The Sleep, Subjective Fatigue, and Sustained Attention of Commercial Airline Pilots during an International Pattern

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THE SLEEP, SUBJECTIVE FATIGUE, AND SUSTAINED ATTENTION OF COMMERCIAL AIRLINE PILOTS DURING AN INTERNATIONAL PATTERN

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International commercial airline pilots may experience heightened fatigue due to irregular sleep schedules, long duty days, night flying, and multiple time zone changes. Importantly, current commercial airline flight and duty time regulations are based on work/rest factors and not sleep/wake factors. Consequently, the primary aim of the current study was to investigate pilots’ amount of sleep, subjective fatigue, and sustained attention before and after international flights. A secondary aim was to determine whether prior sleep and/or duty history predicted pilots’ subjective fatigue and sustained attention during the international flights. Nineteen pilots (ten captains, nine first officers; mean age: 47.42 ± 7.52 years) participated. Pilots wore wrist activity monitors and completed sleep and duty diaries during a return pattern from Australia to Europe via Asia. The pattern included four flights: Australia-Asia, Asia-Europe, Europe-Asia, and Asia-Australia. Before and after each flight, pilots completed a 5 min PalmPilot-based psychomotor vigilance task (PVT) and self-rated their level of fatigue using the Samn-Perelli Fatigue Checklist. Separate repeated-measures ANOVAs were used to determine the impact of stage of flight and flight sector on the pilots’ sleep in the prior 24 h, self-rated fatigue, and PVT mean response speed. Linear mixed model regression analyses were conducted to examine the impact of sleep in the prior 24 h, prior wake, duty length, and flight sector on pilots’ self-rated fatigue and sustained attention before and after the international flights. A significant main effect of stage of flight was found for sleep in the prior 24 h, self-rated fatigue, and mean response speed (all \( p < 0.05 \)). In addition, a significant main effect of flight sector on self-rated fatigue was found (\( p < 0.01 \)). The interaction between flight sector and stage of flight was significant for sleep in the prior 24 h, self-rated fatigue, and mean response speed (both \( p < .05 \)). Linear mixed model analyses indicated that sleep in the prior 24 h was a significant predictor of self-rated fatigue and mean response speed after the international flight sectors. Flight sector was also a significant predictor of...
self-rated fatigue. These findings highlight the importance of sleep and fatigue countermeasures during international patterns. Furthermore, in order to minimize the risk of fatigue, the sleep obtained by pilots should be taken into account in the development of flight and duty time regulations.

Keywords Fatigue, Commercial aviation, Cognitive performance, Sleep, Fatigue risk management, Work Schedules, Aerospace medicine

INTRODUCTION

Functional impairment associated with human fatigue is increasingly being recognized as a significant risk in commercial airline flight operations. Fatigue has been defined as the decreased capability to perform mental or physical work, or the subjective state in which one can no longer perform a task, produced as a function of inadequate sleep, circadian rhythm disruption, or time on task (Brown, 1994). Fatigue experienced by domestic and international pilots is largely due to sleep irregularities, long duty days, early starts, and night flying (Caldwell, 2005; Graeber, 1988; Klein et al., 1972). Furthermore, international pilots must also deal with multiple time zone changes, which can lead to circadian desynchrony (Graeber et al., 1986; Orlady & Orlady, 1999). Circadian desynchrony is caused by the inability of the 24 h period sleep/wake cycle (and other physiological measures) to instantly readjust to the rapid phase shift of zeitgebers (i.e., time givers, such as social cues/sunlight) that occur during multiple time-zone crossings (Arendt et al., 2000; Graeber, 1988). Research indicates that circadian desynchrony is associated with sleep disruption and decreased alertness (Caldwell & Caldwell, 2003; Gander et al., 1998; Graeber, 1988).

Several reports have identified fatigue as a contributor to numerous aviation incidents and accidents. For example, fatigue was determined to be a major factor in the Collision With Trees on Final Approach accident, where a Boeing 727 crashed short of the runway (NTSB, 2002). Similarly, the Swiss Aircraft Accident Investigation Bureau (BEAA, 2001) found that in the Flight CRX 3597 accident, the captain’s “ability to concentrate and take appropriate decisions as well as his ability to analyze complex processes were adversely affected by fatigue” (p. 11).

