Flight Crew Alertness and Sleep Relative to Timing of In-Flight Rest Periods in Long-Haul Flights

Kevin B. Gregory; Rhiannon N. Soriano-Smith; Amanda C. M. Lamp; Cassie J. Hilditch; Michael J. Rempe; Erin E. Flynn-Evans; Gregory L. Belenky

BACKGROUND: In-flight breaks are used during augmented long-haul flight operations, allowing pilots a sleep opportunity. The U.S. Federal Aviation Administration duty and rest regulations restrict the pilot flying the landing to using the third rest break. It is unclear how effective these restrictions are on pilots' ability to obtain sleep. We hypothesized there would be no difference in self-reported sleep, alertness, and fatigue between pilots taking the second vs. third rest breaks.

METHODS: Pilots flying augmented operations in two U.S.-based commercial airlines were eligible for the study. Volunteers completed a survey at top-of-descent (TOD), including self-reported in-flight sleep duration, and Samn-Perelli fatigue and Karolinska Sleepiness Scale ratings. We compared the second to third rest break using noninferiority analysis. The influence of time of day (home-base time; HBT) was evaluated in 4-h blocks using repeated measures ANOVA.

RESULTS: From 787 flights 500 pilots provided complete data. The second rest break was noninferior to the third break for self-reported sleep duration (1.5 ± 0.7 h vs. 1.4 ± 0.7 h), fatigue (2.0 ± 1.0 vs. 2.9 ± 1.3), and sleepiness (2.6 ± 1.4 vs. 3.8 ± 1.8) at TOD for landing pilots. Measures of sleep duration, fatigue, and sleepiness were influenced by HBT circadian time of day.

DISCUSSION: We conclude that self-reported in-flight sleep, fatigue, and sleepiness from landing pilots taking the second in-flight rest break are equivalent to or better than pilots taking the third break. Our findings support providing pilots with choice in taking the second or third in-flight rest break during augmented operations.

KEYWORDS: augmentation, in-flight sleep, rest break, circadian rhythm.

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Commercial passenger flights require two pilots in active roles to operate the aircraft, one as the flying pilot (pilot flying; PF) and the other as the monitoring pilot (pilot monitoring; PM). When flight timing exceeds 9 h, the Federal Aviation Administration (FAA) requires an augmented flight crew of three or four pilots, where one or two pilots act as a relief pilot to provide the PF and PM with in-flight sleep opportunities. Extensive literature supports the recuperative and performance benefits of short sleep periods or naps in laboratory and operational settings.[24]

Even when an opportunity for sleep is provided, it is important to understand that a number of factors influence the ability of a pilot to convert that opportunity into beneficial sleep. Foremost, pilots must be physiologically ready for sleep.[4,23] Sleep initiation, duration, and architecture is determined by the homeostatic drive for sleep and by circadian time of day.[2] For example, naps attempted soon after a prior sleep episode tend to be associated with longer sleep latency and less deep sleep.[5] Similarly, alertness and sleep propensity fluctuate with the circadian rhythm, with the strongest circadian drive to be awake, or a 'wake maintenance zone', occurring a few hours before an individual's habitual bedtime.[21,29] Conversely, when an individual attempts to initiate sleep at the circadian nadir, occurring a few hours before an individual's habitual wake time, sleep may come easily, but taking a nap at that circadian time is associated

From the Fatigue Countermeasures Laboratory, NASA Ames Research Center, Moffett Field, CA, USA.

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Address correspondence to: Kevin Gregory, Fatigue Countermeasures Laboratory, NASA Ames Research Center, Mail Stop 262-4, Moffett Field, CA 94035, USA; kevin.b.gregory@nasa.gov.

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with cognitive impairment upon waking due to sleep inertia.[13,26] This means that depending on the timing of the sleep opportunity relative to prior sleep and time of day, a pilot may not be able to fall asleep, or may fall into a deep sleep and have difficulty performing upon waking. Field studies of in-flight rest support these laboratory observations, with pilots reportedly having a harder time sleeping during the first half of ultra-long-haul flights (16+ h)[28] and during the circadian day.[11]

In addition to physiological readiness for sleep, the sleep environment must be appropriate for the initiation and maintenance of sleep.[3] Flatter surfaces promote greater sleep quantity and quality, with seats that recline (to an angle of at least 40°), enabling sleep that is comparable to that obtained in a bed.[22] Longer sleep duration in flight has been associated with having comfortable bedding and sound attenuation.[23] Similarly, random noise events, such as those caused by passengers or cabin crew, and turbulence have been reported as negatively affecting in-flight sleep.[23,30] Interindividual differences in morningness-eveningness preference,[16] circadian phase,[17] habitual sleep need,[14] and sleep inertia[19] may be considerable within a diverse population of pilots and may also potentially impact the efficacy of fatigue risk management practices during long-haul operations.[9]

As part of the U.S. FAA's integration of sleep and circadian science into flight crew duty and rest regulations, a provision was made for augmented crews specifying that the pilot landing the aircraft is required to have 2 consecutive hours of in-flight rest in the second half of the flight duty period (FDP; FAR 117.17.c.1).[7] This rule was intended to provide the landing pilots with the most recent sleep opportunity in order to reduce sleepiness prior to the critical flight phase initiating landing, top of descent (TOD). However, for single-augmented (i.e., three-pilot) crews with an FDP under 14 h, this rule may be unnecessarily restrictive as only the final (third) in-flight rest break is compliant with the regulation. The third rest break may occur at any point in the circadian cycle depending on the timing of the flight and could result in the landing pilot experiencing sleep inertia, coinciding with the greater likelihood of environmental sleep disruption due to the timing of meal service to passengers. For those reasons this rule may not provide the best sleep opportunity for the landing pilot to sustain alertness and performance during the critical landing phase of flight. Therefore, we aimed to measure pilots' self-reported fatigue and sleepiness at TOD in relationship to the in-flight break taken and duration and quality of the sleep obtained. We hypothesized that the second rest break would be statistically noninferior to the third rest break for measures of sleep, fatigue, and sleepiness.

