Sleep on Long Haul Layovers and Pilot Fatigue at the Start of the Next Duty Period

Jan Cosgrave; Lora J. Wu; Margo van den Berg; T. Leigh Signal; Philippa H. Gander

INTRODUCTION: Layovers are critical for pilot recovery between flights and minimum layover durations are required by regulation. However, research on the factors affecting layover sleep and safety performance indicators (SPIs) before subsequent flights is relatively sparse. The present project combined data from 6 studies, including 8 long-range and 5 ultra-long range out-and-back trips across a range of different layover destinations (299 pilots in 4-person crews, 410 layovers, 1–3 d layover duration).

METHODS: Sleep was monitored via actigraphy from 3 d pre-trip to at least 3 d post-trip. Pilots rated their sleepiness (Karolinska Sleepiness Scale, KSS) and fatigue (Samn-Perelli scale, SP) at duty start for the inbound flight. Mixed model ANOVAs identified independent associations between fatigue and sleepiness SPIs and operational factors (domicile time of duty start for the inbound flight in six 4-h bins, layover duration, and total sleep time (TST) in the 24 h prior to inbound duty start).

RESULTS: TST was greatest on layovers ending between 1200–1559 domicile time (time in the city from which the outbound flight departed) and TST was a significant predictor of both KSS and SP ratings at duty start for the inbound flight.

DISCUSSION: TST in the 24 h prior to the inbound flight was greatest when duty start time allowed for the inclusion of a full domicile night time period. In this dataset, circadian end-time of layovers is a key determinant of pilot fatigue status at the beginning of the inbound duty period.

KEYWORDS: sleep of long haul airline pilots, safety performance indicators, actigraphy, Karolinska Sleepiness Scale, Samn-Perelli Crew Status Check.

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Pilot fatigue is defined as "a physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties."[12,13] Pilot fatigue has been identified as a contributor to operational errors, 'near-misses' and fatal accidents in civil aviation.[3,9] However, while fatigue is frequently cited as a safety risk, limited research is available on successful fatigue mitigation in commercial airline operations.[18] One such mitigation is the sleep obtained by pilots during layovers between long-haul flights, which enables them to recover from the outbound flight and prepare for the next flight.[19]

Airlines often have limited ability to control factors such as flight duration and timing.[19] However, layover duration is a potentially modifiable scheduling parameter. Few previous studies have addressed the effects of layover duration. A study by Roach and colleagues found that pilots who had a short (39 h) layover had higher subjective fatigue levels and poorer sustained attention when compared to those who had a long (62 h) layover.[19] Similar findings have also been reported by Lamond et al., who concluded that short layovers (< 40 h) do not allow pilots sufficient sleep opportunities to recover from the outbound flight.[16] However, for a long-haul flight with 3-pilot crews (Los Angeles-Auckland), increasing the layover from 1 to

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2 nights resulted in no significant improvement.[18] The authors propose that this may be due to a mismatch between the pilots' biological night and local night resulting from the time zone difference between the cities (3–5 h depending on the time of year), which could reduce the recovery value of the additional layover time. Different flight directions, durations, and departure times, as well as crew complement (3 vs. 4 pilots) mean that the available studies cannot be directly compared.

The recovery value of a layover is expected to depend on the duration and quality of sleep that pilots are able to obtain,[15] but research on the multiple factors that can influence layover sleep is sparse. These include pilot age, flight direction, layover duration, the scheduling of the layover relative to a pilot's circadian body clock cycle, and other activities available during a layover that might reduce the time spent trying to sleep.[20] Individual pilots also vary in the strategies they employ with regard to layover sleep timing in relation to circadian body clock time and local time.[5,10,15]

The available studies have limited sample sizes and statistical power. The present study combined data from six studies to expand current knowledge of the factors affecting pilots' layover sleep on out-and-back trips and the relationship between layover sleep and inbound preflight fatigue safety performance indicators (SPIs).

