin and jet lag syndrome: Experimental model and clinical implications, *CNS Spectrum,* 8, 139-48.

Paakkonen, R., and Lehtomaki, K. (2005). Protection efficiency of hearing protectors against military noise from handheld weapons and vehicles, *Noise and Health*, 7(26), 11-20.

Paddan, G.S., and Griffin, M.J. (1988). The transmission of translational vibration to the head, *Journal of Biomechanics*, 21, 195-197.

Palminteri, R., and Narbonne, G. (1988). Safety profile of zolpidem. In: Sauvanet, J.P., Langer, S.Z., and Morselli, P.L. (Eds.). *Imidazopyridines in Sleep Disorders*. New York: Raven Press.

Pandi-Perumal, S.R., Seils, L.K., Kayumov, L., Ralph, M.R., Lowe, A., Moller, H., and Swaab, D.F. (2002). Senescence, sleep, and circadian rhythms, *Ageing Research Reviews,* 1, 559-604.

Papathanasiou, G., Georgakopoulos, D., Georgoudis, G., Spyropoulos, P., Perrea, D., and Evangelou A. (2007). Effects of chronic smoking on exercise tolerance and on heart rate-systolic blood pressure product in young healthy adults, *European Journal of Cardiovascular Prevention and Rehabilitation*, 14(5), 646-52

Parry, B.L. (2002). Jetlag: Minimizing its effects with critically timed bright light and melatonin administration, *Journal of Molecular Microbiology Biotechnology,* 4, 463-466.

Parsons, K.C. (2003). *Human Thermal Environments*, London: Taylor and Francis Incorporated.

Paul, M.A., Gray, G., MacLellan, M., and Pigeau, R.A. (2004). Sleep-inducing pharmaceuticals: A comparison of melatonin, zaleplon, zopiclone, and temazepam, *Aviation Space and Environmental Medicine,* 75(6), 512-519.

Pearson, P., and Timney, B. (1998). Effects of moderate blood alcohol concentrations on spatial and temporal contrast sensitivity, *Journal of Studies on Alcohol*, 59(2), 163-73.

Pearsons, K.S., Barber, D.S. Tabachnick, B.G., and Fidell, S. (1995). Predicting noise-induced sleep disturbance, *Journal of the Acoustical Society of America,* 97, 331-338.

Pelham, T.W., White, H., Holt, L.E., and Lee, S.W. (2005). The etiology of low back pain in military helicopter aviators: Prevention and treatment, *Work: A Journal of Prevention, Assessment and Rehabilitation,* 24 (2), 101-110.

Pelmear, P., and Wasserman, D.E. (1998). *Hand-Arm Vibration: A Comprehensive Guide for Occupational Health Professionals.* (2nd Edition). Beverly Farms, MA: OEM Medical Publishers.

Penetar, D.M., McCann, U., Thorne, D., Kamimori, G., Galinski, C., Sing, H., Thomas, M., and Belenky, G. (1993). Caffeine reversal of sleep deprivation effects on alertness and mood, *Psychopharmacology (Berlin),* 112, 359-365.

Penn, P.E., and Bootzin, R.R. (1990). Behavioral techniques for enhancing alertness and performance in shift work, *Work and Stress,* 4(3), 213-226

Perry, I.C. (Ed.) (1974). *Helicopter aircrew fatigue* (AGARD Advisory Report No. 69). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development.

Petrie, K., Conaglen, J.V., Thompson, L., and Chamberlain, K. (1998). Effect of melatonin on jet lag after long haul flights, *British Medical Journal,* 298, 705-7.

Petrie, K.J., Power, D., and Broadbent, E. (2004). Fatigue self-management strategies and reported fatigue in international pilots, *Ergonomics,* 47, 461-68.

Pevet, P., Bothorel, B., Slotten, H., and Saboureau, M. (2002). The chronobiotic properties of melatonin, *Cell Tissue Research,* 309, 183-91.

Physician's Desk Reference. (2003). *Dexedrine (brand of dextroamphetamine sulfate).* In: Physician's Desk Reference. New Jersey: Medical Economics Co., Inc.; p. 1500-1501.

Pigeau, R.A., Naitoh, P., Buguet, A., McCann, C., Baranski, J., Taylor, M., et al. (1995). Modafinil, d-amphetamine and placebo during 64 hours of sustained mental work. Effects on mood, fatigue, cognitive performance and body temperature, *Journal of Sleep Research,* 4, 212-228.

Pilcher, J.J., Nadler, E., and Busch, C. (2002). Effects of hot and cold temperature exposure on performance: A meta-analytic review, *Ergonomics*, 45, 682-698.

