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Chapter 12

Fatigue and its Effect on Performance in Military Environments

N.L. Miller, P. Matsangas and L.G. Shattuck

1 Introduction

> Saddam Hussein and his sons must leave Iraq within 48 hours. Their refusal to do so will result in military conflict (President George W. Bush, 17 March 2003).
>
> My fellow citizens, at this hour, American and coalition forces are in the early stages of military operations to disarm Iraq, to free its people and to defend the world from grave danger. On my orders, coalition forces have begun striking selected targets of military importance to undermine Saddam Hussein's ability to wage war. These are opening stages of what will be a broad and concerted campaign (President George W. Bush, Address to the Nation, 19 March 2003).

With these words, US President George W. Bush announced to the citizens of the United States that *Operation Iraqi Freedom* had begun. The campaign commenced with the US Air Force bombing Baghdad and other strategic targets. Shortly thereafter, on Thursday, March 20, US and Allied Coalition Ground Forces crossed the Kuwaiti–Iraqi border and began their attack north to Baghdad and other key locations. Over the next few days, Coalition aircraft flew between 1500 and 2000 sorties per day, warships launched 500 cruise missiles, and ground troops traveled hundreds of kilometers often meeting fierce resistance along the way. Coalition forces pressed on day and night with little rest. According to the 3rd Infantry Division After Action Report (AAR), a senior leader noted that he "slept for about half an hour at the assault position and really did not rest again until 24 March. The troops did not rest either." The AAR also stated that another leader "recalled that at one point [his] battalion moved only to discover that it had left a battery asleep by the side of the road."

Reporters embedded with the ground forces and military analysts provided vivid descriptions of the impact of prolonged wakefulness on performance. Here are a few comments from them.

- A Marine Company Commander stated, "I didn't get my first hour of sleep until after 48 hours, and I've been catching 20-minute catnaps ever since."
- A soldier confided, "Yesterday I finally got a little bit of sleep. The three days with only three or four hours sleep was pretty rough."
- A correspondent reported, "In the fifth day of their race northward, troops of the U.S. 3rd Infantry Division were showing the effects of sleeplessness and tension…. Drained by an armored march that U.S. commanders said was unprecedented in size, speed and distance traveled, drivers of tanks, Bradley fighting vehicles and humvees kept falling asleep at the wheel and veering off course. Then a soldier behind them would fight through the sandstorm on foot to wake a sleeping driver and get him moving again."

- A military analyst discussing the numerous accidents that occurred in the initial stages of *Operation Iraqi Freedom* stated, "Fatal mishaps soon will 'level out." They are apt to rise again with 'fatigue and combat stress,' as the war gets longer and tougher. The biggest killer is fatigue, and right now we have a whole Army running toward Baghdad on zippo hours of sleep."

Aside from the few references to fatigue cited in the 3rd Infantry Division AAR (above), many official documents seem to avoid the subject of fatigue completely. There appears to be an attitude that, similar to casualties, sleep deprivation is inevitable in war. Giving in to this viewpoint is akin to asking combatants to engage in warfare without ammunition or food and water. Consider the following comment by Shay (1998):

> Pretending to be superhuman is very dangerous. In a well-led military, the self-maintenance of the commander, the interests of his or her country, and the good of the troops are incommensurable only when the enemy succeeds in making them so. It is time to critically reexamine our love affair with stoic self-denial, starting with the service academies. If an adversary can turn our commanders into sleepwalking zombies, from a moral point of view the adversary has done nothing fundamentally different than destroying supplies of food, water, or ammunition. Such could be the outcome, despite our best efforts to counter it. But we must stop doing it to ourselves and handing the enemy a dangerous and unearned advantage.

The impact of fatigue is not restricted to the military, nor is it unique to recent military campaigns. This chapter, however, will focus on the effects of fatigue on performance in military environments. We begin with a discussion of circadian rhythms, sleep requirements, sleep architecture, and sleep debt in humans. We then examine the relationship between fatigue and human performance. Specifically, we describe the effects of insufficient sleep, both acute and chronic sleep deprivation, and the effects of circadian rhythm disruption caused by shift work or crossing time zones. We then review research efforts (historical and recent) to assess the operational effects of fatigue and sleep. After examining various behavioral and pharmacological countermeasures currently available for use in military populations, we conclude the chapter with suggestions for the direction of future efforts.

2 An Overview of Sleep

2.1 Circadian Rhythms

Over the course of a 24-hour day, human alertness waxes and wanes in a highly predictable manner. This naturally occurring pattern is known as the circadian cycle (circa = about, dies = day) and is mirrored in the diurnal pattern of sleep and wakefulness. Many other physiological parameters are governed by this same circadian rhythm, e.g., core body temperature and endocrine function such as cortisol and human growth hormone (HGH). Evolving over millennia, this circadian pattern is consistent across mammalian species, including humans, and is highly resistant to change. Most humans have adapted to the standard 24-hour Earth Day although research indicates that without light or other temporal cues, most humans have an innate 24.5 to 25.0 hour clock (Horne, 1988). This 24-hour circadian clock is regulated by cues or "zeitgebers" such as exposure to light, meals, exercise and social cues.

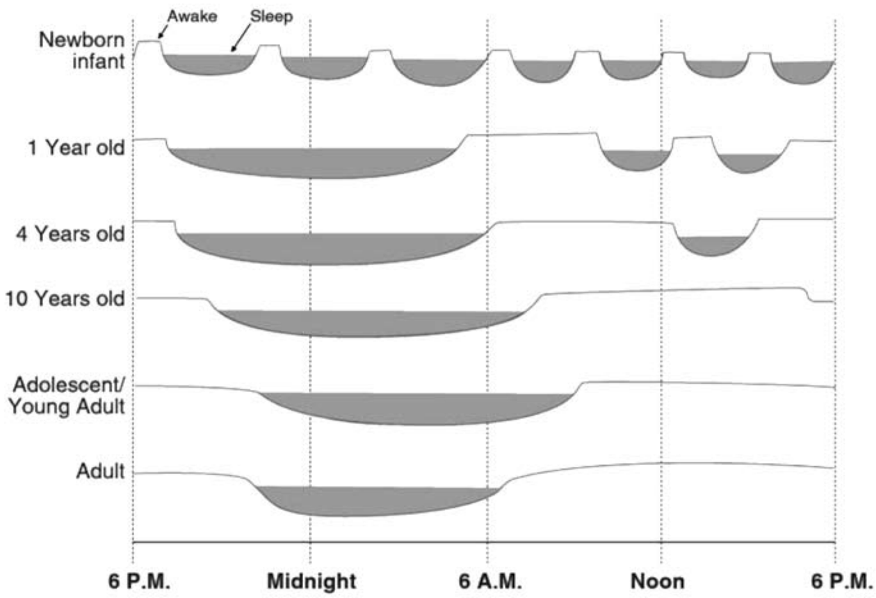

Figure 12.1 Sleep patterns over the lifespan

2.2 Sleep Requirements in Humans

In many ways, sleep remains a mysterious, yet vital, commodity. Sleep has been the topic of intensive scientific study for years – yet no one fully understands its purpose. Horne (1988) defines sleep as "the rest and recovery from the wear and tear of wakefulness". Approximately one-third of our lives are spent in this elusive condition known as sleep. In fact, there is almost universal acknowledgment that healthy adult humans require approximately eight hours of sleep per night to maintain full cognitive effectiveness (Anch et al., 1988). Like many other physiological parameters, there are individual variations in this requirement for sleep with some individuals requiring more and some less than eight hours of sleep per night (Van Dongen and Dinges, 2000).

