

Safety Regulation Group



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**A Review of In-flight Napping Strategies -
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A Review of In-flight Napping Strategies - Updated 2003

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Executive summary

1 Terms of reference

This report reviews the value of in-flight sleep and napping in civil air operations. It has been prepared for the Safety Regulation Group of the Civil Aviation Authority under contract number 7D/S/952/2 and 7D/S/952/5 amendment 2, as part of a programme of research into the sleep and wakefulness of the airline pilot.

2 Overview

- 2.1 The increasing range of aircraft has led to a situation in which the endurance of the aircraft may sometimes exceed that of the aircrew. As a result, on longer flights, crews are augmented to enable individual crew members to rest and sleep for some time during the flight. Augmentation can be made by the provision of an additional pilot who is qualified to fly in both seats (three-man augmented crew), or by a relief crew (four-man augmented or double crew). The UK requirements for the avoidance of fatigue in aircrew (CAP 371) allow for the extension of flight duty periods on the basis of the length of the in-flight rest periods and the type of rest facility available (bunk or a reclining seat away from the flight deck).
- 2.2 A considerable amount of information exists on the value of naps, both in the laboratory and in the field, including some studies of aircrew. This report reviews these studies and establishes the extent of current knowledge of the benefits and problems conferred on aircrew by napping.
- 2.3 The dictionary definition of a 'nap' is a 'short sleep'. Within the scientific literature, naps may vary in duration from a few minutes to several hours, and the term has been used to describe sleep taken in the daytime, involuntary sleep, sleep not taken in bed and 'light' sleep. For the purpose of this review, the term 'nap' will be used to describe a voluntary sleep, ranging from about 10 minutes ('power naps') to 4 hours in duration, taken at any time of day or night, either in a bed (e.g. in an aircraft bunk) or in a seat (e.g. a seat on the flight deck).
- 2.4 A nap may be followed by a period of 'sleep inertia', which is a transitory deficit in mood and performance. In this report sleep inertia is considered at some length, because of the implications for aircrew who return to duty soon after waking.

3 Conclusions

- 3.1 Naps are a beneficial countermeasure to fatigue and are most effective if they are taken prior to the onset of fatigue rather than after it has become established. Episodes of sleep of just under half an hour have been shown to increase levels of alertness towards the end of a duty period.
- 3.2 The determination of the optimum nap duration should take into account two factors: the duration and magnitude of sleep inertia, and the duration and extent of the beneficial effects on alertness and performance. Whilst the adverse effects of sleep inertia following short naps (e.g. 10 minutes) are limited, the long-term benefits are not as great as those following longer naps (e.g. 40–60 minutes). With a longer period of sleep, sleep inertia is more severe but the beneficial effects can be sustained over a longer period.

- 3.3 Sleep inertia is the main factor limiting the effectiveness of naps and it has been observed following naps as short as 10 minutes. It occurs on waking and it may persist for between 5 and 35 minutes before performance returns to pre-nap levels. The duration of sleep inertia appears to be influenced by the amount of sleep loss prior to the nap, the time of day that the nap is taken, and the duration of the nap. It has been shown to occur after in-flight naps.
- 3.4 This review of the literature has revealed large variations in experimental design and measurement, and this has made the provision of guidance on the recovery from napping very difficult. However, based on current knowledge, at least 20 minutes should be allowed to elapse between awakening and the resumption of duties. This may be easily achieved with augmented crews, where aircrew rotate through seats or bunks. However, even when the use of rest on the flight deck is not specifically permitted, such as with two-man non-augmented crews, sleep is known to occur. In these circumstances, sleep inertia may be present on awakening, resulting in impaired alertness and performance.
- 3.5 For augmented crews who take the opportunity to sleep in a reclining seat, it is likely that the quality of sleep will not be as good as when it is taken in a bunk. There is evidence that the angle of the backrest is an important factor influencing the quality of sleep in aircraft seats.
- 3.6 Sleep in an aircraft bunk can be as recuperative as sleep taken in a bed provided that disturbances are minimised (e.g. the use of sound attenuation, air-conditioning, screening from light). Other factors that are likely to disturb sleep in a bunk include inadequate bedding, not being tired and anxiety. In-flight sleep quality and quantity are likely to be optimum when the rest period follows a reasonable period of wakefulness and coincides with the phase of the circadian cycle during which sleep normally occurs.
- 3.7 There is currently a lack of information in the following areas:-
- The influence of the circadian rhythm on the composition of sleep stages during the nap and the subsequent impact on sleep inertia and performance;
 - The efficacy of using multiple napping strategies in-flight.

4 Recommendations

- 4.1 Because of the effects of sleep inertia, non-augmented crews who may need to operate at short notice in-flight should not rely on napping to maintain acceptable levels of alertness. Short naps on the flight deck of no more than 30 minutes should only be used to combat unexpectedly low levels of alertness that could not have been anticipated when the flight was scheduled. If a single 30-minute nap is insufficient to raise alertness to an acceptable level, the use of further 30-minute naps should be considered, although further studies are required to establish the efficacy of this strategy.
- 4.2 To limit sleep to 30 minutes, crews should be provided with a 60-minute rest period, comprising an initial 5-10 minutes for sleep preparation, a 30-minute sleep opportunity, and around 20 minutes for recovery.
- 4.3 Where augmented crews are provided, napping should be arranged to avoid sleep inertia: crews should not recommence duty for at least half an hour after waking from sleep. However, it is difficult to give more than general guidance on the required recovery time from sleep inertia. To maximise the beneficial effects of naps and

- sleep, rest should be scheduled to occur after a reasonable period of wakefulness but before excessive fatigue has set in.
- 4.4 Careful consideration should be given to the facilities in which crews rest. It is likely that more effective rest will be achieved if augmented crews rest in crew bunks as opposed to airline seats.
- 4.5 The in-flight rest environment should be as conducive to sleep as possible. When rest is taken in a bunk, this may include the provision of air-conditioning, adequate bedding, sound-proofing and screening from light. For rest taken on the flight deck a good sleeping environment will be more difficult to achieve. However, the comfort of the resting crew member can be improved by the provision of a footrest, ear-plugs and eyeshades.
- 4.6 Generally, greater benefits from a nap in a bunk are obtained if one long rest period is provided rather than two short rest periods. However, when departures occur early in the morning, it may be more beneficial to schedule two short rest periods. For double crews, this would allow both crews to rest later in the flight at a time when they are more likely to fall asleep, rather than one of the crews having a single opportunity to rest early in the flight when they may not be able to sleep at all.
- 4.7 Aircrew should be provided with advice on strategies that may enhance their chances of sleeping during rest periods and help them avoid unintentional naps. The benefits of good sleep hygiene, relaxation techniques to aid sleep, the importance of nap timing, duration, circadian cycle and the influence of time-zone transitions on layover sleep should be emphasised.

A Review of In-flight Napping Strategies - Updated 2003

1 Introduction

1.1 Terms of reference

This report reviews the value of in-flight sleep and napping in civil air operations. It has been prepared for the Safety Regulation Group of the Civil Aviation Authority under contract number 7D/S/952/2 and 7D/S/952/5 amendment 2, as part of a programme of research into the sleep and wakefulness of the airline pilot.

1.2 Background

1.2.1 The increasing range of aircraft has led to a situation in which the endurance of the aircraft may exceed that of the aircrew. As a result, on longer flights, crews are augmented so that individual crew members are given the opportunity to sleep for some time during the flight. Augmentation can be achieved by the provision of an additional pilot, who is qualified to fly in both seats (three-man augmented crew) or by a relief crew (four-man augmented or double crew). The UK requirement for the avoidance of fatigue in aircrew [15] allows for the extension of flight duty periods on the basis of the length of the in-flight rest periods and the type of rest facility available (bunk or a reclining seat away from the flight deck).

1.2.2 Even when crews are not augmented (e.g. two-pilot or two-pilot and a flight engineer) studies have shown that aircrew do nap in the flight deck seat, although the conditions under which these naps can take place are not covered by the regulations.

1.2.3 Naps have been described in the scientific literature as sleep, of between a few minutes to several hours, taken outside or in addition to the normal sleep period. In the context of this report, naps are used to describe those periods of voluntary sleep, ranging from about 10 minutes ('power naps') perhaps up to 4 hours, taken at any time of day or night, either in a bed (e.g. in an aircraft bunk) or in a seat (e.g. a seat on the flight deck).

1.2.4 The duration of in-flight naps can vary between a few minutes in an aircraft seat and 4 hours or longer in a relatively comfortable bunk bed (separated and screened from the rest of the aircraft). Various claims have been made concerning the beneficial effects of naps and, in particular, the value of short naps (so-called 'power napping') has been extolled. However, because of the many factors involved, such as time of day, time into flight, the previous pattern of sleep and the number of time zone transitions, as well as the duration of the nap itself, clear guidelines for aircrew have not been established.

1.2.5 A considerable amount of information exists on the value of naps, both in the laboratory and in the field, including some studies of aircrew. The purpose of this report is to review these studies and hence to establish the extent of current knowledge of the benefits and problems conferred on aircrew by napping. The report is restricted to in-flight naps, and does not cover anticipatory naps taken prior to the start of a duty period, except where these might influence the ability of crews to sleep during the subsequent flight.

1.3 Overview of this report

1.3.1 Section 2 of this report consists of an introduction to sleep, including sleep structure and the various sleep stages. Section 3 gives an overview of the relationship between sleep, alertness and performance. These two sections provide the information

necessary for an understanding of the issues specifically related to napping that are covered in the remainder of the report.

- 1.3.2 The literature on napping is reviewed in Section 4. Factors that influence the quality of a nap, including environmental influences and those related to the duty schedule, are discussed, as well as the associated performance benefits and possible negative effects. The issue of 'sleep inertia' is considered at some length, because of the implications for aircrew who return to duty soon after waking. All these factors and their interactions are summarised in a diagram at the end of this section.
- 1.3.3 Sections 5 and 6 review the field investigations of in-flight rest. Issues relating to the scheduling of in-flight rest are also discussed.
- 1.3.4 Conclusions and recommendations are given in Sections 7 and 8. Areas where information is lacking are highlighted.

2 Sleep

2.1 Normal sleep

- 2.1.1 Sleep is a fundamental requirement for humans. The amount of sleep required for the maintenance of physiological and psychological health is around 7 to 8 hours per 24 hours, although this varies between individuals.
- 2.1.2 The electroencephalogram (EEG) is a measure of brain activity during sleep, variations in which enable sleep to be categorised into a number of stages. Stage 1 or 'drowsy' sleep usually occurs during the transition from waking to sleep. Stage 2 sleep normally occupies up to 50% of the sleep period. The time taken to reach the first episode of stage 2 is termed 'sleep onset latency', and includes any intervening stage 1 sleep. 'Deep' sleep (stages 3 and 4), otherwise known as slow wave sleep (SWS), predominates in the early part of the night and is influenced by the length of prior wakefulness [100]. Episodes of rapid eye movement sleep (REM) occur at intervals, and are associated with dreaming.
- 2.1.3 A typical night's sleep pattern of a young adult is illustrated in Figure 1. Generally, the sequence of sleep stages during the night is: waking, stage 1, stage 2, stage 3, stage 4, stage 3 and then stage 2. At this point the first period of REM sleep occurs. It is followed by stages 2, 3, 4, 3 and 2 and a further REM episode. Sleep cycles recur throughout the night, with each cycle lasting around 90 minutes. As the night proceeds, the content of the sleep cycle alters, with less SWS and more REM sleep in the later cycles.