METHODS

Subjects

Volunteer participation was solicited from pilots actively flying three-pilot operations with an FAA-approved in-flight rest facility across all fleet types within two U.S.-based airlines. Flights considered for the study included those with a scheduled FDP less than 14 h and a minimum rest opportunity for the landing pilots of 105 min (during second or third rest break). Flights could include both outbound and inbound (from/to the United States) flights. All participants provided informed consent prior to participating in the study and the research protocol was reviewed and approved by NASA Ames Human Research Institutional Review Board (protocol HRI-332). The study was deemed exempt by the Washington State University Institutional Review Board (IRB-15,311).

Procedure

For the purposes of this study, the two participating commercial airlines received FAA approval to use an alternative in-flight rest scheme other than that prescribed in the regulation when collecting data on applicable three-pilot augmented operations. Participants completed an electronic survey delivered via company-issued iPads while operating one of the eligible routes. For all in-flight rest breaks, participants were instructed to wait 10 min after waking to minimize sleep inertia impacting their rating responses. Pilots were allowed to complete TOD ratings for more than one eligible flight during the data collection period.

Materials

The survey consisted of 50 items that included: flight duty information; pilot information (e.g., duty during landing); timing of the in-flight rest break taken; sleep duration; sleep quality ratings at end of break; fatigue and sleepiness ratings at start of break, end of break, and TOD; and additional information (e.g., break preferences, rest schedule determination, trip assignment procedures, self-reported morningness/eveningness). Sleep quality was rated on a 5-point scale from "1 - very good" to "5 - very poor." The Samn-Perelli (SP) Fatigue Scale is a 7-point scale that ranges from "1 - fully alert, wide awake" to "7 - completely exhausted, unable to function effectively."[25] One airline used a Karolinska Sleepiness Scale (KSS) version with a 9-point scale that ranges from "1 - extremely alert" to "9 - very sleepy, great effort keeping alert (fighting sleep)."[18] The other airline used a modified KSS version with a 10-point scale that ranges from "1 - extremely alert" to "10 - extremely sleepy, can't keep awake."[1] When KSS data was combined for the two airlines for analysis, the 9-point scale was rescaled to the 10-point scale using the equation $(X - 1) * 9/8 + 1$. The use of SP and KSS ratings have been proposed and used as safety performance indicators in a manner consistent with fatigue management guidance by the International Civil Aviation Organization.[10,20]

Statistical Analysis

Data visualization and statistical analysis were done using the open source statistical programing language R (https://www.R-project.org). One-way Wilcoxon and *t*-tests were used to compare baseline data between the airline carriers. Given the application of the FAA rule to landing pilots specifically, our primary analyses were limited to the flying and monitoring pilots who landed the aircraft and excluded responses from relief pilots.

We used noninferiority testing to evaluate the hypothesis that the second in-flight rest break would be noninferior to the third in-flight rest break for landing crew pilots (PF and PM) by comparing measures of in-flight sleep, and fatigue and sleepiness at TOD.

Noninferiority testing can be used to detect whether there is equivalence between two groups or superiority of one group and provides a clear graphical representation of the results. It requires an estimate of delta (also called epsilon), a quantity expressing the maximum allowable difference before the measurement in question is deemed no longer equivalent. Delta values of $\pm$ 1 rating point for both the SP and KSS and 0.5 h for sleep duration were selected a priori. These delta values are considered the smallest meaningful value with operational significance and are used in FAA fatigue risk management exemption procedures.[20]

In order to evaluate the influence of time of day on self-reported sleep quantity and quality, fatigue, and sleepiness, the data were binned in 4-h blocks by home-base time (HBT).[11] Repeated measures ANOVA were used to evaluate differences in binned data with Tukey post hoc comparisons for significant findings. The goal of the study was to compare the different in-flight rest periods as predictors of subsequent fatigue and sleepiness at TOD.

RESULTS

Pilot Information

Data collection was conducted between October 2016 and February 2018. There were 500 pilots who provided 787 total survey responses from Carrier 1 (C1) and Carrier 2 (C2). Some C1 pilots provided a survey response for more than one flight. General characteristics of the survey respondents are presented in **Table I**.

Table I. General Characteristics of Survey Respondents.

