

Fatigue in Trans-Atlantic Airline Operations: Diaries and Actigraphy for Two- vs. Three-Pilot Crews

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Introduction: The aim was to compare intercontinental flights with two-pilot and three-pilot crews with respect to fatigue/sleepiness and sleep, as there is considerable economic pressure on the airlines to use two-pilot crews. **Methods:** Twenty pilots participated. Data were collected before, during, and after outbound and homebound flights using a sleep/wake diary (sleepiness ratings every 2–3 h) and wrist actigraphy. The duration of flights was approximately 8 h, and six time zones were crossed. The same pilots participated in both conditions. **Results:** Napping during the outbound flight was 26 min for the two-pilot crew, and 48 min for the three-pilot crew. Napping during the homebound flight was 54 min and 1 h 6 min, respectively, and the difference was directly related to the time allotted for sleep. Subjective sleepiness was significantly higher for the two-pilot condition in both directions, peaking a few hours into the flight. Performance at top of descent for the two-pilot condition was rated as lower than the three-pilot condition. In the overall evaluation questionnaire there was a significant negative attitude toward two-crew operations. Sleep, sleepiness, subjective performance, boredom, mood, and layover sleep were assessed as having deteriorated in the two-pilot condition. The homebound flight was associated with considerably higher levels of sleepiness than the outbound flight. **Discussion:** The study indicates that the reduction of crew size by one pilot is associated with moderately increased levels of sleepiness. It is also suggested that time allotted to sleep in the two-pilot condition might be somewhat extended to improve alertness.

Keywords: pilots, sleep, jet-lag, work hours, time of day, circadian rhythm.

FLYING ACROSS TIME zones causes disruption of the circadian system, and excessive sleepiness is often reported by flight crews after flights across multiple time zones during the period that coincides with the circadian minimum (11,18,27). One reason for the reduced alertness is the well established effect of being awake and active at the “circadian low,” that is, the circadian phase of reduced metabolic rate, normally around 03:00 to 06:00 (8). The second reason is the extended time awake which will subtract from maximum alertness (after full sleep) in an essentially linear fashion across hours since sleep termination (8). The combined effects of the two lead to excessive sleepiness in the morning when the circadian trough (around 05:00) coincides with 22 h since previous sleep. This is the time when the risk of road accidents reaches a maximum (4) and when the performance level of an operator is comparable to that of an individual who has consumed alcohol to a blood alcohol level of approximately 0.08% (7). Even if this is called “jet lag” (27), the

phenomenon is virtually the same as that seen in shift work (1), with the slight exception that sleep after a westward flight is taken in an environment without daylight. Gradually, across days, an adjustment occurs, but aircrews seldom experience more than a day or two of adjustment due to short layovers.

The effects of flying at the wrong circadian time and with extended time awake on accident risk in air transport seem well established (20), and several countermeasures have been developed, the most important of which is sleep aboard the aircraft through different types of crewing and rest practices. Most airlines permit crews on long-haul flights to use scheduled breaks in which sleep can be taken in the cockpit or in a crew bunk; a relatively comfortable bed insulated from much of the aircraft noise. This clearly reduces the physiological and perceived sleepiness among the crew (23).

There are various crewing practices currently in use. These include two “separate” crews that operate on ultra long range (ULR) routes on flights over 16 h. This gives the crews the opportunity of more than 8 h of sleep in a crew “bunk.” Four pilots are commonly used in 12–16-h “long-haul” flights, which provide the opportunity for more than 5 h of bunk sleep. There are also three-pilot crews on intermediate duration flights who are either permitted to sleep in a bunk, or who are only permitted to sleep in the cabin or cockpit seat. Also, two-pilot crews operate such flights with napping opportunity in the cockpit only.

A three-pilot system has traditionally been used for intercontinental flights of intermediate duration. However, several airlines have been using two pilots for a number of years. The effects have been extensively discussed and evaluations seem to indicate that there are fatigue effects (26). To the best of our knowledge, however, there have not been any studies published comparing two- and three-pilot manning in the same

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group of pilots. One could hypothesize that with one pilot asleep, the remaining pilot might have greater difficulties remaining awake due to the lack of social interaction, particularly in connection with flights that operate during the circadian nadir, when sleep is promoted. Possibly, rest/sleep during flight may be less restorative due to restrictions for two-pilot crews.

Under traditional three-pilot operations, the crew may use the crew bunk as determined by the crew and the pattern may vary from very short bouts to more than an hour. In the present study, the two-pilot system, agreed upon in industrial negotiations, permits one pilot to take an unplanned "controlled rest" period in the pilot's seat for a period of 45 min. Since sleeping in a relatively upright position seems to interfere with sleep (19), and since the time permitted for sleep is limited, there is a possibility that sleepiness may be increased. In order to counteract negative effects, the pilots are required to alert the cabin crew before a controlled rest and set a timer to terminate the rest period. It is not permitted to pre-schedule the controlled rest as it might encourage carelessness with obtaining sufficient sleep before a flight, in reliance on the possibility of a compensatory nap on board.