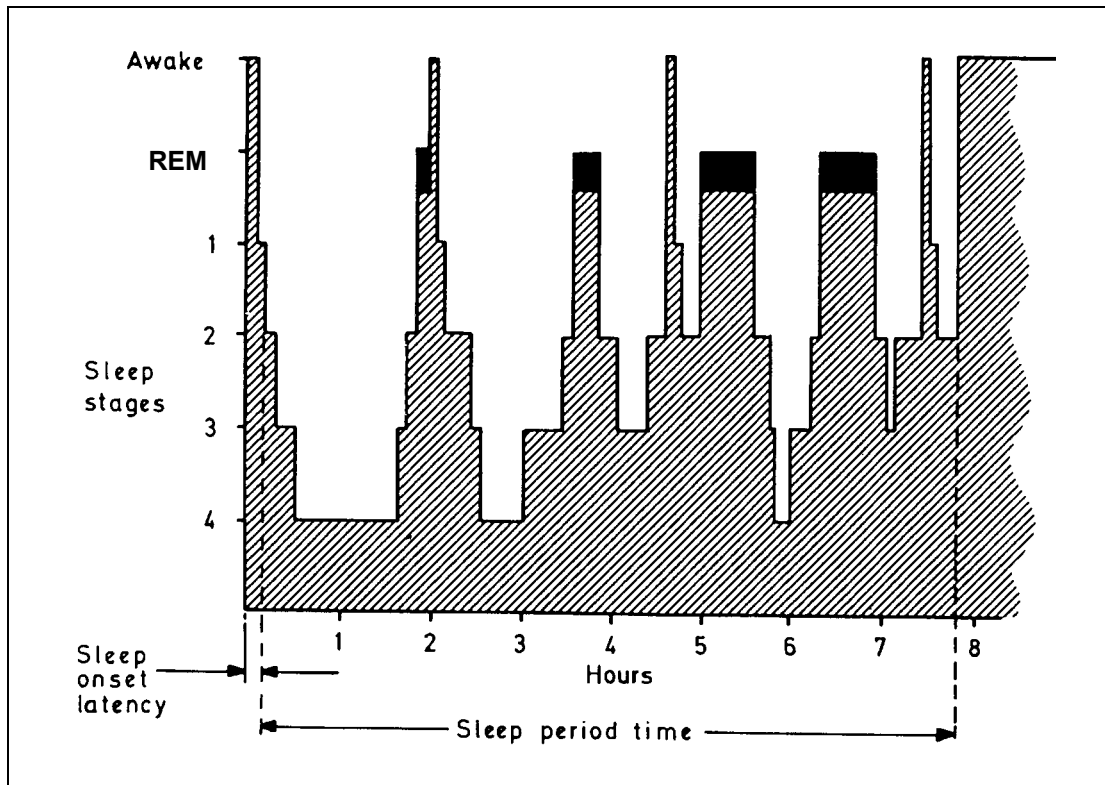


Figure 1 Typical nocturnal pattern of sleep in a young adult

2.2 The effect of the circadian rhythm on sleep

- 2.2.1 Physiological and psychological activities such as body temperature, sleep tendency and mental performance normally exhibit a 24-hour rhythm. This circadian rhythm is controlled by a biological 'clock' in the brain, and remains in phase through the influence of environmental cues. The pattern of light and dark is the most important cue which, in association with other factors, such as the timing of meals, ensures that individuals maintain their 24-hour rhythm.
- 2.2.2 Sleep is initiated at preferred times relative to the circadian rhythm of core body temperature [112]. In general, the longest sleep episodes are initiated several hours prior to the body temperature minimum (02:00 - 06:00). There is also a tendency for naps of approximately 2 hours to be taken close to the temperature maximum (14:00 - 17:00). Indeed, napping in the afternoon is traditional in some cultures. Generally, the duration of sleep decreases as onset times approach the temperature maximum [1], and this tendency has been confirmed in aircrew [91].
- 2.2.3 The two sleep phases in the circadian cycle, namely the mid-afternoon naps and nocturnal sleep, are thought to be separated by an evening period of increased alertness, known as the 'forbidden zone' for sleep [52]. During this period, which precedes the normal nocturnal sleep by approximately 2-3 hours, sleep initiation and maintenance are difficult. This phenomenon has been observed in shiftworkers who often experience difficulties in falling asleep when they retire to bed early in preparation for an early morning start [33].
- 2.2.4 The timing of REM sleep is coupled to the circadian rhythm of core body temperature. The peak in REM propensity occurs just after the mid-trough of this cycle, at the beginning of the rising phase (approximately 06:00 [20]). REM sleep typically increases if sleep extends through the morning [24].

2.3 The effect of sleep loss on subsequent sleep

2.3.1 The requirement for SWS increases with the time since awakening, according to a simple exponential function. This is known as the 'S process' [21]. For a normal sleep-wake pattern (where an individual sleeps for 7-8 hours at the same time every day), the S process will peak prior to the start of the sleep period, and the propensity for SWS will be high. The minimum value for S will occur on waking, when the propensity for SWS is low. The S-process is illustrated in Figure 2.

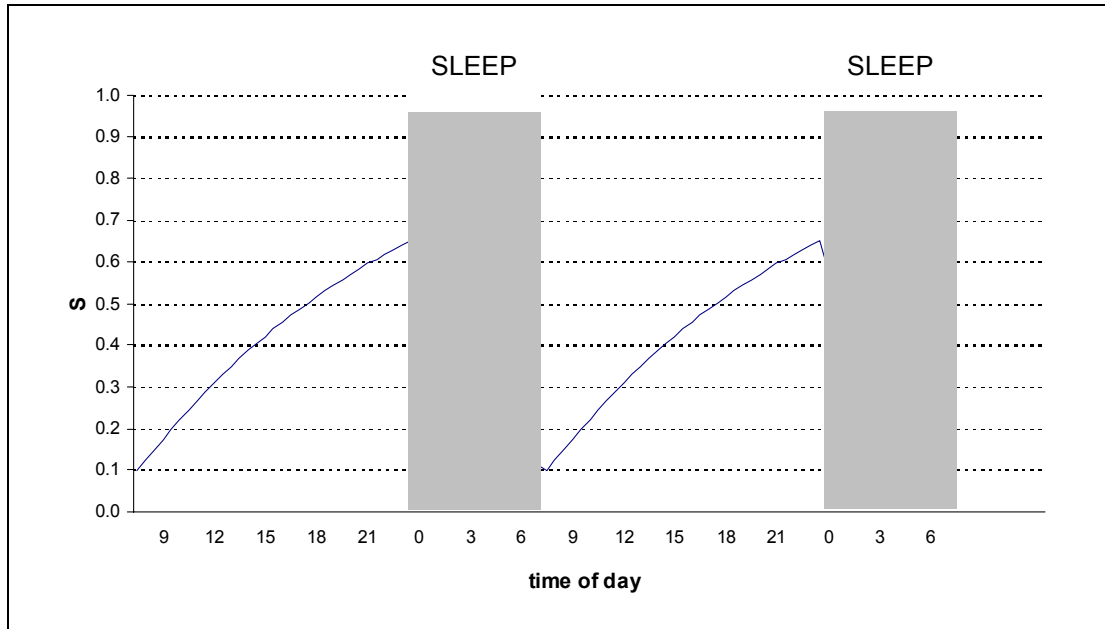


Figure 2 Illustration of the S-process during two normal sleep-wake cycles. The pressure to sleep (S, arbitrary units) is lowest following a sleep period, and builds up gradually through the day or waking period.

2.3.2 After sleep loss, SWS will be recovered first, possibly at the expense of the REM sleep, which may be recouped later in the night or on the following night. This indicates that the recovery of SWS is more important, although the reasons for this are unclear. It will not be necessary to regain the total SWS that has been lost [11, 17] as the requirement for SWS is not a linear function of the time awake.

2.4 The interaction between sleep loss and the circadian rhythm

2.4.1 Sleep is often disrupted after travel across time zones or after a change in the work/rest schedule. This leads to a major deterioration in the quality of sleep (e.g. increased frequency of awakenings, delayed REM sleep, less SWS) and alterations in the timing of REM sleep, related to the direction of the flight or shift change [22, 64, 106].

2.4.2 Nicholson et al. [64] investigated the effects of east and west time zone transitions on sleep quality. Subjects flew from London to Detroit, and returned to London seven days later. They were not allowed to nap prior to or during the flights, or on the day of the return to London. There was a 5 hour delay in the first sleep period, relative to normal bedtime, following the westbound flight (23:30 EST, 04:30, GMT). Decreased latency to SWS and longer duration of SWS occurred during this sleep. This was attributed to the increased duration of prior wakefulness combined with the rest period occurring in the circadian trough.

2.4.3 During the second and third nights, REM sleep increased. This was ascribed to a lowered requirement for SWS (owing to recovery of SWS during the first night) and

shifting of the sleep period into the latter part of the 'home time' morning. Subjects' sleep patterns had adapted to the new time zone by the fourth night.

2.4.4 Sleep after the return eastbound flight was more disturbed and the period of adaptation was greater than after the westbound flight. Individuals took longer to fall asleep on all of the 5 nights monitored, relative to baseline. In addition, REM sleep declined during the second and third nights. By the 5th night, the sleep pattern had not adjusted to the new time zone. The time zone change, combined with the duration of the flight, delayed the first sleep period by 19 hours (23:30 GMT, 18:30 EST). As subjects had adapted to EST, this period (23:30 GMT) coincided with the 'forbidden zone' for sleep (18:30 EST), unlike the westbound journey, where the first rest period coincided with the circadian trough.

2.4.5 Individuals are more likely to experience problems adapting to time zone transitions when the direction of travel is eastwards, as opposed to westwards. Generally, westward travel results in a need to lengthen the day and hence delay the circadian rhythm, whereas eastbound travel results in a need to shorten the day and advance the circadian rhythm. The latter adjustment appears to be more difficult for the biological clock [109].

2.5 **Environmental influences on sleep quality**

2.5.1 Sleep may be disturbed by a variety of environmental factors. These can include noise, sleep facilities (chair, bunk), light and temperature. Disturbance of sleep can result in increased fatigue and reduced performance during the subsequent day or duty period.

2.5.2 **Sleep facilities**

2.5.2.1 Nicholson and Stone [66] investigated the quality of sleep overnight in subjects (aged 35 to 50 years) who slept in an armchair with a backrest angle to the vertical of 17.5°, (equivalent to a seat on the flight deck), a reclining chair with a 37.0° backrest angle, a sleeperette (equivalent to a first-class seat) with a 49.5° backrest angle, and a bed. Subjects reported significantly poorer sleep quality when they slept in an armchair than in the other chairs and the bed. This was characterised by lighter sleep stages, shorter total sleep time (TST) and more awakenings. There were significantly more awakenings and shorter TST in the reclining chair than in the bed. Sleep in the sleeperette was not significantly different from sleep in a bed. Nicholson and Stone concluded that acceptable sleep quality may be achieved in chairs as long as the back angle to the vertical is more than 40 degrees.