In a recent survey of 739 airline pilots, it was found that fatigue for international pilots was caused primarily by night flights (59%) and jet lag (45%) (Bourgeois-Bougrine et al., 2003). Pilots reported that fatigue caused a decline in attention and concentration and increased the difficulty in completing a task. These findings are consistent with other survey reports (e.g., ATSB, 2004, 2005) and commensurate with findings observed in the field. For example, Samel et al. (1997) collected pre-, in-, and post-flight data about pilots’ sleep patterns, task
load, fatigue, and stress using polysomnographic and subjective measures in 25 return long-haul operations. Results revealed that fatigue ratings and spontaneous micro-sleeps increased as a function of flight duration, particularly during extra and night-time flights. Similarly, Wright and McGown (2001) found episodes of sleepiness or actual sleep as measured by polysomnographic measures in pilots during international flights.

In spite of the growing evidence demonstrating detrimental effects of international flights on pilots’ sleepiness and subjective fatigue, little is known about the impact of international flights on pilots’ ability to operate aircraft safely. Furthermore, flight and duty regulations around the world typically take into account the amount of hours of work and hours of rest, but do not take into account how much sleep a pilot may have obtained prior to duty (Caldwell, 2005; Dawson & McCulloch, 2005). Indeed, numerous studies have established that the disruption or restriction of sleep can lead to heightened levels of subjective fatigue and/or impaired performance (e.g., Belenky et al., 2003; Lamond et al., 2005). Nonetheless, little scientific evidence has quantified the effects of prior duty and actual prior sleep obtained on the subjective fatigue and performance of commercial airline pilots. It is probable that this is one of the main reasons why regulators around the world have not integrated these factors into their flight and duty regulatory systems.

Based on these limitations, the primary aim of the current study was to investigate commercial airline pilots’ self-rated fatigue and sustained attention using a psychomotor vigilance task (i.e., PVT) before and after international flights. A secondary aim was to determine the impact of prior duty and prior sleep on pilots’ self-rated fatigue and sustained attention throughout a duty schedule (i.e., pattern).

**METHOD**

**Recruitment and Participants**

Participants were recruited from a population of approximately 230 captains and 210 first officers in the Boeing 747-400 fleet of a commercial airline that operated international flights into and out of Australia. A total of 19 male pilots (ten captains and nine first officers) participated in the study (mean age: 47.42 ± 7.52 years). Participants had been flying commercial aircraft for a total of 12,848 ± 4,392 h, had 18.16 ± 7.21 years of long-haul aircraft experience, and been flying Boeing 747-400 aircraft for a total of 3,678 ± 1,222 h. The age and experience of the pilots in the current sample were similar to that of the pilot population at the commercial airline.
Participation was on a voluntary basis, and pilots were free to withdraw from the study at any time. Given that pilots at the commercial airline are subject to twice-yearly physical examinations as part of their employment, all pilots were assumed fit to participate in the study. Advertisements were distributed to potential participants via company noticeboards and e-mail. Prior to commencing the study, participants were provided with an information sheet that contained details about the experiment. The information sheet also outlined their rights, including their rights to confidentiality and anonymity and their freedom to withdraw from the study at any stage without explanation or obligation. Informed written consent was obtained from each participant. Participants did not receive any additional payment above their usual salary. Ethics approval was granted by The University of South Australia Human Research Ethics Committee, and the conduct of the research was consistent with the standards of journal (Touitou et al., 2004).

Flight Pattern

The pattern targeted for the current study was a return Australia-Europe pattern. This pattern included four flight sectors:

1. Australia-Asia, with a layover in Bangkok or Singapore;
2. Asia-Europe, with a layover in London;
3. Europe-Asia, with a layover in Bangkok or Singapore; and
4. Asia-Australia.

Table 1 presents the mean flight departure and arrival times, sector durations, time zone change, and layover length of each intercontinental flight sector. The mean flight durations for the Asia-Europe and Europe-Asia sectors were approximately 4 h longer than the Australia-Asia and Asia-Australia flights. Pilots were provided with an opportunity to sleep on board the aircraft throughout the international pattern.

