



# Sleep, alertness and alertness management among commercial airline pilots on short-haul and long-haul flights



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## ABSTRACT

Airline pilots' sleep and on-duty alertness are important focus areas in commercial aviation. Until now, studies pertaining to this topic have mainly focused on specific characteristics of flights and thus a comprehensive picture of the matter is not well established. In addition, research knowledge of what airline pilots actually do to maintain their alertness while being on duty is scarce.

To address these gaps in research knowledge, we conducted a field study on a representative sample of the airline pilots of a medium-sized airline. The sample consisted of 90 pilots, of whom 30 flew long-haul (LH) routes, 30 short-haul (SH) routes, and 30 flew both. A total of 86 pilots completed the measurements that lasted for almost two months per pilot. The measurements resulted in a total of 965 flight duty periods (FDPs) including SH flights and 627 FDPs including LH flights. During the measurement periods, sleep was measured by a diary and actigraphs, on-duty alertness by the Karolinska Sleepiness Scale (KSS) in all flight phases, and on-duty alertness management strategies by the diary.

Results showed that SH and LH FDPs covering the whole domicile night (00:00–06:00 at home base) were most consistently associated with reduced sleep-wake ratio and subjective alertness. Approximately every 3rd FDP falling into this category involved a reduced sleep-wake ratio (1:3 or lower) and every 2nd a reduced level of subjective alertness (KSS rating 8–9 in at least one flight phase). The corresponding frequencies for the SH and LH FDPs that partly covered the domicile night were every 10th and every 5th FDP and for the pure non-night FDPs every 30th and every 36th FDP, respectively. The results also showed that the pilots tended to increase the use of effective on-duty alertness management strategies (consuming alertness-promoting products and taking strategic naps) in connection with the FDPs that overlapped the domicile night. Finally, the results showed that the frequency of flights involving reduced subjective alertness depended on how alertness was assessed. If it was assessed solely in the flight phase just before starting the landing procedures (top of descent) the phenomenon was less frequent than if the preceding cruise phase was also taken into account.

Our results suggest that FDPs covering the whole domicile night should be prioritised over the other FDPs in fatigue management, regardless of whether an FDP is a short-haul or a long-haul. In addition, the identification of fatigue in flight operations requires one to assess pilots' alertness across all flight phases, not only at ToD. Due to limitations in our data, these conclusions can, however, be generalised to only LH FDPs during which pilots can be expected to be well acclimatised to the local time at their home base and SH night FDPs that include at least 3 h of flying in the cruise phase.

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## 1. Introduction

Sleepiness and shortage of sleep are known to be safety hazards in many 24/7 industries (Sallinen and Hublin, 2015; Sallinen and Kecklund, 2010). In this study, we focus on one of these industries,

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namely commercial aviation, and examine airline pilots whose job is characterised by irregular working hours and high demands for alertness.

Across the 24/7 industries, the timing and duration of work shifts and the rest time between consecutive work shifts are amongst the most important determinants of employees' sleep and on-duty alertness (Sallinen and Hublin, 2015; Sallinen and Kecklund, 2010) and commercial aviation makes no exception (Gander et al., 2013, 2015; Powell et al., 2007, 2008; Roach et al., 2012a, b; Vejvoda et al., 2014). In addition to these common determinants, airline pilots' sleep and alertness are affected by factors specific for their job, such as the phase of flight, the duration of lay-over, and the number of flight segments within a flight duty period (Gander et al., 2014a,b; Honn et al., 2016; Powell et al., 2007; Roach et al., 2012a).

Until now, studies on airline pilots' sleep and alertness have either concentrated on limited types of flights, such as long-haul on a certain route, or some specific elements of flights (Gander et al., 2013; Honn et al., 2016; Roach et al., 2012a,b). For this reason, it is difficult to create a comprehensive picture of airline pilots' sleep and alertness on different duty rosters and different types of routes. In addition, only little is known about airline pilots' on-duty alertness management strategies on different types of routes, with the exception of strategic napping (Hartzler, 2014). The extent to which different strategies are used, however, affects airline pilot's alertness.

To fill these gaps in knowledge we conducted a field study on a representative sample of the long-haul, short-haul, and mixed fleet (flying both long-haul and short-haul flights) pilots of a medium-sized airline. We measured pilots' sleep-wake patterns and on-duty alertness levels and management strategies for a period of almost two months while the pilots were working on their typical monthly duty rosters.

## 2. Material and methods

### 2.1. Ethics statement

The study was approved by the Ethics Committee of the Finnish Institute of Occupational Health. All participants provided written informed consent prior to starting the field measurements. Participants were not paid for their time or effort.

### 2.2. Participants and flight duty periods

Participants were selected from a group of 274 pilots who replied to a questionnaire on well-being at work and volunteered for the field study. The questionnaire was originally sent to all 608 eligible pilots of the airline (response rate 79%). Thirty long-haul (LH) pilots (flying LH flights only), 30 short-haul (SH) pilots (flying SH flights only), and 30 mixed fleet pilots (flying both the SH and LH flights) were finally selected for the field study out of the 274 volunteers. The selection process followed a proportional stratified sampling procedure to make the age distribution in each group equal to the age distribution of all pilots in that particular group within the participating airline. A total of 29 LH, 28 SH, and 29 mixed fleet pilots completed the field measurements resulting in a total of 383, 701, and 532 flight duty periods (FDPs), respectively. Of these FDPs, all those that included SH flights (scheduled flight time  $\leq 6$  h, operated by narrow body aircrafts) and 96% of those that included LH flights (scheduled flight time  $> 6$  h, operated by wide body aircrafts) were utilised in the statistical analyses. The excluded LH FDPs were operated to destinations that were rare and deviated geographically from the other destinations. The descriptive statistics of the pilots are given in Table 1. The table also shows

the corresponding figures of all eligible pilots of the airline, which were very similar to the group of pilots who participated in the field study.

### 2.3. Measurements

The pilots filled in a questionnaire where they were inquired about their diurnal type ("One hears about 'morning' and 'evening' types of people. Which one these types do you consider yourself to be?") (Horne and Östberg, 1976), habitual daily sleep time ("How many hours do you sleep, on average, per day including daytime sleeps? Give your estimate based on the past three months"), and daily sleep need ("How many hours of sleep do you need per day to be alert and in good shape at work the next day?").