2.5.2.2 The duration and quality of sleep in an armchair has been reported to be poorer than sleep in a bed [26], being characterised by significantly less stage 4 sleep and more stage 1 sleep. However, this may partly be explained by the fact that sleep in the armchair occurred under alerting conditions (lights on, background noises), whereas sleep in the bed occurred under conducive conditions (lights off, soundproofing). In addition, the backrest angle of the armchair was not reported.

2.5.2.3 Under laboratory conditions, nocturnal sleep quality and duration in a bunk was not significantly different from sleep in a bed [4].

2.5.3 **Noise**

2.5.3.1 Noise disturbs sleep [67, 68, 69] and this is recognised as an environmental sleep disorder that gives rise to insomnia and subsequent excessive sleepiness [3]. In particular, difficulty in falling asleep is considered an important aspect of noise-induced sleep disturbance in man.

- 2.5.3.2 The sleep of aircrew is likely to be disturbed by exposure to intermittent rather than continuous noise. For intermittent noise, the upper limit has been suggested to be between 45 and 68dB(A) [38]. This wide range is related to the fact that awakening reactions are not only determined by the maximum sound level and the number of noise events but also by individual susceptibility to noise.
- 2.5.3.3 For aircrew attempting to sleep during the day, noise may be factor which leads to disturbed sleep and reduced alertness during subsequent duty periods. In a recent laboratory study, SWS was reduced by up to 50% when noise exposure occurred during the first hour of daytime sleep [76]. Individuals slept for 4 hours and were exposed to noises that might be heard in an hotel bedroom, such as a hairdryer, a vacuum cleaner, and a car alarm.
- 2.5.3.4 Peak noise levels of 45dB(A) increase the time taken to fall asleep. However, the number of events and the difference between background and peak level seem to be more important than the absolute peak level. When noise sensitive individuals were exposed to four noise events per hour at maximum noise level of 45dB(A) there was a reduction in sleep quality. When they were exposed to eight events per hour, sleep onset was delayed [68].

2.5.4 **Temperature**

- 2.5.4.1 Sleep in cold environments seems to be associated with greater sleep disturbance than that experienced in the heat. However, there is a lack of consistent findings among studies, particularly with respect to REM sleep suppression [12]. High environmental temperatures have been associated with difficulties initiating and maintaining sleep. SWS may be suppressed, or may cease altogether, if high environmental temperatures are imposed during the sleep period. However, sleep deprivation appears to be a greater stressor than temperature e.g. following a long period of wakefulness, the increased pressure for sleep will counteract the effect of the increased temperature and the suppression of SWS [12].
- 2.5.4.2 In a study investigating the combined effect of noise and heat on sleep, sleep was more disturbed by exposure to heat (35°C) than to traffic noise (71dB(A)). Exposure to high temperature increased the number of awakenings and the amount of stage 1 sleep and reduced TST. With exposure to noise at night, there was an increase in the number of stage changes and the number of episodes of stage 1 sleep. The combined effects of noise and heat were to reduce the REM sleep cycle length and TST. Increases were also seen in stage 1 sleep, the number of stage changes and the number of awakenings [53].

2.6 **Individual differences**

- 2.6.1 Individual differences in age, psychological well-being and general ability to sleep may influence the quality and duration of sleep.
- 2.6.2 Individuals classed as 'flexible types' find it relatively easy to sleep at unusual times and have no preference for regular sleeping or meal times. In contrast, 'rigid types' have difficulty in getting to sleep early, or sleeping in late, even when tired. They also prefer to sleep and eat at regular times and maintain their normal sleeping habits even on holiday [19].
- 2.6.3 As people age, the quantity of slow wave sleep declines [7, 111]. They also become less adaptable to changes in their normal sleep pattern and are more susceptible to disturbances in the sleep period following a nap [59]. There is also evidence that they may find it more difficult to adapt to a new time zone. Gander et al. [35] reported a significant increase in the average daily percentage of sleep loss in non-augmented aircrew with increasing age, over the range of 20-60 years. Inability to adapt to an

unusual sleeping schedule and a new time zone could result in greater sleep loss in older pilots.

- 2.6.4 Anxieties are considered to be a major contributor to sleep problems [78] resulting in poor sleep quality, reduced sleep duration, and consequentially, sleep loss. Sleep loss may result in a general decline in performance and increased severity of sleep inertia following a nap (see Section 4.4).

3 Performance

3.1 Sleep deprivation

- 3.1.1 Many studies have shown that mental (cognitive) performance is impaired after sleep loss [60, 110]. When nocturnal sleep is restricted to less than 4-5 hours per night, performance will deteriorate [103, 106, 107] and even as little as 2 hours sleep loss can result in impaired performance and reduced levels of alertness [18]. The tasks most likely to be affected include those which are of long duration, machine-paced, or monotonous, and those that require sustained attention or that are poorly learned [6, 40, 56].
- 3.1.2 In some cases, accuracy on cognitive tasks may not be impaired, but the tasks will take longer to complete. In addition, there may be lapses in attention, an inability to concentrate [6], a failure to take all relevant information into account when making decisions, an acceptance of lower performance standards, a neglect of routine or self-initiated tasks, and an increasingly erratic operation of controls [32, 39].
- 3.1.3 Studies of shiftworkers have indicated that individuals often take very little, if any, sleep before the first night duty [51]. This means that almost 24 hours may be spent awake before retiring to bed and, consequently, individuals will feel very tired towards the end of the shift. This situation may also apply to aircrew, when individuals do not take the opportunity to nap before evening departures, although the evidence suggests that aircrew generally nap more than shiftworkers [91]. In addition, aircrew may have difficulty initiating sleep and napping during the 'forbidden zone' for sleep (see Section 2.2).
- 3.1.4 There is evidence that a decline in performance will be associated with extended duty periods [23, 50, 81]. Scheduling duty periods for safety-critical industries such as air transportation should include consideration of the circadian rhythm. Performance will be impaired during the circadian trough between 02:00-06:00, and this impairment will be exacerbated if this occurs near the end of the duty period [89].

3.2 Sleep inertia

- 3.2.1 Sleep inertia can be defined as a transient state of confusion accompanied by impairment of performance and mood following awakening from sleep. It can result in profound performance decrements on a variety of tasks, which can be worse than the impairment caused by sleep deprivation [5]. Sleep inertia can result in significant decrements in vigilance, memory, reaction times and general cognitive abilities.
- 3.2.2 Sleep inertia also occurs after awakening from naps [25]. It is therefore an important consideration in situations where naps are used to counteract fatigue, especially if duties must be resumed immediately after waking. For this reason, the majority of research into sleep inertia has investigated performance after sudden arousal from a nap. This will be discussed further in Section 4.4.

4 Naps

4.1 Background

The term 'nap' is usually defined as 'a short sleep'. However, within the scientific literature, naps may vary in duration from a few minutes to several hours, and the term has been used to describe sleep taken in the daytime, involuntary sleep, sleep not taken in bed and 'light' sleep. For the purpose of this review, a nap will be considered to be a voluntary sleep, ranging from about 10 minutes up to 4 hours, taken at any time of day or night, and either in or out of bed (e.g. in an aircraft bunk or in a seat on the flight deck).

4.2 Factors influencing nap quality

4.2.1 Provided that the environmental conditions are conducive to sleep, the quality of sleep taken as a nap is unlikely to be very different from that taken during the early part of the night [79]. However, other factors such as anxiety and apprehension can influence sleep quality. Apprehension, associated with being on-call, has been shown to reduce TST, and reduce the amount of SWS and REM sleep [105]. A similar situation may sometimes be associated with the use of in-flight rest. If the operating captain finds it difficult to relinquish command, this may affect the quality of his sleep during a rest period.

4.2.2 Timing of a nap

4.2.2.1 The timing of a nap is an important factor, which will influence the structure of sleep during air operations. Therefore, when planning an in-flight napping strategy, careful consideration should be given to the timing of the rest period. All the factors that influence the onset of sleep will, in a similar way, affect the ability to nap. These include the time of day at which the nap is taken, time since the last sleep period, and individual differences (e.g. age, anxiety).

4.2.3 Duration of a nap

4.2.3.1 When a nap is of very short duration, it is likely to be composed of mainly stage 1 and 2 sleep. Nevertheless, if individuals are sleep deprived, there is a possibility that they could reach the deeper stages of sleep within 10 minutes [77].

4.2.3.2 Horne and Reyner [46] asked subjects to nap for 15 minutes between two performance sessions. The average latency to stage 1 sleep was 7.4 minutes, and the TST was 10.8 minutes. The sleep stages during the nap were not reported.

4.2.4 Where naps are of longer duration, e.g. 1-2 hours, and the conditions are conducive to sleep, the quality of sleep will be similar to that during the first part of nocturnal sleep (Section 2.1.3). Individuals are likely to experience a complete cycle of sleep stages and are likely to obtain some SWS. (see 4.5.2.2).

4.2.5 Environmental influences on nap quality

4.2.5.1 The environment in which individuals nap is likely to affect the quality of sleep. Factors such as noise, temperature, humidity, and the sleeping facilities themselves (e.g. bed, chair), have all been shown to affect the duration and quality of sleep (see Section 2.5). The influence of these factors on the quality of naps will be very similar. In general, sleep disturbances arising from poor environmental conditions lead to more awakenings, increased latency to sleep, reduced TST and a greater predominance of the lighter stages of sleep.

4.2.6 **Individual differences in napping ability**

- 4.2.6.1 It is possible to distinguish between 'nappers' who can sleep almost anywhere and 'non-nappers' who report difficulty falling asleep in various environments. Non-nappers are more likely to be disturbed and woken by alerting stimuli such as noise [25].
- 4.2.6.2 Generally, the same individual factors that affect sleep (e.g. age, anxiety) will influence napping ability (see Section 2.6).

4.2.7 **Effect of naps on subsequent sleep**

- 4.2.7.1 A nap may affect subsequent sleep by delaying its onset or disrupting the quality of later sleep periods. Following a 2-hour nap, reduced TST and SWS have been reported in the subsequent sleep of shiftworkers [49, 104]. This truncation of sleep after a nap is especially prevalent in older individuals who find it difficult to adapt to changes in their sleep pattern [36]. It appears that the shorter the nap, the less the truncation of subsequent sleep. Naps of around 50 minutes have been shown to be effective in improving performance and mood overnight without significantly affecting subsequent sleep [85].

4.3 **The beneficial effects of naps on performance**

- 4.3.1 Naps have a beneficial effect on performance and mood [79, 98, 99] and, after careful scheduling, may be the most effective countermeasure against fatigue at work. However, it appears that any performance benefits that may be gained from a nap will be dependent on several factors. These include the timing and duration of the nap and the length of the preceding period of sleep loss. These will be discussed in the following sections, and are summarised in Figure 4 (Section 4.7).