We predicted that layover duration and domicile duty start time for the inbound flight would both have significant effects on total sleep time (TST) in the last 24 h of the layover, which is expected to have the most effect on pilots' fatigue status at the start of duty for the inbound flight. Domicile time (time in the city from which the outbound flight departed) can be considered a surrogate measure of circadian body clock time, assuming that there is minimal adaptation to the layover time zone.[6] We also predicted that layover duration, domicile duty start time, time awake at duty start and TST in the 24 h prior to duty start would influence fatigue SPIs at the beginning of the inbound duty period.

METHODS

All studies had the support of the respective regulatory authorities, labor unions and airline management and were funded by the airlines, with the exception of the Singapore Airlines study which was funded by the Singapore Civil Aviation Authority. Each study underwent independent ethical review and approval. Participation in each study was voluntary and written informed consent was obtained. Subjects had the right to withdraw from the study at any time, and data confidentiality was strictly maintained.

Layovers Included

To maximize the comparability of layovers included in the analyses, they had to meet the following operational criteria: 1) layovers occurred between nonstop flights in an out-and-back trip pattern (single layover at one destination) and lasted 1–3 d; and 2) the preceding outbound flight crossed multiple time zones and was operated by a 4-pilot crew who had access to in-flight rest facilities with horizontal bunks in a compartment separated from the passenger cabin. At the time of data collection, outbound flights were classified as either long-range (LR) flights (maximum scheduled flight time 16 h) or ultra-long range (ULR) flights (scheduled flight time $>$ 16 h).

Subjects

There were 70 Delta Air Lines B-777 200-ER pilots[8] and 72 B-777 200-ER pilots from United Airlines[26] who were monitored as part of a 3-airline study requested by the U.S. Federal Aviation Administration (FAA) to compare flight crew fatigue on out-and-back LR and ULR trips (data for the third airline were not available for these analyses). For 69 Delta Air Lines pilots and 36 United Airlines pilots, data were available for 2 layovers (1 long range and 1 ultra-long range layover). There were 40 Singapore Airlines A340-500 pilots who were monitored as part of the operational validation of the first commercial ULR trips and 6 of these pilots were monitored twice, thus providing data for 2 layovers.[23] In addition, the following pilots were monitored on 1 out-and-back trip, providing data for 1 layover: 47 South African Airways A340-600 pilots who were monitored as part of the operational validation of a ULR trip to the USA[24]; and 34 Delta Air Lines B-767-300-ER and 36 Delta Air Lines A330-200 pilots from 2 more recent (unpublished) LR studies that were part of a successful safety case to the FAA (DAL A330 BCCR Class 1 Exemption No. 10909B).

The analyses were based on data from 128 Captains (median age = 56 yr, range = 41–63 yr; median flight hours = 19,000 h, range = 6497–32,000 h), 164 First Officers (median age = 47 yr, range = 29–63 yr; median flight hours = 12,560 h, range = 1800–33,000 h); and 7 In-Flight Relief Pilots (median age = 29 yr, range = 27–42 yr; median flight hours = 6265 h, range = 2420–7930 h).

Measures

The measures used in the studies follow the recent recommendation in the international fatigue management guidance material for airline operators[11] and they reflect current best practice and scientific understanding. The criteria for selecting these measures are that they have been scientifically validated in the laboratory and in aviation field studies; they do not jeopardize crewmembers' ability to perform their operational duties; and they have been widely used in aviation, so data can be compared between different types of operations.[6]

Sleep was monitored using wrist actigraphy (Actiwatch AW-64, AW2 or Spectrum, Philips Respironics/Mini Mitter, Bend, OR, USA) and duty/sleep diaries for 3 d before each study trip, during the study trip(s) and for at least 3 d after completion of each study trip. The data were analyzed using the software provided by the manufacturer on the medium sensitivity setting, in conjunction with duty/sleep diary timelines in which crewmembers recorded when they were trying to sleep. A custom-built program was used to calculate TST in the last 24 h of the layover, i.e., the 24 h prior to inbound duty start (TST).

