FATIGUE MANAGEMENT IN AVIATION: THE EFFECTS OF TIMING ON IN-FLIGHT SLEEP

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INTRODUCTION

The highly demanding nature of international aviation can generate elevated levels of fatigue in flight crew (1-3). Accordingly, long-haul crew are susceptible to increased sleepiness and impaired performance during flight (3-5). An opportunity for rest during flight duty can improve subsequent alertness and performance (4, 6), and is thereby a valuable means of counteracting the negative effects of work-related fatigue.

Previous research has indicated that the amount and quality of sleep obtained during a break from duty is dependent on the timing of the break (7, 8). As such, variability in the distribution of rest periods within long-haul flight sectors may influence the recuperative value of sleep obtained by crew. Field and simulator studies have revealed that an extended time on task generates elevated levels of fatigue (9-14). Indeed, during long-haul flight, progression of the duty period and time at the controls is associated with a higher frequency of microsleep events, particularly in the final portion of flight (3, 4). Together, this research illustrates an accumulative nature of fatigue and an increased propensity for sleep in the later stages of long-haul flight.

When given the choice between an early or a late rest episode during flight, crew rarely select the first opportunity for sleep (4, 15). It is suggested that flight crew prefer to utilise later rest positions given that, early in the flight, they remain alert from layover or home sleep and have less need for rest. As a result, when initiated in the latter stages of the sector, flight crew may experience sleep of increased length and improved quality. Indeed, comparisons of sleep periods taken in the first and second half of flight demonstrate that the latter sleep period is associated with longer sleep attempt and sleep time, shorter onset latency, and increased efficiency and quality of sleep (6, 16, 17). These differences in quantitative measures of sleep persist when controlling for the amount of sleep in the preceding period (17).

Despite the findings of the aforementioned studies, a standardised protocol for the allocation of in-flight rest periods is not currently implemented within the Australian commercial aviation industry. Australian flight crew distribute rest periods on a mutual ‘ad-hoc’ basis. As such, it is important to determine the most effective allocation of rest periods in order to maximise their benefit. Consequently, the objective of this study is to investigate the influence of timing of in-flight breaks on the duration and quality of sleep that is obtained. It is
hypothesised that sleep periods allocated later in the flight sector will be of (1) longer duration and (2) higher subjective quality compared to sleep earlier in the flight.

METHODS

Participants

The current analysis included data from 102 long-haul flight crew, consisting of 34 Captains, 23 First Officers, and 45 Second Officers (97 male, 5 female). All flight crew were employees of Qantas Airways Ltd., the primary operator of commercial international flight in the Australian aviation industry. Participants (22-56 years, mean ± s.d. = 41.29 ± 9.70 years) were recruited using introductory letters via company noticeboards and intranet. Qantas flight crew are subject to regular physical examinations as part of their employment, so were assumed fit to participate in the study. Flight crew gave written informed consent to participate and were not compensated above their usual wage. Ethics approval was granted by The University of South Australia Human Research Ethics Committee.

Flight schedules

Qantas Airways operates long-haul flight patterns to multiple global regions throughout the day and night. Flight crew and patterns of flights assessed in the current analyses were selected as a representative sample of common operations within the airline. The majority of international flight patterns departed from and terminated on the east coast of Australia (universal time code, UTC +1000h).

In general, international flight locations were clustered into three regions; the United States, Asia, and Europe. The primary destination of flights to the United States was Los Angeles (UTC -8:00). Destinations in Asia were within timezones ranging from UTC +7:00 (Bangkok, Jakarta) to UTC +9:00 (Narita). Flight patterns to Europe terminated in London (UTC 0:00), or in Frankfurt, Paris, or Rome (UTC +1:00). All flight patterns to Europe included a layover in Asia on both the outward and return sectors.
Procedure and Materials

Data were collected between May 2001 and September 2003. Flight crew were requested to participate for a period of at least 15 consecutive days. This permitted the collection of ‘baseline’ data for at least four days prior to departure from Australia and for at least four days following return from an international flight pattern. On average, flight crew participated for 24.25 ± 10.00 days (mean ± s.d.). Data collection was incorporated into the usual duty rosters of Qantas Airways, with flight crew selecting their own patterns of sleep and wake.