4.3.2 **Nap timing and performance benefits**

- 4.3.2.1 Falling asleep may be easier at certain times of the day and night. However, some studies have found that the placement of a nap at different times with respect to the circadian cycle may result in differential performance effects. Naitoh [60] showed that a 2-hour nap, taken between 04:00 and 06:00 after 45 hours awake, did not improve cognitive performance to the same extent as a nap taken between 12:00 and 14:00 after 53 hours awake. A subsequent study [31] found that a 3-hour nap taken in the circadian trough also had a limited beneficial effect on performance.
- 4.3.2.2 On the other hand, Dinges et al. [29] did not observe a difference in the benefits of a 2-hour nap taken either between 15:00 and 17:00 after 30 hours awake, or after a nap taken between 03:00 and 05:00 following 42 hours awake. These inconsistent findings may be due to differences in the elapsed time between waking and performance testing, although this time is not explicitly given. Naps placed in the circadian trough may be easy to initiate and maintain, but may result in greater performance deficits immediately following awakening than naps taken at other times.

4.3.3 **Duration of naps and performance benefits**

- 4.3.3.1 There is some evidence that naps as short as 10 minutes, are restorative to performance [62]. However, this conclusion appears to be based mainly upon studies, which investigated the effects of disturbed sleep over many hours, e.g. awakening subjects every 10 minutes (e.g. references 10 & 30). Hence these 10-minute 'naps' were generally taken close together and in succession.
- 4.3.3.2 Horne and Reyner [46] found that a 15-minute nap taken between two 1 hour sessions of monotonous simulator driving, which commenced five minutes after awakening, significantly improved performance. The performance data suggested

that the benefits were apparent immediately on starting the task, indicating an absence of sleep inertia. Although this short nap was beneficial to performance, two out of the ten subjects were unable to nap, and there was a high degree of variation in sleep latency and nap duration. This highlights a problem with assigning short nap periods: not all individuals will fall asleep within this time (see Section 4.2.6).

- 4.3.3.3 Hayashi et al. [41] investigated the benefits of a 20-minute nap taken at 14:00, on subsequent performance and sleepiness ratings. The duration of the 20-minute nap, taken in a bed, was determined from the start of stage 1 sleep. For all subjects, the nap mostly comprised stage 2 sleep, with no SWS. Relative to a no-nap sitting condition, subjective ratings of sleepiness were reduced at 15:00 and performance on a variety of tasks was significantly better at 15:00, 16:00 and 17:00. This study showed that a 20-minute nap (i.e. a full 20 minutes of sleep) taken in the afternoon can improve subsequent performance for 3 hours under low workload conditions.
- 4.3.3.4 During a workplace evaluation, naps of 20 minutes were shown to be beneficial [73]. Aircraft maintenance engineers were given the opportunity to sleep for 20 minutes between 01:00 and 03:00 on each of two consecutive night shifts. Performance at the end of the first shift improved compared with the control. However, there was no effect during the second night. During the drive home from work, napping during the preceding night shift did not improve subjective ratings of fatigue or sleepiness.
- 4.3.3.5 Following restricted nocturnal sleep, naps of 10 minutes have been shown to improve alertness and/or performance [96, 101]. Takahashi and Arito [96] studied the effect of a nap taken in the early afternoon (12:30-12:45) following sleep restriction. The average amount of sleep obtained was 10 minutes during a 15-minute sleep opportunity. Measures of alertness and performance did not commence until 30-minutes after the end of the nap, when the effects of sleep inertia are likely to have dissipated. Performance continued to be monitored every 1.5 hours until 17:45. Fewer errors were observed following the nap than in the no nap condition.
- 4.3.3.6 More recently Tietzel and Lack [102] have investigated the effectiveness of very short naps of 30 seconds, 90 seconds and 10 minutes, and compared them with a no nap condition. The night prior to the study, sleep was restricted to 5 hours and the various nap conditions were scheduled to finish at around 15:00. Whilst the EEG was monitored throughout each condition, the amount of individual sleep stages obtained during the naps was not reported. Only the 10-minute nap was associated with any improvements in performance and alertness. However, as performance was only assessed on three occasions, once before the nap and at 5 and 35 minutes after waking it is difficult to determine how long any beneficial effects may have lasted. An objective measure of sleepiness, the sleep onset latency test¹, was also used before the nap and 65 minutes after waking. There were no differences in the time taken to fall asleep following the no nap, 30 and 90-second naps. However, following the 10-minute nap the latency to sleep (7.5 minutes) was significantly longer than for the other conditions combined (3.1 minutes). The authors suggested that stage 1 sleep (i.e. 30 and 90-second naps) is insufficient to confer any subsequent beneficial effects.
- 4.3.3.7 Gillberg et al. [37] reported significant improvements in performance on a reaction time and a vigilance task following a 30-minute nap. This nap was taken between two 4-hour testing sessions, the first of which occurred after a 4-hour sleep. To avoid sleep inertia there was a 30-minute period between awakening from the nap and commencement of the task battery. The nap returned performance to baseline levels and generally improved performance over the second 4-hour test battery, relative to the no nap condition.

1. Sleep onset latency was defined as the time taken to reach stage 1 sleep

4.3.3.8 A more comprehensive study of the effect of nap duration and long term benefits has compared naps of 10, 20, 30, 40 and 60 minutes with a no nap condition [77]. Performance and alertness were assessed before and after each nap. After waking from each nap, performance and alertness were assessed at 2, 10, 17, 30, 45 minutes and then every 15 minutes post nap. This continued until approximately 4 hours after waking. For one performance task, the trend in improvements in performance was related to the duration of the nap (Figure 3). However, the measures of performance used in the study involved relatively simple tasks and it is unclear if the benefits would be the same for more complex tasks.

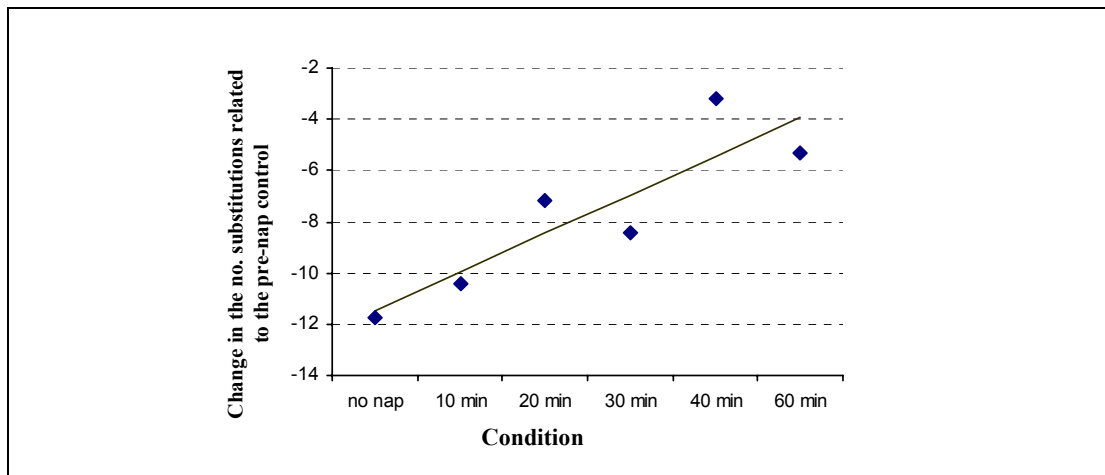


Figure 3 Trend in the improvements in the number of substitutions on a coding task completed 4 hours after the end of the nap

4.3.3.9 Various studies of continuous work have demonstrated that naps of between 1 and 2 hours were beneficial compared to no sleep at all [54, 108]. Generally, the longer the nap the greater the beneficial effects on mood, performance and alertness [28, 54, 55, 70]. It appears that the first 2 or 3 hours of sleep are critical for alleviating performance decrements associated with sustained wakefulness. Additional sleep obtained after this period, although effective, does not appear to be as beneficial in terms of performance compared to the first few hours of sleep [48].

4.3.3.10 In summary, very short naps (30 and 90 seconds) have not been associated with improvements in performance or alertness. Naps of 10 minutes or greater have been shown to be beneficial, although the duration of these effects maybe somewhat short-lived. Generally, the longer nap the greater the benefits, although this may be countered initially by the effects of sleep inertia (see sections 4.4 & 4.5).

4.3.4 Single and multiple naps

4.3.4.1 There remains controversy as to whether naps are more beneficial when taken as a series of short multiple naps or as one long sleep period. A study of sleep loss and nap effects during 42 hours of sustained performance [58] showed that subjects who were allowed a 1 hour nap after every 6 hours did not perform as well during the last 24 hours of the study as subjects who received the same amount of sleep in a continuous block (23:00-05:00). However, operations which involve continuous, prolonged work will often not accommodate a long sleep period, and under these conditions the use of a number of short naps may be more practical. The provision of multiple short naps within a demanding schedule may help to overcome the deleterious effects of sleep loss. Indeed, this can be achieved and sustained for several days in motivated adults under both laboratory [16] and operational conditions [95].

4.3.4.2 In situations where in-flight rest is not scheduled, they may be valuable on occasions to counteract unexpected fatigue. The development of multiple sleep schedules, for use in an operational environment, is a fairly new concept. At present there is insufficient information available to predict how such a pattern may benefit individuals, as performance will be affected by other factors apart from sleep loss (such as the type of task being performed and the ability to function immediately on awakening). It is important that future studies investigate the repeated use of naps during a prolonged work period to determine the extent of their continued efficacy.

4.3.5 **The length of a preceding period of wakefulness prior to a nap**

4.3.5.1 The scheduling of naps during a duty period will depend on the operational demands. However, current data suggest that naps should be taken before an appreciable amount of sleep loss has occurred [28, 58, 79]. Dinges et al. [28] investigated the placement of a 2-hour nap during a 54 hour continuous operation. It was concluded that the beneficial effects of naps occurred after individuals had been awake for only 6 or 18 hours. These effects were substantial and remained beneficial for over 24 hours, whereas performance improvements after later naps were neither as great nor as long-lasting.

4.3.5.2 A 4-hour sleep taken prior to a period of overnight work has been shown to attenuate the usual circadian decline in performance [65]. Similarly, a 2-hour nap taken in the afternoon, after only 6 hours of wakefulness, was shown to have a beneficial effect on a sustained attention task performed 10 hours later [28].

4.4 **The negative effects of naps on performance: sleep inertia**

4.4.1 It is generally accepted that naps are beneficial to performance. However, there are also negative effects, the most important of which is sleep inertia. As described in Section 3.2, sleep inertia is a transient state of confusion accompanied by impairment of performance and mood following forced awakening from sleep.

4.4.2 The duration of sleep inertia is usually measured as the time taken for performance to recover to pre-nap levels and has been shown to vary between 5 and 30 minutes (reviewed by Muzet et al., [59]). For example, Salamé et al. [84] reported that the effects of sleep inertia after a 1-hour nap overnight lasted 27 minutes before returning to pre-nap levels. These transient effects gave rise to performance levels that were significantly worse than during an overnight period without sleep (control; see Figure 4). As the subsequent sections will show, the severity of sleep inertia depends upon a variety of factors.

4.4.3 Similar to the findings of Salamé et al. [84], recent data have shown the effects of sleep inertia on an encoding task to last approximately 30 minutes following a 1-hour nap at 02:00 [45]. Another study showed that performance on a 10-minute sustained attention task carried out immediately on awakening from a 1.5-hour nap was poorer than in the test sessions 3.5 hours before and 30 minutes after the nap [42].