Pilots were asked to rate their fatigue and sleepiness after reporting for duty but prior to the flight departing, and during the flight within an hour of top of descent (TOD). Sleepiness was measured on the Karolinska Sleepiness Scale (KSS) from 1 to 9, where: 1 = extremely alert; 3 = alert; 5 = neither sleepy nor alert; 7 = sleepy, but no difficulty remaining awake; and 9 = extremely sleepy, fighting sleep.[2,14,22] Fatigue was measured on the Samn–Perelli Crew Status Check from 1 to 7, where: 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.[21]

Duty start and end times were identified according to the international definition of a duty period, which starts when a crewmember is required by an operator to report for or to commence a duty and ends when that person is free from all duties. Inbound duty start times were converted to domicile time (time in the city from which the outbound flight departed) and categorized in 4-h bins (0000–0359; 0400–0759; 0800–1159; 1200–1559; 1600–1959; 2000–2359). This is assumed to be a reasonable surrogate measure for circadian phase. It should be noted, however, that the inbound flights analyzed in this study occurred after layovers lasting 1–3 d, during which there may have been some adaptation to the destination time zone. Thus, domicile time is expected to be a less reliable estimate of circadian phase on inbound flights than on outbound flights. Layover duration was categorized as ~24-h, ~36-h, ~48-h, or ~72-h, based on actual layover duration and the number of local layover nights included, e.g., layovers in Hong Kong with a median duration of 36.7 h and spanning one local night were categorized as 36-h layovers, whereas layovers in Shanghai with a median duration of 40.2 h, spanning almost two local nights, were categorized as 48-h layovers. Time awake was calculated as the time from the end of the last sleep period to the time of duty start for the inbound flight.

Statistical Analysis

Mixed-model ANOVA was used to identify associations between SPIs at inbound duty start and sleep/wake history, circadian phase, and layover duration. Linear mixed modeling was undertaken using the PROC MIXED procedure in SAS system for Windows (version 9.4; SAS Institute, Cary, NC). Subject ID (a unique 4-digit identifier) was included as a random effect to account for individual differences and for some pilots being monitored twice, thus the models control for differences both between and within subjects. The Kenward-Roger adjustment was applied to the degrees of freedom estimation. For each model, the assumptions of normality, linearity and constant variance were checked visually and the distribution of the Studentized residuals were tested with the Shapiro-Wilk test of normality and Levene's test for constant variance.[17] Where model residuals were heavily skewed, outcome measures were square-root transformed prior to subsequent model analyses. If the variances were not constant, then a more conservative P-value was used ($P < 0.01$ instead of $P < 0.05$).[25] Where outlying residual values were identified, the model was rerun without these. If removing the outlier(s) altered the findings, then the reported results exclude the outlier(s). Otherwise, the results reported are those including the outlier(s). Where main effects were statistically significant, the level of significance of post hoc t-tests was adjusted for multiple comparisons using the Bonferroni method.[1] To determine if it was statistically valid to include two or more potentially confounded predictor variables in the same model, correlation analyses and colinearity diagnostics were undertaken. Model structures are described below with their respective findings.

A summary of the trips available for analysis in this dataset is presented in **Table I**. The Lagos (LOS) layover is unusual as pilots are confined to a compound for security reasons, which restricts their ability to travel or engage in social activities. This may explain why pilots spend a disproportionate amount of the LOS layover sleeping. It was anticipated that this might bias the mixed model analyses involving TST in the 24 h prior to inbound duty start time. Therefore, models were conducted both with and without the LOS layovers.

RESULTS

A total of 410 layovers from out-and-back trips between 13 city pairs (5 ULR, 8 LR) were included in these analyses. **Table II** summarizes the data available for analyses within each 4-h inbound duty start time bin (domicile time). The 0400–0759 time bin was excluded from analyses because of the paucity of data ($N = 4$ layovers). **Fig. 1** shows the number of layovers available for analyses across the inbound duty start time bins.

Mixed model analysis of variance was used to examine whether TST in the last 24 h of the layover varied with the start time of the inbound duty period (domicile time). The model structure was: subject ID (random factor); and inbound duty start time in 4-h bins. Including the LOS layovers, TST varied by duty start time ($F(4, 365) = 17.74$, $P < 0.01$). Post hoc comparisons (with Bonferroni correction) indicated that the estimated mean TST was highest in the 1200–1559 time bin (510 min) relative to 0000–0359 (393 min); 0800–1159 (425 min); 1600–1959 (399 min); and 2000–2359 (392 min; all $P(t) < 0.05$; **Fig. 2**). When the LOS layovers were excluded the main effect of duty start time remained significant. The only change in the findings of the post hoc tests was that the difference between the 1200–1559 and 0800–1159 time bins was no longer significant.

