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Fatigue in Aviation Sustained Operations, the Utility of Napping, and the Problem of Sleep Inertia

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SUMMARY

Improperly managed aircrew fatigue can seriously degrade the performance, alertness, and safety of personnel in the operational environment. Fortunately, this danger can be minimized by the use of carefully planned napping strategies. Naps are effective because they are known to reduce the homeostatic drive for sleep. In a variety of settings, napping has been shown to produce several relatively long-lasting benefits. Unfortunately, there is a down side to this countermeasure in that personnel can suffer from several minutes of grogginess immediately after a nap has ended. This phenomenon is called sleep inertia. In operational contexts, the negative impact of sleep inertia must be weighed against the longer-lasting benefits of any napping strategy. If napping is to be implemented, specific steps can be taken to reduce the probability that sleep inertia will be severe and/or persistent.

BACKGROUND

The modern military mission requires that forces be able to deploy across multiple time zones, to virtually any destination in the world, with little or no advance notice. In addition, troops must be supported and maintained once they arrive on foreign soil. These requirements raise the necessity of frequent long-haul flight operations in which individual flights may last for 10-12 hours or even longer, especially since aerial refueling is an option. From an equipment/aircraft standpoint, such missions are certainly feasible, and because of system reliability and redundancy, there is little reason for concern over mishaps associated with mechanical or aircraft system failures. From the operator standpoint, however, performance problems represent a source of considerable concern because fatigue from extended cockpit duties can have serious adverse consequences (Dinges et al., 1996). In fact, a report by Ritter (1993) indicated that fatigue from sleep deprivation, circadian disruptions, and other factors is a major contributor to the cognitive and judgement errors made by aircrews.

Evidence of a fatigue problem in aviation

Proof that fatigue is an important aviation concern comes from a variety of sources, both civilian and military. In the civilian sector, the NASA Aviation Safety Reporting System (ASRS) suggests fatigue has been a factor in 21 percent of reported air incidents, and the U.S. National Transportation Safety Board has focused considerable attention on the problem of fatigue (Rosekind et al., 1999). Failure to effectively manage aircrew fatigue has led to such disasters as the crash of Korean Air flight 801 in which 228 people were killed (Hebert, 1999). In addition, fatigue was likely the culprit in the more recent mishap involving American Airlines flight 1420 in which 11 people died (Krause, 1999). Furthermore, fatigue was partially to blame in the 1985 near-crash of a China Airlines Boeing 747 (flight 006) and the crash of a DC-8 at Guantanamo Cuba Naval Base (Battelle Memorial Institute, 1998). From the standpoint of military aviation, Ramsey and McGlohn (1997) note that 25% of the Air Force's night tactical fighter Class A accidents were attributable to fatigue between 1974 and 1992, and 12.2% of the Navy's total Class A mishaps were a result of aircrew fatigue from 1977 to 1990. Furthermore, the U.S. Army Safety Center indicates that 4% of the Army's total mishaps (Class A, B, and C) from 1990 to 1999 were associated with aircrew fatigue (Army Safety Center, 2000).

Although many of these mishaps (particularly in the military sector) are not associated with long-haul flight operations, it is reasonable to postulate that the mere presence of fatigue-related problems in short-duration flights suggests an even larger-scale concern in long-haul settings. In fact, evidence from the civilian sector shows that long-haul, wide-body flight operations are associated with a loss rate that is approximately 3 times higher than the rate found in short and medium-range flights

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(Caesar, 1986). Thus, alertness deficits stemming from prolonged flight duty require urgent attention.

Basic causes of aviator fatigue

During long-duration flights, fatigue/sleepiness stems from three major sources: 1) circadian disruptions associated with time-zone changes or rapid rotations to new work schedules; 2) cumulative sleep loss from extended periods on duty; and 3) the normally-occurring troughs in the circadian/sleep-wake rhythm (Rosekind et al., 1994). Each of these sources must be taken into account when developing an effective fatigue-management strategy.

Circadian disruptions from traveling across time zones (jet lag) result from a loss of synchronization between the body's internal physiological rhythms and the environmental light/dark cycle (Krueger, 1991). A similar difficulty occurs when personnel rotate among different work shifts within the same time zone (shift lag). The problem is that there are numerous internal processes that are normally locked together on a 24-hour schedule, and once disturbed, may require several days to fully readjust (Akerstedt, 1995). In the meantime, performance and alertness will be sub-optimal.