Additionally, sleep requirements are known to change in a fairly predictable manner over the course of a lifetime. Figure 12.1 illustrates the changes in sleep patterns that are seen over the lifespan.

As can be seen in the figure, newborns have very little contiguous sleep. However, by the time they reach one year of age, children typically sleep through the night. Napping is common in babies and young children but for the most part, napping disappears as children reach elementary school age. In adolescents and young adults, there is another shift in sleep patterns. This group actually requires significantly more sleep than their adult counterparts, approximately 0.5 to 1.25 hours more per night. Corresponding to the pattern of melatonin release in this age group, bedtime is delayed with later awakenings (Carskadon, 2002, 2003; Carskadon et al., 1995; Wolfson and Carskadon, 1998, 2003. It is important to recognize that many individuals serving in the military, especially those in the junior enlisted and junior officer ranks, are still in this adolescent and young adult sleep category and require from 8.5 to 9.25 hours of sleep per night (Miller and Shattuck, 2005). By the time individuals reach their mid-20s though the middle age years, sleep requirements are fairly stable at around 8 hours per night.

Morningness-eveningness preference is also a significant determinant of sleep patterns. From a very early age, individuals display differences in alertness from morning to evening and this characteristic has been called the morningness-eveningness (M-E) preference and tends to remain fairly constant over the lifespan (Horne and Östberg, 1976). Individuals who prefer to wake early and retire to bed early have been termed "larks", while those individuals who stay up late at night and sleep in mornings are referred to as "owls". Individuals who do not exhibit a strong morning or evening preference are called "robins". The requirement for 24–7 operations makes it important to have individuals representing all of these categories of ME preference, taking advantage of the natural tendency for individuals to maintain alertness at differing times.

2.3 Sleep Architecture in Humans

At one time, it was thought that the brain was quiet during sleep. However, we now recognize that there are times in which the sleeping brain is more active than during its waking state. When we are asleep, we cannot monitor our own behavior. Scientists have developed elaborate methods (e.g., polysomnography or PSG) to gain insight into the activities of the sleeping brain (Kryger, Roth, and Dement, 2000). These methods include monitoring the electrical activity at the surface of the brain using electrodes placed on the scalp (i.e., electroencephalograms or EEGs). Similar electrodes record the muscle activity associated with eye movements (i.e., electro-oculograms or EOGs).

Recordings show that over the course of a typical eight-hour sleep period, the human brain experiences two types of sleep, rapid eye movement (REM) and non-rapid eye movement (NREM). These two sleep types have different functions and are characterized by distinctive behaviors. NREM sleep can be further divided into four progressively deeper sleep stages (Stage 1 through Stage 4). Stage 0 refers to the awake state. Typical sleep stages over the course of a night's sleep are illustrated in Figure 12.2.

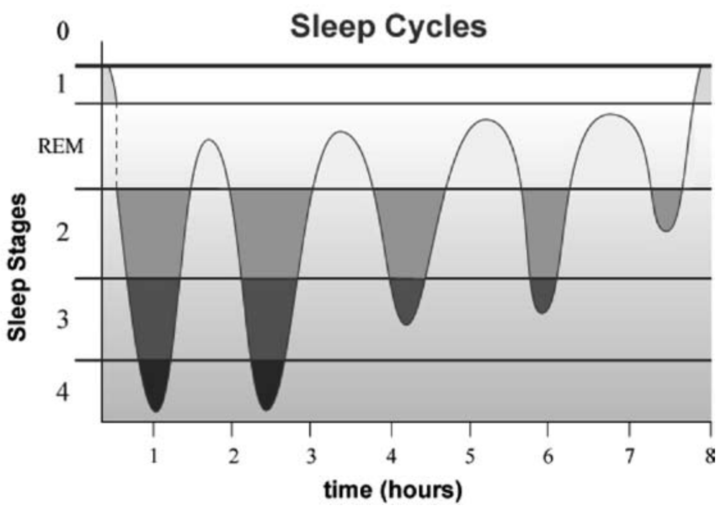

Figure 12.2 Sleep stages over a typical eight-hour sleep period

As shown in Figure 12.2, we experience these sleep stages in approximately 90 minute sleep cycles. In the first half of an eight hour contiguous sleep event, relatively more time is spent in deeper sleep (Stages 3 and 4) while Stage 1 and 2 and REM sleep are more prevalent in the latter half of an eight hour sleep period.

Adequate amounts of both REM and NREM sleep are necessary for optimal functioning in humans. In a sleep laboratory, humans can be deprived of a single stage of sleep, known as partial sleep deprivation or PSD. When allowed to sleep following PSD, the body will then rebound into the sleep stage from which it was deprived, recovering the lost sleep. Total sleep deprivation or TSD, occurs when the research participant is kept awake continuously and may be seen in both laboratory and field conditions. When allowed to sleep after experiencing total sleep deprivation, the body will rebound by rapidly entering deep stages of sleep, leading scientists to speculate that these deep stages of sleep are very important. When awakened from deep sleep, a condition known as sleep inertia is common and is characterized by reduced alertness and cognitive functioning. Although a brief period of sleep inertia typically occurs upon awakening from a normal night's sleep, sleep inertia may last even longer when awakened from deep stages of sleep. In operational environments where humans are deprived of adequate amounts of deep sleep, both conditions, the rebound into deeper sleep stages and the resultant sleep inertia when awakened from deep sleep, may be a recipe for disaster.

2.4 Insufficient Nightly Sleep or "Sleep Debt"

Events such as travel across time zones, shift work, prolonged wakefulness and foreshortened sleep will all contribute to insufficient sleep (see Figure 12.3). Unfortunately, all of these conditions are remarkably common in modern military environments in which continuous or sustained operations are required. In the worst of cases, a condition known as circadian desynchrony may occur in which this natural pattern of sleep and wakefulness is completely disrupted.

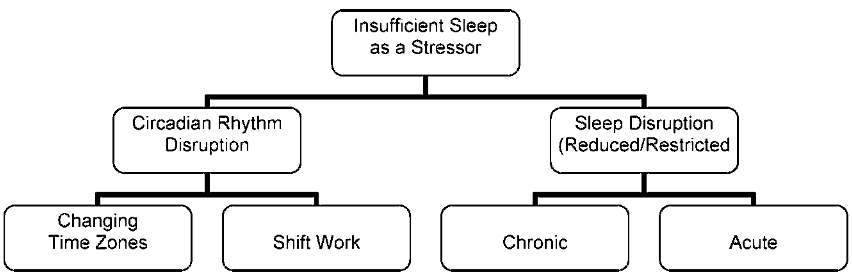

Figure 12.3 Categories of insufficient sleep

Sleep has been likened to a reservoir, filling over the course of a night's sleep and depleting during hours of wakefulness. When this sleep reservoir is not full, there is a "sleep debt", which can accrue in multiple ways. See Van Dongen et al. (2003) for a review of sleep debt. Sleep debt can be caused by acute sleep deprivation resulting from a single period of sustained wakefulness. Acute sleep debt is commonly seen in continuous operations such as those frequently experienced in military and emergency operations such as firefighting and emergency medical and response activities. Sleep debt can also be caused by chronic sleep deprivation from multiple nights of less than eight hours of sleep and is commonly observed in individuals during sustained operations. All too frequently, sleep debt results from a combination of both acute and chronic sleep deprivation conditions, and sometimes has catastrophic consequences. Unfortunately, operational environments are prone to both continuous and sustained conditions that almost inevitably lead to insufficient sleep.