Mixed model analysis of variance was also used to examine whether TST in the last 24 h of the layover varied with layover duration. There was only one inbound duty start time bin (0800–1159) where data were available for all three layover categories (~24-h, ~48-h, and ~72-h layovers). No LOS layovers ended in this time bin. The model structure was: subject ID (random factor); and layover duration (categorical variable). TST in the last 24 h of the layover did not vary significantly with layover duration, after controlling for interindividual variability. A comparable model found that time awake at the start of the inbound duty period did not vary significantly with layover

Table I. Summary of Flights.

OUTBOUND CITY PAIR	LAYOVER DURATION (MEDIAN, RANGE; h)	LAYOVER CATEGORY	N	OUTBOUND FLIGHT DIRECTION	TIME ZONES CROSSED BY OUTBOUND FLIGHT (h)
Atlanta-Dubai	48.5 (46.5-49.3)	~48 h	36	East	+8 (+9)*
Atlanta-Johannesburg	48.7 (45.8-50.9)	~48 h	69	East	+6 (+7)
Atlanta-Lagos	27.2 (25.5-29.5)	~24 h	53	East	+5 (+6)
	51.7 (51.3-52.1)	~48 h	2		
Atlanta-Tel Aviv	27.3 (26.3-29.0)	~24 h	11	East	+6 (+7)
	51.6 (51.4-51.7)	~48 h	2		
Johannesburg-New York	49.9 (47.5-51.1)	~48 h	47	West	-6 (-7)
Newark-Beijing	23.8 (22.3-24.7)	~24 h	9	West	-11 (-12)
Newark-Bombay	23.4 (22.0-25.2)	~24 h	36	East	+9 (+10)
Newark-Delhi	24.5 (20.5-27.7)	~24 h	10	East	+9 (+10)
Newark-Hong Kong	36.7 (31.8-37.8)	~36 h	33	West	-11 (-12)
Newark-Shanghai	24.5 (22.1-24.8)	~24 h	4	West	-12
Newark-Tokyo	24.7 (19.9-25.3)	~24 h	16	West	-10 (-11)
Seattle-Shanghai	40.3 (38.1-41.9)	~48 h	36	West	-9
Singapore-Los Angeles†	50.7 (49.5-51.7)	~48 h	18	East	+9
	75.0 (73.7-76.0)	~72 h	28		

* Brackets indicate the time zones crossed in hours during daylight savings.
† Six pilots participated twice.

duration. (The hypothesis was that a difference in time awake at duty start could indicate different sleep patterns between ~24-h layovers vs. ~48-h layovers vs. ~72-h layovers).

Mixed model analysis of variance was used to examine whether sleepiness and fatigue ratings at the start of the inbound duty period varied with sleep history or duty start time. The model structure was subject ID (random factor); TST in the 24 h prior to duty start; time awake at duty start; and duty start time in 4-h bins. Findings from these models (including the LOS layovers) are presented in **Table III**. KSS scores decreased with greater amounts of TST in the 24 h prior to duty start (the estimated size of this relationship could not be determined as the KSS was square-root transformed). For every 1-h increase in TST in the 24 h prior to duty start, Samn-Perelli fatigue ratings also decreased by an estimated 0.13 points. These findings did not change after removing the LOS layovers.

DISCUSSION

This study, based on a large dataset of pilots on transmeridian long-haul flights, provides the first systematic investigation of some key factors thought to be important determinants of layover sleep and safety performance indicators at duty start for inbound flights. Results indicate that TST in the 24 h prior to duty start varies with inbound duty start time (domicile time), with pilots obtaining significantly more sleep prior to duty periods starting in the 1200–1559 time bin compared to the other time bins. Considering domicile time as a surrogate marker of time in the circadian body clock cycle, the last 24 h of layovers ending between 12 noon and 4 p.m. domicile time would include a full sleep opportunity during the preferred part of the circadian body clock cycle for sleep.[4,22]

Layovers ending between 1600–1959 would also have included a full sleep opportunity in the preferred part of the circadian body clock cycle, but TST in the last 24 h was significantly shorter (mean = 399 min) than for layovers ending between 1200–1559 (mean = 510 min; Table II). The majority of layovers ending between 1600–1959 (95%) followed a westward flight and were 2-d layovers. In contrast, the majority of layovers ending between 1200–1559 (96%) followed an eastward flight and 46% were 1-d layovers. This suggests that prior flight direction and layover duration may also be important factors determining TST in the last 24 h of layovers, but the available data set did not allow more detailed analysis of these factors.