The in-flight sleep/wake behaviour of flight crew was monitored objectively using wrist activity monitors (Mini Mitter, Sunriver, Oregon) and Sleepwatch software (Actiware-SleepTM, Cambridge Neurotechnology Ltd.). The activwatch contained a piezo-electric accelerometer that detected wrist movement with a resultant force above 0.01g. Flight crew wore the activity monitor at all times during the participation period, unless showering or in situations where the monitor was likely to be damaged.

Subjective assessments of flight crews sleep/wake patterns were obtained using personal sleep/wake diaries. Flight crew recorded sleep location, the date and time of ‘lights out’ and wake, pre- and post-sleep fatigue levels, and the quality of the sleep period. Fatigue was scored using the Samn-Perelli fatigue scale, where 1 = fully alert, wide awake and 7 = completely exhausted, unable to function effectively (18).

Details of work schedules and individual flight sectors were reported in duty diaries. Duty information recorded included the start date and time of each duty period, time of flight sector departure and arrival, details of flight origin and destination ports, and the number of crew on duty. All information related to time was recorded in universal time code (UTC).

Measures

To examine the influence of rest period timing on the sleep obtained, several subjective and objective measures of sleep duration and quality were assessed. Measures of sleep extracted from activity monitor records and sleep/wake diaries included:

- Time in bed (TIB): period from lights off to lights on;
- Total sleep time (TST): period between sleep onset and wake time minus awakenings;
- Rest period efficiency: the percentage of time in bed spent sleeping [(TST/TIB) x 100];
- Sleep onset latency: time between lights out and sleep onset;
- Subjective sleep quality: self-rating of sleep quality on a 5-point scale where 1=very good and 5=very poor, compared to a ‘normal’ sleep; and
- Subjective recovery value: self-rating equivalent to post-sleep fatigue minus pre-sleep fatigue score, as determined using the the Samn-Perelli fatigue scale (18).

**Data analysis**

The current analyses examined international flight sectors with duration beyond 10 hours, and four crewmembers on active duty. It has been demonstrated that duty periods longer than 10 hours are associated with a significant increase in error and accident risk (19). Analysis only included flight sectors that incorporated one rest opportunity for each crew member.

For analysis purposes, individual sleep periods were binned in one-hour groups, based on the hour into the flight in which the sleep period was initiated. The beginning of the flight sector was represented as the moment the aircraft was removed from its blocks, prior to take-off. Separation of the data in this way produced samples of unequal size and increased the risk of Type I ($\alpha$) error. To ensure robustness, it was confirmed that the ratio of largest to smallest group size was not more than 4:1 (20).

Due to the repeated measures nature of the data, linear mixed model analysis was applied to account for both within and between flight crew variance (21). Separate mixed model regressions were applied to determine the influence of timing of the in-flight rest period on the duration and subjective quality of sleep obtained. The independent variable specified in each model was the timing of the rest period (hours into flight sector). The quantitative and qualitative sleep measures were specified as the dependent variables.

**RESULTS**

The 216 flight sectors that involved a single sleep period were of mean duration 12.68 (± 1.11) hours. During these flights, flight crew spent 3.58 (± 1.08) hours (range = 1.00-6.08 hours) attempting sleep and obtained 2.79 (± 1.07) hours (range = 0.15-5.27 hours) of sleep. On average, rest periods were initiated 4.84 ± 2.26 hours into the flight and were terminated 4.46 ± 2.16 hours prior to flight end.
Table 1 presents results of mixed model analyses for the timing of in-flight rest periods and six dependent variables of sleep quantity and quality. Significant parameter estimates were revealed for time in bed ($F_{8,207}=4.11$, $p<0.0001$), total sleep time ($F_{8,206}=4.89$, $p<0.0001$), and rest period efficiency ($F_{8,206}=3.26$, $p=0.002$). Linear mixed model analysis revealed that rest period timing in relation to flight start does not influence sleep onset latency, subjective sleep quality or subjective recuperative value of sleep.