Cumulative sleep loss in aviators can stem from the intrusion of pre-mission duties into the normal sleep period, and the fact that by definition, late-afternoon or early-evening departures generally occur several hours past the crewmember's habitual bedtime. If the flight crew wakes at 0600 in the morning, and the flight does not depart until 1800 or later, this means that an 8- to 10-hour flight-duty period may not even start until after 12 hours of continuous wakefulness. Thus, by the scheduled landing time, the crew may have been awake for a continuous 22-24 hours, a period of sustained wakefulness known to produce performance decrements similar to those observed under the influence of alcohol (Dawson and Reid, 1997).

Troughs in the circadian/sleep-wake rhythm also can cause problems in long-haul flights despite the fact that they result from the body's normal daily internal rhythms. Alertness is known to decline at night as body temperature decreases and endogenous melatonin increases (Akerstedt, 1995). If a crew member is required to perform during this period (i.e., 0300-0500), judgement and response speed may be seriously impaired. This is particularly a problem for personnel traveling across multiple time zones because they are required to work when their bodies are normally asleep. Furthermore, they may experience sleep deprivation after arrival because they are attempting to sleep when their bodies are normally awake (Caldwell, 1999).

General fatigue countermeasures

There are countermeasures that can address these fatigue-related problems. Generally, they can be classified into one of two categories: preventive or operational (Rosekind, Gander, and Dinges, 1991). Preventive strategies focus on ensuring that personnel are well-rested prior to the start of each mission and/or that they have already adjusted to a new sleep/wake cycle prior to departing for a new time zone. Examples of specific interventions include: 1) minimizing pre-mission factors that interfere with restful sleep; 2) using hypnotics to promote sleep prior to deployments; 3) reducing the pre-mission time awake with prophylactic naps; or 4) using melatonin or bright lights to adjust the body's internal clock. Operational strategies focus on maintaining the alertness and performance of personnel after they have started the new mission (Rosekind et al., 1995). Examples of fatigue countermeasures that fall into this category are: 1) limiting the amount of continuous time on the flight deck between rest breaks; 2) taking advantage of strategic naps to bridge the gap between full blocks of sleep; and 3) administering stimulants (caffeine, dextroamphetamine, modafinil, etc.) to maintain performance despite sleep loss.

Napping

Of the countermeasures listed above, either normal sleep or napping should be considered first since only sleep can address one of the two primary factors underlying sleepiness/fatigue, namely the homeostatic sleep drive (Akerstedt, 1995). Since adequate continuous sleep is difficult to obtain in sustained operations, the present focus will center on napping. Although napping exerts little or no effect on the circadian influence over sleepiness and alertness, it can mitigate the general impact of fatigue during circadian low points by reducing the homeostatic sleep drive. Thus, a pilot who is suffering on a night flight because 1) he has been awake for 18 continuous hours and 2) he is at the trough of his daily circadian cycle will find significant relief from a nap because he has now, at least, reduced the impact of the continuous wakefulness (or the homeostatic drive for sleep).

Given the right circumstances, napping is easy to implement (unlike regimented crew schedules and duty limitations), is unencumbered by concerns about adverse long-term effects (unlike stimulant compounds), and has been shown to maintain or improve performance across a wide variety of settings (Dinges and Broughton, 1989). Angus, Pigeau, and Heslegrave (1992), for instance, found that even after 40 hours of sleep deprivation, a 2-hour nap prior to an additional night of sleep loss maintained performance at 70 percent of well-rested levels. More to the point for aviators, Rosekind et al.

(1994) has proven that cockpit naps can prevent many of the attention lapses and involuntary episodes of sleep intrusion (micro-events) encountered by crewmembers engaged in long-haul flight operations.

However, the use of napping as a fatigue remedy in operational settings has been slow to gain acceptance because of the problem of *sleep inertia.*

Sleep inertia

Sleep inertia defined. Sleep inertia is the name that has been given to the degraded vigilance, increased drowsiness, and diminished performance that occur right after awakening (Muzet et al., 1995). Kleitman (1963) observed that "immediately after getting up, irrespective of the hour, one is not at one's best." Sleep inertia is paradoxical because people immediately arising from sleep (when they should be most refreshed) consistently perform more poorly than they did hours earlier, just prior to going to bed (when they should have been most fatigued). This may present a serious concern when napping is proposed as an operational fatigue countermeasure, especially if skilled performance will be required immediately following the nap. However, this drawback must be compared to the longer-term performance problems that are known to occur when no napping (or longer sleep) is permitted. Before implementing an effective napping strategy for sustained operations, an understanding of the nature and characteristics of sleep inertia is necessary.

