Managing Fatigue in Operational Settings 1: Physiological Considerations and Countermeasures

Mark R. Rosekind, PhD; Philippa H. Gander, PhD; Kevin B. Gregory, BS; Roy M. Smith, BS, R.PSG.T; Donna L. Miller, BA; Ray Oyung, BS; Lissa L. Webbon, AA; and Julie M. Johnson, BA

The authors consider three aspects of managing fatigue in the workplace. They provide a brief overview of important scientific findings related to sleep and circadian physiology that establish the psychobiological foundation of fatigue. Their major focus is on the relevance of these findings to operational settings. In addition, they provide examples to describe practical fatigue countermeasures that can be used in operational settings.

Index Terms: *alertness, circadian rhythms, fatigue countermeasures, performance, safety, sleep*

Since the Industrial Revolution and the invention of the light bulb, society has relied increasingly on 24-hour operations in many settings, including healthcare, manufacturing, safety (police, fire, nuclear, etc), transportation, and the military. The health, safety, and economy of the United States depend on meeting these around-the-clock needs. Furthermore, the requirement for 24-hour operations will grow as the United States competes in the 24-hour global economy.

For human beings, functioning on a 24-hour basis poses unique physiological challenges. Acknowledging and managing these physiological challenges can promote performance, productivity, and safety in 24-hour operations, whereas ignoring these factors can lead to decrements in human capability and to the potential for incidents and accidents that can result in tremendous societal and individual costs.

Dr Rosekind *is with the NASA Ames Research Center at Moffett Field, California;* ***Dr Gander, Mr Smith, Mr Oyung,*** *and* ***Ms Johnson*** *are with the San Jose State University Foundation; and* ***Ms Miller, Mr Gregory,*** *and* ***Ms Webbon*** *are with Sterling Software in Palo Alto, California.*

Humans are hard-wired with a genetically determined biological need for sleep and with a circadian pacemaker that programs us to sleep at night and to be awake during the day on a 24-hour schedule. Twenty-four hour operations challenge these basic physiological principles. Shift work, altered and changing work schedules, crossing time zones, long hours of continuous wakefulness, and sleep loss can create sleep and circadian disruptions that degrade the waking function. On an individual basis, this translates into fatigue and sleepiness while someone is driving, monitoring equipment, operating aircraft, performing medical procedures; into degraded vigilance and decision-making; and into a wide range of other performance effects that can erode the safety margin in operational settings.

Examples from various segments of society demonstrate how these individual vulnerabilities can translate into significant incidents and accidents. Those who investigate such occurrences have identified fatigue as a probable cause of accidents in different modes of transportation. For example, the National Transportation Safety Board has cited fatigue as a probable cause in the *Exxon Valdez* and *World Prodigy* marine accidents and in the crash of a DC-8 aircraft in Guantanamo Bay, Cuba.[1–3] Fatigue has also been cited in the nuclear accidents at Three Mile Island and Bhopal and

in the decision-making process of the space shuttle *Challenger* accident.[4] Addressing the physiological factors that underlie fatigue has the potential to maintain or improve the safety margin and, concomitantly, to increase performance and productivity.

Basic Human Physiology: Sleep and Circadian Rhythms

The era of modern sleep research began in the mid-1950s with the discovery of two distinct states of sleep.[5] Over the past 40 years, scientists have carried out extensive research on sleep, sleepiness, circadian rhythms, and sleep disorders and studied how these factors affect waking alertness and performance.[6,7] The following is a brief overview of some of the relevant scientific information regarding human sleep, sleepiness, and circadian rhythms.

Sleep—A Vital Physiological Function

Historically, sleep has been viewed as a state during which the human organism is turned off. Scientific findings have clearly established that sleep is a complex, active physiological state that is vital to human survival. When someone is deprived of sleep, the physiological response is sleepiness, which is the brain's signal to prompt an individual to obtain sleep, a signal that a specific physiological requirement has not been met. Eventually, when deprived of sleep (acutely or chronically), the human brain can shift spontaneously and in an uncontrolled fashion from wakefulness to sleep to meet its physiological need for sleep.