4.4.4 Sleep inertia has been reported to result in significant decrements in the speed and accuracy of various tasks. These include long and short term memory tests, simple and complex reaction times, time estimation, mental arithmetic [26], vigilance and monitoring tasks [87], physical strength and co-ordination [47], all of which may be required by aircrew on duty.

4.4.5 There have been few empirical studies into the effects of sleep inertia on different tasks, although it appears that those requiring sustained attention are the most susceptible. Simons et al. [87] reported significantly better performance on a complex, resource management task than on a vigilance test, both of which were undertaken 15 minutes after awakening from a nap. Similar results have been

reported by Naitoh [61]. As with studies of sleep deprivation, this may indicate that more interesting, complex tasks are less susceptible to sleep inertia than more mundane vigilance and monitoring tasks [86].

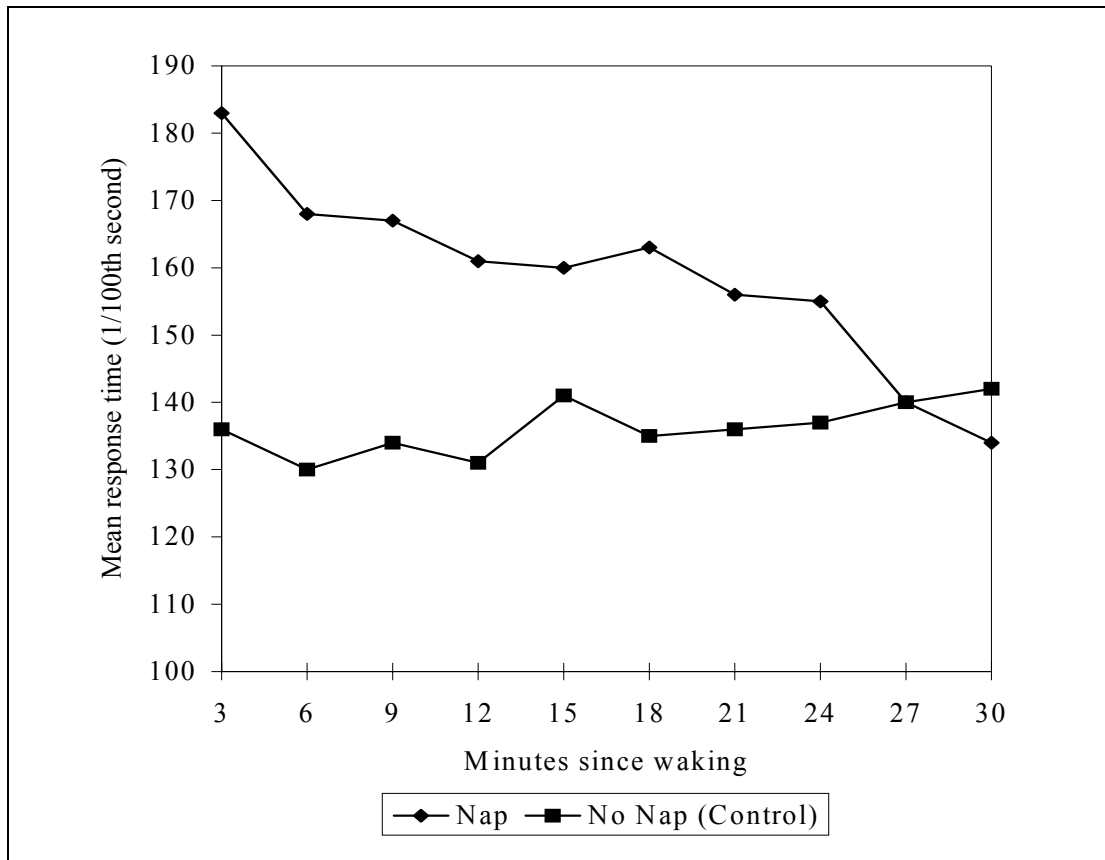


Figure 4 Mean reaction times for a spatial memory task following a one-hour nap

(The duration of performance impairment for a nap group compared to a no-nap control group, adapted from Salamé et. al., [84]).

4.5 Factors influencing the severity of sleep inertia

4.5.1 Depth of sleep

4.5.1.1 The severity of sleep inertia appears to be primarily influenced by the stage of sleep on waking and the quantity of SWS during the nap [63]. Subjects woken from stage 4 sleep had significantly longer reaction times, greater memory impairments and took longer to recover than those awoken from stage 2 sleep [9, 26, 34]. Dinges et al. [27] reported a significant and positive relationship between the duration of stage 4 sleep and the number of incorrect responses on a mental arithmetic task.

4.5.1.2 Bruck and Pasani [14] investigated the effects of waking from SWS or REM sleep on decision making. Subjects slept overnight, and were woken within 1.5 minutes of entering either their first or second SWS or REM period. Almost immediately on awakening, subjects were asked to complete a 3-minute 'fire chief' decision making task and to complete fatigue ratings. These were repeated at 6, 12, 24 and 30 minutes after waking. Relative to baseline, performance after awakening from both sleep stages was impaired, with the greatest decrements occurring in the first 3 minutes. By the end of the 30-minute test period, subjects' performance was 80% of baseline. This result may reflect the effects of sleep inertia coinciding with the normal low in performance during the early hours of the morning.

- 4.5.1.3 This study also showed that performance following waking from REM was significantly better than following waking from SWS for the first two tests (i.e. 0-3 and 6-9 minutes). The increase in the severity of sleep inertia following stage 4 sleep is in accord with the difficulty in awakening from deep sleep. Individuals are unlikely to be as disturbed by environmental noise, such as doors slamming or a telephone ringing, during stage 4 sleep as they would be during stage 2 sleep [13].
- 4.5.1.4 The evidence suggests that the severity of sleep inertia increases with the depth of sleep prior to awakening and the duration of SWS. However, a quantifiable relationship between the severity of sleep inertia, the length of sleep stages during the nap, and the sleep stage on awakening cannot be derived from the current literature.
- 4.5.2 **Duration, time of nap, and length of prior wakefulness**
- 4.5.2.1 Associations between nap duration, time of day and length of prior wakefulness (sleep loss) in relation to the severity of sleep inertia have been reported [25]. These associations may be explained by their influence on the duration and latency of SWS.
- 4.5.2.2 In normal circumstances, SWS occurs mainly in the first few hours of sleep and has a latency of approximately 30 minutes [111]. Naps of 2 to 4 hours are likely to contain significantly more SWS than naps of an hour or less.
- 4.5.2.3 In a recent laboratory study [77], sleep inertia was evident following naps of 10, 20, 30, 40 and 60 minutes. All sleep periods were timed to end at 03:00. Immediately following each nap, the trend in sleep inertia was for performance to be impaired and for participants to feel less alert and sleepier as the duration of the nap increased (Figure 5). During this study, SWS was observed in all naps and as the duration of the nap increased so did the amount of SWS.

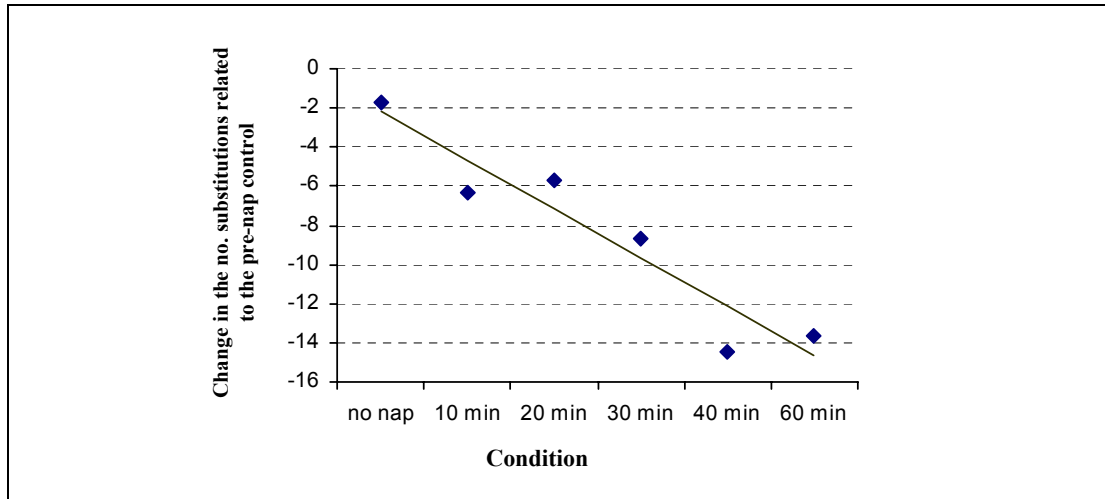


Figure 5 Trend in sleep inertia immediately on waking (substitution task)

- 4.5.2.4 Very short naps of between 30 and 90 seconds have not been associated with sleep inertia [102]. During naps as short as these, individuals did not reach stage 2 sleep or SWS. Unless a nap is of a very short duration (e.g. up to 90 seconds), sleep inertia will occur on awakening. However, what remains unclear is how much time is required after a nap for the negative behavioural effects of sleep inertia to give way to the beneficial effects [63].
- 4.5.2.5 The length of prior wakefulness appears primarily to determine the amount and duration of SWS. In subjects deprived of sleep for 54 hours, with a 1-hour nap at 6, 18, 30, 42, or 54 hours, the latency to, and duration of, SWS increased. The duration

of SWS was positively associated with an impairment in performance on a descending subtraction test on waking [27]. Increased severity of sleep inertia with increased duration of pre-nap wakefulness has been reported elsewhere [5, 59, 82].

- 4.5.2.6 From these studies, it is apparent that an increased length of wakefulness prior to the nap is associated with an increased duration of SWS, and this could result in greater severity of sleep inertia (see Section 2.3). Hence, those subjects who napped during the afternoon, 12 hours later than the early morning nappers, should have shown greater performance impairments. The fact that the performance of these subjects was better than those who napped 12 hours earlier may be attributable to the circadian rhythm in performance. This has a greater effect on performance than sleep inertia. An individual who works overnight will show greater impairments of performance during the early morning hours than those who work during the mid-afternoon. The time of awakening from the nap will have a stronger influence on performance after abrupt awakening than the quantity of SWS.
- 4.5.2.7 The few studies investigating the influence of the timing of a nap on the severity of sleep inertia have usually involved long periods of sleep deprivation. Dinges et al. [28] found that performance decrements in sleep deprived individuals following a 2-hour nap in the early morning (02:00-04:00) were similar to those following an afternoon nap 12 hours later. Similar findings have been reported by Naitoh [61] and Balkin and Badia [5].
- 4.5.2.8 Under normal conditions, the time before performance returns to that obtained in a no-nap control appears to be approximately 30 minutes (e.g. reference 84). However, the duration of sleep inertia may increase to 2 hours or longer under conditions of severe sleep deprivation (e.g. 64 hours of sleep loss) [82]. A systematic investigation of the influence of the timing and duration of a nap, the length of prior wakefulness, the time elapsed from awakening to commencing a task, and the type of task performed in relation to the severity of sleep inertia, has not been consistent. It is, therefore, difficult to provide satisfactory recommendations for the timing of the commencement of duty following a nap.