The question of two vs. three pilots may be of importance to flight safety, and is, therefore, of considerable applied interest. This study set out to assess whether fatigue/sleepiness and sleep amounts would be affected by using a two-pilot crew with a maximum of 45 min sleep time in the pilot seat, compared with a three-pilot crew with more than 1 h of sleep possible in the crew bunk. The same individuals participated in both conditions.

METHODS

The study protocol was approved by the ethical committee at Karolinska Institutet. The pilots did not receive any compensation for taking part, but regarded their participation as part of their job duties. Each subject provided written informed consent before participating.

All pilots, except for those on leave, who were scheduled to fly any of the three routes from Stockholm to New York, Copenhagen to New York, or Copenhagen to Washington, DC, were asked for their voluntary participation as part of a three-pilot crew and a two-pilot crew. Only morning flights leaving at approximately noon local Scandinavian time to their respective destinations are reported here. At the start of the study, the pilots received a questionnaire collecting background data on the pilots' age, gender, and living conditions, as well as habitual sleep quality, overall health, and attitude toward the two-pilot system.

There were 29 male pilots flying morning flights who were asked to participate in this study. No female pilots flew the routes in question. One pilot abstained from participation and eight had to be dropped from the study due to reassignment. This left 20 pilots remaining in the study. All were in very good health as established by regular medical check-ups. The age range of the pilots extended from 40 to 59 yr ($m = 49.7 \pm 1.9$ yr,

mean \pm SE). The average experience flying intercontinental flights was $6.3 \text{ yr} \pm 0.8 \text{ yr}$.

The pilots assessed their need for sleep at $7 \text{ h } 54 \text{ min} \pm 6 \text{ min}$ and their bedtime $22:12 \pm 1 \text{ h } 15 \text{ min}$, and awakening at $07:42 \pm 11 \text{ min}$. The overall sleep quality was rated as "rather good" (2.2 ± 0.2 ; scale 1–5, where 1 = "very good" and 5 = "very poor"). Subjective overall health was rated as "very good" (1.4 ± 0.1). Of the 18 pilots responding to the question of subjective overall health, 11 rated their health as "very good" and 7 as "rather good." Three pilots smoked tobacco. Two pilots occasionally used sleeping pills; no pilots ever used relaxants or anti-depressants. Two occasionally used heartburn medication, and seven occasionally used pain medication.

Each pilot participated with one flight in each of the two crew conditions. The average lengths of the flights from blocks off to blocks on, was $8 \text{ h } 24 \text{ min} \pm 10 \text{ min}$ (mean \pm SE) for the outgoing flights from Scandinavia to New York and Washington, DC. Official takeoffs were at 10:40 from Stockholm to New York, and at 12:05 from Copenhagen to New York and Washington, DC. The homebound flights took approximately $8 \text{ h } 3 \text{ min} \pm 12 \text{ min}$ (mean \pm SE), and departed from the U.S. East Coast between 17:00 and 18:00, arriving in Scandinavia around 07:30.

Sleeping times before the flight roster and during the layover were assessed subjectively by the pilots using a sleep questionnaire, as well as with wrist actigraphy, beginning 2 d before the first flight until 2 d after the final flight for both trials. A questionnaire comparing the two conditions was filled out at the end of the study. The Karolinska Sleep Diary (KSD), an established self-rating instrument for sleep (3), was filled out each morning on awakening from the day before to the day after the flights. The scale contains questions on bed-time, time of rising, time to fall asleep, difficulties falling asleep, difficulties rising, number of awakenings, having had sufficient sleep, restless sleep, sleep quality, difficulties sleeping throughout. To obtain information on sleepiness the Karolinska Sleepiness Scale (KSS) was rated every 2–3 h from before to after the flights (2). The KSS scale ranges from 1–9 where 1 = "very alert," 3 = "rather alert," 5 = "neither alert nor sleepy," 7 = "sleepy, but no difficulty remaining awake," and 9 = "very sleepy, fighting sleep, an effort to remain awake." The KSD and the KSS have been validated against physiological data and provide a good impression of sleep and sleepiness (2,10,21).

During the flight days the KSS was filled out at the following times on the day of departure: on awakening, at "blocks off" (taxiing to runway), at top of climb (ToC = reaching cruising altitude), 2 h after ToC, 4 h after ToC, at top of descent (ToD), at "blocks on" (parking at the gate), at 18:00 (local time), and at bedtime. Thereafter it was filled out on awakening from the first layover sleep, and at 07:00, 10:00, 13:00 (local times), blocks off, ToC, 2 h after ToC, 4 h after ToC, ToD, blocks on, and at 12:00, 15:00, 18:00, 21:00 (local times), and at bedtime. Additional questions at each point were: performance capacity (scale: 1–5, with 1 = "critically low" and 5 = "high"), time with "heavy eyelids" (minutes),

unintentional nodding off, and start/duration of controlled rest. All refer to the time since the previous rating (1–2 h). Objective performance ratings, such as a neurobehavioral performance task like the PVT-test, were also considered but were refrained from because of the logistical problems of handling distribution and collection of hand-held computers. Subjective ratings of performance capacity has a reasonable relation to actual performance (9).