The sleepier the person, the more rapid and frequent are the intrusions of sleep into wakefulness. Such spontaneous sleep episodes can be very short (ie, microsleeps that last only seconds) or extended (ie, lasting minutes). At the onset of sleep, which can occur during periods of intense sleepiness, an individual disengages perceptually from the external environment, essentially ceasing to integrate outside information. A sleepy person's performance can begin to degrade even before actual sleep intrudes into waking. A microsleep can be associated with a significant performance lapse during which an individual does not receive or respond to external information. With sleep loss, these uncontrolled sleep episodes can occur while a person is standing or operating machinery or even in situations, such as driving a car, in which inattention would put an individual at risk.[8–10] Disruption of specific sleep states (eg, rapid eye movement *v* nonrapid eye movement) or stages (eg, nonrapid-eye-movement 1 through 4) can result in differential effects on waking performance and alertness.

How much sleep does an individual need? Basically, an individual requires the amount of sleep necessary to achieve full alertness and an effortless level of functioning during waking hours. Individual sleep needs vary, although most adults require about 8 hours of sleep. Some people need 6 hours, but others require 10 hours to feel wide awake and to function at their peak level during wakefulness.

Sleepiness Affects Waking Performance, Vigilance, and Mood

In controlled laboratory experiments, investigators have demonstrated decrements in most components of human performance as a result of sleep loss. Sleep loss creates sleepiness, which can be associated with decrements in vigilance, reaction time, memory, psychomotor coordination, information processing, and decision making (eg, fixation on certain aspects of a situation to the neglect of other information). With increasing sleepiness, individuals demonstrate poorer performance despite increased effort, and they may report indifference regarding the outcome of their performance. Individuals report fewer positive emotions, more negative emotions, and an overall worsened mood with sleep loss and sleepiness. (For scientific reviews related to the effects of sleep loss on performance, see Broughton and Ogilvie,[11] Dinges,[12] Dinges and Kribbs,[13] and Horne.[14])

With severe sleepiness, an individual may experience an uncontrolled sleep episode and obviously be unable to perform. In other situations, although the person may not actually fall asleep, the level of sleepiness can still degrade human performance significantly in the ways described above. This performance degradation can play an insidious role in the occurrence of an operational incident or accident.[15–17] Examples of fatigue signs and symptoms are shown below.

Even an acute loss of sleep can degrade waking performance and alertness. Laboratory data indicate that, for most people, 1 night with 2 hours less sleep than is usually required is sufficient to degrade subsequent waking performance and alertness significantly.[18]

SIGNS AND SYMPTOMS OF FATIGUE

Forgetful	Fixated
Poor decision making	Apathetic
Slowed reaction time	Lethargic
Reduced vigilance	Bad mood
Poor communication	Nodding off

Sleep Loss Accumulates Into a Sleep Debt

An individual who requires 8 hours of sleep and obtains only 6 hours is essentially sleep deprived by 2 hours. If that individual sleeps only 6 hours each night over 4 nights, then the 2 hours of sleep loss per night would accumulate into an 8-hour sleep debt. It has been estimated that, in the United States today, many adults obtain from 1 to 1.5 fewer hours of sleep per night than they actually need.[19] During a regular workweek, this would translate into the accumulation of a 5-hour to 7.5-hour sleep debt going into the weekend. Hence, the common phenomenon of sleeping late on weekends to compensate for the sleep debt accumulated during the week.

Generally, recuperation from a sleep debt involves obtaining deeper sleep over 1 to 2 nights. Sleep loss also can result in some extension of the usual sleep duration. However, this extension is much less than would be required to make up the lost hours of sleep (ie, by having to sleep 7.5 hours longer on the weekend to make up for the sleep debt accumulated during the week). Both an increased amount of deep sleep and an increased sleep duration can indicate a sleep debt.

Physiological Versus Subjective Sleepiness

Sleepiness can be differentiated into two distinct components: physiological and subjective. Physiological sleepiness is the result of sleep loss: lose sleep, get sleepy. Sleep loss will be accompanied by increased physiological sleepiness that will drive an individual to sleep to meet the physiological need for sleep. Subjective sleepiness is an individual's introspective self-report of how sleepy he or she feels.[8,20] Subjective reports of sleepiness can be affected by many factors, such as physical activity or a particularly stimulating environment, such as an interesting conversation.[21] These factors tend to mask or conceal physiological sleepiness and therefore lead people to overestimate their own level of alertness.