4.6 Countermeasures to sleep inertia

- 4.6.1 In the context of air operations, countermeasures to sleep inertia may involve limiting SWS by, restricting the nap duration, preventing sleep loss and implementing effective nap schedules. Other countermeasures include the use of alerting stimuli such as loud noise and bright light to hasten recovery of performance to pre-nap levels. These factors are illustrated in Figure 4, Section 4.7.

4.6.2 The prevention of sleep loss

- 4.6.2.1 To aid the achievement of adequate rest prior to duty, individuals should be provided with information on optimising their sleep during rest periods. This should include advice on strategies to enhance their chances of sleeping, such as education about nap placement, duration, circadian cycle and the influence of time zone transitions on layover sleep [74, 80]. The rest environment should be as conducive to sleep as possible [76].

4.6.3 Limiting nap duration

- 4.6.3.1 It may be possible to limit SWS by restricting the duration of the nap. As illustrated by Figure 1, the latency to SWS is approximately 30 minutes. A 20-minute nap may consist mainly of stage 1 and 2 sleep. However, the latency to SWS varies between individuals [111] and may also decrease with the duration of prior wakefulness (the S process, see Section 2.3). Total avoidance of SWS cannot be guaranteed. In addition, there are reduced performance benefits with short compared to long naps (see

Section 4.3.3), although these may be overcome by adopting a multiple napping strategy. Taking into account the performance benefits reported from multiple short naps in the laboratory (see Section 4.3.4), a multiple napping strategy consisting of 20-minute naps may minimise the severity of sleep inertia whilst maintaining performance, although further studies are required to verify this.

- 4.6.3.2 The findings from a recent study [101] investigating the beneficial effects of a 10 or 30-minute nap suggest that a 10-minute nap may avoid the effects of sleep inertia. The night prior to the investigation, sleep was restricted to 4.7 hours. On waking from the 10-minute nap there was an immediate and sustained improvement in alertness and performance. These improvements were not evident until an hour after rising from the 30-minute nap. However, performance and alertness were only monitored for an hour after sleep and it is unclear how long these beneficial effects may last.
- 4.6.3.3 However, subjective measure of alertness and sleepiness have been reported to be impaired 2 minutes after waking from a 10-minute nap [77], although the same study did not show decrements in measures of performance.

4.6.4 **Alerting stimuli on awakening**

- 4.6.4.1 There have been few investigations into the use of stimuli on awakening to aid recovery from sleep inertia. Exposure to stimuli such as loud noise and bright daylight may be alerting and therefore reduce the required recovery time. Tassi et al. [97] reported the elimination of sleep inertia in subjects exposed to 75 dB(A) pink noise (band-limited, low-frequency white noise) on awakening from a 1-hour nap in the early part of the night. Åkerstedt and Landström [2] reviewed countermeasures to fatigue during the night shift, and concluded that, although exposure to noise may be alerting, the noise can be unpleasant and performance effects temporary. Exposure to daylight has also been reported as having alerting effects under conditions of fatigue [44], but this has not been studied as a countermeasure to sleep inertia.
- 4.6.4.2 Consumption of caffeine has been frequently reported to improve performance and increase alertness when individuals are fatigued (e.g. reference 79). However, caffeine can take 30 minutes from ingestion until it is effective [8]. This is approximately the same as the time required to recover unaided from sleep inertia.
- 4.6.4.3 Muzet et al. [59] suggested that high levels of motivation may be an effective countermeasure to sleep inertia, but this has not been investigated. However, the use of incentives or the provision of an interesting task have been shown to improve performance during sleep deprivation studies [43, 86]. In the context of an emergency situation, it is currently unknown whether high motivation will overcome sleep inertia.

4.7 **Summary of the factors influencing the effects of naps on performance**

- 4.7.1 In Figure 6, the various factors, which are influential in determining the effect of waking from a nap on performance, are shown. This diagram is a representation of the relationships between factors influencing the effectiveness of naps, as derived from the literature discussed in this report.

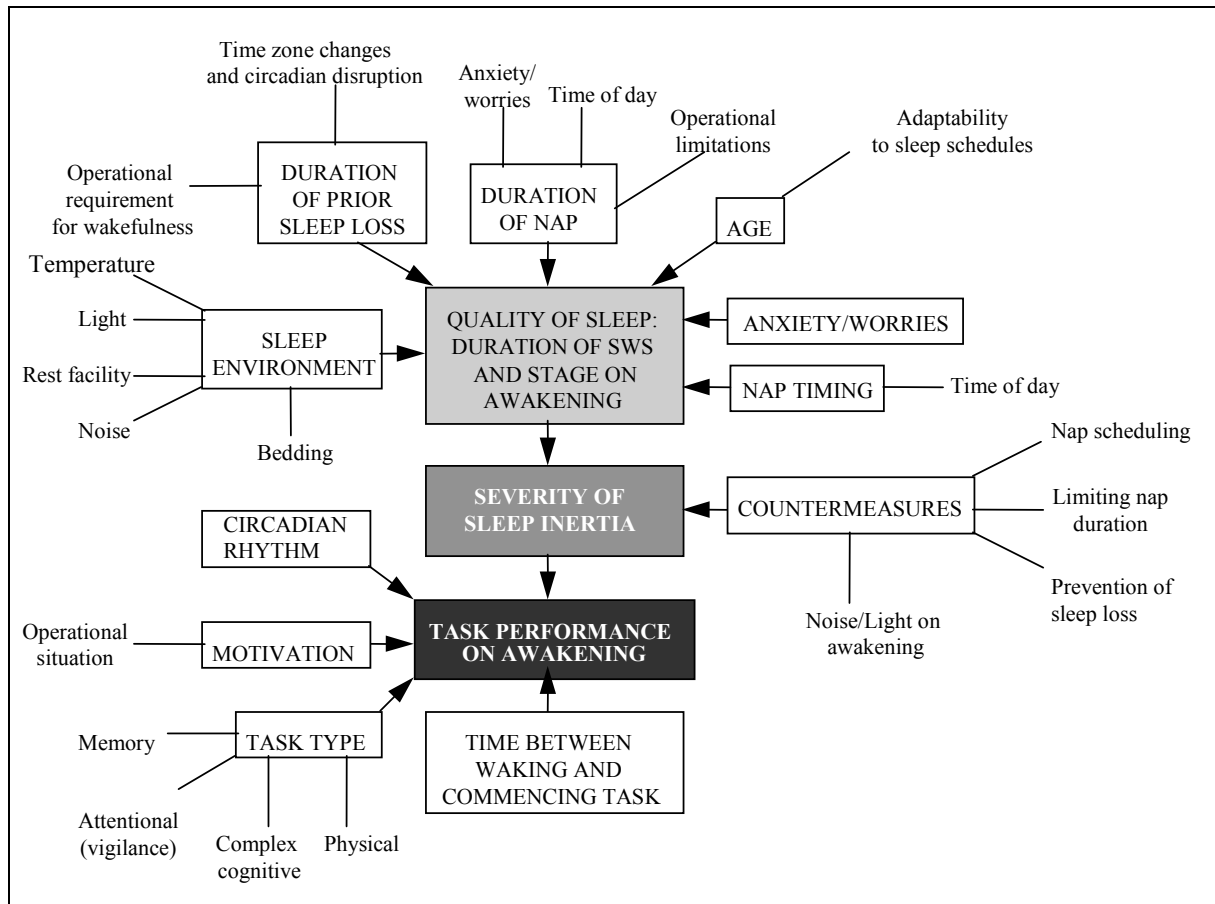


Figure 6 Representation of the factors influencing the quality of sleep, severity of sleep inertia and performance on awakening.

5 In-flight napping

5.1 Background

- 5.1.1 Information contained in the previous sections has provided a background to the issues that affect the ability to sleep, the quality of sleep during a nap, and the effects of napping on subsequent performance. The next two sections address, in turn, napping on the flight deck and naps taken in an aircraft bunk.
- 5.1.2 The rest facilities that are available to aircrew on a specific flight will depend on a number of factors including the aircraft type, route and crew composition. Unaugmented crews (i.e. the crew complement for which the aircraft was certified - usually two pilots or two pilots and a flight engineer) who nap, do so in a seat on the flight deck. Augmented crews (which include an additional pilot to that required for aircraft certification, or an additional full crew) often have two locations in which rest may be taken: in passenger seats away from the flight deck or, where fitted, in bunk facilities.
- 5.1.3 Few studies have investigated the quality of rest on the flight deck, although laboratory studies have shown that the quality of sleep is unlikely to be as good as when it is taken in a bunk (see Section 2.5.2). Furthermore, no studies have examined the influence of the flight deck environment on the quality of sleep. This section examines the effectiveness of sleep obtained on the flight deck, factors which may affect sleep quality and the scheduling of in-flight rest.

5.2 The 'NASA nap' - napping on the flight deck

- 5.2.1 On flights operating with augmented crews, a number of airlines have implemented the use of "controlled" rest on the flight deck. The use of the 'NASA nap' [83], a 40-minute nap opportunity whilst seated on the flight deck, has been reported to be beneficial for the maintenance of performance during the flight. Rosekind et al. [83] limited the nap opportunity to 40 minutes in an attempt to obtain performance benefits whilst minimising the effects of sleep inertia by reducing the possibility of entering SWS.
- 5.2.2 The 'NASA nap' involves a rest period of just over an hour, comprising 3 minutes preparation, a 40-minute nap opportunity and a 20-minute recovery period. In the original study, the normal two pilot crew was augmented by a further pilot on long-haul flights (6.7 - 13.8 hours). Each pilot was scheduled to have one rest period. On average, the sleep latency during these naps was 5.6 minutes, and the TST was 26 minutes, 61% of which was composed of stage 2 sleep. This rested group managed to maintain consistent reaction times on a vigilance test both across and within flight legs. The reaction times of a control (no-rest) group increased steadily within flight legs, and there were twice as many lapses in concentration during the vigilance task compared with the rest group.
- 5.2.3 The possible effects of sleep inertia following awakening from the nap were not fully reported in this study. In the 20 minutes immediately following awakening, the crew was given a 3-minute recovery period before commencing two tasks: an operational problem (calculation of gross-weight take-off) lasting 7 minutes and, subsequently, a 10-minute vigilance task. For reasons, which are not clearly stated, only the results of the vigilance task were reported. Rosekind et al. found no decrements in performance on this task, which started 10 minutes after awakening. Therefore, it is possible that any sleep inertia may have dissipated by this time, and given way to the beneficial effects of the nap.
- 5.2.4 There is little evidence to support the recommendation that naps on the flight deck should be limited to 40 minutes to minimise the possibility of entering deep sleep and hence sleep inertia. Rosekind et al. appear to base this choice of duration on a review by Dinges [24], but the information supplied relates to the REM sleep latency, and not latency to SWS. Normative data for the latency to various sleep stages for different age groups have been reported by Williams et al. [111]. For 35 to 45 year olds, the average latency to stage 3 sleep is between 35 and 40 minutes, ranging between 12 and 58 minutes. Hence, terminating the nap at 40 minutes may result in sleep inertia due to individuals awakening during SWS (see Section 2.1.3). In addition, given this range of values, it is likely that at least some individuals will enter SWS during a 40-minute rest period. Rosekind et al. reported that pilots obtained an average of 8% SWS, showing that SWS did occur to some extent within the 40-minute period.
- 5.2.5 Rosekind et al., [83] did not provide data on the stage of sleep on awakening, and tested pilots after they may have recovered from sleep inertia (10 minutes after waking). In addition, Sallinen et al. [85] reported the duration of sleep inertia to be between 10 and 15 minutes after a 30 or 50-minute nap opportunity during a night shift.
- 5.2.6 Limiting the duration of the nap opportunity to 40 minutes in order to minimise the possibility of entering SWS and therefore reduce the effects of sleep inertia may be problematic. After a period of sleep deprivation, SWS occurs more rapidly and lasts longer [82]. For instance, sleep loss may accumulate during the layover [75, 87], and so there may be a greater requirement for sleep, and especially SWS, during the return flight (see Section 2.3). Hence variations in the requirement for SWS may influence its latency and duration within a 40-minute nap opportunity. Indeed,

Rosekind et al. [83] reported a significantly greater percentage of SWS during naps on overnight flights than on daytime flights (11.4% and 4.3% respectively).