3 Relationship between Performance and Fatigue

Studies examining the effects of sleep deprivation on human cognitive performance have led scientists to the conclusion that the two are inextricably linked. In particular, tasks involving vigilance are exquisitely sensitive to fatigue caused by sleep deprivation. In well-controlled laboratory experiments, sleep deprivation has been linked to degraded cognitive performance, exhibiting a highly convincing dose–response relationship (Belenky et al., 2003; Driskell, Hughes, Willis, Cannon-Bowers and Salas, 1991; Driskell and Salas, 1996; Hursh and Bell, 2001; Van Dongen et al., 2003). Findings from these studies address the profound effect of both acute and chronic sleep loss on cognitive performance. They further demonstrate that recovery from severe sleep loss will not occur overnight or even after three nights of normal sleep. Additionally, the studies allude to the insidious nature of chronic sleep deprivation: although performance is severely degraded, only those individuals who are in the most severely restricted group report being sleepy.

In the scientific literature, learning and memory have been associated with REM sleep, with the assertion that memory consolidation occurs during REM sleep. However, research indicates that deep stages of sleep are also needed for memory. Debate persists regarding the relative importance of various sleep stages but increasing evidence supports the idea that adequate sleep is a requirement for effective learning and memory (Karni et al., 1994; Wilson and McNaughton, 1994; Gais et al., 2000; Stickgold, James and Hobson, 2000; Fenn, Nusbaum and Margoliash, 2003; Walker et al., 2003).

Physical health also depends on receiving adequate amounts of sleep. Research shows that resistance to disease is degraded when deprived of sleep. Studies of antibody production have demonstrated that sleep enhances immune response (Lange et al., 2003). Unquestionably, without sleep, both our cognitive and physical performance as well as our health, suffers. Sleep is a critical requirement for humans. Indeed, in the harshest of terms, exposure to total sleep deprivation for an extended period of time will result in death (Coren, 1997).

4 The Effects of Fatigue and Sleep Deprivation in Operational Environments

In combat, the consequences of degraded performance can be much greater than those in the civil arena. Military members not only have to cope with a hostile environment, they must also apply lethal force against a dangerous enemy, maintaining vigilance and exercising good judgment, while ensuring they protect those in their own unit. Since the Second World War, numerous studies have attempted to evaluate fatigue in military operations and to assess the effects of sleep deprivation on military performance, for example (Baird, Coles and Nicholson, 1983; Majors, 1984; Nicholson, 1984; Steele et al., 1989; Meyer and DeJohn, 1990; Neri and Shappell, 1993, 1994; Shappell and Neri, 1993; Belland and Bissell, 1994; Neville et al., 1994; Kelly et al., 1996; Paul, Pigeau and Weinberg, 1998; Nguyen, 2002; Doheney, 2004; Sawyer, 2004). For reviews of these research efforts, see Krueger, Barnes and Fort Rucker (1989), and Kruger, Cardenales-Ortiz, and Loveless (1985). Despite the overwhelming evidence that sleep deprivation has a profoundly negative influence on performance, it is not uncommon in the military environment to encounter the belief that fatigue can be overcome by adequate motivation. For millennia, the "myth of the warrior" has haunted military operations (Shay, 1998). However, research has shown that motivation can only partially compensate for sleep deprivation (Pigeau, Angus and O'Neil, 1995). The bottom line is that warfighters, despite their objections and assertions to the contrary, need sleep to perform at anything near their optimal level.

Sleep is only one of the many stressors found in the military operational environment. These stressors do not always occur in isolation: they frequently occur in clusters and their effects can be additive or multiplicative and they may be mitigated by other factors. Depicted in Figure 12.4 are some of these stressors and mediators and their influence on human performance. The left column of Figure 12.4 lists various categories of stressors, all commonly seen in military operations. The middle column lists mediating factors that can change the effects that stressors have on cognitive and physical performance, pictured in the column on the right.

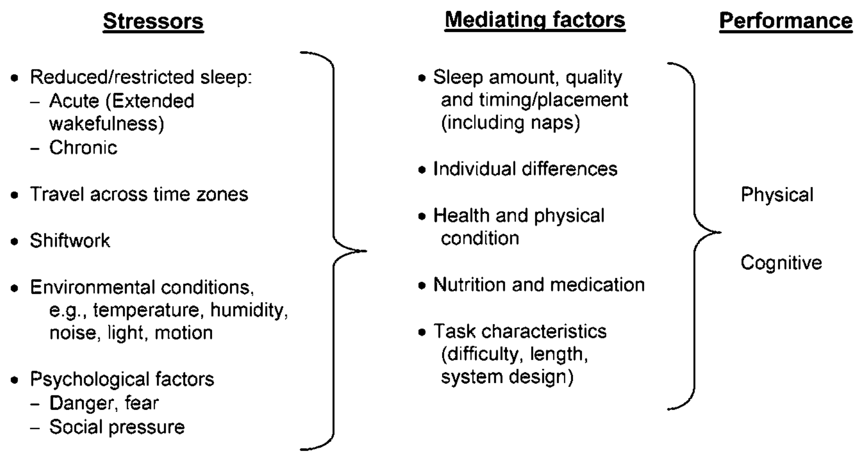

Figure 12.4 Relationship between stressors, mediating factors and performance

The difficulty of assessing war fighter fatigue in the operational environment has led researchers to the evaluation of fatigue and sleep deprivation effects through the simulation of military tasks, for example (Naitoh, Englund and Ryman, 1987; Neri, Shappell and DeJohn, 1992; Lieberman et al., 2006).

In an experiment conducted by Haslam (1985b), a number of soldiers participated in a field exercise of restricted sleep over a 9-day period. The soldiers were divided into three sleep groups: no sleep, 1.5, or 3 hours of sleep per night. At the end of the 9-day period, vigilance and cognitive tasks performance was decreased to 50 per cent of the pre-test levels. This deterioration was cognitive in nature; physical performance was relatively unchanged. The platoon that received 3 hours of sleep/night completed the study, whereas the other groups failed to finish. Only 50 per cent of the 1.5-h sleep platoon completed the 9 days of the study, whereas the no-sleep platoon was militarily ineffective after 48 hours without sleep. As noted by Haslam (1982) "In the event of war, motivation to see and fire at the enemy will be high, but, none the less, vigilance in any situation, and especially under conditions of sleep loss, will almost certainly deteriorate over time". When sleep loss becomes great, against their will, individuals will fall sleep for brief periods of time, known as micro-sleeps.

Research has shown that the effects of fatigue include decreased vigilance, mood changes, perceptual and cognitive decrements (Krueger, 1990). An important skill for soldiers, marksmanship is also known to be affected by sleep debt and circadian variation (Tharion, Shukitt-Hale and Lieberman, 2003; McLellan et al., 2005). Killgore, Balkin and Wesensten (2006) examined how sleep deprivation affects judgment. In their study, they found that individuals who are sleep deprived make riskier decisions on the Iowa Gambling Task. These findings suggest that decision-making under conditions of uncertainty may be particularly vulnerable to sleep loss and that this vulnerability may become more pronounced with increased age.

Task characteristics and complexity are major mediators in the effect of sleep on task performance. In a 48-hour field trial, Ainsworth and Bishop (1971) found that tasks which required consistent, sustained alertness were most susceptible to sleep loss. This finding is consistent with laboratory studies of impaired performance in 24 hours of sustained, continuous work (Mullaney, Kripke and Fleck, 1981). Angus and colleagues also reported performance reductions of 30 per cent during the first night and 60 per cent during the second night when sleep deprivation was combined with continuous cognitive work (Angus, Heslegrave and Myles, 1985). In a simulated sustained operations environment of an artillery fire direction center, performance decrements were evident in the first 24-48 hours; planning and maintaining situational awareness were among the tasks most affected (Banderet et al., 1981).