	CARRIER 1	CARRIER 2
	***N* (%)**	***N* (%)**
Number of responses	485 (62)	302 (38)
Duty during landing		
Pilot flying	259 (53)	138 (45)
Pilot monitoring	144 (30)	146 (49)
Relief	82 (17)	17 (5)
Not reported	–	1
Home-base time zone		
Eastern	98 (49)	196 (65)
Central	90 (45)	72 (24)
Mountain	NA	4 (1)
Pacific	10 (5)	30 (10)
Morning/evening		
Definite morning/early morning	37 (19)	110 (36)
More so morning/late morning	70 (35)	96 (31)
Afternoon	NA	20 (6)
More so evening/early evening	64 (33)	33 (10)
Definite evening/late evening	23 (12)	32 (10)
Not reported	4 (2)	11 (3)

For home-base time zone and morning/evening, results are based on the number of individual pilot respondents (Carrier 1 = 198, Carrier 2 = 302). Morning/evening responses for Carrier 1 included definite morning, rather more morning than evening, rather more evening than morning, and definite evening; Carrier 2 options included early morning, late morning, afternoon, early evening, and late evening.

Duty Information

Most respondents reported their trip as having been assigned through the preferential bidding system, or bidline (71%), with reserve (10%) and pickup (8%) assignments also reported. Data were missing or there was no response to this question from 4% of studied pilots.

Duty report, block-in, and total block times were reported by the pilots. Block time refers to the period of time when the aircraft is in operation, from block-out, when the brakes are released and departure from the gate begins, to block-in, when the brakes are set following arrival at the gate at the flight's destination. FDPs were calculated based on the difference between duty report and block-in time (adjusted to the pilot's HBT). Where information needed for the FDP calculation was missing, an estimate of FDP was determined by adding an hour to actual block time (block-out to block-in) when that was provided or to the scheduled block time (a total of 69 values were estimated in this manner), as duty report time is generally 1 h prior to block-out. For the block time results, when actual block time was not provided, scheduled block time was used (a total of 63 values were substituted in this manner). Results are presented in **Table II**. For these results and subsequent analyses, FDP values $\geq$ 6 h and $\leq$ 14 h were included with long block time entries excluded as outliers, because we wanted to ensure that the duty periods that we selected would be of a duration that would require the landing pilots to take the third rest break under the standard FAA regulations.

In-Flight Rest Break Information

Relief pilots primarily reported using the first rest break (N = 99) while landing crew pilots (PF and PM) primarily reported use of the second and third rest breaks (**Table III**). Respondents reported when rest breaks for all pilots on the flight occurred. The first rest break usually started within 20 min after takeoff, ranging up to 78 min (mean = 19.2 min, N = 601 flights). Following the final rest period, pilots reported that all flight crewmembers were back on the flight deck by about 40 min before landing (mean = 43.1 min, N = 626 flights). Both carriers have crew rest facilities designated as Federal Aviation Regulations (FAR) class 1 (bunk with flat surface in separated area), class 2 (bunk or seat that provides a flat or near flat surface, with at least a separator curtain), and class 3 (seat that reclines at least 40°) as possible options on the studied flights. The breakdown of which type of rest break facility was used is reported in

Table II. Block and Flight Duty Times for All Reported Duty Periods.

	BLOCK PERIODS	TOTAL BLOCK TIME	DUTY PERIODS	FLIGHT DUTY PERIOD
	N	**M (SD)**	***N***	**M (SD)**
Carrier 1	436	8.73 h (1.68)	439	9.73 h (1.40)
Carrier 2	294	8.59 h (1.41)	294	10.24 h (1.54)

Table III. Comparison of Rest Break Facilities Used, and Break Taken for Both Carriers.

	CARRIER 1		CARRIER 2	
	ALL	LANDING	ALL	LANDING
	N (%)	*N* (%)	*N* (%)	*N* (%)
FAR Classification				
Class 1	148 (34)	134 (36)	104 (35)	98 (36)
Class 2	186 (42)	153 (41)	72 (24)	70 (25)
Class 3	78 (18)	63 (17)	36 (12)	33 (12)
Not reported	27 (6)	25 (7)	82 (28)	75 (27)
Rest Period Taken				
Break 1	63 (14)	2 (1)	10 (3)	9 (3)
Break 2	232 (53)	231 (61)	155 (53)	148 (54)
Break 3	144 (33)	143 (38)	125 (43)	117 (42)
Not reported	–	–	4 (1)	2 (1)

All pilots include relief pilot responses. Landing are landing crew pilots only (pilot flying and pilot monitoring).

Table III. For all subsequent results and analyses, we excluded: block time durations that were incomplete or outliers; reports when FDP durations were missing or could not be estimated; and reported FDP values greater than 14 h or less than 6 h.

Relief Pilots

The majority (61; 97%) of first break respondents were relief pilots, with 2 landing crew pilots reporting using the first break. Overall, for both carriers combined, the first break averaged 2.4 ± 0.5 h in duration (maximum = 4.4 h). Sleep duration during this first rest break averaged 1.2 ± 0.7 h, ranging from 0–3.7 h, with 11% reporting no sleep. On average, pilots reported sleeping for about half (51%) of the available rest break period. Of the pilots, 40% rated the quality of this rest period sleep as "very good" or "good," while 27% reported it as "poor" or "very poor." More than half (52%) reported that there were factors that adversely impacted their sleep. About two-thirds (68%) of the respondents reported that the placement of the first break was not optimal for their needs. The pilots taking the first rest break cited "counter to circadian rhythm/not tired" (19%) and "passenger service disruptions" (13%) as the primary reasons for not liking this rest break. Of the pilots, 34% reported themselves as "fully alert" or "very lively" at the start of the rest break. Samn-Perelli and KSS ratings were not significantly different following the rest break when compared to the start of the rest break (SP: 3.0 vs. 2.7, $P = 0.23$; KSS: 4.4 vs. 3.8, $P = 0.09$).