During the whole measurement period, the pilots used a hand-held computer to rate their sleep-wake patterns and on-duty alertness levels and management strategies on a daily basis. The computerized questionnaire was tailored for each route and work schedule and included the Karolinska Sleepiness Scale (Åkerstedt and Gillberg, 1990) and a list of alertness management strategies (Anund et al., 2008). KSS ratings were given in 87% and 95% of all SH and LH flights, respectively. The questionnaire also logged current location (city), work hours (start and end time), naps (timing and duration), and alcohol and coffee consumption to be filled in at bedtime. Upon awakening, participants filled in items on sleep (timing, duration, and quality), and the use of sleep-promoting medication. In addition to filling in the self-report scales, each pilot used a wrist-worn actigraph (GENEActiv, © 2015 Activinsights Ltd.) for collecting objective data on sleep quantity and quality over the whole measurement period. The pilots were instructed to press the event button of the actigraph at lights out and when rising from bed at the end of the sleep period. Eighty-six percent and 84% of the actigraph recordings preceding the SH and LH FDPs, respectively, were successful.

### 2.4. Dependent variables

#### 2.4.1. Sleep-wake pattern

The primary outcomes of the sleep-wake pattern was the sleep-wake ratio (amount of sleep/amount of wakefulness). It was calculated for the flight duty days and covered the period from the beginning of the main sleep that preceded an FDP until the end of the FDP. The amount of sleep was calculated by summing the actigraphy-based total sleep time (TST) of the main sleep period and the diary-based self-estimate of the amount of nap sleep obtained before and during an FDP. The rest of the period was classified as wake.

The sleep-wake ratio was analysed as a continuous and dichotomous variable. In the latter, the criterion of a reduced sleep-wake ratio was set at  $\leq 0.33$ , which means  $\leq 6$  h of sleep for 18 h of wakefulness. This means, for example,  $\leq 6$  h of sleep for 18 h of wakefulness, which is below the sleep-wake ratio proposed in the Flight and Duty Time regulations in the European Union (COMMISSION REGULATION (EU) No 83/2014). According to the regulations, sleep opportunities shorter than 8 h and periods of wakefulness exceeding 18 h should be avoided. The cut-off for the amount of sleep ( $\leq 6$  h) was also below the average daily sleep need (8 h 5 min) and the habitual sleep time (7 h 21 min) the airline pilots who participated in the field study reported in a questionnaire. In addition to the sleep and waking times, napping before FDPs and during controlled rest breaks while being on-board an aircraft was used to describe the sleep-wake pattern.

#### 2.4.2. On-duty alertness

The primary outcomes of on-duty alertness were the mean KSS ratings calculated across five flight phases (blocks off (Boff), top

**Table 1**  
Descriptive statistics of the pilots who completed the field study and all pilots who filled in a questionnaire before the selection process for the field study (“all eligible pilots”). LH = long-haul, Mixed = pilots who flew both long-haul and short-haul flights, SH = short-haul. Means and standard deviations in parentheses.

Individual factors	Field study			All eligible pilots		
	LH pilots (n = 29)	Mixed pilots (n = 28)	SH pilots (n = 29)	LH pilots (n = 143)	Mixed pilots (n = 178)	SH pilots (n = 156)
Age, years	45.2 (6.8)	40.6 (6.4)	39.8 (5.8)	45.3 (6.8)	41.1 (6.9)	41.5 (6.7)
Flight experience, years	18.9 (7.4)	14.4 (6.4)	14.0 (7.5)	20.4 (7.6)	15.5 (7.4)	16.0 (8.1)
Diurnal type, %						
Morning type	14	24	14	25	24	24
Evening type	52	59	71	59	57	65
Intermediate type	34	17	15	16	19	11
Habitual daily sleep length, h:min	7:17 (0:51)	7:25 (0:48)	7:22 (0:54)	7:22 (0:58)	7:35 (0:49)	7:25 (0:44)
Daily sleep need, h:min	8:19 (0:48)	7:59 (0:49)	7:55 (0:49)	8:12 (0:59)	8:12 (0:53)	7:56 (0:49)
Body mass index, kg/m <sup>2</sup>	26.0 (3.5)	25.1 (2.5)	24.3 (2.4)	25.7 (2.8)	25.5 (2.8)	25.0 (3.1)

of climb (ToC), cruise phase (CP), top of descent (ToD), blocks on (Bon)) and the mean KSS ratings at ToD, which is the flight phase often used to evaluate how tiring a flight is. In addition to these two outcomes, percentage of flights involving a KSS rating 8–9 in any flight phase and at ToD were used to describe the occurrence of reduced subjective alertness. These KSS ratings have been shown to coincide with increases in physiological and behavioural signs of reduced alertness (Åkerstedt et al., 2014).

#### 2.4.3. Alertness management strategies

The primary outcome of the use of alertness management strategies while on duty was the combined measure of consuming alertness-promoting products (coffee, energy drinks and nicotine containing snuff) and taking a strategic nap either in the cockpit or in the separate rest facility. In addition to the combined measure and its two elements, the use of alertness-promoting activities (e.g., moving the body) and taking a break without sleep were assessed.

#### 2.5. Independent variables

The flight routes were first divided into SH, LH outbound, and LH inbound categories and then into following five types based on their timings: an early morning FDP (starts between 03:01–05:59 h), a morning FDP (starts between 06:00–08:00 h), a day FDP (starts after 08:00 h and ends no later than 21:00 h), an evening FDP (at least 3 h after 18:00 h and is not categorised as a night FDP), and a night FDP ( $\geq 3$  h between 23:00–06:00 h). This classification closely followed the criteria recommended for epidemiological studies of shift work (Härmä et al., 2015).

#### 2.6. Covariates

The following individual-related and FDP-related factors were included in the statistical models as covariates to balance the data: age, body mass index, self-reported sleep need, diurnal type (three-graded), flight group, FDP duration, and time off before the FDP. The factors were selected because their imbalance, which is often present in observational data, may complicate comparisons between different shift schedules in terms of sleep and alertness (Härmä et al., 2002; Sallinen et al., 2003; Sallinen and Hublin, 2015; Sallinen and Kecklund, 2010). None of the covariates showed a strong correlation ( $|r| \geq 0.05$ ) with any other covariate or the FDP type in question.