Pitts, D.G. (1993). Electromagnetic spectrum. Chapter Four. In: Pitts, D.G., and Kleinstein, R.N. (Eds.), *Environmental Vision: Interactions of the Eye, Vision, and the Environment.* Boston: Butterworth-Heinemann.

Polse, K. (Chair) (1990). *Contact lens use under adverse conditions: Applications in military aviation*. Washington, DC: National Academy Press.

Popke, E.J., Allen, S.R., and Paule, M.G. (2000). Effects of acute ethanol on indices of cognitive-behavioral performance in rats, *Alcohol*, 20(2), 187-192.

Porcu, S., Bellatreccia, A., Ferrara, M., and Casagrande, M. (1997). Performance, ability to stay awake, and tendency to fall asleep during the night after a diurnal sleep with temazepam or placebo, *Sleep,* 20(7), 535-541.

Pozos, R.S., and Danzl, D.F. (2001). Human physiological responses to cold stress and hypothermia. In: Pandolf, K.B. (Ed.), *Medical Aspects of Harsh Environments*. Washington, DC: Borden Institute.

Pulling, N.H., Wolf, E., Sturgis, S.P., Vaillancourt, D. R., and Dolliver, J. J. (1980). Headlight glare resistance and driver age, *Human Factors*, 22(1), 103-112.

Purkinje J. (1823). Beobachtungen und Versuche zur Physiologie der Sinnesorgane I, Ch.11 and 12. Berlin: Reiner.

Pyykko, I., Starck, J., Färkkila, M., Hoikkala, M., Korhonen, O., and Nurminen, M. (1981). Hand-arm vibration in the etiology of hearing loss in lumberjacks, *British Journal of Industrial Medicine*, 38(3), 281-9.

Quintyn, J.C., Massy, J., Quillard, M., and Brasseur, G, (1999), Effects of low alcohol consumption on visual evoked potential, visual field and contrast sensitivity, *Acta Ophthalmologica Scandinavica*, 77(1), 23-6.

Rash, C.E. (2006). Shutting out the noise. *Flight Safety Foundation*. November.

Rash, C.E., Kalich, M.E, van de Pol, C., and Reynolds, B.S. (2003). The Issue of Visual Correction Compatibility with Helmet-Mounted Displays. Fort Rucker, AL: U.S. army Aeromedical Research Laboratory. USAARL Report No. 2003-04.

Rash, C.E., and Manning, S. (2001). Laser-light displays, laser pointers disrupt crewmember vision, *Human Factors and Aviation Medicine*, 48(6) 1-8.

Rash, C.E., and McLean, W.E. (2000). Optical performance. In: Rash, C.E. (Ed.), *Helmet-Mounted Displays: Design Issues for Rotary-Wing Aircraft*. Bellingham, WA: SPIE Press.

Rash, C.E., Verona, R.W., and Crowley, J.S. 1990. Human factors and safety considerations of night vision systems flight using thermal imaging systems, *Helmet-Mounted Displays II, Proceedings of SPIE*, 1290, 142-164.

Recht, L.D., Lew, R.A., and Schwartz, W.J. (1995). Baseball teams beaten by jet lag, *Nature,* 377, 583.

Records, R.E. (1979). *Physiology of the Human Eye and Visual System.* New York: Harper and Row.

Refojo, M.F. (1991). Tear evaporation considerations and contact lens wear. In: Flattau, P.E. (Ed.) *Considerations in Contact Lens Use Under Adverse Conditions: Proceedings of a Symposium.* Washington, DC: National Academy Press.

Reinhart, R.O. (1992) *Basic Flight Physiology*. Blue Ridge Summit, PA: TAB Books

Reiter, R.J. (2003). Melatonin: Clinical relevance*, Best Practice and Research in Clinical Endocrinology Metabolism,* 17, 273-85.

Reppert, S.M., Weaver, D.R., Rivkees, S.A., and Stopa, E.G. (1988). Putative melatonin receptors in a human biological clock, *Science,* 242, 78-81.

Rezvani, A.H., and Levin, E.D. (2001). Cognitive effects of nicotine, *Biological Psychiatry,* 49(3), 258-67.

Roehrs, T., Burduvali, E., Bonahoom, A., Drake, C., and Roth, T. (2003). Ethanol and sleep loss: A 'dose' comparison of impairing effects, *Sleep,* 26(8), 981-985.

Rosa, R.R. (1995). Extended workshifts and excessive fatigue. *Journal of Sleep Research, 4*(Suppl. 2), 51-56.

Rosekind, M.R., Graeber, R.C., Dinges, D.F., Connell, L.J., Rountree, M.S., Spinweber, C.L., and Gillen, K.A. (1994). *Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations* (NASA Technical Memorandum no. 108839). Moffett Field, CA: National Aeronautics and Space Administration.