At the outset, it is important to note that generalizations about sleep inertia are sometimes difficult to make since similar measures appear to be affected inconsistently across different studies. For instance, Takahashi, Arito, and Fukuda (1999) found that sleep inertia suppressed subjective sleepiness/fatigue ratings for 2 hours after a nap, while Dinges (1990) saw no changes in subjective sleepiness ratings, even during severe sleep inertia. Sleep inertia also appears to have differential effects on different types of tasks (even within the same study). Ferrara, DeGennaro, and Bertini (2000), for instance, found that performance accuracy on a descending subtraction task was initially affected by sleep inertia but recovered after 30 minutes, whereas auditory tracking and finger tapping did not recover to baseline levels even after 75 minutes. Of course, differences among studies may simply be due to factors such as study design, the variables chosen for analysis, the samples on which the research was conducted, and differences within the same study could be due to other extraneous factors as well. But despite the discrepancies, it remains possible to make some basic assumptions about the problem of sleep inertia that may accompany naps in operational environments.

General effects of sleep inertia. In general, it should be expected that sleep inertia will affect both mood and cognitive performance, especially in highly demanding situations (such as prolonged periods of military sustained operations). In their review, Ferrara and DeGennaro (2000) concluded that tasks entailing high cognitive demands and those requiring a high degree of attention are affected more by sleep inertia than tasks involving simple motor skills. Furthermore, Bruck and Pisani (1999) revealed that complex decision-making ability may decline by as much as 49 percent within the first 3 minutes after an abrupt nighttime awakening. In addition, sleep inertia has been found to impact performance on a variety of other tasks.

Duration of sleep inertia. The precise duration of post-nap grogginess and disorientation depends on many factors; however, it appears that most sleep inertia dissipates 1-35 minutes after awakening. Akerstedt, Torsvall, and Gillberg's (1989) review of the issue cited one study that indicated sleep inertia persisted from 1-5 minutes, and another that suggested a more variable 5-35 minute range. Wilkinson and Stretton (1971) estimated the duration of sleep inertia to be 15 minutes, and Rosekind et al. (1995) generally concurred with this estimate, stating that most of the residual negative effects of napping appear to last no longer than 10-15 minutes. This is likewise consistent with the findings of Sallinen et al. (1998) who found that sleep inertia lasted only 10-15 minutes after subjects were aroused from 50-minute naps. Of course, there are other investigators who have estimated the duration of sleep inertia to be much longer (for example, Jewett et al., 1999; and Takahashi, Arito, and Fukuda, 1999 who suggested durations of 1-4 hours); but, these appear to be in the minority. Thus, for operational planners, it seems conservative to allow crewmembers at least 30 minutes from the time of awakening to the duty time for the purpose of ensuring that sleep inertia has fully dissipated.

Factors underlying sleep inertia. What are the factors that will determine the degree to which sleep inertia may affect performance in the operational environment? The answer to this question is not straightforward, but sleep inertia seems to be primarily a function of the stage of sleep from which someone is awakened. The phase of the circadian cycle may be important as well, although the research is less definitive on this point.

With regard to the importance of *sleep stage*, Wilkinson and Stretton (1971) concluded that awakenings from slow-wave sleep (SWS) produced more sleep inertia than awakenings from shallower stages. This was based on the finding that reaction time was worse when subjects were awakened in the earlier part of the night than the later part (because most SWS occurs during the first half of the night and most of rapid eye movement [REM] sleep occurs during the second). These results were supported by Stones (1977), who found that performance on a memory task was worse when subjects were awakened from non-REM sleep than when awakened from REM sleep. Bonnet (1983) also showed that short- and long-term memory were worse after awakening from deep stage 4 sleep than after awakening from lighter stage 2 sleep. Additionally, Webb and Agnew (1964) found that reaction time and performance on a serial response task declined significantly from baseline levels when subjects were aroused from stage 4 sleep. These results concur with those of Ferrara et al. (2000), who found that large amounts of SWS rebound, during recovery from selective SWS deprivation, produced the greatest cognitive decrements associated with sleep inertia. Specifically, there were reported losses in both speed and accuracy, although the latter was affected most.