A questionnaire comparing the two-pilot system to the three-pilot system was filled out at the end of the study period. Questions included comparing the total amount of sleep during two-pilot and three-pilot operations, the amount of sleepiness during flight, performance capacity during flight, boredom during flight, lower mood during flight, amount of layover sleep, and overall view of the two-pilot system. The response alternative of all except the last item used a scale from 1–7, with 1 = “more” or “better” for the two-pilot conditions and 7 = “more” or “better” for the three-pilot condition; 4 = “no difference” between conditions. The last item, “overall view,” was scaled from 1–4, where 1 = “acceptable” and 4 = “not acceptable.”

Activity was measured with an actigraph—a watch-size device, worn on the wrist, and which measures acceleration/movement (5,14–16,24). It is a reliable and objective instrument for measuring sleep duration, sleep quality, and level of activity, including periods of nap-like behavior. The actigraph was used as an objective measure to confirm the subjective estimates of sleep duration and timing made in the diaries. The estimate is based on the number of 30-s intervals of zero activity of at least 1.5-min duration and the validity of the actigraph is good for estimating sleep in a bed. It has not been as well validated with respect to identifying sleep in the active individual, however. It will, however, indicate periods of non-activity. In recognition of this, the results section uses the term sleep/rest when describing actigraphy measures during flight.

A repeated measures analysis of variance with time (days or time into flight) and crew size as main factors was used for the statistical analysis. All F-ratios involving time were corrected for sphericity using the Huynh-Feldt method and p-values are given after this correction. Significant main effects or interactions were subjected to post hoc tests of crew condition.

RESULTS

Table I summarizes the results of subjective sleep duration. For the five main sleep episodes the variation across time was significant ($F_{4/19} = 19.7$; $p < 0.0001$), but the effect of crew size was not ($F_{1/19} = 0.1$; ns). There was no significant interaction between the two ($F_{4/76} = 0.8$; ns). Maximum sleep was obtained after return and minimum before the outbound flight. The times of retiring and rising also differed significantly across the five main sleep periods. There was no difference between two- and three-pilot crews with regard to bedtimes ($F_{1/38} = 1.5$; ns), but there was, of course, a significant difference over the course of the study ($F_{4/18} = 33.0$; $p < 0.0001$) without interaction ($F_{4/152} = 0.1$; ns). For rising, the results were: $F_{1/38} = 1.6$; ns; F

TABLE I. BEDTIME, WAKE UP, AND TOTAL SLEEP TIME (MEAN \pm SE). DIARY DATA ACROSS DAYS.

Sleep Pattern	Bedtime, Mean (\pm SE) [†]	Wake Up, Mean (\pm SE) [†]	Total Sleep Time, Mean (\pm SE, min)
Two-pilot			
Home	23:48 (\pm 12)	08:12 (\pm 18)	7 h 45 min (\pm 12)
Before			
outbound	23:42 (\pm 12)	07:24 (\pm 18)	7 h 03 min (\pm 17)
Layover/before			
homebound	21:48 (\pm 18)	06:54 (\pm 24)	8 h 00 min (\pm 18)
After return	23:24 (\pm 12)	09:06 (\pm 18)	9 h 08 min (\pm 20)
2nd day after			
return	00:18 (\pm 18)	08:18 (\pm 24)	7 h 08 min (\pm 15)
Three-Pilot			
Home	23:42 (\pm 18)	07:36 (\pm 18)	7 h 30 min (\pm 12)
Before			
outbound	23:12 (\pm 12)	06:18 (\pm 18)	6 h 40 min (\pm 12)
Layover/before			
homebound	21:18 (\pm 18)	06:36 (24)	8 h 26 min (\pm 27)
After return	23:00 (\pm 12)	08:24 (\pm 24)	8 h 51 min (\pm 21)
2nd day after			
return	00:12 (\pm 24)	08:12 (\pm 24)	7 h 29 min (\pm 18)
F-Crew Size (df)	1.5 (1/38)	1.6 (1/38)	0.1 (1/19)
F-Time (df)	33.0*** (4/18)	17.4*** (4/18)	19.7*** (4/19)
F-Crew Size \times Time (df)	0.1 (4/152)	0.7 (4/152)	0.8 (4/76)

[†]Clock Time \pm SE (in minutes).