The discrepancy between subjective sleepiness and physiological sleepiness can be operationally significant. A person might report a low level of sleepiness (ie, high level of alertness) but be carrying an accumulated sleep debt with a high level of physiological sleepiness. This person, in an environment stripped of factors that conceal the underlying physiological sleepiness, would be susceptible to the occurrence of spontaneous, uncontrolled sleep and to the performance decrements associated with sleep loss.[22–24]

Sleep Disorders

A range of physiological sleep disorders exist. They can disturb the quantity and quality of sleep and subsequently can degrade waking performance and alertness. For example, sleep apnea, a disorder as prevalent as asthma, is characterized by a cessation of breathing during sleep that causes the sleeper to awaken repeatedly to resume breathing. The breathing pauses can last from 10 seconds to several minutes and can occur hundreds of times each night. The sleeper is usually unaware of the repeated apnea episodes and associated brief awakenings that occur throughout the night. A cardinal symptom of sleep apnea is snoring (although snoring can result from other causes). Therefore, a sleep disorder unrelated to waking activities may be a physiological cause of reduced performance and alertness.[6] *Principles and Practice of Sleep Medicine* [6] is the first medical textbook to provide a comprehensive review of the full range of sleep disorders and their treatments.

The Circadian Pacemaker

Human beings, like other mammals, have a circadian (*circa* = around; *dies* = day) pacemaker in the brain that regulates physiological and behavioral functions on a 24-hour basis. It is located in the suprachiasmatic nucleus of the hypothalamus. The clock coordinates daily cycles in such functions as sleeping and waking, body temperature regulation, hormone secretion, digestion, performance capabilities, and mood. Its role is to program us on a 24-hour schedule to sleep at night and to be awake during the day and to have daily peaks and troughs in different functions at specific times. The circadian rhythm of core body temperature is commonly used to track the position of the circadian clock. On a regular 24-hour schedule with sleep at night, core body temperature is lowest between 3 AM and 5 AM,[25] which is also the time when physiological sleepiness is greatest and performance capabilities are lowest.

The circadian clock normally keeps in step with local time because it is sensitive to specific time cues from the environment, notably sunlight and patterns of social activity. When a person suddenly changes the pattern of time cues (eg, by changing to a new work–rest schedule or flying to a new time zone), the circadian clock cannot adjust immediately. This is the basis for the circadian disruption associated with shift work and jet lag. Shift work requires that the individual try to override the basic circadian pattern of sleeping at night and being awake during the day. This sets up a situation in which the clock is receiving conflicting time cues from the environment.

For example, working at night creates a reversed pattern of nighttime activity and daytime sleep. The unchanged day–night cycle and the activities of the rest of the day-oriented society, however, tend to maintain the circadian clock

in the usual pattern of daytime activity and nighttime sleep. In addition, most shift workers revert to the usual pattern of daytime activity on their days off. This frequent switching from one activity–rest pattern to another can lead to the circadian clock's becoming chronically out of step with local time.

Having the circadian clock incompletely adapted to a work–rest schedule can affect on-the-job alertness and performance in two ways. People may be trying to work when the brain is programmed to be asleep, during the circadian low point in alertness and performance capacity. Conversely, they may be trying to sleep when the brain is programmed to be awake, leading to sleep loss and poor sleep quality, which further degrades alertness and performance capacity.

Flying to a new time zone produces a different challenge to the circadian clock. The time cues in the new time zone provide consistent (not conflicting) information to the internal clock, but it can take from several days to weeks for the clock to get into step with the new local time. In addition, circadian rhythms in different body functions do not all adjust at the same rate and therefore may be out of step with each other for an extended period of time.