Landing Crew Pilots

There were 639 responses from landing crew pilots who reported using the second or third rest break (C1, $N = 374$ responses from 157 pilots; C2, $N = 265$ from 265 pilots). Most of these pilots (69%) reported a preference for the second rest break, while 16% preferred the third, and 14% did not report a preference. For C1, about two-thirds of the landing crew pilots reported that the rest break schedule was determined by "crew consensus" (68%), with about a third reporting "captain" (29%). For C2, pilots reported that the rest break schedule was determined by "crew consensus" (56%) and "captain" (27%).

The majority (379; 98%) of pilots who took the second rest break were landing pilots. Eight relief pilots who used the second break were excluded from these analyses. Overall, the second break averaged 2.4 ± 0.5 h (maximum = 4.9 h). Sleep duration averaged 1.5 ± 0.7 h, ranging from 0–3.4 h, with 3% reporting no sleep. Pilots reported sleeping for 64% of the available rest break period, on average. More than half (58%) of the pilots rated the quality of their rest break sleep as "very good" or "good," while 12% reported it as "poor" or "very poor." About a third (34%) of the pilots reported that factors adversely impacted their sleep, primarily citing cabin noise (19%; e.g., passenger service, flight attendants), discomfort in the rest facility (17%; e.g., hard mattress, uncomfortable seat), and turbulence (8%). The majority (97%) of these pilots reported that the placement of the second rest break was optimal for their needs. About a quarter of the pilots (29%) reported themselves as "fully alert" or "very lively" at the start of this rest break. Samn-Perelli [$t(741) = 11.26$, $P < 0.001$] and KSS [$t(750) = 14.34$, $P < 0.001$] ratings were significantly better following the rest break when compared to the start of the rest break.

There were 260 (97%) landing pilots who took the third rest break. Nine relief pilots reported use of the third break and were excluded from these analyses. The third break averaged 2.3 ± 0.4 h (maximum = 3.8 h). Sleep duration averaged 1.4 ± 0.7 h, ranging from 0–3.3 h; with 5% reporting no sleep. On average, landing crew pilots reported sleeping for 58% of the available rest break period. About a third (31%) of these pilots rated the quality of their rest break sleep as "very good" or "good," while 28% reported it as "poor" or "very poor." Almost half of the pilots (48%) reported that factors adversely impacted their sleep, primarily citing cabin noise (13%), discomfort (9%), and turbulence (6%). About two-thirds (64%) of these pilots reported that the placement of the third break was optimal for their needs. For those pilots that reported the third break as not optimal and cited a reason why, "wake time too short between rest and landing/sleep inertia" (40%) and "passenger service disruptions" (10%) were the two most common reasons cited. Of the pilots, 14% reported being "fully alert" or "very lively" at the start of this rest break. Samn-Perelli [$t(519) = 7.37$, $P < 0.001$] and KSS [$t(525) = 9.04$, $P < 0.001$] ratings were significantly better following the third break when compared to the start of the rest break.

Sleep by Rest Break

Rest break and sleep duration for all pilots are presented in **Table IV**. There was no significant difference in rest break duration across breaks. Pilots reported, on average, the most sleep during break 2, although this difference in duration was not statistically different.

Landing pilot ratings of sleep quality were significantly better for break 2 compared to break 3 [$t(508) = -7.22$, $P < 0.001$]. Significantly more pilots rated sleep quality as "good" or "very good" for the second rest break (58%) compared to the third (31%, $\chi^2 = 44.60$, $P < 0.001$). A significantly higher proportion of landing crew pilots reported adverse factors affecting

Table IV. Sleep and Break Duration by Rest Break Period.

	BREAK PERIODS	BREAK DURATION	SLEEP PERIODS	SLEEP DURATION
	N	M (SD)	*N*	M (SD)
Break 1	62	2.37 h (0.53)	62	1.22 h (0.73)
Break 2	359	2.39 h (0.52)	374	1.55 h (0.66)
Break 3	248	2.30 h (0.43)	256	1.36 h (0.66)

Frequency counts include relief pilot responses and reflect usable responses (break start and end time, sleep duration value) that were provided.

sleep during break 3 (46%) compared to break 2 (32%, $\chi^2 = 13.25$, $P < 0.001$).

Top of Descent

Landing crew pilots provided SP and KSS ratings at TOD, both of which were rated significantly better by pilots who used the second break (SP mean 2.0 ± 1.0; KSS mean 2.6 ± 1.4) as compared to those who used the third break [SP, mean 2.9 ± 1.3, $t(500) = -10.25$, $P < 0.001$; KSS, mean 3.8 ± 1.8, $t(462) = -9.63$, $P < 0.001$; **Fig. 1**]. Both the SP and KSS ratings showed noninferiority for the second break compared to the third (**Fig. 2**).

Time of Day

Samn-Perelli and KSS at the start and end of the rest break and at TOD were compared by home base time of day as a proxy for the influence of the circadian rhythm. "Body" time was determined based on each pilot's HBT and mean ratings were calculated in 4-h bins (0200–0600, 0600–1000, 1000–1400, 1400–1800, 1800–2200, 2200–0200) based on the time at which the measure was made (**Fig. 3**).