Cumulative sleep debt results in reductions in overall performance, but also results in longer and more sleep inertia. Sleep inertia is characterized by confusion, disorientation, and increased response latencies (Downey and Bonnet, 1987), and may be exacerbated by circadian desynchrony and the level of sleep debt (Dinges, Orne and Orne, 1985). Operational environments share common characteristics such as long work hours, working conditions that vary from boring to extremely stressful, less-than-optimal working and sleeping environments, occasional high operational tempos, sustained operations which may lead to continuous operations, and reduced staffing. In addition to their primary job and responsibilities, military personnel frequently have demanding collateral duties, e.g., pilots are required to participate in detailed mission planning, briefing, and debriefing as well as flying the mission.

Although fatigue due to sleep loss is common in all branches of the military service, it has been difficult to objectively assess due to operational considerations and equipment limitations. Until relatively recently, objective measures were extremely hard to capture so subjective evaluation was used extensively (Pereli, 1980; Chidester, 1986; Shappell and Neri, 1993). In current field studies, wristworn activity monitors (WAMs) make the process of quantifying work and rest cycles objective and fairly easy. Used along with activity logs or sleep diaries, WAMs or actigraphy measures can give unbiased estimates of quantity and quality of sleep (Ancoli-Israel et al., 2003).

In both civil and military aviation, pilot fatigue poses a significant problem because of the unforgiving nature of the aviation environment. For a review of this research, see (Caldwell, 2005). Fatigue is known to lead to less accurate flight maneuvers, increased error rates, and to significant lapses in judgment (Billings et al., 1968; Pereli, 1980; Krueger, Armstrong and Cisco, 1985). Studies in US Naval aviation during fleet operations have found correlations between pilot performance and increased levels of fatigue (Brictson, McHugh and Naitoh, 1980; Brictson and Young, 1980; Brictson, 1990). In studies conducted with soldiers deployed in Bosnia (Operations Joint Endeavor I and II), 56 per cent of respondents reported that the number of hours worked was a stressor. According to research, lack of sleep was a common occurrence in deployments in Haiti, Bosnia, Somalia, and Kuwait (French, 1995).

During *Operation Desert Shield* and *Operation Desert Storm*, a study was conducted onboard the *USS AMERICA* using A-6 and F-14 pilots. Although, fatigue was evident in both campaigns, flight operations during *Operation Desert Storm* were found to be more fatiguing due to differences

Photo 12.1 Soldier sleeping in combat conditions

in the time of day the missions were flown, mission length, and the type of aircraft involved. In both campaigns, no evidence of fatigue accumulation was found because of effective management of air combat operations (DeJohn and Neri, 1992; Shappell and Neri, 1993). In the same study, the researchers noted that pilot fatigue level was reduced with circadian synchronization. During *Operation Desert Storm*, surveys of C 141 aircrews (airlift operations) reported occasions when the aircrew was fatigued to the point that they felt unable to function (Neville et al., 1994).

Research conducted on Navy surface ships and submarines has shown that work conditions on naval vessels (shift working, and lack of natural light) leads to increased fatigue due to circadian desynchrony and reduced sleep (Steele et al., 1989; Comperatore, Bloch and Ferry, 1999; Horn et al., 2003; Arendt et al., 2006).

5 Fatigue Countermeasures and Intervention Strategies

5.1 Fatigue Countermeasures

Perhaps due to the high incidence of sleep deprivation in its ranks, the US military, the US Coast Guard and to the US transportation industry have all continued to search for ways to combat the effects of sleep deprivation. These agencies have sought to develop fatigue countermeasures which are safe and effective for individuals working in their organizations. Although the best way to overcome fatigue is through adequate amounts of quality sleep, this may be quite difficult to achieve in the operational environment. To the extent possible, military operations should include interventions in all the factors that are known to interfere with or contribute to sleep hygiene.

Fatigue countermeasures can be placed into two categories: pharmacological agents (i.e., drugs of either the prescription or non-prescription variety) and non-pharmacological agents (Figure 12.5). These interventions may also be divided by their mode of action: stimulants/performance boosters or sedatives/sleep aids.

Non-pharmacological Interventions

- Sleep conditions
  - Dark
  - Quiet
  - Temperate
  - Safe
- Work/rest schedules
- Naps, rest breaks
- Exercise
- Environmental stimulation
- Physical fitness
- Task attributes

Pharmacological interventions

- Prescription stimulants or alerting drugs
  - Dexedrine (dextroamphetamine)
  - Modafinil
- Non-prescription stimulants or alerting drugs
  - Caffeine
- Prescription sedatives or sleep aids
  - Ambien (zolpidem)
  - Restoril (temazepam)
- Non-prescription sedatives or sleep aids
  - Melatonin
  - Benedryl
  - Trytophan

Figure 12.5 Fatigue countermeasures

5.2 Non-pharmacological interventions

Many non-pharmacological interventions have been tried, some with more success than others. Figure 12.5 lists a variety of these non-pharmacological interventions in the column on the far left. While recognizing that these conditions are highly dependent on the combat conditions, sleep quarters should be designed for dark, quiet, temperate and safe conditions while sleeping. Light exposure has been shown to be especially important for sleep and is associated with suppression of melatonin release. A study by Miller and Nguyen (2003) on the *USS STENNIS* during night operations examined the role of sunlight exposure and sleep. Sailors in this study had wakeup call at 18.00 while bedtime was at 10.00. This study showed that Sailors who worked belowdecks with no exposure to sunlight before bedtime had much better sleep than those Sailors who worked topside and received several hours of exposure to sunlight before retiring for bed. This finding is in agreement with research on light exposure in shift workers.

Sleeping in an unfamiliar environment is also known to affect sleep quality. A recent survey of Army pilots revealed that, even during peacetime, 26 per cent of pilots complained of poor sleep while in the field or while traveling away from home compared with only 5 per cent complaining of poor sleep at their home post (Caldwell et al., 2000). In combat, this unfamiliarity with sleep conditions is compounded by concerns about one's physical safety and the many other psychological stressors that accompany combat.

When work is extended to include schedules other than a standard eight hour workday during daylight hours, appropriate scheduling of work and rest for individuals is crucial. Tools are available to assist in optimizing scheduling. The Fatigue Avoidance Scheduling Tool or FAST™

is one such tool that is used by various military services including the US Air Force, US Navy and US Marines (Eddy and Hursh, 2001). Using the Sleep and Fatigue, Task Effectiveness (SAFTE) model developed by Hursh and others, FAST™ uses the 72 hour sleep history of an individual to predict their cognitive effectiveness at a given point in time.

Output from FAST™ is displayed in Figure 12.6. Predicted effectiveness is shown on the left and ranges from 0 to 100 per cent while blood alcohol equivalence is shown on the right. The three horizontal bands indicate level of predicted effectiveness with the top narrow band representing the safe zone (greater than 90 per cent effectiveness), The middle bad is the cautionary zone and the lower, darkest band is the danger zone where lapses in attention are greatly increased. Predicted effectiveness for 5 days of work and rest are shown for a single individual and are represented by the undulating gray line. Circadian peaks and troughs are distinct with dips in the wee hours of the morning and in the afternoon. The first 3 days show predicted effectiveness while receiving eight hours of sleep while the last 2 days show what happens to predicted effectiveness when sleep is reduced (day 4) and eliminated (day 5). The FAST tool can be used as a retrospective instrument as well as predicting future performance. The USAF uses the dotted line (the "criterion line") on the FAST plot as a cutoff point when scheduling pilots for long-range missions. At all times in their flight profile, the pilot-in-command must have performance above the dotted line. During mission critical phases of flight (e.g., takeoff, landing, weapons delivery) predicted effectiveness must be in the 90 per cent or above band. For extended missions, e.g., B 2 flights of 40 hours duration and two pilots, in-flight napping procedures have been used to ensure these criteria are met in USAF pilots.