Specific factors affect the rate of adaptation of the circadian clock to a new time zone. Adaptation takes longer when more time zones are crossed. It also takes longer after an eastward flight than after a westward flight in which the same number of time zones are crossed, a directional difference that is physiologically based. Without any time cues from the environment, the "biological day" generated by the circadian clock is longer than 24 hours for most people. Flying westward requires lengthening the day, in keeping with the natural tendency of the clock. For example, flying from New York to San Francisco produces a 27-hour "day." Conversely, flying from San Francisco to New York produces a 21-hour "day." It is also physiologically more difficult to move a work–rest schedule backward over the 24-hour day (eg, from night shift, to swing shift, to day shift) than to move it forward. All of the symptoms associated with moving the clock (poor sleep, sleepiness, degraded performance, gastrointestinal problems, more negative mood, and so on) dissipate as the clock adapts to the new schedule or time zone.[26,27]

Scientific studies have revealed that people living on a regular 24-hour routine with sleep at night have two periods of maximal sleepiness. One occurs at night, roughly from 3 AM to 5 AM, and the other is in the afternoon, from approximately 3 PM to 5 PM. Performance and alertness, however, can be affected throughout a period from 12 AM to 8 AM. People on a regular day–night schedule typically sleep through the 3 AM to 5 AM period of sleepiness. The afternoon sleepiness period can be masked by factors described previously or can present at a time when people are particularly vulnerable to the effects of sleepiness. This also means that a person working through the night is maintaining wakefulness from 3 AM to 5 AM, when the circadian pacemaker is promoting sleep. Conversely, a person sleeping during the day is attempting to sleep when the circadian pacemaker is promoting wakefulness. People searching for specific opportunities when they are physiologically prepared to sleep, either for an extended sleep period or a strategic nap, can use these periods to their advantage.[8]

Fatigue Countermeasures: Personal Strategies

For the individual facing the problem of fatigue at work, a variety of well-tested countermeasure strategies can help maintain alertness and on-the-job performance. It is important to emphasize, however, that there is no simple, universal solution to fatigue in the workplace. Different operations pose different demands, and people vary widely in their reactions to these demands. Sleep and circadian physiology are complex and change systematically across the life span, making adaptation to changing schedules more difficult as one gets older.[28] The following strategies should therefore be viewed as recommendations. For the individual, effective fatigue management requires a personal collection of strategies to be used singly or in combination to address varying work demands and changing needs.

Fatigue countermeasures can be divided into two categories: those used before work and during rest periods (preventive strategies) and those used on the job (operational countermeasures).[29] Preventive strategies, aimed at the physiological causes of fatigue, are designed to keep the sleep loss and circadian disruption caused by work demands to a minimum. Operational countermeasures, which provide temporary relief from the symptoms of fatigue, are designed to minimize the impact of sleep loss and circadian disruption on alertness and on-the-job performance. The operational measures help a person get the job done as safely and efficiently as possible.

Preventive Strategies

Minimizing sleep loss. A number of preventive strategies can be used to minimize sleep loss. The effective use of days off and rest periods to catch up on sleep is critical. Field studies in flight operations[30–35] and other shift work environments[23] have indicated that sleep loss during shift work is common. Because the effects of sleep loss are cumulative, it is important not to begin a new work schedule with an existing sleep debt. Generally, this requires 2

nights of unrestricted sleep. Under normal circumstances, it does not seem to be possible to obtain extra sleep to "stock up" on sleep against an anticipated debt in the future.

On working days, it is desirable to get at least as many hours of sleep as a normal night of sleep on a nonworking day. If the work schedule requires wakefulness during the part of the circadian cycle normally programmed for sleep, it may not be possible to obtain the usual daily quota of sleep in a single episode. In this case, it may be necessary to sleep more than once (eg, morning and evening) or to take naps.

At certain times in the circadian cycle it is easy to fall asleep, and at other times the brain is programmed to be awake.[31] For this reason, it is important to take advantage of feeling sleepy by sleeping if circumstances permit. Conversely, it is impossible to force sleep. Trying unsuccessfully for 15 to 30 minutes to fall asleep is a signal to abandon the effort for the time being and to get out of bed. If the time available for sleep is limited, a quiet activity conducive to relaxing, such as reading, can be undertaken until sleepiness signals that it is time to go to bed and try again.

Naps. Naps can acutely improve alertness, even when people do not report feeling well rested on awakening. If a nap is just before work, or is likely to be interrupted for a call to come to work, then it should be limited to a maximum of 45 minutes. This minimizes the chances of entering deep sleep.[34] Waking out of deep sleep may lead to feelings of grogginess and disorientation for several minutes (a phenomenon called "sleep inertia").