Samn-Perelli ratings combined for both breaks differed significantly across time bins [$F(5619) = 7.52$, $P < 0.01$] at break start for all landing pilots. Tukey post hoc comparisons ($P < 0.05$) revealed that ratings during the nighttime bin (0200–0600) were significantly higher than those during the afternoon and early evening bins (1400–1800, 1800–2200). Ratings during the early evening bin (1800–2200) were significantly lower than bins earlier (0600–1000, 1000–1400) and later (2200–0200) in the day. Karolinska Sleepiness Scale ratings at break start differed significantly across time bins [$F(5617) = 5.18$, $P < 0.01$] for all landing pilots. Tukey post hoc comparisons ($P < 0.05$) revealed that ratings during the nighttime and early morning bins (2200–0200, 0200–0600, 0600–1000) were significantly higher than those during the afternoon and early evening bins (1400–1800, 1800–2200).

Samn-Perelli ratings combined for both breaks differed significantly across time bins [$F(5611) = 7.36$, $P < 0.01$] at break end for all landing pilots. Tukey post hoc comparisons ($P < 0.05$) revealed that ratings during the nighttime bins (2200–0200, 0200–0600) were significantly higher than those during the midday bin (1000–1400). Karolinska Sleepiness Scale ratings at break end differed significantly across time bins [$F(5611) = 3.66$, $P < 0.01$] for all landing pilots. Tukey post hoc comparisons ($P < 0.05$) revealed that ratings during the nighttime (2200–0200) were significantly higher than those during the midday and early evening bins (1000–1400, 1800–2200).

Samn-Perelli ratings at TOD differed significantly across time bins [$F(5617) = 3.17$, $P < 0.01$] for all landing pilots. Tukey post hoc comparisons ($P < 0.05$) revealed that ratings during the nighttime bin (0200–0600) were significantly higher than those during the midday bin (1000–1400). Karolinska Sleepiness Scale ratings at TOD differed significantly across time bins [$F(5617) = 3.32$, $P < 0.01$] for all landing pilots, although Tukey post hoc comparisons did not reveal any significant differences between particular pairs of circadian bins.

Sleep duration was also compared by time of day, relative to each pilot's HBT (**Fig. 4**). Average sleep duration differed significantly across time bins [$F(5666) = 4.97$, $P < 0.001$]. Tukey post hoc comparisons ($P < 0.05$) revealed that significantly more sleep was reported when the break was initiated during the morning bin (0600–1000) than when initiated during later daytime and nighttime bins (1400–1800, 2200–0200, 0200–0600).

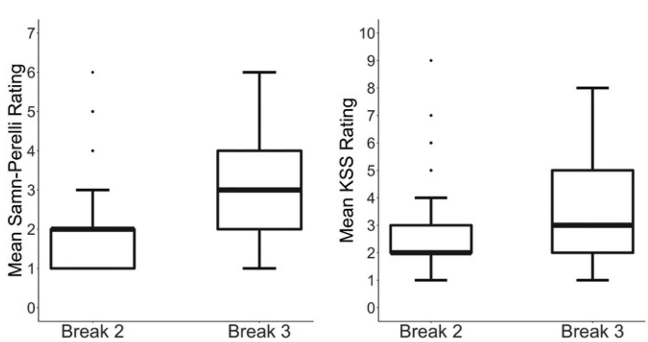

Fig. 1. Samn-Perelli (left) and Karolinska Sleepiness Scale (KSS; right) ratings at top of descent from landing crew pilots by rest break taken. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the largest value no further than 1.5 *IQR from the hinge (where IQR is the interquartile range, or distance between the first and third quartiles). The lower whisker extends from the hinge to the smallest value at most 1.5 *IQR of the hinge. Outlier points are plotted individually.

DISCUSSION

Our study represents the first evaluation of self-reported in-flight sleep, fatigue, and sleepiness by rest break for augmented flight operations following the implementation of FAA flight crew duty and rest regulations. In a large cohort of pilots comprising data from two commercial airlines, we found that the second in-flight rest break was noninferior to the third in-flight rest break on a range of outcomes related to alertness at TOD for landing crew pilots. Pilots reported having better sleep quality and fewer environmental disruptions during the second rest break compared to the third rest break. While rest break duration did not significantly differ, both the second and third rest breaks significantly reduced fatigue and sleepiness from the start to the end of the rest break period. Pilots taking the second rest break had significantly lower fatigue and sleepiness ratings at TOD compared to pilots who took the third rest break. When we evaluated sleep by time of day, we found that pilots reported

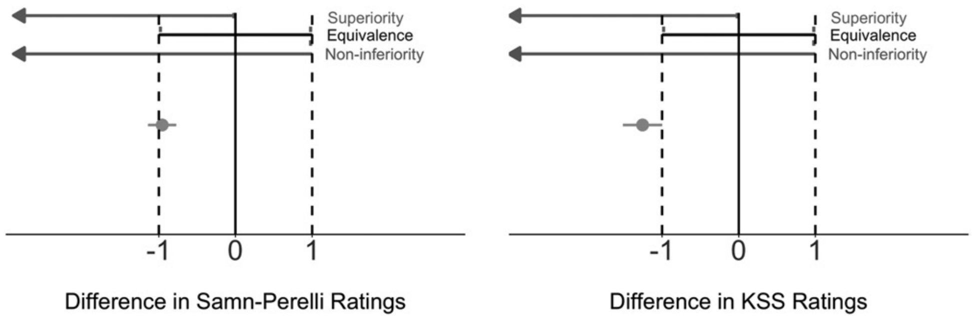

Fig. 2. Noninferiority plots show Samn-Perelli (left) and Karolinska Sleepiness Scale (KSS; right) ratings to be noninferior for the second break compared to the third break for landing crew pilots at top of descent. The mean difference in ratings is represented by the grey circle, with a 95% confidence interval (grey line). The arrow at the top represents the range of superiority (delta ≤ 0), the middle line represents the range of equivalence ($-1 < \text{delta} < 1$), and the bottom arrow represents noninferiority (delta < 1).

obtaining more sleep during the morning relative to their home-base time.