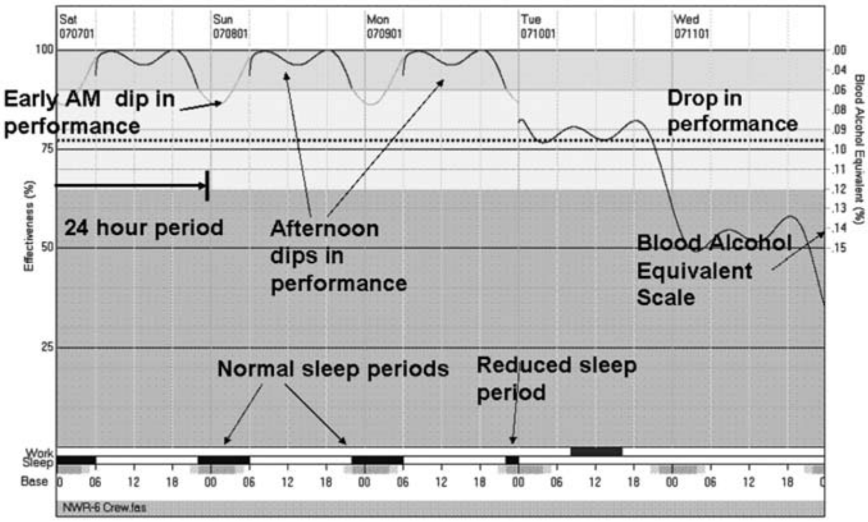

Figure 12.6 Fatigue Avoidance Scheduling Tool (FAST)

Sleep debt can be reduced through napping which has been shown to moderate the effect of fatigue on human performance (Haslam, 1985a; Rosekind, Gander and Dinges, 1991). Unfortunately, napping may be impossible when combat conditions become intense. Although napping is not as effective as contiguous nocturnal sleep and the time spent in naps is not equivalent to night sleep (Moses et al., 1975), in operational environments, napping may be the only route to provide sleep to individuals in combat for extended periods (Haslam, 1982). So as to optimize the beneficial quality of napping, Naitoh noted three factors that should be considered: the amount of prior wakefulness, the timing, and the duration of the nap (Naitoh, 1981). Warfighters should be allowed to take naps when possible, given the operational limitations. Strategic naps can help alleviate sleep-deprivation-related performance decrements in situations where naps are feasible (Dinges et al., 1988). An excellent review of napping is available in a thesis by Godfrey (2006).

Physical fitness has been shown to be important for sleep quality. However, heavy exercise immediately before sleep is not recommended since it may delay sleep onset. Light exercise such as jogging in place and jumping jacks has been shown to have an immediately alerting effect that dissipates quickly. Nutrition is also important for sleep and timing of meals should allow for digestion to occur before the major sleep episode (i.e., no heavy late night meals). Alcohol ingestion, while sedating, has an adverse effect on sleep quality and is not recommended.

5.3 Pharmacological interventions

The second category for countering fatigue is through the use of pharmacological agents, either prescription or non-prescription. Pharmacologic agents can be thought of as falling into one of two categories: those that promote sleep and those that promote wakefulness. Historically, the use of pharmacologic agents to promote either sleep or wakefulness extends back to the Second World War. Also called "go-no go" pills, amphetamines and sedatives have been used by American, British, and German aviators since the Second World War and their use is also documented in conflicts in Vietnam, the Falkland Islands, and Iraq in Operation Desert Storm (Winfield, 1941; Graf, 1946; Nicholson, 1984; Nicholson, Roth and Stone, 1985). Caffeine, slightly less effective to amphetamines in terms of its alerting effects, was used in flight operations in Iraq during Operation Southern Watch (Belland and Bissell, 1994).

Unfortunately, both interventions (i.e., promoting sleep or wakefulness) are challenging to implement in military operational environments where chaotic "sleep windows" (i.e., those time periods when individuals can sleep) may be unscheduled, disrupted, or of short duration. Some pharmacologic agents that promote sleep may impair performance after awakening, causing "hangover effects" (Giam, 1997). Similarly, sleep impairing agents may degrade the amount and quality of sleep when the opportunity to sleep does become available. Numerous pharmacologic agents have been used in various military missions, like bombing, very long air transport flights, and long-range reconnaissance patrols. The pharmacological intervention information presented in this chapter is meant to convey the history and current state of use in military operations and represents only a small fraction of the information available on this topic.

5.3.1 Stimulants or alerting pharmacological interventions The use of the prescription drug, dextroamphetamine, as an alerting agent for aviators in the combat environment has been hotly debated for years, but its use is still fairly widely accepted during periods of combat or extreme operational necessity when approved by higher authority. The street name for this medication is "speed" and its use by the USAF, US Navy, USMC and the US Army must be approved by a flight surgeon who may prescribe it. Modafinil is a recent prescription medication that is now available for pilots and may have fewer side effects than dextroamphetamine.

Over the counter (OTC) medications are also available in the form of caffeine and nicotine. Caffeinated beverages include coffee and soft drinks such as Jolt and Mountain Dew. Chewing gum augmented with caffeine is now marketed and is included in Meals Ready to Eat (MREs). Marksmanship, affected by sleep debt and circadian variation, is improved by the use of caffeine (Tharion, Shukitt-Hale and Lieberman, 2003; McLellan et al., 2005). The effects of sleep inertia have also been show to be greatly reduced from use of caffeine (Van Dongen et al., 2001). Chronic exposure over long periods of time reduces the effectiveness of caffeine and nicotine.

5.3.2. Sedatives or sleep aiding pharmacological interventions Prescription sedatives or sleep aids are available for use when prescribed by a flight surgeon and include zolpidem (Ambien) and temazepam (Restoril). Both medications are currently being prescribed for use by aircrew. However, their use must be timed carefully so that their sedating effects have worn off before personnel are expected to engage in misssion-related tasks. The US Navy gives guidance to flight surgeons on the use of prescription in their manual authored by CAPT Dave Brown (NASA astronaut on the Columbia) *Performance Maintenance During Continuous Flight Operations* (Brown, 2000).

Non-prescription (OTC) agents are also used by military members to aid in getting sleep. These include melatonin and tryptophan as well as medications with sedating properties such as Benedryl and Tylenol PM. The use of OTC medications by aircrew is not approved since their side effects can be potentially hazardous during routine or combat operations.

6 Conclusion

Warfare has become a “24-7” activity and requires highly skilled practitioners to operate complex systems. In addition, the military services have reduced personnel strength and project additional manpower decrements. Individuals in demanding operational environments are almost certain to experience some level of sleep deprivation and the resultant performance decrement. In an eloquent article about the implications of fatigue for warfighters, CAPT Nick Davenport describes fatigue as “…the big gray elephant we muscle out of the cockpit when we fly, step around when we enter the bridge, and push aside when we peer into the periscope” (Davenport, 2006). Ignoring the “big gray elephant” of fatigue in operational settings has not been effective in the past. The “myth of the warrior” (Shay, 1998) is, unfortunately, alive and well.