### Table 1

<table>
<thead>
<tr>
<th>Sector</th>
<th>Departure time (local)</th>
<th>Arrival time (local)</th>
<th>Duration (h)</th>
<th>Time zone change</th>
<th>Layover length (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUS-Asia</td>
<td>15:30–18:20 h</td>
<td>20:50–00:00 h</td>
<td>8.22 ± 0.82</td>
<td>−2</td>
<td>24.14 ± 0.76</td>
</tr>
<tr>
<td>Asia-EU</td>
<td>22:45–01:20 h</td>
<td>04:20–07:15 h</td>
<td>13.02 ± 0.61</td>
<td>−6</td>
<td>49.76 ± 11.77</td>
</tr>
<tr>
<td>EU-Asia</td>
<td>21:00–22:50 h</td>
<td>15:20–20:30 h</td>
<td>12.02 ± 1.12</td>
<td>+6</td>
<td>48.23 ± 0.86</td>
</tr>
<tr>
<td>Asia-AUS</td>
<td>17:40–21:10 h</td>
<td>05:10–09:50 h</td>
<td>8.52 ± 0.61</td>
<td>+2</td>
<td>—</td>
</tr>
</tbody>
</table>
Materials

Subjective Fatigue

Subjective fatigue was assessed using the Samn-Perelli Fatigue Checklist (Samn & Perelli, 1982). The checklist is a seven-point Likert scale with the following categories:

1 = “Fully alert, wide awake”;
2 = “Very lively, responsive, but not at peak”;
3 = “Okay, somewhat fresh”;
4 = “A little tired, less than fresh”;
5 = “Moderately tired, let down”;
6 = “Extremely tired, very difficult to concentrate”; and
7 = “Completely exhausted, unable to function effectively.”

The dependent measure derived from the Samn-Perelli Fatigue Checklist was self-rated fatigue. Higher scores indicated a higher level of subjective fatigue.

Sleep/Wake Schedules

Pilots’ sleep/wake schedules were obtained using sleep diaries and activity monitors. Pilots kept self-recorded sleep diaries for the entire study period (i.e., approximately 15 days) where they recorded information for each sleep period (including all in-flight sleep periods). This included the start and end time of each actual and attempted sleep period (i.e., bedtime), their subjective fatigue before and after each sleep period using the Samn-Perelli Fatigue Checklist, and perceived sleep quality using a five-point Likert Scale.

Objective sleep/wake schedules were assessed using activity monitors (Mini Mitter™, Sunriver, Oregon, USA), which were worn by each pilot for the entire study period. Activity monitors are devices worn like a wristwatch on the wrist that allow for 24 h recordings of activity (see Ancoli-Israel et al., 2003). The activity monitor is a light-weight device containing a piezoelectric accelerometer that measures the timing and quantity of body movement. It also contains light sensors that continuously record exposure to light. Data were recorded in 1 min epochs. The activity monitor is a reliable measure of sleep quantity, with a strong correlation of $r = .90$ with polysomnographic measures (Jean-Louis, 2001; Sadeh et al., 1994).

To determine participants’ actual sleep onset and sleep offset times, the bedtimes of the participants as designated in their sleep diaries were used.
in combination with the activity monitor files using an algorithm from SleepWatch Software. The following measures were derived from the sleep diaries and the activity monitor records:

**Sleep (in h) in the prior 24 h**: the amount of sleep that a participant had obtained in the 24 h prior to the start and end of flights; and

**Prior wake (in h)**: the number of hours that a participant had been awake since his last sleep period at the start and end of flight sectors.

**Work/Rest Schedules**

The work/rest schedules of the pilots were obtained from duty diaries that were kept for the entire study period (i.e., approximately 15 days). In the duty diaries, participants recorded information for every work period, which included the on-blocks and off-blocks time (i.e., start and end) of each flight, the origin and destination ports, and subjective fatigue using the Samn-Perelli Fatigue Checklist before and after each flight. Time was recorded as universal time, coordinated (UTC). The duty diaries were used to determine **duty length (in h)**, the number of hours worked between the start and end of a flight sector.

**Psychomotor Vigilance Task**

Sustained attention was measured using a PalmPilot version of the psychomotor vigilance task (PVT, Ambulatory Monitoring Inc., Ardsley, New York, USA), developed by the Walter Reed Army Institute of Research (see Thorne et al., 2005). This version of the task has been validated in several studies (Belenky et al., 2003; Lamond et al., 2005) and has been shown to be sensitive to the effects of fatigue, irrespective of how fatigue accumulates (i.e., through sleep deprivation, sleep restriction, or circadian factors).