At other times, longer naps can be beneficial. Two hours will normally allow completion of one cycle through the different states and stages of sleep.[36] A nap reduces the duration of continuous wakefulness before a work period and can be particularly beneficial before a period of night work, when the challenge of working through the circadian low point is also a factor. Getting some sleep is always better than getting none.

Good sleep habits. A variety of preventive strategies can be used to help improve sleep quality. In a clinical setting, these come collectively under the heading of "sleep hygiene."[37] A regular presleep routine can condition relaxation in preparation for falling asleep. It breaks the connection between the psychological stressors of the day and the sleep period. Once this pattern of cues is established, it can be used anywhere and anytime. It may include such things as checking the security of the sleeping environment and putting the cat out or reading something relaxing and entertaining (but not work related).

In addition, various physical and mental relaxation techniques such as meditation, autogenic training, yoga, and progressive muscle relaxation can be learned and used in this way. These skills need to be practiced and developed before they can be expected to provide benefit. It is also important that the bedroom remains an environment conducive to relaxation and sleep and does not become associated with stressful activities, such as work or worry.

Sleep time needs to be given priority and kept as free as possible from other commitments and activities. This may be difficult when the sleeper is on a routine that does not match that of others, such as trying to sleep during the day in a home with toddlers.

Effects of food, alcohol, and exercise. The discomfort associated with being hungry or with having eaten too much may interfere with falling asleep. If one is hungry or thirsty at bedtime, a light snack or a small drink is preferable. In general, evidence for effects of common dietary constituents on sleep is not yet conclusive, although both alcohol and caffeine have well-documented disruptive effects.

Alcohol is reputedly the most commonly used sleep aid used in the United States. It can promote relaxation and thereby help a person fall asleep, but it also produces easily disrupted, lighter sleep. It suppresses REM (rapid-eye-movement) sleep in the first half of the night, leading to REM rebound and withdrawal effects in the second half. Awakenings from intense dreaming activity, with sweating and headaches, are not uncommon.[37] The amount of alcohol required to produce adverse effects is variable, depending on several factors, including gender (women appear to be more sensitive), body mass, and age.

In normal, nonalcoholic volunteers, a blood level of 50 mg/kg (half the legal intoxication level in most states) is sufficient. Alcohol is metabolized at a rate of approximately one drink per hour. It is advisable to finish drinking sufficiently early to allow the blood alcohol level to return to zero before sleep. Even then, sympathetic arousal follows the decline of blood alcohol levels and may persist for 2 to 3 hours after the blood alcohol concentration returns to zero. Alcohol also worsens breathing disorders during sleep, including apnea, and reduces associated oxygen levels.

Caffeine stimulates the nervous system, generally taking effect in 15 to 45 minutes after ingestion; it usually remains active for 3 to 5 hours, although the effects can continue for up to 10 hours in sensitive individuals. The effects of caffeine depend on a number of factors, including habitual usage, body mass, and previous food intake. Regular high caffeine consumption tends to reduce the individual's sensitivity to its effects. Regardless of the level of habitual consumption, caffeine before sleep leads to lighter sleep with more awakenings and reduced total sleep time. Some con-

servative recommendations suggest stopping caffeine consumption as much as 6 hours before bedtime.

Nicotine has much the same effects on nocturnal sleep and subsequent daytime sleepiness and performance as caffeine does. Like caffeine, nicotine consumption (either tobacco smoking or patch) should not occur within several hours before the desired onset of sleep.

Strenuous exercise results in physiological activation, which may interfere with sleep. Therefore, it is advisable to avoid strenuous exercise within 6 hours of going to bed. There is also evidence that regular exercise may enhance deep sleep, which has been shown to be physically restorative.

Sleep environment. Physical aspects of the environment can also affect sleep. A dark, quiet room is preferable. Eye shades are a simple and portable solution to the problem of light. Unless it is necessary to be available to be awakened (eg, being on call or needing to wake up for duty), earplugs can be helpful to reduce noise. Sudden sounds can disturb sleep, so providing continuous background "white" noise can be helpful. One suggestion from flight crews is to set the radio between two stations for this purpose. In general, sleep quality is better if the environment is cooler rather than hotter. A comfortable sleep surface is also important.