Our finding that the second rest break is noninferior to the third rest break during three-pilot long-haul operations has important implications for fatigue risk management practices and policy. The current FAA provision for augmented crews requires the landing pilot (PF) to have 2 consecutive hours of in-flight rest in the second half of the flight duty period (FAR 117.17.c.1).[7] For single-augmented (three-pilot) crews with FDP under 14 h, such as those we studied, only the final (third) in-flight rest break is compliant with the regulation. The intent of this requirement was to ensure that landing pilots would obtain rest in close enough proximity to landing to ensure that they would still reap the beneficial effects of the nap during the final, critical phases of flight. In our combined analysis, we found that contrary to the FAR, the second rest break was superior to the third rest break.

Our findings demonstrate that while both the second and third rest breaks reduced self-reported fatigue and sleepiness across the rest break period, the second rest break resulted in significantly reduced fatigue and sleepiness at TOD relative to the third rest break. There are several factors that may have contributed to this result. Firstly, the mean sleep duration was slightly higher among pilots taking the second rest break and only 3% of pilots taking the second rest break were not able to sleep at all compared to 5% taking the third rest break. This is consistent with Gander et al., who reported that longer sleep duration was correlated with lower KSS scores at TOD in a study of four-pilot crews.[12] The duration of sleep reported in the rest break may also relate to environmental factors. Previous research has shown that fewer disturbances due to random noise, often related to passengers and cabin crew services, promote better in-flight bunk sleep periods.[23,30] In a review of aviation fatigue countermeasures, Caldwell et al. noted that using periods of increased physiological sleep propensity can help the quality and quantity of sleep obtained during bunk periods, but that these periods "often unavoidably end up at less than optimal times" due to flight responsibilities (p. 36).[4] The logistics of international long-haul flights generally involve cabin crew services during the latter portion of the flight, which often coincides with the timing of the third rest break, while the middle portion of the flight has minimal cabin crew and passenger activity, coinciding more with the timing of the second rest break. Most of our respondents reported a preference for the second rest break, often citing being ready for sleep and fewer disturbances as reasons. More than half of the pilots reported "good" or "very good" sleep quality ratings following the second rest break, which was significantly better than the quality ratings reported for the third break. Thus, the timing of the second rest break relative to in-flight services appears to provide a less disruptive opportunity for sleep compared to the third rest break, leading to better quality sleep and ultimately lower sleepiness and fatigue ratings at TOD.

Sleep inertia, the grogginess that one feels upon waking, may have contributed to why the pilots rated the second rest break to be superior to the third rest break at TOD. Indeed, more than a third of pilots cited sleep inertia as the reason that the third rest break was not optimal for the landing pilot. Sleep inertia may have also influenced the TOD ratings for pilots taking the third rest break. For example, a number of pilots reported that the third rest break was influenced by "wake time too short between rest and landing/sleep inertia," whereas no pilots from the other rest breaks reported this as a factor. We found that following the third rest break, pilots were back on the flight deck on average about 40 min prior to landing, which would typically only be 10 min prior to TOD. Sleep inertia effects typically dissipate within 20 min, with longer durations depending on circadian time of day, sleep stage upon waking, and prior sleep history.[13] These findings further support the suggestion that the effects of sleep inertia following the third rest break may have influenced the pilots' ratings at TOD. Some groups have recommended that pilots refrain from safety sensitive tasks, including controlling the aircraft, during the 20–30 min following sleep.[4,6] Our findings, combined with current recommendations surrounding sleep inertia, suggest that recovery time from the third rest break may be inadequate for landing crew pilots.

Although we found the second rest break to be superior to the third rest break according to a variety of measures, it is important to note that the drive for sleep is determined by both homeostatic sleep pressure and the circadian rhythm. Gander et al. found that during augmented operations, the interaction of flight timing with circadian phase and flight duration had an influence on in-flight sleep and fatigue measures.[11] We estimated diurnal changes as a proxy for circadian influence by applying the pilot's HBT zone to the timing of their in-flight ratings and sleep episodes. The longest sleep durations occurred when the break started during the morning hours (0600–1000),