Analyses addressing the influence of layover duration on TST in the last 24 h of the layover, and on time awake at inbound duty start, were limited by the fact that such comparisons could only

Table II. Summary of Layovers Included in Analyses.

DUTY START (DOMICILE) TIME BIN*	*N*	PREVIOUS FLIGHT DIRECTION (EAST)	PREVIOUS FLIGHT DIRECTION (WEST)	LAYOVER DURATION (24 h)	LAYOVER DURATION (36 h)	LAYOVER DURATION (48 h)	LAYOVER DURATION (72 h)	TST † MEAN (min)	KSS MEAN	SAMN PERELLI MEAN
Total	410	265	145	139	33	210	28	450	2.68	2.13
0000–0359	29	0	29	29	0	0	0	393	3.07	2.59
0800–1159	106	106	0	31	0	47	28	425	2.75	2.26
1200–1559	162	155	7	75	0	87	0	510	2.54	1.96
1600–1959	78	4	74	4	0	74	0	399	2.70	2.07
2000–2359	35	0	35	0	33	2	0	392	2.74	2.29

* The 0400–0759 time bin was excluded from these analyses due to the limited data within this category ($N = 4$).
† TST was calculated for the 24 h prior to inbound duty start.

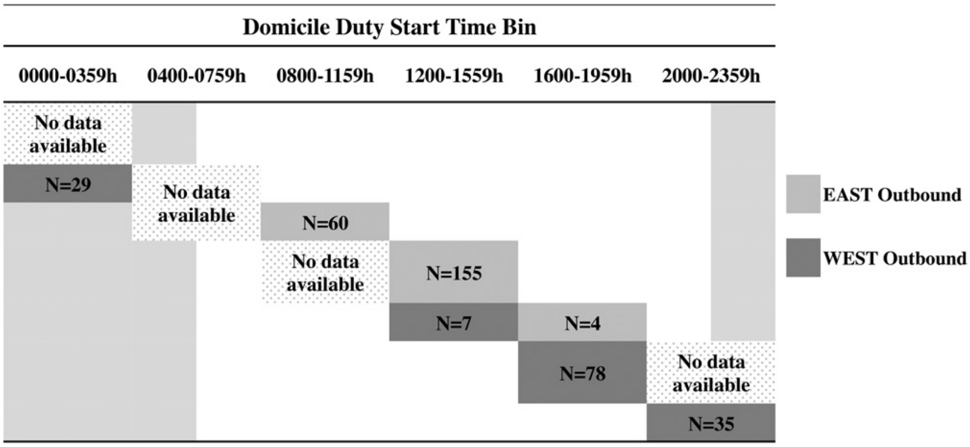

Fig. 1. Number of layovers available for analysis by domicile duty start time bin and outbound (prior) flight direction. Note that layovers after eastward and westward outbound flights ended predominantly in different 4-h domicile time bins; prior flight direction was collapsed within time bins prior to analyses.

be made for layovers ending between 0800–1159 domicile time. It would therefore be premature to conclude that layover duration does not influence sleep patterns in the last 24 h of layovers.