#### 2.7. Statistical analyses

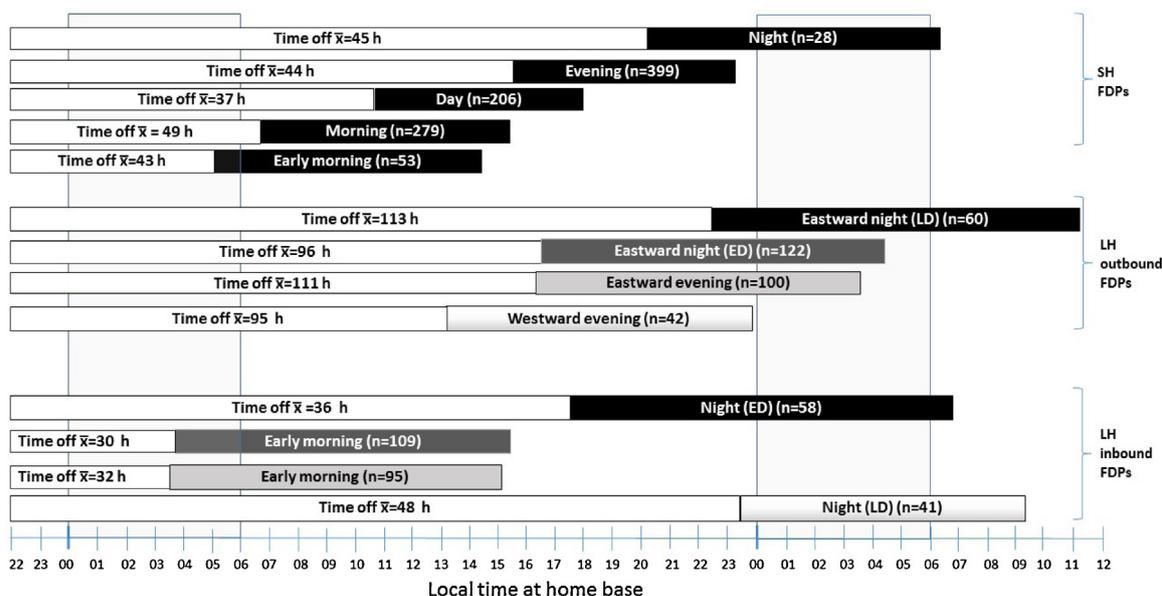
Mixed and generalized estimating equations (GEE) procedures were used to study associations between the FDP types (early morning, morning, day, evening, night) and the outcomes of sleep wake behaviours and disturbances within three FDP categories (SH FDPs, LH outbound FDPs, LH inbound FDPs). In the analyses, all cases in which the variables of interest were present were utilised. The mixed procedure was applied to the continuous outcomes and the GEE procedure to the dichotomous outcomes. In both cases, two models were used: one with the FDP type without the covariates (crude model) and the other adjusted for the covariates (adjusted model). When the response data were binary, the variance function for binomial probability distribution and logit link function were specified as the model type. In all models, compound symmetry was chosen as the correlation structure based on the examination of fit statistics. Alpha was set at 0.05 for all analyses. The analyses were carried out using the SAS 9.4. software package.

### 3. Results

#### 3.1. Flight duty periods

Fig. 1 shows the average timing, duration and the number of FDPs and average time off prior to the FDPs in the three FDP categories. The LH outbound eastward night FDPs were divided into the eastward night (early departure, ED) and the eastward night (late departure, LD) types because 67% of these FDPs started already in the afternoon (mean start time 16:35 (SD 60 min)) and 33% not until the late evening (mean start time 22:46 (SD 7 min)). In addition, these FDP types also differed in their end times that were, on average, 7 h 37 min later for the eastward night (LD) FDPs. The inbound FDPs were categorised not just by timing but also by the prior outbound FDP. Fig. 1 also illustrates which of the FDPs covered either the whole domicile night (00:00–06:00 at home base) or a part of it. The time difference between the home base and the outbound destinations was  $-7$  h for the LH westward route and  $+3.5$ – $+7$  h (mean 6 h) for the LH eastward routes. The number of pilots was two for all SH routes, all westward LH routes, 30% of the eastward LH routes starting with the evening outbound flight, and 20% of the eastward LH routes starting with the night (1) outbound flight. The length of the layover for the eastward LH routes with two pilots was at least two local nights whereas in case of 3 pilots it was only one night.

Within the measurement period, the LH, Mixed, and SH pilots had monthly, on average, a total of 83 h, 96 h, and 105 h of work,



**Fig. 1.** Illustration of short-haul (SH) and long-haul (LH) flight duty periods (FDP). The different colors of the long-haul FDPs denote the pairs of the outbound and inbound FDPs. The horizontal axis denotes time and the two vertical grey bars nights (00:00–06:00) at home-base (Helsinki). The EDs and LDs in parentheses denote early and late departure times, respectively.

respectively. The corresponding figures for all LH, Mixed, and SH pilots of the airline were 83 h, 95 h, and 104 h, respectively.

### 3.2. Sleep-wake patterns

**Table 2** shows the descriptive results of the sleep-wake ratio and sleep-wake patterns of the airline pilots in connection with the SH, LH outbound, and LH inbound FDPs.

#### 3.2.1. SH FDPs

The sleep-wake ratio varied by the timings of the FDPs in both the crude ( $F(4,133)=61.06$ ,  $p<0.001$ ) and adjusted ( $F(4,133)=62.49$ ,  $p<0.001$ ) mixed models. The ratio was lower for the night FDP than the other FDP types ( $t(133)=2.52$ – $8.29$ ,  $p<0.05$ – $0.001$ ). The ratio was also lower for the early morning and evening FDPs than the morning and day FDPs ( $t(133)=5.69$ – $12.69$ ,  $p<0.001$ ). The relative frequency of the reduced sleep-wake ratio ( $\leq 0.33$ ) was 20–27 percentage points higher in connection with the night FDP than the other SH FDP types.

**Table 2** shows that the reason for the low sleep-wake ratio in connection with the night FDP was an extended wake period. The time spent awake until the end of the FDP was, on average, 9 h 40 min greater for the night FDP than the other FDPs.