Rosekind, M.R., Gregory, K.B., Miller, D.L., Co, E.I., Lebacqz, J.V., and Brenner, M. (1996). Crew fatigue factors in the Guantanamo Bay aviation accident, *Sleep Research*, 25*,* 571.

Roth, T., Piccione, P., Salis, P., Kramer, M., and Kaffeman, M. (1979). Effects of temazepam, flurazepam and quinalbarbitone on sleep: Psychomotor and cognitive function, *British Journal of Clinical Pharmacology,* 8, 47S-54S.

Roth, T., and Roehrs, T. (1991). A review of the safety profiles of benzodiazepine hypnotics, *Journal of Clinical Psychiatry,* 52(9) (Suppl), 38-47.

Russell, R.M., Carney, E.A., Feiock, K., Garrett, M., and Karwoski, P. (1980), Acute ethanol administration causes transient impairment of blue-yellow color vision, *Alcoholism Clinical and Experimental Research*, 4(4), 396-9.

Rycroft, N., Rusted, J.M., and Hutton, S.B. (2005). Acute effects of nicotine on visual search tasks in young adult smokers, *Psychopharmacologia*, 181(1), 160-169.

Sacco, R.L., Elkind, M., Boden-Albala, B., Feng Lin, I., Kargman, D.E., Hauser, W.A., Shea, S., and Paik, M.C. (1999). The protective effect of moderate alcohol consumption on ischemic stroke, *Journal of the American Medicine Association*, 281, 53-60.

Sack, R.L., Lewy, A.J., Hughes, R.J., McArthur, A.J., and Blood, M.L. (1996). Melatonin as a chronobiotic drug, *Drug News Perspective* 9, 325-32.

Sagawa, K., and Takeichi, K. (1992). System of mesopic photometry for evaluating lights in terms of comparative brightness relationships, *Journal of the Optical Society of America*, 9(8), 1240-1246.

Salas, E., Driskell, and Hughes, S. (1996). Introduction: The study of stress and human performance. In: Driskell, J.E., and Salas, E. (Eds.), *Stress and Human Performance.* New Jersey: Lawrence Erlbaum.

Samel, A., Wegman, H.M., Vejvoda, M., Drescher, J., Gundel, A., Manzeu, D., and Wenzel, J. (1997). Two-crew operations: Stress and fatigue during long-haul night flights, *Aviation Space and Environmental Medicine,* 68(8), 679-687.

Sanders, M.S., and McCormick, E.J. (1993). *Human Factors in Engineering and Design*. New York: McGraw-Hill.

Sanger, D.J., Perrault, G., Morel, E., Joly, D., and Zivkovic, B. (1987). The behavioral profile of zolpidem, a novel hypnotic drug of imidazopyridine structure, *Physiology and Behavior,* 41, 235-240.

Sawka, M.N., and Pandolf, K.B. (2001). Physical exercise in hot climates: Physiology, performance, and biomedical issues. In: Pandolf, K.B. (Ed.), *Medical Aspects of Harsh Environments*. Washington, DC: Borden Institute.

Schallhorn, S.C. (1994). Photorefractive surgery in the Navy, *Navy Medicine*, 85, 27-32.

Schallhorn, S.C. (1999). PRK in Naval Aviation. Presented at Naval Aeromedical Medical Institute, Pensacola, FL. November 12, 1999.

Schallhorn, S.C., Blanton, B.L., Kaupp, S.E., Sutphin, J., Gordon, M., Goforth Jr, H., and Butler Jr, F.K. (1996). Preliminary results of photorefractive keratectomy in active-duty United States Navy personnel, *Ophthalmology*. 103, 5-22.

Schallhorn, S.C., Reid, J.L., Kaupp, S.E., Blanton, C.L., Zoback, L., Goforth Jr., H., Flowers, C.W., and McDonnell, P.J. (1998). Topographic detection of photorefractive keratectomy, *Ophthalmology*, 105, 507-16.

Schieber, F. (1994a.). Age and glare recovery time for low-contrast stimuli, *Proceedings of the Human Factors and Ergonomics Society*. Santa Monica, California: Human Factors and Ergonomics Society. p. 496-499.

Schieber, F. (1994b). *Recent Developments in Vision, Aging and Driving: 1988-1994*. Report No. UMTRI-94-26. Ann Arbor, Michigan: University of Michigan, Transportation Research Institute. Retrieved from: www.usd.edu/ ~schieber/pdf/umtri.pdf

Schieber, F. (1995). Effects of visual aging upon driving performance. In: Adrian, W. (Ed.), *Lighting for aging vision and health.* New York: Lighting Research Institute.

Schneck, M.E., Adams, A.J., Huie, K. and Lee, E. (1993). A filter for simulating color and spatial vision of the elderly. In: Drum, B. (Ed.), *Colour Vision Deficiencies XI*. Kluwer Academic Publishers: Netherlands.