F = F-ratio, *** = $p < 0.001$, df = degrees of freedom

$4/18 = 17.4$, $p < 0.0001$; and $F_{4/152} = 0.7$, ns, respectively. The time from landing in the U.S. to departure was 27 h 56 min \pm 12 min for the two-pilot crew, and 27 h 27 min \pm 9 min for the three-pilot crew ($t = 1.96$; $p < 0.0591$).

The results from actigraphy for the duration of main sleep showed essentially the same results as the subjective estimates, but some data were lost due to malfunction or pilots forgetting to put them on after showers. The effect of time was significant ($F_{4/34} = 3.6$; $p < 0.008$), but not the effect of crew condition ($F_{1/34} = 1.6$; ns). The interaction term between sleep and crew size was also significant ($F_{4/34} = 2.4$; $p < 0.05$). During layover more time was spent awake than at any other time during the study. Total sleep times in the two-pilot condition were: 7 h 8 min \pm 12 min (mean \pm SE) at home, 7 h \pm 24 min before the outbound flight, 07 h 21 min \pm 24 min during layover, 8 h 24 min \pm 18 min after return, and 6 h 48 min \pm 18 h on day 2 after return. For the three-pilot condition, the total sleep times were: 6 h 50 min \pm 12 min, 6 h 35 min \pm 24 min, 7 h 34 min \pm 18 min, 7 h 58 min \pm 18 min, and 6 h 42 min \pm 18 min, respectively. Sleep efficiency showed no effects of crew condition ($F_{1/34} = 0.9$; ns), but effect of days was significant ($F_{4/34} = 4.2$; $p < 0.003$). The interaction between days and crew size was not significant. Sleep efficiency for the five main sleep episodes were 91.2 \pm 0.9%, 91.1 \pm 0.8%, 89.4 \pm 0.8%, 91.3 \pm 0.9%, and 90.4 \pm 1.0%, respectively, for the two-pilot condition. Corresponding results for the three-pilot conditions were 91.9 \pm 0.7%, 90.5 \pm 1.5%, 87.8 \pm 1.7%, 91.7 \pm 0.4%, and 91.3 \pm 0.3%.

For time with heavy eyelids there was a significant effect of flight direction ($F_{1/19} = 7.0$; $p < 0.05$) and a

TABLE II. NAPPING START TIME, END TIME, TOTAL NAP TIME FOR NAPPERS, AND TOTAL NAP TIME FOR ALL PILOTS (N, MEAN \pm SE). DIARY DATA DURING NON-FLIGHT HOURS.

Napping Pattern	Nap From [†]	Nap To [†]	Total Nap Time/ Nappers	N	Total Nap Time/All Pilots	N
Two-pilot						
Home	13:30 (2 h 0 min)	13:54 (1 h 54 min)	23 min (\pm 8)	2	3 min (\pm 2)	18
Before outbound	—	—	—	0	—	0
Layover/before						
homebound	13:24 (30 min)	14:12 (36 min)	48 min (\pm 15)	6	16 min (\pm 7)	18
After return	12:22 (1 h 14 min)	14:10 (1 h 3 min)	1 h 48 min (\pm 29)	8	48 min (\pm 18)	18
2nd day after return	—	—	—	0	—	0
Three-pilot						
Home	21:00 (0)	21:18 (0)	18 min (0)	1	1 min (\pm 1)	17
Before outbound	—	—	—	0	—	0
Layover/before						
homebound	14:18 (1 h 12 min)	16:00 (1 h 18 min)	1 h 42 min (\pm 20)	7	42 min (\pm 15)	17
After return	11:17 (58 min)	13:16 (54 min)	1 h 59 min (\pm 26)	7	49 min (\pm 18)	17
2nd day after return	17:30 (0)	18:00 (0)	30 min (0)	1	2 min (\pm 2)	17
F, Crew Size (df)	—	—	—	—	1.1	1/33
F, Time (df)	—	—	—	—	9.9***	4/33
F, Crew Size \times Time (df)	—	—	—	—	0.7	4/132

[†]Clock time \pm hours and minutes.

F = F-ratio, *** = $p < 0.001$, df = degrees of freedom

trend for a significant effect of crew size ($F_{1/19} = 3.7$; $p < 0.08$). The interaction was not significant ($F_{1/19} = 0.1$; ns). The average time with heavy eyelids on the outbound flight for the two-pilot condition was 29 ± 16 min (mean \pm SE), and 3 ± 2 min for the three-pilot condition. The homebound flight showed 44 ± 16 min and 15 ± 6 min for the two-pilot and three-pilot crews, respectively.