The mean TST for the main sleep was between 5 h and 6 h for the early morning and morning FDPs and between 7 h and 8 h for the evening and night FDPs. Only the night FDP was frequently preceded by a nap (61%). On-duty naps taken during the periods of controlled cockpit rest occurred in 29% of the night FDPs and in 14% of the early morning FDPs while in the other FDP types they occurred only rarely.

#### 3.2.2. LH outbound FDPs

The sleep-wake ratio varied by the timings of the outbound FDPs in both the crude ( $F(4,101)=33.35$ ,  $p<0.001$ ) and adjusted ( $F(4,97)=17.36$ ,  $p<0.001$ ) mixed models. The ratio for the eastward night (LD) FDP was lower than the ratio for the other FDP types ( $t(97)=4.47$ – $6.87$ ,  $p<0.001$ ). The ratio was also higher for the westward evening FDP than for the eastward evening ( $t(97)=3.42$ ,  $p<0.001$ ) and the eastward night (ED) FDPs ( $t(97)=2.66$ ,  $p<0.01$ ). The relative frequency of the reduced sleep-wake ratio ( $\leq 0.33$ ) was

45–46 percentage points higher in connection with the eastward night (LD) FDP than the other LH outbound FDP types (**Table 2**).

**Table 2** shows that the low sleep-wake ratio in connection with the eastward night (LD) FDP resulted from an extended wake period. For this FDP the wake period was, on average, 8 h 41 min longer, than the other LH outbound FDP types.

The mean TST for the main sleep was between 7 and 8 h for each FDP type. Only the eastward night (LD) FDP was frequently preceded by a nap (32%). On-duty naps taken during the periods of controlled rest in either the cockpit or the rest chamber were frequent in all FDP types (75%–97%), except for the westward evening one (19%).

#### 3.2.3. LH inbound FDPs

The sleep-wake ratio varied by the timings of the LH inbound FDPs in both the crude ( $F(3,78)=6.11$ ,  $p<0.001$ ) and adjusted ( $F(3,78)=13.79$ ,  $p<0.001$ ) mixed models. The ratio for the night (LD) FDP (return from the west destination) was lower than the ratio for the other inbound FDPs ( $t(78)=5.07$ – $6.30$ ,  $p<0.001$ ). The relative frequency of the reduced sleep-wake ratio ( $\leq 0.33$ ) was highest in connection with the two night FDP types (27%–29% of the FDPs) (**Table 2**).

**Table 2** shows that the low sleep-wake ratio in connection with the night (LD) FDP resulted from an extended wake period. It was, on average, 6 h 33 min longer for this FDP than the two early morning FDPs. The waking time was even longer, on average 2 h 56 min, in connection with the night (ED) FDP (return from an east destination) but then also the amount of sleep was high (mean 9 h 28 min).

The mean TST for the main sleep was below 5 h and slightly above 6 h for the two early morning FDPs while for the two night FDPs the corresponding value was slightly below 8 h and 7 h. Only the night (ED) FDP (return from an east destination) was frequently preceded by a nap (47%). On-duty naps taken during the periods of controlled rest in either the cockpit or the rest chamber were frequent in all FDP types (range 80%–98%).

**Table 2**  
Sleep-wake patterns in connection with short-haul (SH), long-haul (LH) outbound, and long-haul inbound flight duty periods (FDPs). TST=total sleep time. Means and standard deviations in parentheses. “ED” and “LD” in parentheses denote early and late departure times, respectively.

Sleep outcome	SH FDP					LH outbound FDP				LH inbound FDP			
	Early morning	Morning	Day	Evening	Night	Eastward evening	Eastward night (ED)	Eastward night (LD)	Westward evening	Early morning <sup>a</sup>	Early morning <sup>b</sup>	Night (ED) <sup>c</sup>	Night (LD) <sup>d</sup>
Main sleep TST, h:min	5:00 (1:06)	5:59 (1:00)	7:11 (1:11)	7:17 (1:14)	7:43 (1:31)	7:22 (1:07)	7:31 (1:10)	7:22 (1:00)	7:25 (1:05)	4:46 (1:32)	5:11 (0:32)	7:58 (1:26)	6:54 (1:13)
Off-duty nap, % of FDPs	0	0	0	8	61	14	16	32	5	3	4	47	0
Off-duty nap sleep, h:min	–	–	–	0:26 (19)	0:27 (29)	0:30 (25)	0:23 (16)	0:26 (31)	0:18 (7)	0:26 (20)	0:07 (5)	0:50 (50)	–
On-duty nap, % of FDPs	14	4	2	2	29	75	90	97	19	84	94	98	80
On-duty nap sleep, h:min	0:10 (0:02)	0:10 (3)	0:07 (4)	0:09 (5)	0:11 (6)	0:30 (23)	0:39 (27)	0:73 (28)	0:09 (4)	0:47 (29)	0:54 (31)	1:07 (32)	0:12 (8)
Total time asleep, h:min	5:03 (1:06)	5:59 (1:00)	7:12 (1:11)	7:20 (1:13)	7:43 (1:30)	7:50 (1:08)	8:09 (1:08)	8:39 (1:14)	7:57 (1:02)	5:26 (1:26)	6:00 (1:27)	9:28 (1:56)	7:12 (1:15)
Total time awake, h:min	10:19 (2:07)	9:34 (1:36)	9:57 (2:09)	14:14 (1:47)	20:41 (2:15)	17:52 (1:22)	18:39 (1:37)	26:02 (1:45)	15:32 (1:29)	13:16 (0:49)	13:25 (0:54)	22:49 (2:25)	19:53 (1:24)
Sleep-wake ratio	0.53 (0.27)	0.66 (0.23)	0.77 (0.26)	0.53 (0.13)	0.38 (0.09)	0.44 (0.09)	0.44 (0.08)	0.34 (0.06)	0.49 (0.09)	0.41 (0.11)	0.45 (0.11)	0.42 (0.11)	0.36 (0.07)
Sleep-wake ratio $\leq 0.33$ , % of FDPs	7	1	0	4	27	7	8	53	8	18	11	29	27

<sup>a</sup> Inbound FDP preceded by the eastward evening outbound FDP.

<sup>b</sup> Inbound FDP preceded by the eastward night (ED) outbound FDP.

<sup>c</sup> Inbound FDP preceded by the eastward night (LD) outbound FDP.