Schmitz, F.H. (1995). Reduction of blade-vortex interaction (BVI) noise through x-force control. Moffett Field, CA: Ames Research Center. NASA Technical Memorandum 110371.

Schouten, J.F., and Ornstein, L.S. (1939). Measurements on direct and indirect adaptation by means of a binocular method, *Journal of the Optical Society of America,* 29, 168-182.

Schumer, D.J., Bains, H.S., and Brown, K.L. (2000). Dark-adapted pupil sizes in prospective evaluation of laser in situ keratomileusis patients, *Journal of Refractive Surgery,* 16, S239-S41.

Schwartz, S.H. (1994). *Visual Perception: A Clinical Orientation*. Norwalk, Connecticut: Appleton and Lange.

Seidel, H., and Heide, R. (1986). Long-term effects of whole-body vibration: A critical survey of the literature, *International Archives of Occupational Environment and Health*, 58, 1-26.

Selye, H. (1946). The general adaptation syndrome and the diseases of adaptation, *Journal of Clinical Endocrinology,* 6, 117-230.

Selye, H. (1952). *The Story of the Adaptation Syndrome*. Montreal, Quebec, Canada: Acta Inc.

Senechal, P.K. (1988). Flight surgeon support of combat operations at RAF Upper Heyford, *Aviation Space and Environmental Medicine,* 59, 776-777.

Serafin, W.E. (1996). *Drugs used in the treatment of asthma*. In: Hardman, J.G., Limbird, L.E., Molinoff, P.B., Ruddon, R.W., and Gilman, A.G. (Eds.), *Goodman and Gilman's The Pharmacological Basis of Therapeutics*. (9th Ed.). New York: McGraw Hill.

Shanahan, D.F., Shannon, S.G., and Bruckart, J.E. (1993). Projected effectiveness of airbag supplemental restraint systems in U.S. Army helicopters. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 93-31.

Shappell, S.A., Neri, D.F., and DeJohn, C.A. (1992). Simulated sustained flight operations and performance, Part 2: Effects of dextro-methamphetamine, *Military Psychology,* 4(4)*,* 267-287.

Sheehy, J.B., and Wilkinson, M. 1989. Depth perception after prolonged usage of night vision goggles, *Aviation, Space. and Environmental Medicine*, 64(6), 573-579.

Shinsuke, S., Kamitani, Y., and Nishida, S. (2001). Afterimage of perceptually filled-in surface, *Science*, 293, 1677-1680.

Short, R.V., and Armstrong, S.M. (1984). Method for minimizing disturbances in circadian rhythms and bodily performance and function, *Australian Patent Application*. PG 4737, April 27, 1984.

Simmons, S.E., Saxby, B.K., McGlone, F.P., and Jones, D.A. (2008) The effect of passive heating and head cooling on perception, cardiovascular function and cognitive performance in heat, *European Journal of Applied Physiology*, 104, 271-280.

Simpson, H.W. (1980). Chronobiotics: Selected agents of potential value in jet-lag and other desynchronisms. In: Scheving, L.E., and Halberg, F. (Eds.), *Chronobiology: Principles and Applications to Shifts in Schedules*. The Netherlands: Nijthoff and Noordhoff.

Skene, D.J., Aldhous, M., and Arendt, J. (1988). Melatonin, jet-lag and the sleep-wake cycle. In: Horne, J. (Ed.), *Proceedings of the Ninth European Congress on Sleep Research*, 89, 39. Stuttgart, Germany: Gustav Fischer Verlag.

Smith, A.M. (2005). Hypoxia symptoms reported during helicopter operations below 10,000 feet: A retrospective survey, *Aviation Space and Environmental Medicine*, 76, 794-798.

Smith, A.M. (2006). The impact of short-duration light and moderate physical activity at 7,000 ft and 9,000 ft on the development of hypoxia, *Aviation Space and Environmental Medicine,* 77, 274.

Smith, A.P. (1989). A review of the effects of noise on human performance, *Scandinavian Journal of Psychology,* 30, 185-206.

Smith, A.P. (1992). Noise and performance. In: Smith, A.P., and Jones, D.M. (Eds.), *Handbook of Human Performance: The Physical Environment.* London: Academic Press.

Smith, D.G., Baranski, J.V., Thompson, M.M., and Abel, S.M. (2003). The effects of background noise on cognitive performance during a 70 hour simulation of conditions aboard the International Space Station. *Noise Health*, 6, 3-16.

Smith, G. (2002). Disability glare and its clinical significance, *Optometry Today-Optics Today*, 34-37. Retrieved 15 March 2009 from: http://www.optometry.co.uk/articles/20020419/smith20020418.pdf

Smith, S.D. (2002). Characterizing the effects of airborne vibration on human body vibration response, *Aviation, Space and Environmental Medicine*, 73(1), 36-45.