In the current study, the PVT was loaded onto a Zire71™ PalmPilot (Palm, Inc., Sunnyvale, California, USA) that contains a color display and two push-button response keys. Participants attended to the display for the duration of the test (5 min) and pressed the left or right response key, depending on which was their dominant hand, as quickly as possible after the appearance of a visual timer bull’s-eye stimulus. The participant’s response stopped the timer stimulus, and the response time was displayed at the center of the bull’s-eye for a period of 500 ms. The interval between stimuli presentations varied randomly from 2,000–10,000 ms.

The dependent measure derived from the PVT was mean response speed, expressed as the mean reciprocal response time multiplied by 1000, as per standard methodology (e.g., Belenky et al., 2003). Lower scores indicated reduced sustained attention and greater level of impairment.
Procedure

Approximately one week prior to the international pattern, pilots were sent a package that contained an information sheet, consent form, a demographic questionnaire, a sleep and duty diary, an activity monitor, and a Zire71™ PalmPilot containing the PVT software. In order to familiarize participants with the performance task and to extinguish learning effects, participants completed three practice trials of the PVT as soon as they received the package. (Learning effects are typically extinguished after three trials, according to Dinges & Kribbs [1991].) At this time, participants also commenced wearing the activity monitor and began to fill in the sleep and duty diaries.

During the international pattern, pilots filled in the sleep and duty diaries and completed self-ratings of fatigue before and after each sleep period. Furthermore, pilots completed a PVT task and self-rated their fatigue level approximately 5 min before and after each flight. Importantly, participants were instructed that operational requirements always took precedence over completing the experimental tasks. It should also be noted that completion of the PVT tasks and recording of sleep periods throughout the entire study were carried out unsupervised.

Statistical Analyses

Two types of analyses were conducted using SPSS software (version 11; SPSS Inc., Chicago, Illinois, USA). For the first set of analyses, separate repeated-measures analysis of variance (ANOVA) with two within-subjects factors were conducted to determine main effects of and interactions between flight sector (i.e., Australia-Asia, Asia-Europe, Europe-Asia, and Asia-Australia) and stage of flight (i.e., before flight, after flight) on the sleep of the participants in the prior 24 h, self-rated fatigue, and mean response speed (see Figure 1). If analyses revealed a significant interaction effect, post-hoc mean comparisons were conducted to determine the source of the significance. Mauchly’s statistic was calculated for each ANOVA to test for violations of the assumption of sphericity (Tabachnick & Fidell, 2000). Mauchly’s statistic was significant for all ANOVAs, so all $p$-values were corrected using the Greenhouse-Geisser epsilon.

For the second set of analyses, several linear mixed model regression analyses were used to determine whether factors associated with pilots’ sleep and/or duty history could predict self-rated fatigue and mean response speed. Mixed model analysis includes both fixed and random effects, taking into account that repeated measurements over time on each participant are most likely to be correlated (Everitt, 2004; Landau & Everitt, 2004). In the present analyses, sleep in the prior 24 h, prior wake time, and duty length were modeled by treating them as fixed
effects. Flight sector was treated as a repeated fixed effect, as this variable would have the same four levels in any repeat of the study. Participant-specific effects were modeled by treating them as random. Parameters of the models were estimated using a technique known as “restricted maximum likelihood,” which takes into account missing data (Landau & Everitt, 2004). Initial analyses using first-order auto-regressive (AR1) covariance structures indicated that the estimates of the AR1 rho parameter were not significant for any of the models. This indicated that simple scalar identity matrices could be used (SPSS, 2002). A Wald test statistic was employed to test the significance of the models.

As pilots had not worked prior to the start of flights, pilots’ self-rated fatigue and mean response speed at this time could not be predicted by duty length (i.e., length of flight). Consequently, self-rated fatigue and mean response speed data were analyzed separately for the start and end of flights.

RESULTS

Sleep in the Prior 24 Hours

Repeated measures ANOVA revealed no significant main effect of flight sector for participants’ sleep in the prior 24 h (F$_{3,51}$ = 2.74, $p = .06$). However, analyses did reveal a significant effect of stage of flight (F$_{1,51}$ = 64.32, $p < .001$) and a significant interaction between flight sector and stage of flight (F$_{3,51}$ = 4.79, $p < .01$). The amount of sleep obtained at the end of the flights was lower than the amount of sleep obtained at the start of flights (see Figure 2). Post-hoc mean comparisons revealed that the amount of sleep participants’ obtained per 24 h at the end of the third (Europe-Asia) and fourth (Asia-Australia) sectors was
significantly lower than the amount of sleep obtained per 24 h at the end of the first Australia-Asia sector (all \( p < .05 \)).