**TABLE 1.** Mixed model results for test of fixed effects of timing of rest period on the sleep obtained during long-haul flights.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Numerator df</th>
<th>Denominator df</th>
<th>F</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>time in bed (TIB)</td>
<td>8</td>
<td>207</td>
<td>4.114</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>total sleep time (TST)</td>
<td>8</td>
<td>206</td>
<td>4.888</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>period efficiency</td>
<td>8</td>
<td>206</td>
<td>3.256</td>
<td>0.002</td>
</tr>
<tr>
<td>sleep onset latency</td>
<td>8</td>
<td>206</td>
<td>1.832</td>
<td>NS</td>
</tr>
<tr>
<td>subjective quality</td>
<td>8</td>
<td>196</td>
<td>1.501</td>
<td>NS</td>
</tr>
<tr>
<td>recuperative value</td>
<td>8</td>
<td>206</td>
<td>1.081</td>
<td>NS</td>
</tr>
</tbody>
</table>

Figure 1(a) illustrates the relationship between the timing of the in-flight rest period and time in bed. Visual inspection of the figure demonstrates that flight crew initiating sleep within one hour of flight start spent the most time attempting sleep within the in-flight rest facilities. On average, rest periods initiated up to one hour into the flight sector were associated with 43.0 minutes longer TIB than those initiated in the second hour. Flight crew initiating rest periods between two and seven hours into the flight spent similar periods dedicated to sleep attempt. After more than eight hours of the flight had elapsed, rest periods were associated with a further reduction in TIB. TIB for rest periods initiated 8 hours into the flight sector was 31.7 minutes shorter than for rest periods initiated 7 hours in the flight.

Inspection of Figure 1(b) indicates that total in-flight sleep time parallels the relationship of time in bed with respect to timing of the in-flight rest period. Most sleep was obtained during sleep episodes initiated one hour after flight start ($3.63 \pm 0.26$ hours). When between 2 and 7 hours of flight time had passed, TST ranged between $2.75 \pm 0.16$ and $3.10 \pm 0.30$ hours. Total
sleep time was truncated to 2.07 (± 0.24) hours after 8 hours of flight time and to 1.82 (± 0.24) hours beyond the 9th hour of flight.

Visual inspection of data for rest period efficiency (Figure 1(c)) indicates that the efficiency of the rest period was consistent across the first 7 hours of the flight sector (range= 76.99 – 81.13%). Subsequently, after more than eight hours of the flight had elapsed, the efficiency of the rest period was considerably reduced to below 66%.
FIGURE 1. Mean (± s.e.m.) (a) time in bed, (b) total sleep time, and (c) period efficiency for individual sleep periods initiated at advancing periods into the flight.
DISCUSSION

The aim of the current study was to examine the effect of timing of rest periods within long-haul flights on the amount and quality of sleep obtained. Separate mixed model regressions were conducted to examine the quantity and subjective quality of sleep during flight sectors associated with a single sleep attempt. The results revealed that time spent in bed and the amount of sleep obtained were significantly influenced by the timing of the in-flight rest period. In contrast, sleep onset latency and subjective ratings of sleep quality were not influenced by the timing of rest.

Numerous field and simulator investigations have revealed that an extended time on task is associated with elevated levels of fatigue (9-13). Therefore, it was anticipated that progression of the flight period and time at the controls may increase the level of fatigue experienced by flight crew. Corresponding to the anticipated increase in sleepiness, it was hypothesised that sleep periods allocated later in the flight would be of longer duration and better quality compared to sleep initiated earlier in the flight. However, the results of this study do not support this hypothesis.

During the international flights analysed, rest periods initiated within an hour of flight commencement were associated with the greatest time in bed and total sleep. For sleep periods beginning after the first hour, total sleep time and time in bed were constant. Notably, after two-thirds of the flight duration had elapsed [i.e. after 8 hours of a 12 hour flight], the time spent dedicated to sleep and the amount of sleep obtained were considerably shortened. It is apparent that this pattern of change in sleep duration was not due to increasing propensity for sleep across the flight sector. This is supported by the finding that sleep onset latency was not influenced by rest period timing. Sleep latency is measure of the need to sleep (22, 23). The constant sleep onset latency during all stages of flight indicates that flight crew were not experiencing increased sleepiness as the flight progressed.