The reported napping pattern during free time was not testable in the same way as the main sleep episodes since napping did not occur on some of the days. Only the days "before homebound" and "after return" provided any variance that could be used for testing. The non-parametric Wilcoxon test did not show any significant difference between the crew conditions. Note that only about one-third took a nap before the homebound flight. **Table II** summarizes the results of total nap duration. Considering total nap time for all pilots across the 5 d, the variation across time was significant ($F_{4/33} = 9.9$; $p < 0.0001$), but the effect of crew size was not ($F_{1/33} = 1.1$; ns). There was no significant interaction between the two ($F_{4/132} = 0.8$; ns). For reported duration of napping during flight, crew condition was significant ($F_{1/38} = 5.9$; $p < 0.02$), as well as the direction of flight ($F_{1/38} = 16.8$; $p < 0.0002$), and there was a trend for the interaction between the two ($F_{1/38} = 3.2$; $p < 0.08$). The homebound flight and the three-pilot condition involved longer napping, even if the difference was smaller (non-significant) during the homebound flight.

The actigraphy data were also used to judge sleep/rest during the flight. Since the actigraph is optimized for use in the supine position and there may be difficulties differentiating sleep from quiet rest, we refer to the outcome variable as sleep/rest. Short, unplanned naps were assumed during the flight, and actigraphy data was easier to access than having the pilots estimate what time they took their naps and for how long. The two-pilot crew napped for 26 ± 6 min ($n = 9$) during

the outbound flight, and 54 ± 12 min ($n = 15$) during the homebound flight. The three-pilot crew napped for 48 ± 6 min ($n = 15$) during the outbound flight, and $1 \text{ h } 21 \text{ min} \pm 10 \text{ min}$ ($n = 17$) during the homebound flight. The ANOVA showed a significant difference between crew conditions ($F_{1/14} = 2.3$; $p < 0.05$) and between flight directions ($F_{1/14} = 16.9$; $p < 0.01$), and there was a trend for interaction ($F_{1/14} = 3.7$; $p < 0.08$). Two-pilot crews obtained less sleep/rest during the outbound flight with just under an hour, whereas the three-pilot crews had 1 h 30 min. Both crews had approximately the same amount on the homebound flights.

It might be of interest to consider prior wake excluding in-flight rest at the end of the flight. On the outbound flight this was $12 \text{ h } 36 \text{ min} \pm 2 \text{ min}$ and $13 \text{ h } 54 \text{ min} \pm 18 \text{ min}$ for the two- and three-pilot conditions, respectively ($t = -3.6$; $p < 0.002$). For the homebound flight the values were $18 \text{ h } 36 \text{ min} \pm 24 \text{ min}$ and $19 \text{ h } 12 \text{ min} \pm 30 \text{ min}$, respectively ($t = -1.3$; ns). Prior wake including in-flight rest on the outbound flight was $12 \text{ h } 21 \text{ min} \pm 18 \text{ min}$ and $13 \text{ h } 14 \text{ min} \pm 18 \text{ min}$ for the two- and three-pilot conditions, respectively ($t = -2.8$; $p < 0.0131$). For the homebound flight the values were $17 \text{ h } 49 \text{ min} \pm 27 \text{ min}$ and $18 \text{ h } 11 \text{ min} \pm 31 \text{ min}$, respectively ($t = -0.8$; ns).

For sleepiness during the outbound flight (**Fig. 1**) there was a significant effect of time ($F_{8/19} = 73.9$; $p < 0.0001$), but not for crew size ($F_{1/19} = 0.6$; ns). However, the interaction term was significant ($F_{8/152} = 2.6$; $p < 0.05$). Sleepiness was highest at bedtime in the evening at the destination and at awakening on the morning of the outbound flight. The interaction was mainly due to increased sleepiness for the two-pilot crew after ToC. For sleepiness during the homebound flight (**Fig. 2**) there was a significant effect of time ($F_{11/19} = 28.6$; $p < 0.0001$) and of crew size ($F_{1/19} = 7.8$; $p < 0.01$), but no significant interaction ($F_{11/209} = 1.3$; ns). The two-pilot crew showed a higher level of sleepiness during much