<sup>d</sup> Inbound FDP preceded by the westward evening outbound.

**Table 3** On-duty alertness based on Karolinska Sleepiness Scale (KSS) ratings during short-haul (SH), long-haul (LH) outbound, and long-haul inbound flights. FDP = Flight Duty Period. Standard deviations are given in parentheses. “ED” and “LD” in parentheses denote early and late departure times, respectively.

Alertness outcome	SH FDP				LH outbound FDP				LH inbound FDP			
	Early morning	Morning	Day	Night	Eastward evening	Eastward night (ED)	Eastward night (LD)	Westward evening	Early morning <sup>a</sup>	Early morning <sup>b</sup>	Night (ED) <sup>c</sup>	Night (LD) <sup>d</sup>
KSS, overall mean across flight phases	5.3 (1.2)	4.4 (1.2)	4.0 (1.1)	5.5 (1.2)	4.9 (0.8)	4.9 (0.8)	5.8 (1.0)	4.0 (0.8)	5.3 (1.0)	5.1 (1.1)	5.6 (1.0)	5.7 (1.0)
KSS, mean at ToD	5.4 (1.3)	4.5 (1.4)	4.1 (1.2)	5.6 (1.3)	5.7 (1.3)	5.6 (1.4)	5.5 (1.5)	4.1 (1.0)	5.0 (1.2)	4.5 (1.3)	6.0 (1.6)	6.1 (1.3)
KSS 8–9 at any flight phase, % of flights	14	5	1	21	15	20	55	5	27	28	54	40
KSS 8–9 at ToD, % of flights	4	2	0	5	6	10	8	0	0	1	19	11

<sup>a</sup> Inbound FDP preceded by the eastward evening outbound FDP.

<sup>b</sup> Inbound FDP preceded by the eastward night (ED) outbound FDP.

<sup>c</sup> Inbound FDP preceded by the eastward night (LD) outbound FDP.

<sup>d</sup> Inbound FDP preceded by the westward evening outbound.

### 3.3. On-duty alertness

Table 3 shows the descriptive results of the on-duty alertness of the airline pilots during the SH, LH outbound, and LH inbound flights.

#### 3.3.1. SH FDPs

The mean KSS ratings varied by the timings of the flights in the crude ( $F(4,139) = 52.61$ ,  $p < 0.001$  for overall KSS;  $F(4,132) = 27.76$ ,  $p < 0.001$  for ToD KSS) and adjusted mixed models ( $F(4,135) = 30.77$ ,  $p < 0.001$ ;  $F(4,121) = 11.39$ ,  $p < 0.001$ ). The ratings, shown in Table 3, indicated reduced subjective alertness during the flights of the early morning and night FDPs as compared to the flights of the other SH FDP types ( $t(139) = 6.49$ – $10.63$ ,  $p < 0.001$  for overall KSS;  $t(132) = 4.93$ – $8.28$ ,  $p < 0.001$  for ToD KSS). When the 1st and 2nd flights of the night FDPs were studied separately it was found that the mean level of KSS sleepiness was 1.5 steps higher for the 2nd flight (6.3, SD 0.9) than for the 1st one (4.8, SD 1.3).

The relative frequency of the flights including a KSS rating 8–9 at any flight phase was highest for the night (21%) and early morning (14%) FDPs (Table 3). In case of the night FDP, the KSS 8–9 ratings were exclusively given during the 2nd flight of the FDP (38% of the 2nd flights), while within the early morning FDPs the corresponding ratings were evenly distributed between the 1st and 2nd flight (11% of the flights in each case). The frequency of the flights with a KSS rating 8–9 at ToD was low for all FDP types (0%–5%). During the night flights, the KSS 8–9 ratings occurred most frequently at ToC and Bon (9% of the flights) and during the early morning flights at CP (6% of the flights).

#### 3.3.2. LH outbound FDPs

The mean KSS ratings varied by the timings of the flights in the crude ( $F(4,113) = 52.15$ ,  $p < 0.001$  for overall KSS;  $F(4,104) = 20.11$ ,  $p < 0.001$  for ToD KSS) and adjusted ( $F(3,106) = 38.41$ ,  $p < 0.001$  for overall KSS;  $F(3,95) = 18.53$ ,  $p < 0.001$  for ToD KSS) mixed models. The overall ratings indicated reduced subjective alertness during the eastward night (LD) FDP as compared to the other LH outbound FDP types ( $t(113) = 7.04$ – $12.44$ ,  $p < 0.001$ ). Both types of KSS ratings indicated a higher alertness level for the westward evening FDP than for the other FDP types ( $t(113) = 6.56$ – $12.44$ ,  $p < 0.001$  for overall KSS;  $t(104) = 5.12$ – $7.40$ ,  $p < 0.001$  for ToD KSS).

The relative frequency of the flights with a KSS rating 8–9 at any flight phase was highest for the eastward night (LD) FDP (55%) and lowest for the westward evening FDP (5%) (Table 3). The relative frequency of the flights with a KSS rating 8–9 at ToD varied between 0% and 10%. In all LH outbound FDP types, KSS 8–9 ratings were given most frequently at the CP flight phase (10% of the eastward evening FDPs, 13% of the eastward night (ED) FDPs, 55% of the eastward night (LD) FDPs, 5% of the westward evening FDPs).

#### 3.3.3. LH inbound FDPs

The KSS ratings varied by the timings of the FDPs in the crude ( $F(3,107) = 13.30$ ,  $p < 0.001$  for overall KSS;  $F(3,100) = 27.51$ ,  $p < 0.001$  for ToD KSS) and adjusted ( $F(3,107) = 10.81$ ,  $p < 0.001$  for overall KSS;  $F(3,100) = 24.46$ ,  $p < 0.001$  for ToD KSS) mixed models. The KSS-ratings indicated reduced alertness during both night FDP types as compared to both early morning FDPs ( $t(107) = 2.81$ – $5.68$ ,  $p < 0.01$ – $0.001$  for overall KSS;  $t(100) = 5.11$ – $7.51$ ,  $p < 0.001$  for ToD KSS).