Circadian strategies. There are currently more practical, well-tested preventive strategies for minimizing sleep loss than for speeding circadian adaptation to different schedules. Resetting the circadian clock in an operational setting is complex for a number of reasons. First, interventions that can reset the circadian clock (called chronobiotics) can produce opposite effects, depending on when in the circadian cycle they are administered. Scientists have found no simple, practical way of measuring precisely where a person is in the circadian cycle, particularly in an operational setting. Without this information, an intervention intended to move the circadian clock in one direction may end up sending the clock in the other direction.

For a chronobiotic treatment to be successful, it is also necessary to control exposure to all the natural time cues, such as sunlight and the social routine, in the environment. In practice, this can be very cumbersome and compliance is a major challenge. In some situations, it may not be possible or desirable to have the clock fully adapted to rapidly changing schedules. During long-haul flight operations, for example, crew members usually spend each consecutive rest period (layover) in a different time zone, so it is unclear to which time zone it would be preferable to be adapted. All of the proposed chronobiotics have yet to be tested for their feasibility and effectiveness in improving alertness and performance in operational settings.

Operational Countermeasures

Once the individual is on the job, the range of available strategies to combat fatigue is more restricted. An additional constraint in commercial aviation is that crew members must remain in their cockpit seats, except for "biological need," which does not currently include sleep. In general, operational countermeasures do not address the underlying physiological causes of fatigue. Instead, they are meant to enhance alertness and performance temporarily so that operational safety and efficiency are maintained.

Social interaction and conversation can be a useful operational strategy. To maintain alertness, the individual must be actively involved in the conversation, not just listening and nodding. Findings in some studies have indicated that the lack of conversation is a predictor of declining physiological alertness.[38] Experience from sleep-deprivation experiments showed that physical activity is one of the most effective ways of combating sleepiness. Some stretching and isometric exercises can be done in a seat, and even writing or chewing gum may help a drowsy crew person stay awake.

The alerting effects of caffeine, although they are disruptive to sleep, can be used strategically when it is necessary to stay awake. Strategic caffeine use includes avoiding it when already alert—at the beginning of a daytime work period or just after a nap, for example. Instead, consumption should begin about an hour before expected times of decreased alertness (eg, 3 AM to 5 AM). It is preferable to stop caffeine consumption at least 3 hours ahead of a planned bedtime to avoid its disruptive effects on sleep.

In some situations, these requirements may be in conflict. For example, using caffeine to help work through the circadian low point at the end of a period of night work could result in problems in trying to fall asleep after coming off duty in the morning. In this case, the benefits and drawbacks must be considered in light of overall operational demands.

Caffeine is also a diuretic, a fact that should be considered, given that dehydration is already an issue for flight crew because of low humidity in the cockpit. Other considerations when using caffeine are that, in very high habitual doses, caffeine can lead to anxiety, irritability, tremulousness, and insomnia.

Evidence for direct effects of specific types of food on alertness and performance is not yet very compelling. Simple carbohydrates can produce a transient increase in alertness ("sugar highs"), but this is frequently followed by a decrease in alertness as blood glucose levels fall (hypoglycemia). Gastrointestinal upsets can be disruptive to sleep, and maintaining a balanced diet is important. Work

schedules can make it difficult to maintain a regular pattern of well-balanced meals. Individuals need to be encouraged to plan ahead, therefore, and provide themselves with nutritious snack foods.

The goal of all operational countermeasures is to improve workplace performance and alertness when compared with the condition in which no countermeasures are taken. Napping is one of the few countermeasures that has been rigorously tested in this way in a real-world operational setting. A joint study by scientists with the National Air and Space Administration (NASA) and the Federal Aviation Administration (FAA) examined the effectiveness of a planned cockpit rest period in improving subsequent performance and alertness in commercial long-haul flight operations.[34] The authors of the study compared two groups of long-haul flight crew members flying the same sequence of four scheduled 9-hour transpacific flights. One group was allowed a 40-minute nap opportunity (one crew member at a time) during a period of low workload while the aircraft was at cruise altitude. The other group followed the same procedures, but they were instructed to continue their normal flight activities during the designated 40-minute period.