A few years ago, a general officer in the US Army was asked how many hours of sleep leaders needed each day to remain effective during sustained operations. Essentially, he stated that leaders only needed about three and a half hours of sleep every 24 hours – two hours between 2.00 and 4.00 and then a nap later in the morning. He said that this pattern of sleep, coupled with a lot of caffeine and staying “actively fearful of screwing up” will sustain a leader indefinitely. His answer is contrary to decades of research in sleep and the effects of sleep deprivation.

How do we protect warfighters from buying in to the “myth of the warrior?” There are several possibilities. Since this chapter is scholarly in nature, the reader might assume that we would first recommend additional research. And perhaps additional research is warranted in certain areas of sleep and fatigue. However, since there are hundreds of articles and books that have already been published in these areas, it is doubtful that the argument for the need to reduce the effects of fatigue will be bolstered by additional research. Another possibility is education. The National Sleep Foundation maintains an excellent website (http://www.sleepfoundation.org/) which contains a wealth of information. However, it is not likely that this website is visited regularly by leaders in the military and other organizations engaged in sustained, risky, and demanding activities. These professions need to acknowledge the “big gray elephant” and educate the practitioners on how to cope with the debilitating effects of fatigue. In the military, such information should become a part of the curricula at all schools.

Education, however, often is not enough. Many professions (e.g., commercial trucking and airline industries) are governed by regulatory policies that dictate the amount of rest required. Other professions (e.g., medical, police, firefighting) have less formal policies. In the military, such policies are restricted almost exclusively to aviators. Those who work on the aircraft, those who drive tanks, or those who stand watch on warships are not governed by any formal policies. The work-rest schedules of these warfighters are governed by the availability of personnel, the requirements of the mission, and the standard operating procedures of the organization. Given the complexity and inherent danger in virtually any job in the military, it may be time to consider implementing formal policies for all warfighters, similar to those that govern aviators.

Another area in which work needs be done is the improvement of the existing tools for assessing and predicting the effects of sleep deprivation. The Fatigue Avoidance Scheduling Tool (FAST) is excellent for modeling and assessing performance given an individual's sleep schedule but its use is not widespread it is not in a form that is usable at the tactical level. A similar tool that could assess and predict performance of multiple individuals (e.g., teams, squads, platoons) given their sleep schedules is being developed by researchers at the Walter Reed Army Institute of Research (WRAIR) but is not yet available.

None of the possible solutions discussed above truly get at the heart of the problem. More research, better education, formal policies, better assessment and predictive tools, and even non-pharmacologic and pharmacologic interventions will help warfighters do more with less for only so long. Beyond a certain point these warfighters bump up against the inflexible boundary of human capacity. It is imperative that we acknowledge these human limitations and design our work environments so that practitioners function within these limitations.

A more holistic approach must encompass solutions offered by such areas as manpower, personnel, and human factors engineering. Increasing manpower will have a direct effect on work schedules. While this is a costly solution, it is, in the long run, less costly than a human life or than a fighter aircraft. Personnel solutions could include screening candidates to identify those who will perform well in continuous and sustained operations. Investments in training can lower the cognitive demand of many tasks and, therefore, reduce the likelihood that those tasks would be affected by warfighters experiencing mild amounts of fatigue. Finally, carefully designed human—machine systems also may help to reduce the effects of fatigue by reducing the workload of human operators. In the end, if we employ a comprehensive and holistic approach to the design of military organizations and the technological systems of warfare, we should be successful in assisting them to reduce their fatigue and to improve both their sleep patterns and their overall quality of life.

References

Ainswoth, L.L. and Bishop, H.P. (1971), *The Effects of a 48-hour Period of Sustained Field Activity on Tank Crew Performance* (Alexandria, VA: Human Resources Research Organisation).

Anch, A.M., Browman, C.P., Mitler, M. and Walsh, J.K. (1988), *Sleep: A Scientific Perspective* (Englewood Cliffs, NJ: Prentice-Hall, Inc.).

Ancoli-Israel, S., Cole, R., Alessi, G., Chambers, M., Moorcroft, W. and Pollak, C.P. (2003) "The Role of Actigraphy in the Study of Sleep and Circadian Rhythms", *Sleep*, **26**(3), 342–392.

Angus, R.G., Heslegrave, R.J. and Myles, W.S. (1985) "Effects of Prolonged Sleep Deprivation, with and Without Chronic Physical Exercise, on Mood and Performance", *Psychophysiology*, **22**, 276–282.

Arendt, J., Middleton, B., Williams, P., Francis, G. and Luke, C. (2006) "Sleep and Circadian Phase in a Ship's Crew", *Journal of Biological Rhythms*, **21**(3), 214–221.

Baird, J.A., Coles, P.K.L. and Nicholson, A.N. (1983) "Human Factors and Air Operations in the South Atlantic Campaign: Discussion Paper", *Journal of the Royal Society of Medicine*, **76**, 933–937.

Banderet, L.E., Stokes, J.W., Francesconi, R., Kowal, D.M. and Naitoh, P. (1981) "Artillery Teams in Simulated Sustained Combat: Performance and other Measures" in *DHHS*, Johnson, L.C., Tepas, D.I., Colquhoun, W.P. and Colligan, M.J. (eds.) (Department of Health and Human Services) *NIOSH (National Institute for Occupational Safety and Health) Report 81-127: The twenty four-hour workday: Symposium on Variations in Work-Sleep Schedules* (pp. 581-604). Washington, DC: Government Printing Office.

Belenky, G., Wesensten, N.J., Thorne, D.R., Thomas, M.L., Sing, H.C. and Redmond, D.P. et al. (2003) “Patterns of Performance Degradation and Restoration during Sleep Restriction and Subsequent Recovery: A Sleep Dose-Response Study”, *Journal of Sleep Research*, **12**, 1–12.

Belland, K.M. and Bissell, C.A. (1994) “A Subjective Study of Fatigue during Navy Flight Operations over Southern Iraq: Operation Southern Watch”, *Aviation, Space, and Environmental Medicine*, **65**(6), 557–561.

Billings, C.E., Eggspuehler, J.J., Gerke, R.J. and Chase, R.C. (1968) Studies of Pilot Performance. II Evaluation of performance during Low Altitude Flight in Helicopters. *Aerospace Medicine, 39*, 19-31.

Brictson, C.A. (1990) Pilot Landing Performance under High Workload Conditions (No. AGARD-CPP-146) Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.

Brictson, C.A. and Young, P.A. (1980), *Measures of Navy Pilot Workload, Sleep and Performance in Stressful Environments* (*Final Report*) (Arlington, VA: Office of Naval Research) (Code 441), Environmental Physiology Division.

Brictson, C.A., McHugh, W. and Naitoh, P. (1980), “Prediction of Pilot Performance: Biochemical and Sleep-Mood Correlates under High Workload Conditions”. Paper presented at the AGARD-CPP-146, Neuilly-sur-Seine, France.

Brown, D. (2000) Performance Maintenance during Continuous Flight Operations, A Guide for Flight Surgeons (No. NAVMED P-6410 (01 Jan 2000)).

Caldwell, J.A. (2005) “Fatigue in Aviation”, *Travel Medicine and Infectious Disease*, **3**, 85–96.

Caldwell, J.A., Gilreath, S.R., Erickson, B.S. and Smythe, N.K. (2000) Is Fatigue a Problem in Army Aviation? The Results of a Survey of Aviators and Aircrews (Final Report No. USAARL Report No. 2001-03), *Fort Rucker, AL: U.S.* Army Aeromedical Research Laboratory.

Carskadon, M.A., Wolfson, A.R., Tzischinsky, O. and Acebo, C. (1995) “Early School Schedules Modify Adolescent Sleepiness”, *Sleep Research*, **24**, 92.