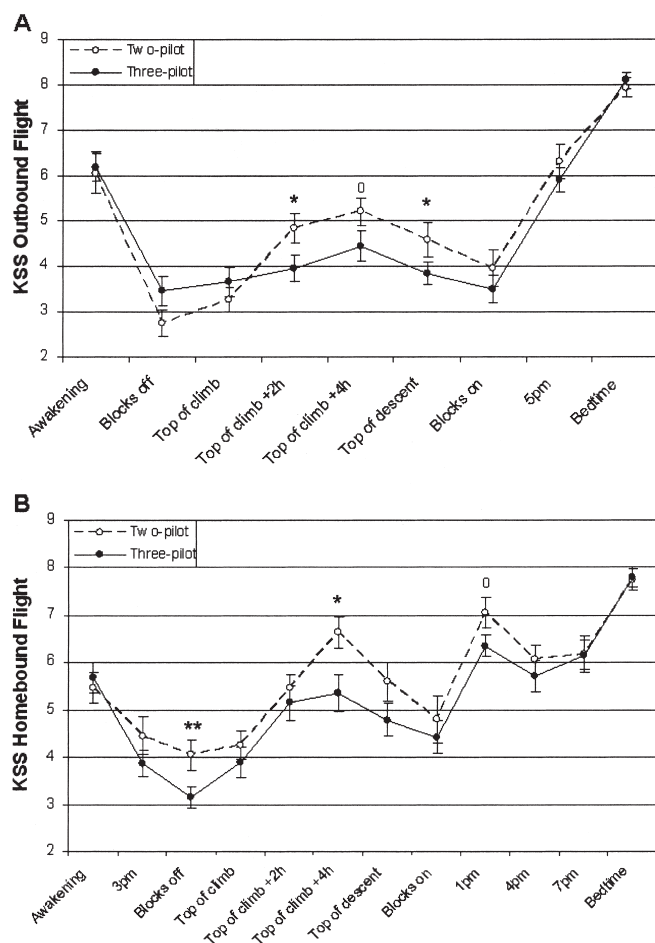


Fig. 1. Sleepiness (KSS) during A) outbound and B) homebound flights (mean \pm SE). Asterisks indicate significant differences between conditions: * = $p < 0.05$; ** = $p < 0.01$; 0 = $p < 0.10$ (trend).

of the flight, in particular 2–4 h after ToC. However, peak sleepiness was reported after arrival.

Also, KSS at home before and after flights were analyzed. There was no significant difference in sleepiness between the crews the day after the homebound flight ($F_{1/38} = 0.2$; ns), but the effect of time of day was significant ($F_{5/38} = 51.7$; $p < 0.0001$). The interaction term was not significant ($F_{5/190} = 0.2$; ns). There was a highly significant circadian pattern for sleepiness before the flight ($F_{5/38} = 57.2$; $p < 0.0001$) with maximum in the morning and evening. The effects of crew condition ($F_{1/38} = 0.6$; ns) and interaction ($F_{5/190} = 0.9$; ns) were not significant. Because of the lack of effect of condition or interaction, no figures are included.

Comparing sleepiness in the two-pilot condition for outbound and homebound flights, the results yielded a significant effect of direction ($F_{1/19} = 10.1$; $p < 0.005$) and of time ($F_{7/19} = 42.0$; $p < 0.0001$), as well as a significant interaction ($F_{7/133} = 5.1$; $p < 0.0001$). In the three-pilot condition for outbound and homebound flights, the results were significant for direction ($F_{1/19} = 4.2$; $p < 0.05$), for time ($F_{7/19} = 50.0$; $p < 0.0001$), and for the interaction ($F_{7/133} = 4.1$; $p < 0.0005$).

Rated performance (Fig. 2) showed a significant effect of time ($F_{4/19} = 10.4$; $p < 0.00001$) and of crew size ($F_{1/19} = 4.5$; $p < 0.05$) for the outbound, as well as for the

homebound flight ($F_{4/19} = 11.0$; $p < 0.0001$ and $F_{1/19} = 8.6$; $p < 0.01$, respectively). The interaction term was not significant in any of the analyses ($F_{4/76} = 1.3$; ns and $F_{4/76} = 1.6$; ns, respectively). The difference between the crew conditions was particularly pronounced 2–6 h after top of climb for the homebound flight.

In order to evaluate the relationship between sleepiness/performance and sleep, correlations were carried out between ratings at top of descent and sleep during the flight as well as with total prior sleep time (naps + layover sleep). None of these correlations were significant. To investigate whether the role at the controls of the aircraft was related to sleepiness and sleep, the group was divided into pilots at the controls during takeoff and landing, and those not at the controls. This yielded two groups with 10 pilots in each. The ANOVAs were repeated, and no significant group difference ($F_{1/18} = 0.01$; ns) or interaction group/condition ($F_{7/126} = 0.55$; ns) was found. However, the effect of time was significant in the two-pilot condition ($F_{7/18} = 43.8$; $p < 0.0001$). Corresponding results in the three-pilot condition were $F_{1/18} = 0.21$, ns; $F_{7/126} = 1.7$, ns; and $F_{7/18} = 33.2$, $p < 0.0001$.