Smith, S.D. (2004). Cockpit seat and pilot helmet Vibration during flight operations on aircraft carriers, *Aviation, Space, and Environmental Medicine,* 75(1), 247-254.

Soames-Job, R.F., and Hatfield, J. (2000). Effective communication of health messages regarding noise-induced health effects, *Noise Health*, 2, 33-8.

Sobotta, J. (1990). *Atlas of Human Anatomy*. Baltimore: Urban and Schwarzenberg. Jochen. Vol. 1.

Solomon, Z. (1993). *Combat Stress Reaction*: *The Enduring Toll of War*. New York: Springer.

Stabell, B., and Stabell, U. (1998). Chromatic rod-cone interaction during dark adaptation, *Journal of the Optical Society of America*, 15(11), 2809-2815.

Stabell, B., and Stabell, U. (1979). Rod and cone contributions to change in hue with eccentricity, *Vision Research*, 19, 1121-1125.

Stanley, P.F., Tanzer, D.J., and Schallhorn, S.C. (2008). Laser refractive surgery in the United States Navy. *Current Opinions in Ophthalmology*, 19(4), 321-4.

Stansfeld, S.A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Ohrstrom, E., Haines, M.M., Head, J., Hygge, S., van Kamp, I., and Berry, B.F. (2005). Aircraft and road traffic noise and children's cognition and health: A cross-national study, *Lancet*, 365, 1942-1949.

Stevens, S.S. (1975). *Psychophysics: Introduction to its perceptual, neural and social prospects*. New York: Wiley.

Stiles, W.S. (1929). The effect of glare on the brightness difference threshold, *Proceedings of the Royal Society (London*) B 104, 322-350.

Stiles, W.S., and Crawford, B.H. (1937). The effect of a glaring light source on extrafoveal vision, *Proceedings of the Royal Society (London)* B, 122, 255-280.

Stocks, J.M., Taylor, N., Tipton, M.J., and Greenleaf, J.E. (2004). Human physiological responses to cold exposure, *Aviation, Space, and Environmental Medicine*, 75, 444-457.

Stone, B.M., and Turner, C. (1997). Promoting sleep in shiftworkers and intercontinental travelers, *Chronobiology International, 14*(2), 133-143.

Stone, B.M., Turner, C., Mills, S.L., and Nicholson, A.N. (2000). Hypnotic properties of melatonin, *Sleep,* 23, 663-69.

Suhner, A., Schlagenhauf, P., Hofer, I., Johnson, R., Tschopp, A., and Steffen, R. (2001). Effectiveness and tolerability of melatonin and zolpidem for the alleviation of jet lag, *Aviation Space and Environmental Medicine,* 72(7), 638-646.

Swanson, M.W. (1998). Changes in crystalline lens density with age, and fundus reflections. In: Benjamin, W.J. (Ed.), *Borish's Clinical Refraction*. Philadelphia: W.B Saunders Company.

Takahashi, J.S., DeCoursey, P.J., Bauman, L., and Menaker, M. (1984). Spectral sensitivity of a novel photoreceptive system mediating entrainment of mammalian circadian rhythms, *Nature,* 308, 186-88.

Talbott, E.O., Brink, L.L., Burks, C., Palmer, C., Engberg, R., Cioletti, M., and Ingman, C. (1996). Occupational noise exposure, use of hearing protectors over time and the risk of high blood pressure, *Proceedings of Internoise '96*. U.K.: Institute of Acoustics. p. 2131-2136.

Tanzer, D.J., Isfahani, A., Schallhorn, S.C., LaBree, L.D., and McDonnell, P.J. (1998). Photorefractive keratectomy in African Americans including those with known dermatologic keloid formation, *American Journal of Ophthalmology*, 126, 625-9.

Task, H. L, and Gleason, G. 1993. Eyepiece focus for night vision goggles (NVGS) and helmet-mounted displays: Fixed or adjustable? Wright-Patterson AFB, OH: Armstrong Laboratory. Preliminary report of two focus studies prepared for the Fall 1993 TARP Meeting.

Tennyson, E.A. (2001). How to buy a headset: A guide to get you started, *AOPA Flight Training*, 44(4).

Teo, R.K.C., and Ferguson, D.A. (1986). The acute effects of ethanol on auditory event-related potentials, *Psychopharmacology*, 90(2), 179-184.

Teschke, K., Nichol, A.M., Davies, H., and Ju, S. (1999). Whole body vibration and back disorders among motor vehicle drivers and heavy equipment operators: A review of the scientific evidence. Report to the Workers' Compensation Board of British Columbia.