- 5.2.7 The avoidance of SWS may adversely affect improvements in performance. However, the relationship between nap duration, sleep stages and subsequent performance benefits has not been empirically investigated. In addition, limiting the nap opportunity period on the flight deck to 40 minutes may result in some individuals obtaining very little sleep due to the disturbing environment (e.g. noise, light etc. see Section 2.5).
- 5.2.8 Overall, Rosekind et al. [83] demonstrated that a 26-minute nap maintained alertness during long-haul flights. However, it is possible that sleep inertia occurred during the 10 minutes which elapsed between awakening and the onset of the vigilance task. Limiting the nap opportunity period to 40 minutes did not avoid SWS. The latency to SWS varies as a function of duration of prior wakefulness, time of day and age, as well as between individuals.
- 5.2.9 Subsequent to the study by Rosekind et al. [83], a second study into the effectiveness of flight deck napping in 3-crew (Captain, First Officer, Flight Engineer) long-haul operations was completed by Simons and Valk [88]. Data were collected from 59 pilots flying North-Atlantic B747-300 routes. During the flights the Captain and First Officer were asked to complete a dual vigilance and tracking task on a palmtop computer and to wear an activity monitor. In addition, crews rated alertness using the Stanford sleepiness scale and, if appropriate, sleep quality, although objective measures of sleep (EEG) were not obtained. Performance and subjective measures were taken approximately 15 minutes before and after the rest period and 30 minutes before the top of descent. However, the duration of the naps was not reported.
- 5.2.10 For both the outbound and return flights, rest on the flight deck was considered to improve alertness and tracking performance up to the top of descent. Those crews who had rested showed improved performance on the tracking task whereas performance was impaired in those who had remained awake (the no-rest group). No differences in performance for the rest and no-rest groups could be detected using the vigilance task during both the outbound and return trips.
- 5.2.11 For the outward flight, crews who had rested were more alert at the top of descent than the no-rest group. However, there were no differences in alertness post-rest between the rest and no-rest groups. On the return flight, crews who had rested were more alert post-rest and at the top of descent than the no-rest group.
- 5.2.12 Almost half the pilots (outbound flights 48%, inbound flights 41%) who participated in the trial reported that they were unable to sleep during the scheduled rest period. Crews also commented on the shortcomings of the flight deck seat and, in particular, the absence of a headrest was considered to be detrimental to the quality of sleep.
- 5.2.13 Overall, the evidence suggests that napping on the flight deck may help to maintain alertness and performance on certain tasks (perceptual-motor and vigilance) throughout a long-haul flight. However, it seems that it is difficult to initiate and maintain sleep in the flight deck environment. In the cases where sleep is achieved, the extent and duration of sleep inertia on awakening is unknown.
- 5.3 **Other studies of rest on the flight deck**
- 5.3.1 In a recent study, the quality of sleep in a seat on the flight deck of a Boeing 767 was investigated [93], during flights of between 9 and 10 hours. The seat was located to the rear of the flight deck and, when it was reclined, the pilot's legs were in front of the flight deck door. Crews had to improvise their leg support with flight bags. This position meant that pilots attempting to sleep were often disturbed by other people

entering or leaving the flight deck. Subjective estimates of sleep duration and quality were obtained, together with details of those factors that disturbed sleep.

- 5.3.2 In spite of the uncomfortable conditions and the poor leg support, 65% of the crews managed to achieve some sleep, and those that did slept for an average of 54 minutes. However, the duration of the rest period and the amount of sleep obtained varied according to the length of the flight, timing of the duty period and the time within the flight when the pilot attempted to rest. The longest periods of sleep tended to occur towards the end of flights that departed in the evening. Improvements in alertness following naps in the seat were consistent with the earlier NASA study. Nevertheless, there were occasions, towards the end of the flights, when the nap was insufficient to prevent the development of high levels of fatigue.

5.4 **Scheduling in-flight rest on the flight deck**

5.4.1 **Two-pilot crews (unaugmented)**

- 5.4.1.1 Even when the use of in-flight rest on the flight deck is not specifically permitted, such as with two-pilot unaugmented crews, sleep does occur [83]. Schedules should be designed to avoid high fatigue levels, and hence the need to nap, but unexpected events may lead to a requirement for a short, in-flight nap. Due to the limitations of this operational situation, the rested pilot may be required to resume duties shortly after awakening from a nap. Sleep inertia may occur during this time, resulting in impaired alertness and performance (see Section 4.4).
- 5.4.1.2 There are other safety implications associated with the flight deck rest of two-pilot unaugmented crews. It is important to ensure that the crew member who is not resting, i.e. the operating pilot, remains awake and alert. The introduction of an alarm system to monitor the status of the operating pilot may be one way of addressing this issue. Research has been carried out to develop a monitoring system based on wrist activity [57]. Other monitoring systems integral to the flight deck have been introduced [94].
- 5.4.1.3 Recently, there has been much debate concerning in-flight napping in two-crew operations, and various amendments to the current Joint Aviation Authorities operating requirements have been discussed. The Centre for Human Sciences, in conjunction with other research groups within Europe that are studying aircrew fatigue, has provided input to this debate in the form of the following 5 guidelines:
- i) In-flight napping should not be pre-planned on 2-crew operations.
 - ii) Napping should only be used in exceptional circumstances to overcome high levels of fatigue that could not be anticipated at the start of the flight.
 - iii) When naps are taken, they should be short. It is recommended that the maximum duration of actual sleep time should be 30 minutes. A minimum 20-minute period should be allowed after waking to overcome the effects of sleep inertia and to allow for adequate briefing.
 - iv) There should be a formal wake-up call that should not be from the operating pilot.
 - v) Measures should be in place to ensure that the operational pilot is reactive.

These guidelines have been based on a careful consideration of several factors, including the need to balance the benefits of in-flight napping against the risks that may be associated with the effects of sleep inertia.

5.4.2 **Two-pilot plus flight engineer (unaugmented)**

- 5.4.2.1 For some aircraft, such as the B747-100, the certified crew complement is two pilots and a flight engineer (FE). This allows the more generous limits for 3-pilot operations, contained within CAP371, to be applied. In this situation the third crew member is considered to perform a monitoring role throughout the flight. Crew rotation (where one individual rests whilst the other two remain on duty) does not occur and all members of the crew are required to remain awake throughout the flight. However, it is generally understood that pilots operating under these conditions do take naps.
- 5.4.2.2 During long-haul return trips between Saudi Arabia and Indonesia [92], extensive napping did occur among unaugmented crews (two pilots and a flight engineer) and this was beneficial for subsequent levels of alertness. During the 207 flights that were monitored, 51 in-flight naps were reported. The average duration was 47 minutes, with most naps occurring during the return flight when the aircraft had no passengers. Napping during the return flight could therefore have been taken away from the flight deck in passenger seats, although no information was available regarding the location of the rest. The majority of the naps were taken between 2 and 5 hours after the start of the duty period. In addition to the naps recorded in crew diaries, there was also evidence that some naps were not reported. This information was obtained from recordings of activity made via accelerometers strapped to the wrist. There was evidence of high fatigue levels when return flights departed in the early morning or in the evening. It is likely that more effective rest would have been achieved if crews had been given the opportunity to rest in crew bunks.

6 **Sleeping in bunks**

6.1 **Quality of sleep in bunks**

- 6.1.1 Sleep in bunks during long-haul flights has been reported to be poorer than sleep in a bed [4, 72]. This has been attributed to both environmental and non-environmental factors such as noise, temperature, bedding, and insomnia caused by anxiety. In a retrospective survey of long-haul pilots, the most frequently cited factor that disturbed sleep in-flight was random noise (59% of respondents). When crews were asked to complete a similar questionnaire in-flight, random noise was again listed as the most disturbing factor [71].
- 6.1.2 Other factors that have been attributed to poor sleep on board aircraft are: inadequate bedding, turbulence, general background noise of the aircraft, low humidity, high temperature [4, 71, 74, 75, 87], not feeling tired and anxiety [72].
- 6.1.3 In their survey of in-flight rest, Pascoe et al. [72] were able to correlate some sleep-disturbing factors with subjective assessments of sleep quality and with alertness at the end of the sleep period. Both turbulence and random noise impaired sleep quality and subsequent levels of alertness. The constant ambient noise of the aircraft was negatively related to the quality of sleep, and alertness after sleep was reduced by feeling too hot. The duration and quality of sleep, as well as alertness after sleep, were all reduced as a result of 'having thoughts on one's mind' and 'not feeling tired'.
- 6.1.4 The effect of a poor sleep environment was highlighted by the subjective quality of sleep that crews obtained in temporary bunks assembled on a Boeing 767 [93]. There was no means of controlling the flow of air, and the bunk compartment was not adequately light-proofed. The crews also complained about the lack of comfort and inadequate bedding. Compared with crews resting at a similar time of day and on a flight of similar duration in the standard bunks on the Boeing 747-400 [71], the crews on the Boeing 767 slept for approximately 30 minutes less.

6.1.5 To optimise the quality of rest in-flight, it is therefore necessary to ensure that the bunk facilities are provided with good environmental control, isolation from disturbing factors, and eyeshades and earplugs [74]. However, crews will still be exposed to some factors that cannot be moderated e.g. turbulence.

6.2 **Three-pilot (augmented) crews: single rest opportunity**

6.2.1 In-flight rest is taken in a bunk as a single period for many three-pilot augmented crews. The aircrew bunk is usually located immediately behind the flight deck. Augmented crews rotate from the flight deck into the bunk, with the relief crew member taking the first opportunity to rest. The length of the rest period is dependent on the flight length and crew composition. For a three-pilot crew this means that the cruise phase of the flight is, in general, split into three equal rest periods.

6.2.2 The departure time and the timing of the rest period are important factors influencing the quality of sleep in bunks [71, 74]. In-flight sleep quality and quantity are likely to be optimum when the scheduled rest follows a reasonable period of wakefulness and coincides with the phase of the circadian cycle during which sleep normally occurs. Difficulties initiating and maintaining sleep may arise if individuals attempt to sleep at other times (see Section 2.2).