Differences in performance upon arousal from sleep also have been attributed to *circadian fluctuations*, although there is less agreement on this point than on the importance of sleep stage. Wilkinson and Stretton (1971) found that performance on a task requiring continuous concentration, as opposed to reaction time, was worse during the latter part of the night than during the earlier part of the night. The investigators attributed this difference to circadian fluctuations (performance during circadian troughs being worse than performance during circadian peaks). Circadian fluctuations were also found by Dinges, Orne, and Orne (1985) in a study in which people napped for 2 hours during circadian troughs and peaks over a 54-hour period. Performance immediately after awakening from naps during circadian troughs was impaired compared to performance immediately after awakening from naps during circadian peaks. However, in a study during which subjects were kept awake for 64 continuous hours with only brief naps (i.e., 20-minute naps) at 6-hour intervals, Naitoh, Kelly, and Babkoff (1993) failed to identify a specific circadian time at which sleep inertia was more or less severe. It may be that different conclusions on this issue are related to methodological factors, differences in the depth of sleep that is actually obtained at different times, or some other issue. Until this is resolved, the focus on minimizing sleep inertia probably should remain more on the effects of sleep stage (and sleep depth) than on other factors that are not presently well-understood.

Minimizing sleep inertia in operational settings

From an operational standpoint, it will not be possible to monitor the brain activity of personnel in order to ensure that they are not awakened from a strategic nap in the midst of SWS. Thus, other means should be used to minimize the possibility of such awakenings:

1) Avoiding high levels of sleep deprivation is one way to minimize the amount of SWS that will occur once personnel are afforded an opportunity to sleep. Bonnet (2000) reports that there are large increases in the percentage of time spent in SWS following total sleep deprivation; and Dinges, Orne, and Orne (1985) found that this increased SWS in naps (after sleep loss) was associated with greater postnap performance decrements. Thus, napping should be implemented before a significant sleep debt develops.

2) Placing naps at times when SWS is known to be reduced is another possibility. Generally speaking, young adults will spend most of the first third of their nightly sleep period in SWS, while the early morning phase consists primarily of REM sleep (Carskadon and Dement, 2000). Also, it has been found that naps taken later in the day contain more slow-wave activity than those taken earlier in the day (Borbely and Achermann, 2000). Thus, placing naps in the morning hours will reduce the possibility of awakening someone from SWS.

3) Keeping the nap period either short (less than 45 minutes) or allowing the nap to persist at least 110-120 minutes should reduce sleep inertia. The sleep pattern of a normal young adult during the first cycle of the night (nonsleep-deprived) will consist of 1-7 minutes of stage 1 sleep, followed by 10-25 minutes of stage 2 sleep, before reaching the deeper stage 3-4 sleep (Carskadon and Dement, 2000). Thus, assuming that it will take less than 10 minutes to initiate sleep in an operational setting (Rosekind et al., 1994), the occurrence of SWS should be minimized by allowing no more than a total of 45 minutes for the entire napping period. Alternatively, nap durations of 110-120 minutes should maximize the chances of awakening from either stage REM, stage 1, or stage 2 sleep (under normal, nonsleep-deprived conditions).

4) Finally, although debate remains about the importance of circadian factors in the management of sleep inertia, an effort should be made to avoid awakening personnel around the circadian trough (approximately 0300-0400). Although this is not a time when the amount of SWS would be expected to be high, it is a time when, generally speaking, cognitive/psychomotor performance and subjective sleepiness tend to be at their greatest (Van Dongen and Dinges, 2000).

SUMMARY AND CONCLUSIONS

It is well known that napping is an effective fatigue countermeasure for use in sustained operations. In fact, a real-world cockpit-napping strategy developed by Rosekind et al. (1994) has already gained acceptance in both military and civilian long-haul flight operations. Strategic napping consistently attenuates the decrements in alertness and performance that are known to occur as a result of sustained operations without any sleep. However, the problem of sleep inertia is a point of concern when there is a high probability that personnel will be expected to perform demanding tasks immediately upon awakening.

To address this issue, operational planners must first weigh the difficulties associated with immediate, transient, nap-related decrements against the longer-term degradations that will no doubt occur in the presence of sustained continuous wakefulness (with no naps). If the benefits of naps appear to outweigh the drawbacks, every effort must be made to use napping strategies that are designed to minimize sleep inertia. In these situations, naps should be scheduled at intervals that will avoid the build-up of significant sleep debt, they should be placed in the morning as opposed to late at night, and their duration should be controlled so as to minimize the possibility of awakening personnel during slow-wave sleep.

DISCLAIMER

The opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the U.S. Army and/or the Department of Defense.

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