The European Union. (2002). European Union Directive 2002/44/EC (for HAV and WBV), The minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration), *The European Union.*

The University Health Center. (2008). Alcohol and athletic performance. Retrieved on 15 August 2008 from: http://www.uhs.uga.edu/aod/athletic-performance.html

Thomas, J.R., Ahlers, S.T., House, J.F., and Schrot, J. (1989). Repeated exposure to moderate cold impairs matching-to-sample performance, *Aviation, Space, and Environmental Medicine*, 1989, 1063-1067.

Thomas, M., Sing, H.C., and Belenky, G. (1993). Cerebral glucose utilization during task performance and prolonged sleep loss, *Journal of Cerebral Blood Flow and Metabolism,* 13(1), S351.

Thomson, D. (2001). Methods of assessing cataracts and the effect of opacities on vision, *Optometry Today-Optics Today*. 26-30. http://www.optometry.co.uk/articles/ 20010601/thomson.pdf

Thompson, M. (2008). America's Medicated Army, *Time Magazine,* June, 38-42.

Tikuisis, P., and Keefe, A.A. (2007). Effects of cold strain on simulated sentry duty and marksmanship, *Aviation, Space, and Environmental Medicine*, 78, 399-407.

Tilley, A.J., Wilkinson, R.T., Warren, P.S.G., Watson, B., and Drud, M. (1982). The sleep and performance of shift workers, *Human Factors,* 24, 629-641.

Toff, W.D., Jones, C.I., Ford, I., Pearse, R.J., Watson, H.G., Watt, S.J., Ross, J.A.S., Gradwell, D.P., Batchelor, A.J., Abrams, K.R., Meijers, J.C.M/. Goodall, A.H., and Greaves, M. (2006). Effect of hypobaric hypoxia, simulating conditions during long-haul air travel, on coagulation, fibrinolysis, platelet function, and endothelial activation, *Journal of the American Medical Association*, 295, 2251-2261.

Tredici, T.J., and Flyinn, W.J. (1987). The use of contact lenses by USAF aviators, *Aviation, Space, and Environmental Medicine*, 58(5), 438-443.

Troy, S.M., Lucki, I., Unruh, M.A., Cevallos, W.H., Leister, C.A., Martin, P.T., Furlan, P.M.B., and Mangano, R. (2000). Comparison of the effects of zaleplon, zolpidem, and triazolam on memory, learning, and psychomotor performance, *Journal of Clinical Psychopharmacology*, 20(3), 328-337.

Tyler, D.B. (1947). The effect of amphetamine sulfate and some barbiturates on the fatigue produced by prolonged wakefulness, *American Journal of Physiology,* 150, 253-262.

Upile, T., Sipaul, F., Jerjes, W., Singh, S., Nouraei, S.A.R., Maaytah, M.E., Andrews, P., Graham, J., Hopper, C., and Wright, A. (2007). The acute effects of alcohol on auditory thresholds, *BMC Ear Nose Throat Disorders*, 7, 4.

U.S. Air Force School of Aerospace Medicine. (2008). Official Air Force Approved Aircrew Medications. Retrieved 15 July 2008 from: https://kx.afms.mil/kxweb/dotmil/kj.do?functionalArea=WaiverGuide

U.S. Army Aeromedical Research Laboratory and the Army Safety Center. (1996). *Leader's Guide to Crew Endurance.* Fort Rucker, AL: U.S. Army Safety Center.

U.S. Bureau of Labor Statistics. (2004). Workers on flexible and sift schedules in May 2004. Retrieved 7 Nov 2008 from: https://data.bls.gov/cgi-bin/print.pl/news.release/flex.nr0.htm

U.S. National Library of Medicine and the National Institutes of Health. (2004). Drug information: Temazepam. In: *Medline Plus*.

U.S. Navy Aerospace Medical Research Laboratory. (2001). *Performance maintenance during continuous flight operations.* Pensacola, FL: U.S. Navy Aerospace Medical Research Laboratory.

U.S. Navy Safety Center. (2008). Acquisition safety – Noise control aboard ships. Retrieved 15 August 2008 from: http://safetycenter.navy.mil/acquisition/noise/index

van de Pol, C., Greig, J.L., Estrada, A., Bissette, G.M., and Bower, K.S. (2007). Visual and flight performance recovery after PRK or LASIK in helicopter pilots, *Aviatian Space and Environmebntal Medicene*, 78(6), 547-53.

van de Pol, C., Schallhorn, S.C. , Brown, M.C., Tanzer, D.J., Kaupp, S.E., and Lattimore, M.R.J. (2000). Effect of altitude on anterior and posterior corneal curvature: LASIK, PRK, and RK compared. *Association of Research in Vision and Ophthalmology*, Ft. Lauderdale, FL.