6.2.3 The timing of the flight will also influence the quality of sleep. Sleep was less disturbed on a flight departing in the early evening with minimal time zone change, than on an eastward flight with a daytime departure. Individuals attempting to rest following a mid-day departure had greater difficulty sleeping than those attempting to sleep in the early evening [71].

6.3 **Double crews: two rest opportunities**

6.3.1 From the above sections (5.4.1-6.2) it is clear that the timing of rest within a flight is one important factor determining the quality of sleep. Although the prime consideration should be the scheduling of rest for the crew responsible for landing the aircraft, the relief crew should also obtain some benefit from the use of in-flight rest. With a four-man crew, two individuals rest at the same time (i.e. the 2 relief or 2 operating crew) and therefore the rest period is approximately half the duration of the cruise phase. Generally, the relief crew are scheduled to rest during the early part of the flight when they are more likely to experience difficulties sleeping.

6.3.2 A study has investigated whether the use of two short rest periods may be more beneficial, in terms of the quality of sleep, than one long opportunity [75]. Two strategies were employed: strategy one involved the main and relief crews each taking a single long rest period; strategy two involved aircrew alternating in the rest facilities, with each member taking two shorter rest periods. The outbound flight departed from London at 12:00 UCT and the return departed Seoul at 03:30 UCT (12:30 local time).

6.3.3 During outbound flights, most aircrew who were scheduled with two rest periods chose to go into the bunk on only one occasion (4/12 during the first rest period, and 10/12 during the second). All individuals scheduled with one long rest period attempted to sleep. On average, the TST obtained by pilots who had two short opportunities to sleep was less than that obtained by crews who took one long rest period (108 minutes compared with 143.8 minutes). When comparisons were made between individuals who were scheduled with a single long nap, those who had slept during the first half of the flight were found to have spent less time asleep and in bed than those who slept in the second half of the flight.

6.3.4 The requirement for naps on the return flight was different from the outbound flight. There were no differences in sleep duration or quality between the early or late nap

periods. It was concluded that this may have been attributable to an increased need for sleep resulting from sleep loss and disruption to the circadian rhythm during the layover. This was reflected by significantly greater TST, stage 2 and REM sleep compared to the outbound flight.

6.3.5 These findings confirmed those of other studies that have also shown that the quality of rest on long-haul flights is influenced by the time of departure and the requirement for sleep [71, 87]. It was concluded that when the requirement for sleep is high (e.g. during the second part of the flight, during a night flight or when the crews are unacclimatised) it is more beneficial to take one long rest period.

6.3.6 When the requirement for sleep is low (e.g. during the first part of a flight with a morning departure) it may be more beneficial for crews to have two opportunities to rest so that they have the chance to obtain some sleep during the flight.

6.4 **In-flight sleep and sleep inertia**

6.4.1 Simons et al. [87] recorded the quality of sleep during a 1.5-3 hour nap in a bunk on civil aircraft. They found that those pilots who obtained less SWS performed better on a vigilance task (undertaken 15 minutes after awakening) than those whose sleep consisted of significantly more SWS. Performance benefits were reported following in-flight rest, although sleep inertia was present for a vigilance task for approximately 30 minutes after awakening. Both Simons et al. [87] and Robertson et al. [75] recommended allocating the final rest period to the aircrew responsible for landing to ensure they are alert during this phase of the flight.

6.5 **Comparison between rest taken in a seat and in a bunk**

6.5.1 Spencer and Robertson [93] compared the quality of sleep, based on subjective ratings, obtained in a reclining seat on the flight deck with that taken in a bunk. Sleep in the bunk was considerably better than that in the seat, in terms of the ability to fall asleep and the quality and quantity of sleep obtained (Table 1). In addition, levels of alertness were higher after rest taken in the bunk than in a seat.

Table 1 Subjective assessment of sleep during in-flight rest periods

Sleep variable	Seat	Bunk
Number succeeding in getting to sleep	65%	82%
Average sleep duration (hours)	0.57	1.22
Average sleep duration (hours) - excluding individuals who did not fall asleep	0.91	1.45
Average sleep quality (where 1= extremely good, 7=extremely poor)	5.41	4.52
Average sleep quality - excluding individuals who did not fall asleep	5.05	4.33

6.6 **Future operations**

6.6.1 Future operations with ultra long-range (ULR) aircraft (e.g. A340-500) will involve flights in excess of those currently being undertaken and they will fall outside the scope of existing flight time limitations. For some routes it is proposed that block times would be in the region of 19 hours. To advise operators on the management of alertness and in-flight rest, some initial studies have been completed.

- 6.6.2 The advice was based partly on the predictions of a model of bunk sleep developed from data collected during a questionnaire study completed during the 1990s [72]. The model predicts the duration of sleep based on two factors, the duration of the rest period and the time at which it starts [90]. The conclusions from this modelling exercise were that to maintain levels of alertness within acceptable limits, crews should be advised of the benefit of taking two rest periods. Using this strategy, a crew of 4 could operate ULR flights, subject to a number of provisos, namely: the rest facilities should be of a high standard and provide a comfortable environment that is conducive to sleep, and the initial operations should be monitored to ensure that individuals are able to achieve sufficient sleep.

7 Conclusions

- 7.1 Fatigue, resulting from prolonged periods of wakefulness and time on duty, has been shown to impair the performance of subjects in the laboratory, and aircrew during long-haul flights.
- 7.2 Naps are a beneficial countermeasure to fatigue, and when taken in flight can increase levels of alertness towards the end of a duty period. One study has shown that the use of a 40-minute nap opportunity on the flight deck was beneficial in maintaining alertness, although sleep inertia may have occurred on awakening.
- 7.3 The determination of the optimum nap duration should take into account two factors: the duration and magnitude of sleep inertia, and the duration and extent of the beneficial effects on alertness and performance. Whilst the effects of sleep inertia following short naps (e.g. 10 minutes) are limited, the long-term benefits are not as great as those following longer naps (e.g. 40–60 minutes). With a longer period of sleep, sleep inertia is more severe but the beneficial effects can be sustained over a longer period.
- 7.4 Naps are most effective if they are taken prior to the onset of fatigue rather than after it has become established. The ability to nap is influenced by factors such as the time of day and the time since the last sleep. It is easier to initiate sleep around the time of the body temperature minimum (02:00 - 06:00). If a nap is taken too soon after awakening from nocturnal sleep (07:00 - 12:00) or during the forbidden zone for sleep (17:00 - 21:00), it will be difficult to fall asleep and sleep quality will be reduced. Napping may affect the quality and onset of subsequent sleep if taken in close proximity to the next main sleep period.
- 7.5 Individual differences also affect the ability to nap: some individuals find it easier to nap than others. Sleep quality reduces and sleeping habits and patterns become more difficult to alter as age increases.
- 7.6 Environmental factors such as noise, temperature, humidity, and the sleeping facilities (e.g. bed, angle of chair backrest, inadequate bedding) have all been shown to affect the duration and quality of sleep. Factors such as not being tired and anxiety are also likely to disturb sleep. In general, sleep disturbances arising from environmental conditions lead to more awakenings, increased latency to sleep, reduced TST and a greater predominance of the lighter stages of sleep.
- 7.7 Due to the backrest angle and the disturbing environment, it is likely that the quality of sleep in a reclining seat will not be as good as that taken in a bunk. For augmented crews, naps and periods of sleep in an aircraft bunk can be as recuperative as those taken in a bed provided that disturbances are minimised (e.g. the use of sound attenuation, air-conditioning, screening from light). In-flight sleep quality and quantity are likely to be optimum when the rest period follows a reasonable period of

wakefulness and coincides with the phase of the circadian cycle during which sleep normally occurs.

- 7.8 Sleep inertia, a transitory deficit in mood and performance, is the main factor limiting the effectiveness of naps. It occurs on waking and it may persist for between 5 and 35 minutes before performance returns to pre-nap levels. It therefore appears that at least 20 minutes should be allowed to elapse between awakening and the resumption of duties. However, this review of the literature has revealed large variations in experimental design and measurement, and this has often prevented direct comparisons between studies.
- 7.9 The severity of sleep inertia appears to be associated with the stage of sleep on waking and the duration of SWS. The latter is influenced by the amount of sleep loss prior to the nap, the time of day that the nap is taken, and the duration of the nap.
- 7.10 Sleep inertia may be reduced by ensuring crews are not excessively sleep deprived before the nap, and that the duration of the nap is sufficiently short to avoid SWS. However, the latter may not be feasible due to the variety of factors that influence the latency and duration of SWS. Other strategies such as the use of alerting stimuli on waking (e.g. pink noise or bright light) may aid recovery from sleep inertia, although they may not be practical on the flight deck.
- 7.11 There is currently a lack of information in the following areas:-
- The influence of the circadian rhythm on the composition of sleep stages during the nap and the subsequent impact on sleep inertia and performance;
 - The efficacy of using multiple napping strategies in-flight.

8 Recommendations

- 8.1 Because of the effects of sleep inertia, unaugmented crews who may need to operate at short notice should not rely on napping to maintain acceptable levels of alertness. Short naps on the flight deck of up to 30 minutes should only be used to combat unexpectedly low levels of alertness that could not have been anticipated when the flight was scheduled. If a single 30-minute nap is insufficient to raise alertness to an acceptable level, the use of further 30-minute naps should be considered, although further studies are required to establish the usefulness of this strategy.
- 8.2 To obtain 30 minutes of sleep crews should be provided with a 60-minute rest period, comprising an initial 5-10 minutes for sleep preparation, a 30-minute sleep opportunity, and a 20-minute recovery period.
- 8.3 Where augmented crews are provided, napping should be arranged to avoid sleep inertia. Therefore it is recommended that crews should not recommence duty for at least half an hour after waking from sleep. However, it is difficult to give more than general guidance on the required recovery time from sleep inertia. To maximise the beneficial effects of naps, rest periods should be scheduled to occur before an appreciable amount of sleep loss, but after a reasonable time of wakefulness.
- 8.4 The facilities in which crews rest and the rest environment should be as conducive to sleep as possible. Where rest is taken in a bunk this should include the provision of air-conditioning, adequate bedding, sound-proofing and screening from light. Benefits from rest taken on the flight deck will be more difficult to achieve. However, the resting crew member could be provided with ear-plugs and eyeshades in order to reduce the disturbances from random noise and light. To optimise the quality of rest

in a chair, the backrest angle should be at least 40° from the vertical, and leg support should be provided.

- 8.5 Where the crew is not augmented, measures should be in place to ensure that the operating pilot remains awake and alert should the other crew member require a short nap.
- 8.6 Generally, greater benefits are obtained from bunk rest if one long rest period is provided rather than two short rest periods. However, when departures occur early in the morning, it may be more beneficial to schedule two short rest periods so that some sleep can be obtained during the flight.
- 8.7 Aircrew should be provided with advice on strategies that may enhance their chances of sleeping during rest periods and help them avoid unintentional naps. The benefits of good sleep hygiene, relaxation techniques to aid sleep, the importance of nap placement, duration, circadian cycle and the influence of time-zone transitions on layover sleep should be highlighted.

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10 List of abbreviations

EEG	Electroencephalogram
REM	Rapid Eye Movement
SWS	Slow Wave Sleep
TST	Total Sleep Time