The relative frequency of the FDPs with a KSS rating 8–9 was highest for the night (LD) FDP (return from the west destination) (54% of the FDPs) and lowest for both early morning FDP types (27%–28% of the FDPs) (Table 3). The frequency of flights with a KSS rating 8–9 at ToD varied between 0% (the early morning FDP following the eastward evening outbound) and 19% (the night (ED) FDP). In all LH inbound FDP types, the KSS 8–9 ratings occurred most frequently

at the CP flight phase (24%–27% of the two early morning FDP types, 47% of the night (ED) FDPs, 40% of the night (LD) FDPs).

### 3.4. On-duty alertness management strategies

In addition to on-duty nap breaks (see above), the airline pilots reported using alertness-promoting products and activities and rest breaks without sleep to maintain alertness during all FDP types (Fig. 2a, b).

#### 3.4.1. SH FDPs

During the SH FDPs, alertness-promoting products and activities were used frequently in all FDP types (45%–82% of the FDPs), while rest breaks without sleep were taken quite rarely, especially during the non-night FDPs (3%–13% of the FDPs) (Fig. 2a). In 98%–100% of the SH FDPs involving the use of alertness-promoting products, one of the products was coffee. The corresponding frequency rate for energy drinks and snuff were much lower (1%–5% and 3%–19%, respectively). The combination of alertness-promoting products and napping was most frequent during the night FDP (24% of the FDPs) and least frequent during the morning, day and evening FDPs (1%–2% of the FDPs). The association between the FDP type and the use of this combined countermeasure was significant in the crude GEE model ( $X^2(4) = 12.44$ ,  $p < 0.05$ ), but not in the adjusted model ( $X^2(4) = 5.21$ ,  $p = 0.27$ ).

#### 3.4.2. LH outbound FDPs

Alertness-promoting products and activities were used frequently (55%–71% of the FDPs), while rest breaks without sleep were taken quite rarely (12%–26% of the FDPs) in all LH outbound FDP types (Fig. 2b). Of the LH outbound FDPs with the use of alertness-promoting products, 93%–98% involved coffee intake, while the use of energy drinks and snuff was reported less frequently (3%–5% and 9%–22%, respectively).

The combination of alertness-promoting products and napping was most frequent during the eastward night (LD) FDP (68% of the FDPs) and least frequent during the westward evening FDP (17% of the FDPs). The association of this combined countermeasure with FDP type was significant in the crude GEE model ( $X^2(3) = 10.22$ ,  $p < 0.05$ ), but not in the adjusted one ( $X^2(3) = 6.38$ ,  $p = 0.095$ ).

#### 3.4.3. LH inbound FDPs

Similar to the outbound FDPs, the use of alertness-promoting products and activities were reported frequently (50%–73% of the FDPs) and rest breaks without sleep infrequently (14%–26% of the FDPs) in all LH inbound FDP types (Fig. 2b). Of the LH inbound FDPs with the use of alertness-promoting products, 89%–100% involved coffee intake. The use of energy drinks and snuff was reported in 5%–10% and 8%–17% of these FDPs, respectively.

The combination of alertness-promoting products and napping was most frequent during the early morning FDP following the eastward night (ED) FDP (71% of the FDPs) and least frequent during the night (LD) FDP (56% of the FDPs). The association of this combined countermeasure with FDP type remained non-significant in both the crude GEE model ( $X^2(3) = 5.52$ ,  $p = 0.138$ ) and the adjusted model ( $X^2(3) = 5.73$ ,  $p = 0.125$ ).

## 4. Discussion

### 4.1. Main results

The present study shows that SH and LH FDPs covering both the early (00:00–03:00) and late (03:01–06:00) part of the domicile night (00:00–06:00 at home base) are most consistently associated with reduced sleep sufficiency and subjective alertness. Approximately every 3rd FDP falling into this category involved a reduced

sleep-wake ratio (1:3 or lower) and every 2nd a reduced level of subjective alertness (KSS rating 8–9 in at least one flight phase). The corresponding frequencies for the SH and LH FDPs that partly covered the domicile night were every 10th and every 5th FDP and for the pure non-night FDPs every 30th and every 36th FDP, respectively.

Our results also provide some evidence that airline pilots increase the use of effective on-duty alertness management strategies in connection with the most tiring FDPs, that is, the FDPs that overlap either completely or partly the domicile night.

Finally, our results show that the flight phase(s) where on-duty alertness is measured affects whether or not an FDP proves tiring. This phenomenon became particularly evident when comparing the results of the occurrence of reduced subjective alertness across all flight phases and separately at ToD. For example, 55% of the eastward night (LD) outbound FDPs involved severe sleepiness at CP but only 8% at ToD.