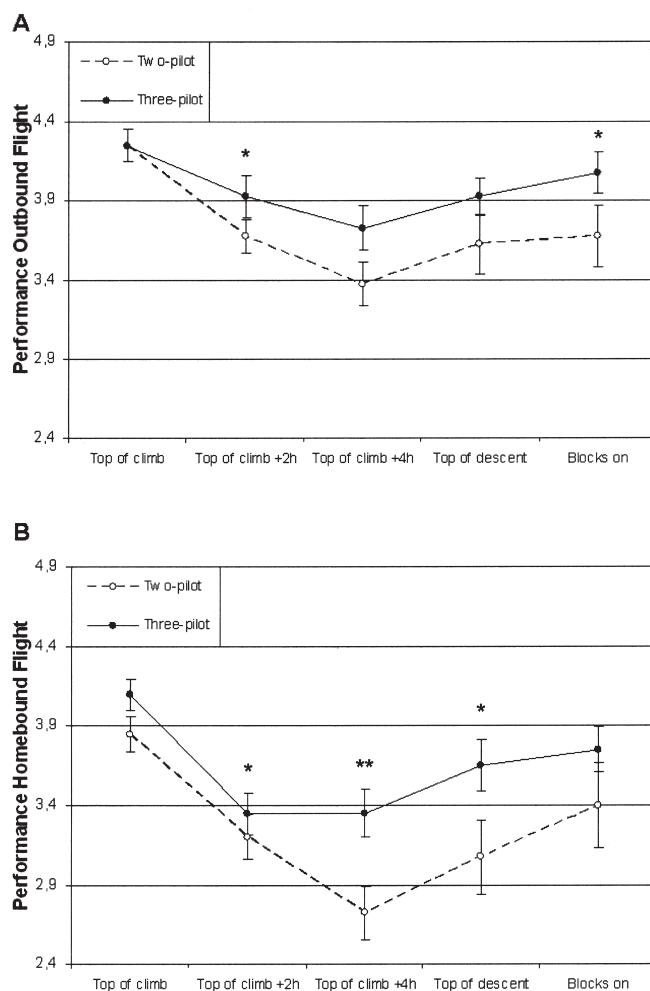


Fig. 2. Performance during A) outbound and B) homebound flights (mean \pm SE): 1 = critically low, 5 = high. Asterisks indicate significant differences between conditions: * = $p < 0.05$; ** = $p < 0.01$.

To obtain a retrospective opinion on the two- and three-pilot crew operations we asked for ratings on a scale from 1–7, where 4 = no difference and values above and below indicating (more/less or better/worse). There was a significant negative attitude toward two-crew operations. The effect on amount of sleep during the flight was 5.9 ± 0.2 (mean \pm SE) ($p < 0.0001$); sleepiness during flight, 2.4 ± 0.2 ($p < 0.0001$); performance during flight, 5.8 ± 0.2 ($p < 0.0001$); boredom during flight, 2.4 ± 0.2 ($p < 0.0001$); lower mood during flight, 3.0 ± 0.2 ($p < 0.0001$); and layover sleep, 4.4 ± 0.2 ($p < 0.0471$). These were assessed as being more negative when flying with two pilots. Furthermore, the overall view of two- and three-pilot-crew effects had a mean of 3.11 ± 0.2 on a scale of 1–4 where 1 = acceptable and 4 = not acceptable; in other words, quite negative ($p < 0.0001$). In order to see which variables predicted attitude to the two-pilot system, a stepwise regression analysis was performed using sleepiness, performance, total sleep time, boredom, mood, and layover total sleep time as predictors. Sleepiness ($\beta = -0.46$, $R^2 = 0.29$) and performance ($\beta = +0.55$, $R^2 = 0.21$) accounted for half of the explained variance.

DISCUSSION

The aim of the present study was to compare intercontinental flights with two pilots to flights with three pilots, with respect to fatigue/sleepiness and sleep. The results show that total sleep times varied over days with short sleep the night before the outbound flight, and a peak for the night after returning home. It is likely that the anticipation of the upcoming departure, as well as having to wake up early, significantly truncates the sleep time before flight, and the need for recovery and opportunity of ad lib sleep leads to the extended sleep after arrival home. The actigraphy showed similar results. No differences were seen between the crew size conditions, which seem to indicate that the need for recovery was not affected by crew size. Napping during time off was limited and mainly occurred before and after the homeward flight. No difference between crew sizes was seen. This adds to the impression of a lack of effect of crew size on the need for recovery. Since crew size has not been studied before in this respect, there is an obvious need for corroboration of the tentative conclusion.

The sleep pattern highlights a reduction of sleep before the outbound flight and 2 d after the return flight. It is likely that the pilots have adjusted to their normal rhythm after a night's extended sleep on return. The lack of naps 2 d after return seems to corroborate that notion. However, a study examining total sleep time for additional days after return might further illuminate why such a reduction occurs. More extended naps were taken on the homebound flights compared with the outbound flights, and this supports the notion that the crews were sleepier on the homebound flights, which is also supported by previous studies (25).

During flight the two-pilot crews slept less than during the three-pilot conditions. This was particularly prominent during the outbound flight, and was apparently directly related to the time allotted for sleep,

which had a maximum of 45 min in the two-crew condition and longer in the three-pilot condition, but without any formally imposed limit. The absolute levels were higher using actigraphy, probably because the actigraph may interpret very peaceful rest as sleep. But the pattern was similar for ratings and actigraphy. It seems obvious that a moderate extension of time allotted for sleep would extend sleep.