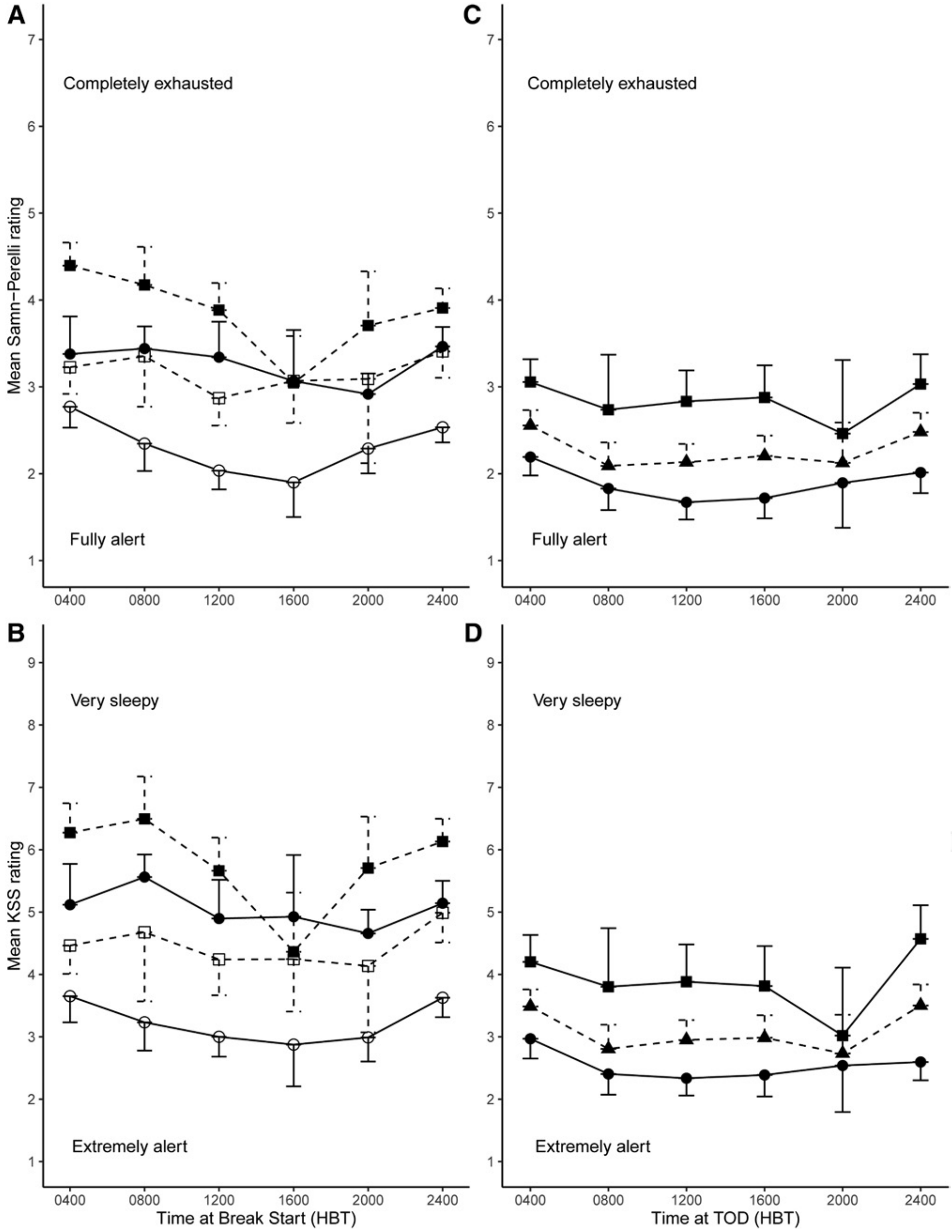

Fig. 3. A) Samn-Perelli and B) Karolinska Sleepiness Scale (KSS) ratings at the start (black symbols) and end (white symbols) of break 2 (solid lines, circles) and break 3 (dashed lines, squares) by landing crew pilots binned across time of day. C) Samn-Perelli and D) Karolinska Sleepiness Scale (KSS) ratings at top of descent by landing crew pilots for break 2 (solid line, circles), break 3 (solid line, squares), and both breaks combined (dashed line, triangles) as binned across time of day, for the time at which the rating was done. Mean ratings plotted with 95% confidence interval (one-way error bars). Bins are labeled by the midpoint of the bin, such that 0400 indicates the 0200–0600 time period.

irrespective of the rest opportunity. This coincided with the highest ratings of sleepiness at break start (0200–0600, 0600–1000), indicating that pilots were ready for sleep at this time. The shortest sleep episodes occurred during the HBT afternoon (1400–1800), which coincided with the lowest sleepiness ratings at break start, indicating that pilots were less ready for sleep at this time. The highest fatigue and sleepiness ratings occurred during the HBT night (2200–0200) and early morning hours (0200–0600), for start and end of break, and at TOD, findings that coincide with the influence of the circadian system on sleepiness.[21] While not significant, fatigue and sleepiness at TOD for all landing pilots were rated lower during the HBT morning (0600–1000) and early evening hours (1800–2200), outcomes that coincide with the daily periods of increased wake maintenance.

In our study, timing of the rest breaks could occur at any time of night or day, depending on the timing of the flight. Given interindividual differences in pilot internal circadian timing, rest breaks were distributed across circadian phases, which could have dampened the influence of circadian time of day.[8] Despite these factors, we found the second rest break to be superior to the third rest break. These findings suggest that the interactions between circadian time of day and an individual's likelihood of being able to sleep should be considered in conjunction with the influence of environmental factors that may cause sleep disruption during flight.