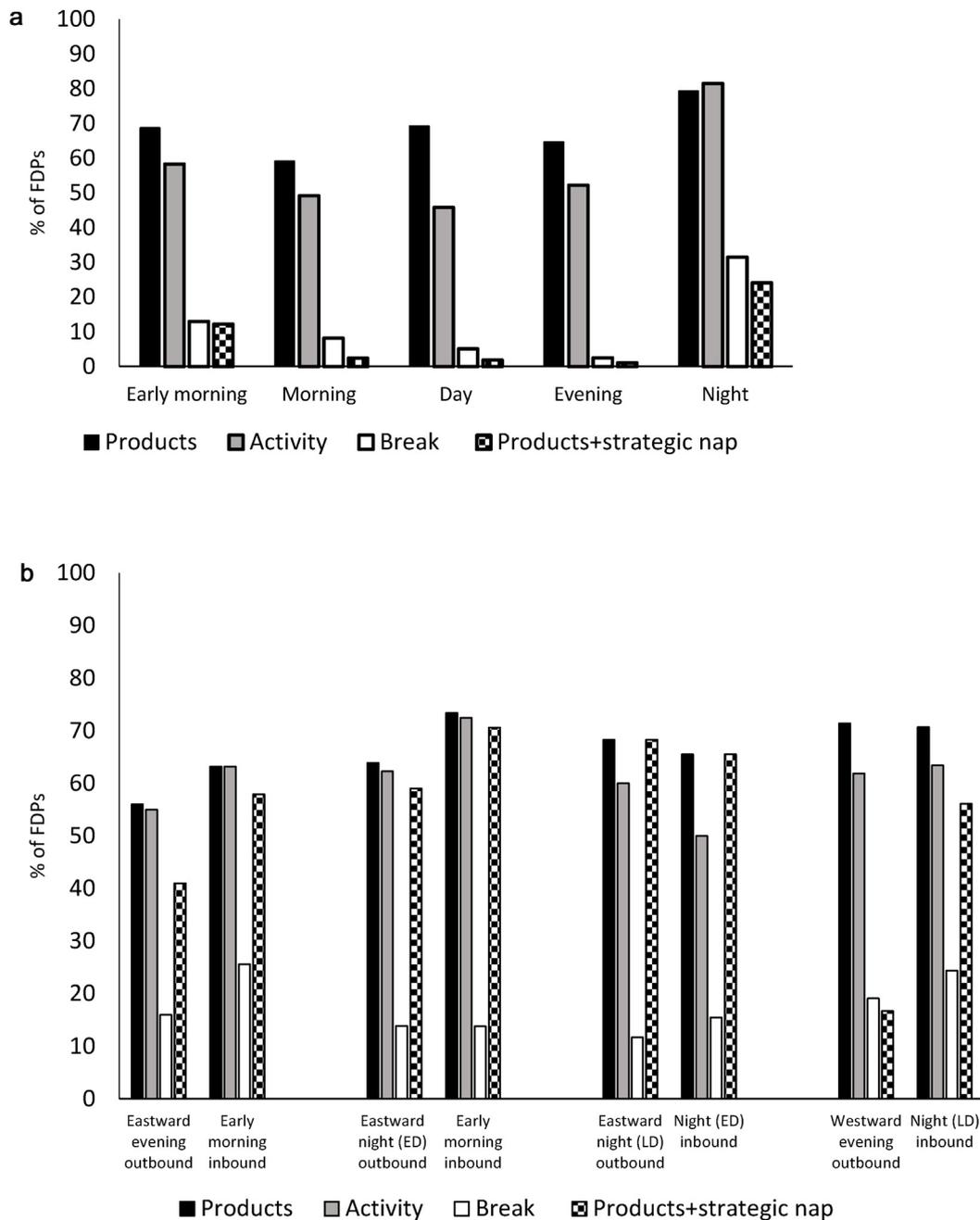
### 4.2. Timing of an FDP in relation to the nighttime at home base

The finding of reduced sleep sufficiency and subjective alertness especially in connection with whole night FDPs is well in line with a number of previous studies conducted on airline pilots and other groups of transport professionals (Eriksen and Åkerstedt, 2006; Gander et al., 2015; Härmä et al., 2002; Sallinen and Hublin, 2015; Sallinen and Kecklund, 2010). The mean levels of subjective alertness found during the whole night FDPs (KSS rating 5–6) is well within the range reported in these previous studies. These FDPs represent the first night duty, as all of them were separated by at least one night sleep. The mechanism underlying increased sleepiness under these conditions is known to consist of two main factors: exposure to an extended waking period and the circadian nadir of alertness during the second part of the night. In addition, task monotony that characterises flying at CP probably intensifies the feeling of sleepiness caused by a reduced sleep-wake ratio and circadian misalignment (Åkerstedt et al., 2014).

An interesting and new finding was that subjective alertness was similarly reduced during the whole night FDPs independent of whether they were SH, LH outbound or LH inbound FDPs. This finding is understandable, since the SH night FDPs usually consisted of 3–4 h of flying at CP generally characterised by a low activity level, which, in turn, can be expected to exacerbate manifested sleepiness (Åkerstedt et al., 2014). Thus, it remains an open question whether SH FDPs consisting of only little time at CP are characterised by decreases in self-rated alertness comparable to LH night FDPs.

In addition to the whole night FDP, the SH and LH FDPs that covered either the first or second part of the night were, to some extent, associated with a lowered sleep-wake ratio and subjective alertness. This finding is in accordance with previous studies conducted on a wide range of occupational groups (Härmä et al., 2002; Pylkkönen et al., 2015; Roach et al., 2012b; Sallinen and Hublin, 2015; Sallinen and Kecklund, 2010). The level of subjective alertness was, on average, 1.0 step lower on the KSS during these FDPs than during the pure non-night FDPs, but 0.5 step higher than during the whole night FDPs. A similar pattern was found for the proportion of FDPs characterised by reduced subjective alertness. These differences are comparable to those produced by for example, marked reductions in environmental stimulation (from high to low) and the amount of sleep during a single night (from 8 h to 4 h) (Sallinen et al., 2004).

In addition to the timing of a flight, the time difference between the destination and home base plays a role in LH inbound flights. In the present study, some differences were observed between LH night inbound flights from eastern and western destinations. The flights from east were frequently preceded by a nap, while the flights from west were not, even though the returns from west



**Fig. 2.** a, b. Use of alertness management strategies. Relative frequency of short-haul (a) and long-haul (b) flight duty periods (FDPs) involving use of alertness management strategies broken down by FDP type. Products = alertness-promoting products; activity = alertness-promoting activity; break = rest break without sleep; products + strategic nap = combination of alertness-promoting products and a strategic nap break. The EDs and LDs in parentheses denote early and late departure times, respectively.

started approximately 6 h later than those from east. A probable reason for this difference is that the pilots woke up early in relation to their domicile time zone, on average at 06:22, prior to the flights from east but quite late, on average at 13:23, prior to the flights from west. On the other hand, despite the differences in pilots' behaviours between these inbound flights, there were also similarities between them: both flights were characterised by reduced alertness and frequent use of the combination of alertness-promoting products and napping while on duty.

In all, our findings suggest that all FDPs, regardless of whether they fall into the SH, LH outbound or LH inbound category, could be prioritised according to the extent they overlap the domicile night. The pure non-night FDP is associated with least severe and the whole night FDP with the most severe perceived sleep-wake

disturbances. The partial night FDPs that cover either the first or the second part of the domicile night fall between these two.

This used simple and straightforward classifying system is, in principle, quite well in line with the European Union (EU) flight and duty time limitations (FTL) (COMMISSION REGULATION (EU) No 83/2014). These limitations define an FDP as a disruptive schedule if it starts early (05:00 h – 06:59 h) or ends late (23:00 h – 01:59 h) or covers night hours from 02:00 h to 04:59 h in the time zone to which a crew member is acclimatised. However, these definitions of disruptive schedules do not prioritise the whole night FDPs over the partial night FDPs. One reason for this discrepancy between our results and the EU FTL regulations may be that the definitions disruptive schedules in the regulations are solely based on the extent an FDP can be considered to disrupt an 8-h sleep opportunity during

the biological night. Our results suggest that besides the nocturnal sleep opportunity, the overall sleep-wake ratio and flying or not flying during the circadian nadir of alertness largely determines the disruptiveness of an FDP.