Crew members who were allowed to nap fell asleep on 93% of the available occasions and slept for an average of 26 minutes. They also showed better performance (on a reaction time–vigilance task) and higher physiological alertness during the last 90 minutes of flight (measured by brainwaves and eye movements) than did the control group crew members who had not napped. Planned cockpit rest is not currently sanctioned by FAA regulations, but a proposal to allow planned cockpit rest, based on the findings in this study, is currently under review.

Future Countermeasure Considerations

Bright Light

A number of countermeasures currently under investigation have not yet been demonstrated to be practical or effective in operational settings, but they have the potential to reduce the sleep loss and circadian disruption produced by shift work and transmeridian flight. Bright light (usually more than 2,500 lux) has received particular attention. In addition to its capacity to reset the circadian clock, light of this intensity suppresses secretion of the pineal hormone, melatonin, and appears to have an alerting effect, although the mechanism of this is not clear.[39]

Melatonin

Melatonin is also under active investigation for its sleep-inducing properties and its capacity to reset the circadian clock. It is not now classified as a drug in the United States and is available in health-food stores. No quality assurance mechanism is in force for melatonin, and the percentage of active melatonin in health-food store products may vary widely. The number of shift workers and transportation operators who are already using melatonin is unknown, and members of the scientific community are engaged in active debate about its effectiveness and safety.

Melatonin affects a variety of physiological systems beyond its sleep and circadian effects. It is a powerful modulator of the reproductive system in other mammals, and it is currently being investigated for use as a contraceptive, in combination with progesterone. It has also been reported to have a range of other effects, including restricting the coronary arteries and exacerbating the symptoms of schizophrenia and depression. In high doses, it may produce hangover effects on waking. More extensive scientific information is needed for a complete understanding of the full range of melatonin's effects. Given the current state of scientific knowledge, it would be prudent to take a conservative and reluctant approach to the use of melatonin, particularly on a regular basis, either as a sleeping medication or as a chronobiotic.

Exercise and Diet

The role of physical exercise in resetting the circadian clock is also under investigation. Recent studies with nocturnal rodents (rats, mice, and hamsters) showed that bouts of physical exercise can reset the circadian clock in these species. The pattern of resetting is similar to that observed with light. That is, an exercise bout in the morning advances the circadian clock, whereas an exercise bout in the evening delays it. Preliminary data indicating that exercise in the late evening may delay the human clock have also been reported. Much more research is needed to clarify the effects of different amounts and types of exercise in different parts of the human circadian cycle.

There is also considerable interest in possible dietary constituents that might be able to promote sleep or alertness or to reset the circadian clock. It has been suggested that foods rich in carbohydrates (legumes, pasta, potatoes) may induce sleep by elevating serotonin levels. Conversely, foods high in protein (meats, dairy products, eggs) and certain amino acids are proposed as ways of promoting wakefulness by enhancing catecholamine activity.

A Jet-Lag Diet that tried to accelerate adaptation to a new time zone by exploiting multiple circadian time cues was published some years ago.[40] The steps proposed included meal timing, fasting and feasting periods, high-protein versus high-carbohydrate meals, and timed caffeine consumption,

beginning several days before the day of the flight. Two controlled studies have shown that the diet has equivocal effects, at best, and can actually slow adaptation in some instances. Other dietary effects, such as the impact of the amino acid tyrosine on stress levels, are under investigation.[41] Other dietary factors may well be useful as fatigue countermeasures, and careful research will be needed to demonstrate their effectiveness and define how they might be used.

Anchor Sleep

Another concept that has been considered in the context of shift work and aviation operations is called "anchor sleep." This is based on the idea of having crew members obtain at least part of their off-duty or layover sleep during the normal sleep time at home. Its usefulness over long sequences of transmeridian flights is limited by the fact that the circadian clock drifts away from a 24-hour period,[31] which makes relating sleep to home time physiologically irrelevant.

In the following article, six domains relevant to managing fatigue in operational settings are discussed, along with specific examples from current aviation practice.

NOTE

For further information, please address correspondence to Mark Rosekind, PhD, NASA Ames Research Center, Flight Management and Human Factors Division, Fatigue Countermeasures Program, MS 262, Moffett Field, CA 94035-1000.

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