van den Berg, T.J.T.P. (1991). On the relation between glare and stray light, *Documenta Ophthalmologica*, 78, 177-181.

van den Berg, T.J.T.P., Ijspeert, J.K., and de Waard, P.W.T. (1991). Dependence of intraocular stray light on pigmentation and light transmission through the ocular wall, *Vision Research*, 31(7/8), 1361-1367.

van Dongen, H.P.A., Maislin, G., Mullington, J.M., and Dinges, D.F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation, *Sleep,* 26(2), 117-126.

van Rijn, L.J., Nischler, C., Gamer, D., Franssen, L., de Wit, G., Koper, R., Vanhoff, D., Grabner, G., Wilhelm, H., Volker-Dieben, H.J., and van den Berg, T.J.T.P. (2005a). Measurement of stray light and glare: Comparison of Nyktotest, Mesotest, stray light meter, and computer implemented stray light meter, *British Journal of Ophthalmology*. 89, 345-351. http://bjo.bmjjournals.com

van Rijn, L.J., Wilhelm, H., Emesz, M., Kaper, R., Heine, S., Nitsch, S., Grabner, G., and Volker-Dieben, H.J. (2005b). Relation between perceived driving disability and score of vision screening tests, *British Journal of Ophthalmology*, 86, 1262-1264. http://bjo.bmjjournals.com

Vermeeren, A., Danjou, P.E., and O'Hanlon, J.F. (1998). Residual effects of evening and middle-of-the-night administration of zaleplon 10 and 20 mg on memory and actual driving performance, *Human Psychopharmacology and Clinical Experience*, 13, S98-S107.

Vidacek, S., Kaliterna, L., Radosevic-Vidacek, B, and Folkard, S. (1986). Productivity on a weekly rotating shift system: Circadian adjustment and sleep deprivation effects? *Ergonomics,* 29(12), 1583-1590.

Vos, J.J. (2003). On the cause of disability glare and its dependence on glare angle, age and ocular pigmentation, *Clinical and Experimental Optometry (Journal of the Australian Optometric Association),* 86(6), 363-370.

Vos, J.J. (1963). Contribution of the fundus oculi to entoptic scatter, *Journal of the Optical Society of America,* 53, 1449-1451.

Vos, J.J., and Boogaard, J. (1963). Contribution of the cornea to entoptic scatter, *Journal of the Optical Society of America*, 53, 869-873.

Vos, J.J., and Bouman, M.A. (1964). Contribution of the retina to entoptic scatter, *Journal of the Optical Society of America*, 54, 95-101.

Vos, J.J., and van den Berg, T.J.T.P. (1999). Report on disability glare. In: *CIE Collection 1999: Vision and Colour. Physical Measurement of Light and Radiation. CIE* 135-1999, 1-9.

Wangsa-Wirawan, N.D., and Linsenmeier, R.A. (2003). Retinal oxygen: Fundamental and clinical aspects, *Archives of Ophthalmology*, 121(203), 547-557.

Ward, D. (1993). Developments in noise induced hearing loss during the last 25 years. In: Vallet, M. (Ed.), *Noise as a Public Health Problem*. Arcuil Cedex, France: INRETS.

Wasserman, D.E. (2003). Occupational vibration: Are you at risk? Retrieved 26 July 2008 from Quest Technologies website: http://www.quest-technologies.com/ APP_Notes/Vibration_Paper.pdf

Wasserman, D., Taylor, W., and Behrens, V. (1982). Vibration White Finger Disease In: U.S. Workers Using Chipping and Grinding Hand Tools. Vol.1, Epidemiology. NIOSH Pub. 82-101.

Waterhouse, J., Reilly, T., and Atkinson, G. (1997). Jet-lag, *The Lancet,* 350, 1611-1616.

Waterhouse, J., Nevill, A., Edwards, B., Godfrey, R., and Reilly, T. (2003). The relationship between assessment of jet lag and its symptoms, *Chronobiology International,* 20, 1061-73.

Weaver, D.R., and Reppert, S.M. (1996). The Mel 1a melatonin receptor gene is expressed in human suprachiasmatic muclei, *Neuroreport,* 8(1), 109-112.

Wechsler, H., Lee, J.E., Kuo, M., Seibring, M., Nelson, T.F., and Lee, H. (2002). Trends in college binge drinking during a period of increased prevention efforts, *Journal of American College Health*, 50, 203-217.

Weiss, B., and Laties, V.G. (1962). Enhancement of human performance by caffeine and the amphetamines, *Pharmacology Review,* 14*,* 1-36.

Wells, M.H., and Griffin, M.J. (1984). Benefits of helmet-mounted display image stabilization under whole-body vibration, *Aviation, Space, and Environmental Medicine*, 55, 13-18.