Chidester, T.R. (1986) “Mood, Sleep, and Fatigue Effects in Flight Operations” in *Proceedings of The Tenth Symposium, Psychology in the Department of Defense, Technical Report No*, Lee, G.E. (ed.), 86–81. Colorado Springs, CO: USAFA.

Comperatore, C.A., Bloch, C. and Ferry, C. (1999) Incidence of Sleep Loss and Wakefulness Degradation on a U.S. Coast Guard Cutter under Exemplar Crewing Limits (Final Report No. CG-D-14-99). Groton, CT: US Coast Guard Research and Development Center.

COPE, Warfighter Endurance Management during Continuous Flight Operations. Retrieved September 19, 2006 from http://wwwsam.brooks.af.mil/web/cope.htm.

Davenport, N. (2006) “Elephant Hunting: Spotting the Root Cause of Mishaps” in *Unpublished Manuscript*, Navy, U.S., School of Aviation Safety, Pensacola, F.L.A. and DeJohn, C.A. (eds.); Shappell, S.A. and Neri, D.F. (1992) Subjective Fatigue in A-6, F-14, and F/A-18 Aircrews during Operations Desert Shield and Desert Storm (Interim No. NAMRL-1377). Pensacola, FL: Naval Aerospace Medical Research Laboratory.

Dinges, D.F., Orne, K.T. and Orne, E.C. (1985) “Assessing Performance upon Abrupt Awakening from Naps during Quasi-Continuous Operations”, *Behavior Research Methods, Instruments, and Computers*, **17**, 37–45.

Dinges, D.F., Whitehouse, W.G., Orne, E.C. and Orne, M.T. (1988) “The Benefits of a Nap during Prolonged Work and Wakefulness”, *Work and Stress*, **2**, 139–153.

Doheney, S.W. (2004), *Sleep Logistics as a Force Multiplier: An Analysis of Reported Fatigue Factors from Southwest Asia Warfighters* (Monterey, California: Naval Postgraduate School).

Downey, R. and Bonnet, M.H. (1987) "Performance during Frequent Sleep Disruption", *Sleep*, **10**, 354–363.

Driskell, J.E. and Salas, E. (1996) "Stress and Human Performance", *Hillsdale, NJ* (New England: Lawrence Erlbaum Associates, Inc.).

Driskell, J.E., Hughes, S.C. and Willis, R.C., Cannon-Bowers, J. and Salas. E. (1991). *Stress, stressor, and decision-making* (Technical Report). Orlando, FL: Naval Training Systems Center.

Eddy, D.R. and Hursh, S.R. (2001). Fatigue Avoidance Scheduling Tool: Phase I SBIR Final Report (No. AFRL-HE-BR-TR-2001-0140). Brooks AFB, TX: Air Force Research Laboratory, Human Effectiveness Directorate, Biodynamic and Protection Division, Flight Motion Effects Branch.

Fenn, K.M., Nusbaum, H.C. and Margoliash, D. (2003) "Consolidation during Sleep of Perceptual Learning of Spoken Language", *Nature*, **425**, 614–616.

French, J. (1995, 3-5 April). "Managing Fatigue in Long Duration Airlift Operations 1994". Paper presented at The effect of prolonged military activities in man. Physiological and biochemical changes. Possible means of rapid recuperation, Oslo, Norway.

Gais, S., Plihal, W., Wagner, U. and Born, J. (2000) "Early Sleep Triggers Memory for Early Visual Discrimination Skills", *Nature Neuroscience*, **3**(12), 1335–1339.

Giam, G.C. (1997) "Effects of Sleep Deprivation with Reference to Military Operations", *Annals Academy of Medicine Singapore*, **26**(1), 88–93.

Godfrey, A.G. (2006), *Optimizing Daytime Short Sleep Episodes to Maximize Performance in a Stressful Environment* (Monterey, California: Naval Postgraduate School).

Graf, O. (1946) Increase of Efficiency by Means of Pharmaceutics (stimulants). in German *aviation medicine World War II* (Vol. II): Department of the Air Force.

Haslam, D.R. (1982) "Sleep Loss, Recovery Sleep and Military Performance", *Ergonomics*, **25**(2), 163–178.

Haslam, D.R. (1985a) "Sleep Deprivation and Naps", *Behavior Research Methods, Instruments, and Computers*, **17**(1), 46–54.

Haslam, D.R. (1985b) "Sustained Operations and Military Performance", *Behavior Research Methods, Instruments, and Computers*, **17**, 9–15.

Horn, W.G., Thomas, T.L., Marino, K. and Hooper, T.I. (2003) "Health Experience of 122 Submarine Crewmembers during a 101-day Submergence", *Aviation, Space, and Environmental Medicine*, **74**(8), 858–862.

Horne, J.A. (1988), *Why we Sleep* (Oxford: Oxford University Press).

Horne, J.A. and Östberg, O. (1976) "A Self-Assessment Questionnaire to Determine morningness-eveningness in human Circadian Rhythms", *International Journal of Chronobiology*, **4**, 97–110.

Hursh, S.R. and Bell, G.B. (2001), *Human Performance Cognitive Model for Air Force Information Operations* (Air Force Research Laboratory).

Karni, A., Tanne, D., Rubenstein, B.S., Askenasy, J.J. and Sagi, D. (1994) "Dependence on REM Sleep of Overnight Improvement of a Perceptual Skill", *Science*, **265**, 679–682.

Kelly, T., Grill, J.T., Hunt, P.D. and Neri, D.F. (1996), *Submarines and 18-hour Shift Work Schedules* (*No. 96-2*) (San Diego, CA: Naval Health Research Center).

Killgore, W.D.S., Balkin, T.J. and Wesensten, N.J. (2006) "Impaired Decision Making Following 49 h of Sleep Deprivation", *Journal of Sleep Research*, **15**(1), 7–13.

Krueger, G.P. (1990) "Sustained Military Performance in Continuous Operations: Combatant Fatigue, Rest and Sleep Needs" in *Handbook of Military Psychology*, Gal, R. and Mangelsdorff, A.D. (eds.) (Chichester, England: John Wiley & Sons, Ltd.), 244–277.

Krueger, G.P. and Barnes, S.M. (1989). "Human performance in continuous/sustained operations and the demands of extended work/rest schedules: An annotated bibliography" – Vol. II (Tech. Report No. USAARL Report No.89-8). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Krueger, G.P., Armstrong, R.N. and Cisco, R.R. (1985) "Aviator performance in Week-Long Extended Flight Operations in a Helicopter Simulator", *Behavior Research Methods, Instruments, and Computers*, **17**, 68–74.

Krueger, G.P., Cardenales-Ortiz, L. and Loveless, C.A. (1985), *Human Performance in Continuous/ Sustained Operations and the Demands of Extended Work/Rest Schedules: An Annotated Bibliography (Tech. Rep. No. BB-85-1)* (Washington, DC: Walter Reed Army Institute of Research).

Lange, T., Perras, B., Fehm, H.L. and Born, J. (2003) "Sleep Enhances the human Antibody Response to Hepatitis A Vaccination", *Psychosomatic Medicine*, **65**, 831–835.

Lieberman, H.R., Niro, P., Tharion, W.J., Nindl, B.C., Castellani, J.W. and Montain, S.J. (2006) "Cognition during Sustained Operations: Comparison of a Laboratory Simulation to Field Studies", *Aviation, Space, and Environmental Medicine*, **77**, 929–935.

Majors, J.S. (1984) Human Factors Survey: C-5 Pilots (Final Report No. USAFSAM-TR-84-26) Brooks City-Base, TX: USAF School of Aerospace Medicine.