The results of this study contrast with previous comparisons of the sleep obtained during different stages of long-haul flight (6, 17). In those studies, flight crew who initiated sleep later in flight spent more time attempting sleep and obtained more sleep than those who had a rest opportunity early in the flight. However, these studies are not directly comparable to the current study, given that they compared the sleep obtained during a designated rest opportunity assigned
in either the first or second half of the flight. In this way, they primarily investigated the influence of physiological factors and did not account for in-flight duty responsibilities. Conversely, the present study was conducted under conditions of normal in-flight operations, and did not dictate when flight crew were permitted to attempt sleep. As such, the timing and duration of sleep periods were more likely to be established by the strategies for sleep implemented by the flight crew themselves. The similar sleep duration identified throughout the majority of the flight sector indicates that flight crew generally agree on a consistent duration of rest that fits with flight deck duties and thereby rotate rest opportunities evenly amongst crewmembers. The current airline operation affirms that, in general, crewmembers employ a cooperative approach to the distribution of in-flight rest periods, involving mutual decisions amongst crew.

It is uncommon for flight crew to take advantage of an early opportunity for sleep during flight, given that they remain alert from layover or home sleep and have less need for rest (4, 15). In contrast, the current results revealed a percentage of crew that made use of rest periods during the immediate stages of flight, and subsequently obtained a large quantity of sleep. Sleep and in-flight fatigue management may be a high priority for the individual crew that attempt sleep during this early period. If they are mindful that other crewmembers are unlikely to sleep at this time, they may consciously take advantage of the opportunity for a longer rest before the original crew are in need of a break from duty. Consistent sleep onset latency indicates that the longer sleep period at the start of flight is not the result of increased sleep propensity.

At the other end of the flight sector (i.e. beyond the eighth hour of flight), the duration of sleep obtained was considerably reduced in relation to the earlier portion of the flight. It is likely that this is the result of in-flight operational influences rather than a reduced sleep need. That is, sleep periods initiated beyond this period are approaching the end of the flight sector and are therefore restricted by the upcoming descent, during which time all crew are required to be present on the flight deck. Furthermore, flight crew may be apprehensive to permit an extended sleep during the latter stages of flight because of sleep inertia that typically occurs after wake. Although a nap of duration of one hour can improve alertness (24), a longer period promotes sleep of increased depth and thereby increases the effects of sleep inertia (25). Flight crew may be concerned that they will not sufficiently wake prior to debrief and descent.
Rest periods during the late stages of the flight sector were associated with poorer efficiency. Given that sleep onset latency was not altered, the reduced efficiency of the period indicates a diminished ability to maintain sleep, manifest in an increased number or duration of awakenings. Sleep disturbance during this period may be related to apprehension concerning the pending flight end and associated duty responsibilities. Research has demonstrated that psychological factors including anxiety can strongly interfere with sleep (26, 27), and flight crew remain focused on flight deck operations during break periods within flight (28).

Although the efficiency of the rest period during the final stages of flight was reduced, flight crew did not report degraded sleep quality. Mixed model analysis indicated that the timing of in-flight rest periods did not influence subjective ratings of recovery value or quality of sleep. It has been revealed previously that the quality of sleep obtained during flight is poor in relation to sleep in the home or layover hotel environment (17, 29). As such, crew may perceive all in-flight sleep to be of low quality and recuperative value in general. Hence, the sleep that is obtained during flight is likely to be of similar subjective quality by comparison, regardless of when it occurs.

In the current study, subjective assessments of sleep quality were applied to minimise the degree to which the study protocol interfered with normal airline operations. However, it is important to note that people can experience difficulties in assessing their own sleep (30). Future research by our group will assess objective indications of sleep. As an example, performance on tasks related to psychomotor vigilance during flight may provide useful information on the restorative value of time in bed and the corresponding sleep obtained.

This study aimed to assess the influence of timing of breaks on sleep within flight. The results indicate that operational demands rather than physiological mechanisms have the greatest influence on sleep quantity. Research into the factors that influence sleep during long-haul flight may prove valuable in determining an optimal sleep strategy for maximising flight crew alertness, and thereby improving aviation safety. In-flight management of breaks based on momentary sleep need may prove most beneficial. In particular, flight crew should manage the fatigue level of the crewmembers required to land the aircraft, with the objective of maximising their level of alertness during this safety-critical high workload phase of flight.
ACKNOWLEDGEMENTS

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REFERENCES