Fatigue and sleepiness ratings at the start of the inbound duty period varied with TST in the last 24 h, but not with time awake at duty start, which replicates the findings of Gander and colleagues.[7] In contrast, laboratory studies indicate that sleepiness and fatigue increase across the waking day.[4,22] The difference may be in part due to the limited variability in time awake at duty start in the present study, with 79% of pilots being awake less than 8 h. Time awake has been found to be a significant predictor of fatigue and sleepiness ratings at top of descent (TOD; median = 2.3 h, range 0–11.68 h, N = 709 flights).[7] It is possible that the sleep restriction observed during trips amplifies the circadian variation in these measures at TOD compared to duty start.[4,22]

Based on previous laboratory studies,[4,22] we would have also anticipated that fatigue and sleepiness ratings would vary with time of day, being highest during the preferred part of the

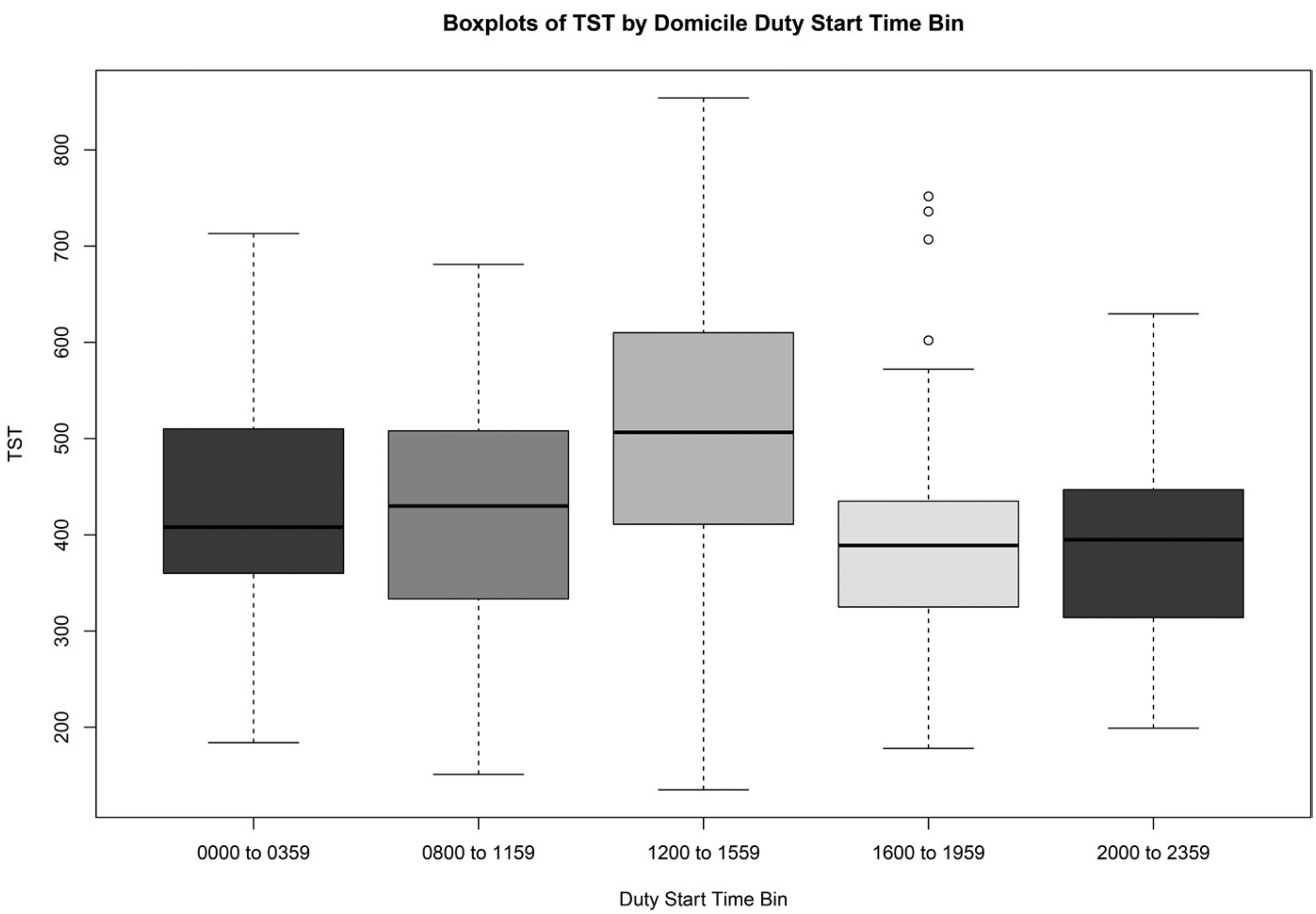

Fig. 2. Total sleep time in the last 24 h prior to duty start time bin (including the LOS layover). Median values are indicated with a thick horizontal bar. Whiskers represent 1.5× the interquartile range of TST in the 24 h prior to inbound duty start (domicile time).