McLellan, T.M., Kamimori, G.H., Bell, D.G., Smith, I.F., Johnson, D. and Belenky, G. (2005) "Caffeine Maintains Vigilance and Marksmanship in Simulated Urban Operations with Sleep Deprivation", *Aviation, Space, and Environmental Medicine*, **76**(1), 39–45.

Meyer, L.G. and DeJohn, C.A. (1990), *Sustained Flight Operations in Navy P-3 Aircraft (Final Report No. NAMRL-1355)* (Pensacola, FL: Naval Aerospace Medical Research Laboratory), Naval Air Station.

Miller, N.L. and Nguyen, J. (2003) "Working the Nightshift on the USS STENNIS: Implications for Enhancing Warfighter Effectiveness", *Proceedings of the Human Systems Integration Symposium*, June, 2003.

Miller, N.L. and Shattuck, L.G. (2005) "Sleep Patterns of Young Men and Women Enrolled at the United States Military Academy: Results from Year One of a Four Year Longitudinal Study", *Sleep*, **28**(7), 837–841.

Moses, J.M., Lubin, A., Johnson, L.C. and Naitoh, P. (1975) "Dynamics of Nap Sleep during a 40-hour Period. EEG", *Clinical Neurophysiology*, **39**(6), 627–633.

Mullaney, D.J., Kripke, D.F. and Fleck, P. (1981), *Sleep Loss Effects on Continuous Sustained Performance* (*Interim Report*) (Arlington, VA: Office of Naval Research) (Code 441).

Naitoh, P. (1981) "Circadian Cycles and Restorative Power of Naps" in *Biological Rhythms, Sleep and Shift Work*, Johnson, L.C., Tepas, D.I., Colquhoun, W.P. and Colligan, M.J. (eds.) (New York: Spectrum Publ), 553–580.

Naitoh, P., Englund, C.E. and Ryman, D.H. (1987) Sustained Operations: Research Results (Interim Report No. NHRC Report No, 87-17). San Diego, CA: Naval Health Research Center.

Neri, D.F. and Shappell, S.A. (1993) Work/rest Schedules and Performance of S-3 Aviators during Fleet Exercise 1992 (No. NAMRL-1382). Pensacola, FL: Naval Aerospace Medical Research Laboratory.

Neri, D.F. and Shappell, S.A. (1994) "The Effect of Combat on the Work/Rest Schedules and Fatigue of Naval Aviators during Operations Desert Shield and Desert Storm", *Military Psychology*, **6**(3), 141–162.

Neri, D.F., Shappell, S.A. and DeJohn, C.A. (1992) "Simulated Sustained Flight Operations and Performance, Part 1: 'Effects of Fatigue'", *Military Psychology*, **4**(3), 137–155.

Neville, H.J., Bisson, R.U., French, J., Boll, P.A. and Storm, W.F. (1994) "Subjective Fatigue of C-141 Aircrews during Operation Desert Storm", *Human Factors*, **36**(2), 339–349.

Neville, K.J., Bisson, R.U., French, J., Boll, P.A. and Storm, W.F. (1994) "Subjective Fatigue of C-141 Aircrews during Operation Desert Storm", *Human Factors*, **36**(2), 339–349.

Nguyen, J.L. (2002) "The Effects of Reversing Sleep-Wake Cycles on Sleep and Fatigue on the Crew of USS JOHN C", *STENNIS* (Monterey, California: Naval Postgraduate School).

Nicholson, A.N. (1984) "Long-range Air Capability and the South Atlantic Campaign", *Aviation, Space, and Environmental Medicine*, **55**, 269–270.

Nicholson, A.N., Roth, T. and Stone, B.M. (1985) "Hypnotics and Aircrew", *Aviation, Space, and Environmental Medicine*, **56**, 299–303.

Paul, M.A., Pigeau, R.A. and Weinberg, H. (1998) "Human Factors of CC-130 Operations. Volume 6: Fatigue in Long-Haul Re-Supply Missions", *No. DCIEM No.*, **98**-R-19). New York, Ontario, Canada: Defence and Civil Institute of Environmental Medicine.

Pereli, L.P. (1980), *Fatigue Stressors in Simulated Long-Duration Flight: Effects on Performance, Information Processing, Subjective Fatigue, and Physiological Cost (No. SAM-TR-80-49). Brooks Air Force* (Base, TX: USAF School of Aerospace Medicine).

Pigeau, R., Angus, B. and O'Neil, P. (1995) "Vigilance Latencies to Aircraft Detection among NORAD surveillance Operators", *Human Factors*, **37**(3), 622–634.

Rosekind, M.R., Gander, P.H. and Dinges, D.F. (1991), "Alertness Management in Flight Operations: Strategic Napping". Paper presented at the Aerospace Technology Conference and Exposition, Long Beach, California.

Sawyer, T.L. (2004) "The Effects of Reversing Sleep-Wake Cycles on Mood States, Sleep, and Fatigue on the Crew of the USS JOHN C", *Stennis* (Monterey, California: Naval Postgraduate School).

Shappell, S.A. and Neri, D.F. (1993) "Effect of Combat on Aircrew Subjective Readiness during Operations Desert Shield and Desert Storm", *Journal of Aviation Psychology*, **3**(3), 231-252.

Shay, J. (1998) "Ethical Standing for Commander Self-Care: The Need for Sleep", *Parameters*, **28**(2), 93–105.

Steele, T.P., Kobus, D.A., Banta, G.R. and Armstrong, C.G. (1989), *Sleep Problems, Health Symptoms, and Tension/Anxiety and Fatigue during Cruising in a Moderately High Heat/ Humidity Naval Environment (Interim No. NHRC Report No. 89-21)* (San Diego, CA: Naval Health Research Center).

Stickgold, R., James, L. and Hobson, J.A. (2000) "Visual Discrimination Learning Requires Sleep after Training", *Nature Neuroscience*, **3**, 1237–1238.

Tharion, W.J., Shukitt-Hale, B. and Lieberman, H.R. (2003) "Caffeine Effects on Marksmanship during High-Stress Military Training with 72 hour Sleep Deprivation", *Aviation, Space, and Environmental Medicine*, **74**(4), 309–314.

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).

Van Dongen, H.P.A., Price, N.J., Mullington, J.M., Szuba, M.P., Kapoor, S.C. and Dinges, D.F. (2001) "Caffeine Eliminates Psychomotor Vigilance Deficits from Sleep Inertia", *Sleep*, **24**(7), 813–819.

Van Dongen, H.P.A., Rogers, N.L. and Dinges, D.F. (2003) "Sleep Debt: Theoretical and Empirical Issues", *Sleep and Biological Rhythms*, **1**, 5–13.

Walker, M.P., Brakefield, T., Hobson, J.A. and Stickgold, R. (2003) "Dissociable Stages of human Memory Consolidation and Reconsolidation", *Nature*, **425**(6958), 616–620.

Wilson, M. and McNaughton, B. (1994) "Reactivation of Hippocampal Ensemble Memories during Sleep", *Science*, **265**, 676–679.

Winfield, R. (1941) The Use of *Benzedrin* to Overcome Fatigue on Operational Flights in Coastal Command (DTIC Technical Report No. AD-B953285) United Kingdom: Flying Personnel Research Committee.

Wolfson, A.R. and Carskadon, M.A. (1998) "Sleep Schedules and Daytime Functioning in Adolescents", *Child Development*, **69**(4), 875–887.

Wolfson, A.R. and Carskadon, M.A. (2003) "Understanding Adolescents' Sleep Patterns and School Performance: A Critical Appraisal", *Sleep Medicine Reviews*, **7**(6), 491–506.