With respect to sleepiness, time with heavy eyelids was clearly increased in the two-pilot crew and during the homebound flight. Differences in KSS ratings were pronounced 2–4 h after ToC. Although subjective sleepiness was not compared between flight directions, visual inspection of the mean levels and dispersion measures indicates higher sleepiness during the homebound flight. The reason for the greater sleepiness on the return flight is, very likely, the combined effect of the circadian nadir and an extended time awake (8). The sleepiness level observed during the latter part of the return flight reached levels similar to that seen in shift workers during night shifts (17). The observation seems logical considering that the return flight is, essentially, a form of night work in the sense that the flight occurs during the biological night, i.e., the circadian low, and occurs during the hours of darkness at home. Similar observations have been made in other studies (11,18,27,28). Other high levels of sleepiness occurred on awakening and before bedtime during layover. The reason for the former is the well-established sleep inertia effect (13), and the reason for the latter is the combined effect of closeness to the circadian low and a long time awake (3). The lowest assessments of subjective sleepiness were obtained in relation to takeoff and landing when work demands normally reach a peak.

The comparison between the homebound and the outbound flights showed that sleepiness was much more pronounced on the homebound flights almost throughout the entire trip, save for takeoff and landing. This is consistent with previous results showing increased sleepiness during the homebound flight (25). However, that study involved multiple flight routes and layovers and clear circadian adjustment, which is different from the present results with a 24-h layover. Different phases in the circadian rhythm plus a sleep debt probably caused by difficulties adapting to local time during layover, are factors most likely comprising elevated aircrew fatigue on homebound flights (11).

Performance ratings differed greatly over the course of the flight, and the pilots rated themselves at lower levels when flying two-pilot operations. Worst performance was assessed at approximately 4 h into the flight. The results agree rather well with the sleepiness ratings, but the differences between crew conditions were more pronounced for performance ratings. Interestingly, the increased alertness at landing was not reflected by a similar increase in performance ratings. Presumably, the participants went beyond their acute "manifest" sleepiness when making performance estimates, including knowledge about prior sleepiness and general sleep loss situation. This has never been explicitly studied, though a few attempts have been made (9,22).

The increased sleepiness with a two-pilot crew is in

line with previous results by Samel et al. (26), and one might assume that the effect is due to the shorter sleep allowed in the two-pilot context, the relatively upright sleep position in the pilot seat, and perhaps a lack of stimulation for the remaining pilot. It is not clear whether this constitutes a situation of decreased safety, but the level of sleepiness is similar to what is seen in car or truck drivers at night (12). While the sleepiness in the latter groups has been related to accident risk (6), it is unlikely to be the case in pilots, since aircrew sleepiness is concentrated to the cruising phase of flight. At start and landing, the critical phases of a flight, the task clearly activates alertness.

In addition, the role of the pilots with regard to whether they were flying the plane was investigated. According to practice, half flew the outbound planes, and were subsequently second chair during the homebound flights. Flying the plane or sitting second chair had no relation to sleepiness or performance.

In the overall evaluation questionnaire there was a significant negative attitude toward two-crew operations. Sleep, sleepiness, performance, boredom, mood, and layover sleep were assessed as having deteriorated in the two-pilot condition. These views closely reflect the sleep diary and actigraphy data.

When interpreting the results of the present study one should keep in mind several possible confounders. Firstly, the sleep diary data are subjective and, thus, subject to the possibility of bias. On the other hand, we have had good experience with using these types of instruments, and they have previously been validated against physiological data (2). One should also note the lack of difference between the conditions before the outbound flight, which suggests that the results may not have been biased against the two-flight operations.

Secondly, the order of the conditions was not balanced—each participant always started the study by flying the two-pilot condition. This was due to organizational reasons and timing of the two-pilot trial. This could have created an order effect, the effects of which, however, are unclear. Another weakness is variability in departures or disruptions of various types. However, in the present study such effects were moderate and did not differ between conditions.

The size of the group seems adequate for the present purpose, but does not permit analyses of subgroups based on gender or age, which might have hidden stronger effects in vulnerable groups. This may, however, be brought up in future research. One would also like to see data collected across longer periods of time, in order to account for the effects of season, long delays, and poor weather conditions. This might be accomplished relatively easily.

In conclusion, the present study indicates that the reduction of crew size by one pilot is associated with moderately increased levels of sleepiness under normal conditions. It is suggested that the experiment be extended across longer periods of time covering a variety of flight conditions, such as time allotted for nap, body position, scheduled vs. non-scheduled napping, layover time, sleep length before outbound

flight, caffeine and nicotine intake, etc. It is also suggested that time allotted to sleep in the two-pilot condition might be somewhat extended to improve alertness. The present study constitutes a rather straightforward independent scientific evaluation of a "safety-case."

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