**Self-Rated Fatigue**

Repeated measures ANOVA indicated a significant main effect of both flight sector (\( F_{3,24} = 4.95, \ p < .01 \)) and stage of flight (\( F_{1,24} = 40.04, \ p < .001 \)) on participants’ self-ratings of fatigue. Self-rated fatigue was higher at the end of flights compared to the beginning of flights (see Figure 3). Furthermore, analyses revealed a significant interaction between flight sector and stage of flight on self-rated fatigue.
(F_{3,24} = 7.56, \ p < .01). Post-hoc mean comparisons revealed that the lowest fatigue ratings occurred after the third flight sector (i.e., Asia-Australia) compared to all other flight sectors (p < .05).

**Mean Response Speed**

Repeated measures ANOVA revealed no significant main effect of flight sector (F_{3,21} = 1.06, p = .39) but did reveal a significant main effect of stage of flight (F_{1,21} = 7.97, p < .05) on participants’ mean response speed. Mean response speed was significantly slower at the end of flights compared to the start of flights (see Figure 4). Analyses revealed no significant interaction effect between flight sector and stage of flight (F_{3,21} = 1.53, p = .24) on participants’ mean response speed.

**Mixed Model Analyses**

There were no significant models achieved for the prediction of self-rated fatigue and mean response speed at the start of flight sectors. It is probable that this was due to there being no significant differences between the start of flight sectors for each of the dependent variables. However, significant models for the prediction of self-rated fatigue and mean response speed after the flight sectors were achieved. As shown in Table 2, the amount of sleep in the prior 24 h was a significant predictor of both self-rated fatigue and mean response speed. Notably, flight sector was also a significant predictor of self-rated fatigue; however, the results indicated that later flight sectors were associated with lower self-ratings of fatigue. It is likely that this counter-intuitive finding may have

**FIGURE 4** Mean response speed (± S.E.M.) before and after the Australia-Asia (AUS-Asia: 8.22 ± 0.82 h), Asia-Europe (Asia-EUR: 13.02 ± 0.61 h), Europe-Asia (EUR-ASIA: 12.02 ± 1.12 h), and Asia-Australia (Asia-AUS: 8.52 ± 0.61) flight sectors. Mean layover length of the outbound Asia stopover was approximately half the length of the Europe and inbound Asia stopovers.
been caused by the fact that pilots’ self-rated fatigue after the third sector (Europe-Asia) was significantly lower compared to the other flight sectors, which may have influenced the linear regression analyses.

**DISCUSSION**

The risks associated with fatigue are becoming increasingly recognized in commercial aviation operations (Caldwell, 2005; Gundel et al., 1995). The findings of the present study provide evidence that at the end of international flights, commercial airline pilots experience higher levels of subjective fatigue and decrements in sustained attention compared to at the start of flights. Furthermore, the amount of actual sleep obtained by pilots in the 24 h prior to the end of flights appears to be a significant predictor of pilots’ subjective fatigue and sustained attention at the end of flights. These findings highlight the importance of adequate sleep during international patterns as well as the importance of in-flight fatigue countermeasures.

Across all flight sectors, participants’ sleep in the prior 24 h was significantly lower after flights compared to before flights. These results are consistent with previous research (Gander et al., 1998; Samel et al., 1997; Signal et al., 2004) and are not surprising, given that most of the time during flights should be spent awake and attending to operational tasks. Nevertheless, these data emphasize the notion that at the end of international flights, pilots typically experience reduced amounts of sleep, which may lead to elevated subjective fatigue and/or performance impairment, as evidenced by the findings of the mixed model analyses.