Table III. Relationships Between Fatigue and Sleepiness Ratings at Duty Start and Sleep History and Duty Start Time (Including LOS Layovers).

DEPENDENT VARIABLE	*N* (USED)/ *N* (TOTAL)	FIXED EFFECTS	DF	F-VALUE	*P*-VALUE
KSS*	386/410†	TST in the 24 h prior	1246	29.15	<0.0001
		Time Awake at Duty Start	1254	0.02	0.8981
		Domicile Duty Start Time Bin	4272	0.79	0.5314
Samn Perelli	387/410‡	TST in the 24 h prior	1293	30.67	<0.0001¶
		Time Awake at Duty Start	1309	0.10	0.7568
		Domicile Duty Start Time Bin	4301	1.27	0.2799¶

* Square-root transformed to normalize residual distribution.
† Includes 7 outliers.
‡ Includes 2 outliers.
¶ Variance not constant.

circadian body clock cycle for sleep. However, in contrast to the airline operations described in this paper, these laboratory studies (28-h forced desynchrony protocols) provided a stable cycle of in-bed and wake times and napping was not permitted. The relationships between fatigue and sleepiness ratings and time of day may also have been obscured in the present study if there were varying amounts of circadian adaptation during the 1–3 d layovers. In addition, there were no layovers available for analyses prior to duty periods beginning in the 0359–0759 time bin, when fatigue and sleepiness ratings would be expected to be highest.

A number of caveats merit mention. First, it was not possible to examine the effects of prior flight direction in the models for fatigue and sleepiness ratings, because layovers after eastward and westward outbound flights ended predominantly in different 4-h domicile time bins. Circadian adaptation is typically faster after westward flights, so prior flight direction may affect the amount and timing of sleep obtained during layovers. Second, TST in the 24 h prior to duty start and time awake at duty start were the only measures of layover sleep considered. Future studies should investigate specific parameters of sleep timing, quality and duration, in order to more fully understand the relationship between layover sleep and SPIs. Third, these results are only applicable to 4-pilot crews. Sleep opportunities on the outbound flight are shorter for 3-pilot crews, who operate shorter flights and each pilot has only about a third of the available time for in-flight rest. In contrast, each pilot in a 4-pilot crew has about half the (longer) flight time available for in-flight rest. Finally, previous research suggests there is variability in pilots' preferences with regards to activities other than sleep at different layover destinations.[15] This is not something that could be investigated further in this dataset.

Possible relationships between fatigue SPIs at TOD on the inbound flight and layover sleep patterns or fatigue and sleepiness ratings at duty start were not examined in the present study. TOD marks the beginning of the safety-critical and high workload approach and landing phases of flight. Previous analyses have shown that fatigue and sleepiness ratings at TOD in these operations increased with longer time awake at TOD and varied by domicile time of arrival, but not with TST in the 24 h prior to TOD or flight direction (eastward outbound, westward outbound, eastward inbound, westward inbound), or flight duration.[7] However, TST in the 24 h prior to TOD would not generally include all the sleep in the last 24 h of the layover, so these analyses do not directly address the question of whether layover sleep or fatigue and sleepiness at the start of the inbound duty period influence fatigue SPIs at TOD.

These limitations notwithstanding, we believe that these findings are a valuable contribution to the field. The current focus in scheduling is often on layover duration as a modifiable factor to ensure adequate layover sleep. However, the present findings highlight the importance of layover timing. Total sleep in the last 24 h of the layover was greatest when it included a full domicile night time period, and greater sleep was associated with lower sleepiness and fatigue ratings at the start of the inbound duty period.

Future research is needed to clarify whether prior flight direction influences pilots' sleep patterns (the number and timing of sleep episodes) during layovers, and whether sleep patterns influence fatigue status at the start of the inbound duty period or during the subsequent inbound flight.

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