Second, the EU FLT regulations state that the definitions of disruptive schedules should be applied only to “operations within the 2-h wide time zone surrounding the local time at the home base, if a crew member is acclimatised to the local time at his/her home base.” Our results of LH inbound FDPs do not support this restriction. Rather they suggest that the simple and straightforward rule on disruptive schedules could be applied also to operations that occur significantly outside a 2-h wide time zone. It is, however, noteworthy that the layovers were relatively short, usually either one or two local nights, and the recovery periods between the successive LH routes rather long, usually four nights at home, in this study. Having a longer stay at a destination or multiple LH FDPs in a row with only short layovers between them would probably undermine the validity of our rule due to a significant circadian drift (Gander et al., 2016).

#### 4.3. On-duty alertness management strategies

The present study provides some evidence for the assumption that airline pilots apply alertness management strategies especially in connection with the most tiring FDPs. This result is in accordance with a previous studies on LH airline pilots and LH truck drivers (Pykkönen et al., 2015; Roach et al., 2011). In the present study, approximately half of the whole night FDPs were preceded by a daytime nap. In addition, the combined countermeasure of consuming alertness-promoting products and taking a strategic nap was used during every 2nd whole night LH FDP but only every 6th pure non-night LH FDP (evening westward outbound FDP). A similar pattern was found for the SH FDPs.

A critical question is whether the alertness management strategies applied by airline pilots are of benefit to maintain on-duty alertness. The design of the present study does not allow one to answer the question properly because it did not contain experimental conditions with and without the use of these strategies. Previous studies support the idea of beneficial effects of the pilots' management strategies (Hartzler, 2014; Ruggiero and Redeker, 2014), but, according to the present study, these effect are not strong enough to remove the fatigue hazard.

The subjectively assessed amount of nap sleep obtained during the in-flight rest breaks of the different types of the whole night FDPs varied between 11 min and approximately an hour. Even though an in-flight nap as short as 10 min can be considered beneficial (Hartzler, 2014) increasing the length of a nap from 10 min to 30 min can be assumed to enhance the positive effects (Centofanti et al., 2016). An evident explanation for the large variation in the length of nap sleep is that the FDPs with the shortest nap sleep (LH night inbound FDPs from the west and SH night FDPs) were operated by a two-pilot cockpit crew. Only having more than two pilots in the cockpit allows having rest break outside the cockpit, which makes it easier for a pilot to sleep longer.

It is interesting that the use of the strategy of consuming alertness-promoting products and taking a strategic nap was generally at a similar level to the use of alertness-promoting activities during the LH FDPs, apart from the westward outbound FDP that was the only pure non-night LH FDP. This pattern deviates from our findings on LH truck drivers, who reported on-duty napping much less frequently than alertness-promoting activities as their alertness management strategy (Pykkönen et al., 2015). A likely explanation for this discrepancy lies in the fact that on-duty napping is based on a standard procedure in aviation but not in road transport where it is more the driver's decision if he/she takes a nap break at the expense of interrupting the journey. This discrepancy

between the occupational groups also highlights the importance of working conditions as a determining factor for the vehicle operator's strategies to maintain alertness under soporific conditions.

#### 4.4. Assessment of on-duty alertness

From the viewpoint of the EU FTL regulations that require a commercial air transport operator to identify fatigue hazards as part of fatigue risk management (FRM), our results on reductions in subjective alertness while on duty are of importance. The results showed that the frequency of flights involving reduced subjective alertness depended on which flight phases were included in the analysis. If alertness was assessed solely at ToD the phenomenon was less frequent than if CP was also taken into account.

A partial explanation for the result is that alertness was rated every two hours across CP but only once at ToD. On the other hand, the difference in the proportion of LH overnight FDPs involving reduced self-rated alertness was larger between the two measures (KSS across a flight vs KSS at ToD) than it should have been if it had just resulted from the difference in the number of measurement points.

It is probable that our result is also influenced by the fact that CP, as opposed to ToD, is characterised by task monotony and inevitably includes at least part of the tiring period of the early morning hours while working on a LH whole night FDP. It is also noteworthy that ToD may occur long after the early morning hours during whole night FDPs and then alertness measured at this point of a flight indicates more likely a high level than a low level (Gander et al., 2014a,b).

On the basis of our result and given the safety-critical nature of airline pilot's job, it would be justified to include not only ToD but all flight phases in the identification process required by the EU FTL regulations to have a comprehensive picture of the fatigue hazard. It should, however, be taken into account when assessing fatigue hazard that the flight portions from take off to ToC and from ToD to landing are most critical due to the high task demands during them.

#### 4.5. Study strengths and limitations

The present study allows for the first time to have a comprehensive picture of pilots' sleep and on-duty alertness levels and management strategies in connection with SH and LH flights with different timings. The study was conducted in naturalistic working and spare time conditions on a representative sample of pilots of an airline over a period of about 50 successive days per pilot by using standardised methodology. However, there are also some limitations to discuss. With regard to our results of the inbound LH FDPs it is important to notice that they apply only those inbound FDPs during which pilots can be assumed to be well acclimatised to their home-base airport time, as the vast majority of the layover periods of the current study were only 1–2 nights in duration. Second, on-duty sleepiness and the use of alertness management strategies were measured by using only subjective measures. This choice may increase the risk of having different kind of biases, such as attentional and recall ones, influencing the results. On the other hand, our results were well in line with the previous pertinent studies, which suggests that these biases were not exceptionally pronounced in the current data.

#### 4.6. Conclusions

To conclude, our results suggest that FDPs that cover the whole domicile night should be prioritised over the other FDPs in fatigue management, regardless of whether an FDP is a short-haul or a long-haul. In addition, the identification of fatigue hazard in flight

operations requires one to assess pilots' alertness across all flight phases, not only at ToD. Due to limitations in our data, these conclusions can, however, be generalised to only LH FDPs during which pilots can be expected to be well acclimatised to the local time at their home base and SH night FDPs that include at least 3 h of flying in the cruise phase.

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