Specifically, the findings of the current study indicated that pilots’ self-rated significantly higher levels of fatigue at the end of flight sectors compared to before the flight sectors, with the highest ratings occurring

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**TABLE 2** Parameter Estimates (with standard errors), 95% Confidence Intervals, and \( p \) values for the Predictors of Self-Rated Fatigue and Mean Response Speed at the End of Flights

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Independent variable</th>
<th>Estimate (SE)</th>
<th>C.I.</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-rated fatigue</td>
<td>Sleep in prior 24 h</td>
<td>−0.12 (.06)</td>
<td>−0.24, −0.01</td>
<td>.045</td>
</tr>
<tr>
<td></td>
<td>Prior wake</td>
<td>−0.01 (.03)</td>
<td>−0.07, 0.04</td>
<td>.619</td>
</tr>
<tr>
<td></td>
<td>Prior duty</td>
<td>−2.18 (.04)</td>
<td>−0.99, 0.05</td>
<td>.560</td>
</tr>
<tr>
<td></td>
<td>Sector</td>
<td>−0.42 (.09)</td>
<td>−0.60, −0.25</td>
<td>.001</td>
</tr>
<tr>
<td>Mean response speed</td>
<td>Sleep in prior 24 h</td>
<td>0.11 (.04)</td>
<td>0.03, 0.19</td>
<td>.005</td>
</tr>
<tr>
<td></td>
<td>Prior wake</td>
<td>0.02 (.01)</td>
<td>−0.06, 0.05</td>
<td>.122</td>
</tr>
<tr>
<td></td>
<td>Prior duty</td>
<td>0.04 (.02)</td>
<td>0.01, 0.08</td>
<td>.062</td>
</tr>
<tr>
<td></td>
<td>Sector</td>
<td>0.08 (.05)</td>
<td>−0.02, 0.19</td>
<td>.106</td>
</tr>
</tbody>
</table>

Significant predictors shown in bold.
at the end of the last sector of the international pattern (i.e., following the Asia-Australia flight sector). However, the findings did not indicate that subjective fatigue linearly increased as a function of the number of flight sectors flown during the international pattern. Rather, the linear mixed model analyses indicated that self-rated fatigue levels decreased across the flight sectors. Importantly, though, this may be associated with the pilots’ self-rated fatigue levels after the third sector (Europe-Asia), which were significantly lower compared to the other flight sectors. This may have been caused by the fact that layovers in London, which were longer than the layovers in Asia, may have provided pilots with a greater opportunity to sleep and therefore recover compared to the other layovers. It should be noted that as subjective ratings can be an unreliable measure of fatigue (Bonnet, 2000), the current findings may be the result of an artifact associated with pilots’ expectations that they would typically feel tired at the end of flights. However, the present findings also revealed that pilots experienced reduced sustained attention after flights compared to before flights, as measured by the Psychomotor Vigilance Task (PVT).

Sustained attention to vigilance tasks is an important factor in pilot operations, as impaired sustained attention can lead to misses of vital environmental cues, which in turn may lead to subsequent errors (Wickens et al., 2004). Notably, results revealed no significant main effect of the flight sector and no significant interaction between flight sector and stage of flight on pilots’ mean response speed. This is quite interesting, given that these effects were found on subjective fatigue. These results may be illustrative of the view that subjective fatigue and sustained attention do not assess the same functional capacity (Signal et al., 2004). On the other hand, they may highlight the fact that subjective ratings can be an unreliable indicator of fatigue because they are also influenced by factors such as food intake, posture, ambient temperature, background noise, lighting conditions, mood, and participants’ expectations (Bonnet, 2000).

The findings that subjective fatigue is higher and mean response speed is slower at the end of flights compared to the start of flights suggest that the latter stages of flight (e.g., descent, approach, and landing) may pose a greater fatigue-risk to aviation operations compared to earlier stages of flight (e.g., early cruise). It has been well established that the descent-approach-landing phase is typically characterized by higher workload demands compared to other phases (e.g., cruise) (Orlady & Orlady, 1999; Thomas et al., 2000). Consequently, this stage may be the most critical with respect to operational safety as high workload demands may exacerbate pilots’ subjective fatigue and/or lead to a further reduction in pilots’ sustained attention. Evidently, the use of in-flight fatigue countermeasures (e.g., napping, caffeine, and food) by pilots prior to the latter
stages of flight appears warranted, as they might help offset heightened subjective fatigue levels and reduced sustained attention at the end of flights. While pre-flight and layover sleep is important, in-flight sleep is considered the most effective fatigue countermeasure, as sleep periods can occur close to operational events and may have the greatest direct influence on fatigue counteraction (Signal et al., 2004).