It should also be noted that survey findings documented that a minority of pilots reported their bunk sleep quality as "poor" or "very poor" and a small number of pilots reported getting no sleep during their bunk period. In our study, most rest periods were taken in a FAR class 1 or class 2 crew rest facility, providing for a flat or near flat sleeping surface. Even with that, sleeping in bunk facilities can be a challenge for some individuals given a variety of factors, including discomfort, noise, turbulence, command responsibilities, and not feeling ready for sleep at that given time.[23] Thus, the availability of a bunk rest facility and sleep opportunity may not prove effective for all pilots. Our finding that most pilots report scheduling of bunk rest periods as determined by "crew consensus" appears to indicate that flight crew practices acknowledge individual differences and other factors that can influence the ability to obtain adequate bunk sleep. However, such consensus is only practical when pilots conduct preflight briefings after ground-based rest opportunities have

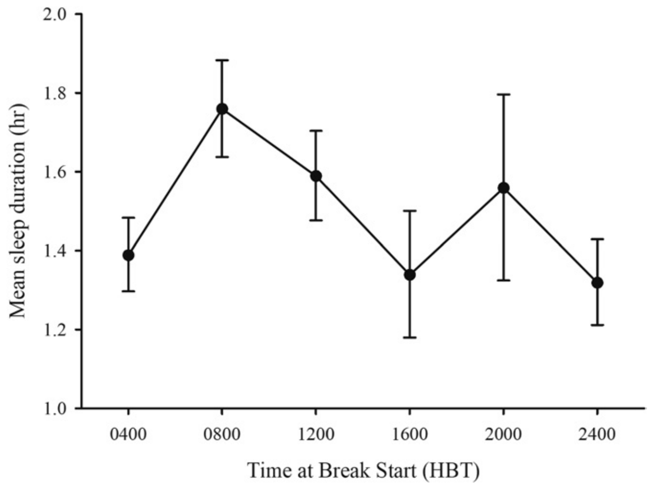

Fig. 4. Mean sleep duration based on the break start time across time of day bins (with 95% confidence interval). Bins are labeled by the midpoint of the bin, such that 0400 indicates the 0200–0600 time period.

occurred. Zaslona et al. found that pilots appeared to be aware of the circadian influence on sleep propensity and that many made efforts to manipulate their layover sleep timing to better enable sleep during in-flight rest opportunities.[30] This suggests that it may be prudent to provide general rest scheme guidance to pilots about the best timing for in-flight rest for both landing crews and relief crews so that they can plan accordingly while on the ground. Verification from the Captain that the rest scheme guidance will be followed (or not and how it will differ) prior to report, however, is crucial. One study providing guidance on configuration of rest breaks found 45% of crews altered this recommended configuration to suit their individual needs.[15] For example, a relief crew pilot who would be scheduled to take the first rest break may not opt to take a nap immediately before flight in order to increase the propensity for sleep during the first rest break. Similarly, allowing pilots to rearrange the timing of in-flight rest prior to (preferable) or during the preflight briefing is also important given individual differences and the influence of the circadian rhythm. For example, a landing pilot may opt to take the third rest break when the second rest break would occur during the wake maintenance zone, where sleep is less likely.

Although we conducted a large survey of in-flight rest practices, our study is not without limitation. Given the logistics of collecting a large amount of data across two airlines, we were unable to collect objective measures of performance, such as with the Psychomotor Vigilance Task. However, the self-report scales that we used have been evaluated in many in-flight studies and are considered reliable measures of pilot sleep quality, fatigue, and sleepiness.[10,23] Further, while our measures of sleep were self-reported, the subjective reports of average in-flight sleep duration have been found to correlate well (84%) with polysomnography.[27] Thus, we believe our survey measure is reasonable for estimating mean in-flight sleep duration in a large population where polysomnography would be logistically prohibitive. Secondly, while we solicited volunteers for the study from all active pilots flying three-pilot augmented operations, it is possible that some individuals were motivated to participate based on their preference for the second rest break. Additionally, our results assume that all pilots were acclimated to their HBT. Commuting practices and individual variation in circadian phase make a precise measure of circadian timing difficult to determine for such a study. However, our analyses of diurnal variation, independent of rest break, followed the expected profile, suggesting that pilots were not manipulating their reports in general.

In conclusion, our analysis indicates that self-reported sleep, fatigue, and sleepiness obtained from landing crew pilots taking the second in-flight rest break are equivalent or better than those from landing crew pilots taking the third in-flight rest break. The present study supports allowing pilots the choice of taking the second or third in-flight rest break during augmented operations. Our findings also suggest that the proximity of the third rest break to the timing of flight duties related to descent and landing may compromise its utility due to the potential effects of sleep inertia. Carriers should be encouraged to continue gathering data from such augmented flight operations, including the use of objective measures of performance (e.g., the Psychomotor Vigilance Task), and to incorporate information about healthy sleep practices to optimize in-flight rest breaks for enhanced alertness and performance. Further, more targeted studies of sleep inertia related to in-flight rest breaks should be undertaken to determine its potential impact on safe flight operations.

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Authors and affiliations: Kevin B. Gregory, B.S., and Erin E. Flynn-Evans, Ph.D., M.P.H., Human Systems Integration Division, NASA Ames Research Center, Moffett Field, CA, USA; Rhiannon N. Soriano-Smith, B.A., Amanda C. M. Lamp, Ph.D., Michael J. Rempe, Ph.D., M.S., and Gregory L. Belenky, M.D., Occupational Sleep Medicine Group, Sleep and Performance Research Center, Department of Medical Education and Clinical Sciences, Elson S. Floyd College of Medicine, Washington State University, Spokane, WA, USA; and Cassie J. Hilditch, Ph.D., San José State University, San José, CA, USA.

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