Wells, M.H., and Griffin, M.J. (1987a). Flight trial of a helmet-mounted display image stabilization system, *Aviation, Space, and Environmental Medicine*, 58, 319-322.

Wells, M.H., and Griffin, M.J. (1987b). Performance with helmet-mounted sights. Institute of Sound and Vibration Research, Technical Report 152.

Wells, M.H., and Griffin, M.J. (1987c). A review and investigation of aiming and tracking performance with head-mounted sights, *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-17, 210-221.

Wells, M.J., and Haas, M. (1992). The Human factors of helmet-mounted displays. *Electro-Optical Displays*. Karim, M.A., (Ed.). Boca Raton, FL: CRC Press.

Wesensten, N., Balkin, T., Thorne, D., Killgore, R., Reichardt, R.M., and Belenky, G. (2004). Caffeine, dextroamphetamine, and modafinil during 85 hours of sleep deprivation. I. Performance and alertness effects, *Aviation Space and Environmental Medicine,* 75(4 [Section II])*,* B108.

Wesensten, N., Belenky, G., Kautz, M.A., Thorne, D., Reichardt, R.M., and Balkin, T. (2002). Maintaining alertness and performance during sleep deprivation: Modafinil versus caffeine, *Psychopharmacology (Berlin),* 159(3), 238-247.

Wesnes, K., and Warburton, D.M. (1984). A comparison of temazepam and flurazepam in terms of sleep quality and residual changes in performance, *Neuropsychobiology,* 11, 255-259.

Wesnes, K., and Warburton, D.M. (1986). Effects of temazepam on sleep quality and subsequent mental efficiency under normal sleeping conditions and following delayed sleep onset, *Neuropsychobiology*, 15*,* 187-191.

Westerman, R.A. (2004). Hypoxia familiarisation training by the reduced oxygen breathing method, *ADF Health,* 5, 11-15

Wickens, C.D., and Hollands, J.G. (2000). *Engineering Psychology and Human Performance (3rd Ed.)*. New Jersey: Prentice Hall Inc.

Widnall, S. (1971). Helicopter noise due to blade-vortex interaction. *The Journal of the Acoustical Society of America*, 50(1B), 354-365.

Wiegmann, D.A., and Shappell, S.A. (2003). *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*. Farnham, UK: Ashgate Publishing.

Wiley, R.W. (1993). Military research with contact lenses. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 93-19.

Winfield, R.H. (1941). *The use of Benzedrine to overcome fatigue on operational flights in coastal command.* Flight Personnel Research Committee Report. London: Flying Personnel Research Committee; Report No. FPRC-361.

Winfree, A.T., (1987). Circadian rhythms: Hamsters without jet lag, *Nature,* 330(6146), 311-312.

Wisor, J.P. (2002). Disorders of the circadian clock: Etiology and possible therapeutic targets, *Current Drug Targets CNS Neurological Disorders,* 1, 555-566.

Woodruff, M. (1988). How to avoid jet lab, *Nature,* 331(6153), 217.

Wooten, B.R., and Geri, G.A. (1987). Psychophysical determination of intraocular light scatter as a function of wavelength, *Vision Research*, 27(8), 1291-1298.

Wright, J.E., Vogel, J.A., Sampson, J.B., Knapik, J.J., and Patton, J.F. (1983). Effects of travel zones (jet lag) on exercise capacity and performance, *Aviation Space and Environmental Medicine,* 54, 132-37.

Wright, K.P., Hull, J.T., and Czeisler, C.A. (2002). Relationship between alertness, performance, and body temperature in humans, *American Journal of Physiology—Regulatory, Integrative, and Comparative Physiology*, 283, R1370-R1377.

Wright, N., and McGown, A. (2001). Vigilance on the civil flight deck: Incidence of sleepiness and sleep during long-haul flights and associated changes in physiological parameters, *Ergonomics,* 44(1), 82-106.

Wyatt, J.K., Cajochen, C., Ritz-De Cecco, A., Czeisler, C.A., and Dijk, D. (2004). Low-dose repeated caffeine administration for circadian-phase-dependent performance degradation during extended wakefulness, *Sleep,* 27(3), 374-381.

Yesavage, J.A., and Leirer, V.O. (1986). Hangover effects on aircraft pilots 14 hours after alcohol ingestion: A preliminary report, *The American Journal of Psychiatry*, 143,1546-1550.

Zingler, V.C., Denecke, K., Jahn, K., von Meyer, L., Krafczyk, S., Krams, M., Elfont, R., Brandt, T., Strupp, M., and Glasauer, S. (2007). The effect of nicotine on perceptual, ocular motor, postural, and vegetative functions at rest and in motion, *Journal of Neurology*, 254(12), 1689-1697.