Interestingly, the mixed model regression analyses indicated that the amount of sleep obtained in the prior 24 h by pilots was a significant predictor of self-ratings of fatigue and the only significant predictor of sustained attention at the end of flights. In particular, a reduction in pilots’ prior sleep per 24 h was associated with an increase in self-rated fatigue and a reduction in mean response speed. This finding provides important evidence that pilots’ sleep is a better predictor of subjective fatigue and performance than pilots’ duty history. Notably, however, most flight and duty rostering systems currently employed by commercial airline organizations around the world are based solely on hours of work and/or rest, and do not take hours of sleep obtained by pilots into account (Dawson & McCulloch, 2005). The results of the current study suggest that this may significantly limit the capacity of commercial airline organizations to effectively manage fatigue in the workplace. What the current findings suggest is that commercial airline organizations should not only provide pilots with an adequate opportunity to sleep (i.e., rest breaks free from duty), they should also attempt to determine the amount of sleep pilots obtain during duty. This may help determine the fitness for duty of pilots prior to operating aircraft at the descent, approach, and landing phase of flights. In cases where adequate sleep has not been obtained, effective countermeasures may be employed or additional support may be supplied. If sleep data are unavailable to an organization, then an alternative is to use biomathematical sleep/wake models to predict the quantity of sleep obtained by pilots during specific flight patterns (e.g., Roach et al., 2004). A caveat to this approach, however, is that current sleep/wake predictive analyses tend to occur at the aggregate level, and therefore may be limited in their generalizability to individual cases.

The responsibility of pilots in their own management of fatigue during flight operations should not be ignored in this discussion. Our results demonstrate the necessity for pilots to obtain adequate sleep whenever possible before and during international flights. This may not only alleviate heightened subjective fatigue and/or reduced sustained attention at the end of flights, but it may also contribute to the reduction of fatigue-related errors, and even further, to the reduction of fatigue-related incidents and accidents.

Importantly, there are several limitations of the present study that need to be discussed. First, the effects observed during the current study may have been understated (or overstated) because of the small
sample size. Furthermore, a self-selection effect may have skewed the results, which may limit the ability to generalize the findings of the study (Meltzoff, 1998). Consequently, future research should attempt to repeat the study using a larger sample size from various airlines and employing random sampling methods to examine the impact of sleep and duty factors on subjective fatigue and performance across different international flight patterns. Second, previous research indicates that sleep efficiency can affect the subsequent alertness and performance of individuals (Rouch et al., 2005); therefore, this should be assessed using polysomnographic measures. However, as polysomnographic measures can be intrusive, labor intensive, and expensive, pilots’ sleep was not objectively measured throughout the current study. Third, the use of the PVT in the current study limits the generalizability of the performance findings to tasks that require sustained attention/vigilance skills only. Future research should attempt to examine the impact of fatigue associated with international flights on performance tasks (e.g., in flight simulators) that offer higher ecological validity to the cockpit environment. Fourth, the impact of workload may have influenced the results. Future research should attempt to control for this factor by using subjective scales such as the NASA-TLX (see Hart & Staveland, 1988). Finally, future research should attempt to control for individual differences in the ability to cope with fatigue, potentially by using post-flight questionnaires or interviews. Accordingly, individual differences in relation to demographic variables should also be considered in future research.

Like many industries involving shiftwork, fatigue poses a significant risk to safety in commercial aviation environments (Caldwell, 2005; Caldwell & Caldwell, 2003). This is particularly the case for international flights, where pilots often have to deal with sleep irregularities and the consequences of circadian desynchrony caused by multiple time-zone transitions (Caldwell, 2005; Graeber, 1988; Graeber et al., 1986; Klein et al., 1972; Orlady & Orlady, 1999). The present study has demonstrated increased subjective fatigue and reduced sustained attention at the end of international flight sectors, which may lead to increased error(s) and potentially an increase in the risk of commercial airline incidents and accidents. Furthermore, the findings demonstrate that the sleep obtained by pilots better predicts subjective fatigue and sustained attention compared to pilots’ duty history. Therefore, pilots’ sleep is an important factor that commercial airlines should take into account when developing flight and duty rostering systems. Importantly, the findings emphasize the importance of fatigue countermeasures and that obtaining adequate sleep by pilots during international patterns is fundamental to the management of fatigue in commercial airline flight operations.
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