Monitoring and Managing Cabin Crew Sleep and Fatigue During an Ultra-Long Range Trip

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BACKGROUND: The aims of this study were to monitor cabin crew fatigue, sleep, and performance on an ultra-long range (ULR) trip and to evaluate the appropriateness of applying data collection methods developed for flight crew to cabin crew operations under a fatigue risk management system (FRMS).

METHODS: Prior to, throughout, and following the ULR trip (outbound flight ULR; mean layover duration = 52.6 h; inbound flight long range), 55 cabin crew (29 women; mean age 36.5 yr; 25 men; mean age 36.6 yr; one missing data) completed a sleep/duty diary and wore an actigraph. Across each flight, crewmembers rated their fatigue (Samn-Perelli Crew Status Check) and sleepiness (Karolinska Sleepiness Scale) and completed a 5-min Psychomotor Vigilance Task (PVT) at key times.

RESULTS: Of crewmembers approached, 73% ($N = 134$) agreed to participate and 41% ($N = 55$) provided data of suitable quality for analysis. In the 24 h before departure, sleep averaged 7.0 h and 40% took a preflight nap. All crewmembers slept in flight (mean total sleep time = 3.6 h outbound, 2.9 h inbound). Sleepiness and fatigue were lower, and performance better, on the longer outbound flight than on the inbound flight. Post-trip, crewmembers slept more on day 1 (mean = 7.9 h) compared to baseline days, but there was no difference from day 2 onwards.

DISCUSSION: The present study demonstrates that cabin crew fatigue can be managed effectively on a ULR flight and that FRMS data collection is feasible for cabin crew, but operational differences between cabin crew and flight crew need to be considered.

KEYWORDS: actigraphy, Karolinska Sleepiness Scale, Samn-Perelli Crew Status Check, Psycho-motor Vigilance Test, Fatigue Risk Management System.

van den Berg MJ, Signal TL, Mulrine HM, Smith AAT, Gander PH, Serfontein W. *Monitoring and managing cabin crew sleep and fatigue during an ultra-long range trip.* Aerosp Med Hum Perform. 2015; 86(8):705–713.

Ultra-long range (ULR) trips are flight operations between a specific city pair in which at least one of the sectors regularly exceeds 16 h planned flight time. The duty periods on these flights range between 18 and 22 h.[7] Such flights present a challenge for airlines and regulators, as they can potentially increase fatigue-related operational risk, particularly during the later stages of the flight, if they lead to restricted sleep, extended periods of wakefulness, and/or high operational demands at suboptimal times in the circadian body clock cycle. They may also require additional time for recovery sleep during the layover or on return home following a ULR trip.

To manage the fatigue risk associated with ULR trips, airlines are usually required to put in place a Fatigue Risk Management System (FRMS). Current ULR scheduling for cabin crew is predominantly based on flight crew data and, to date, studies have focused solely on data collection and the effectiveness of FRMS for flight crew. Hence little is known about how these processes work for cabin crew.

As for flight crew, the main fatigue mitigation strategy on ULR flights is to provide cabin crew with scheduled in-flight rest breaks for sleep in crew rest facilities, which requires additional crewmembers on board. The effectiveness of in-flight rest breaks as a mitigation for fatigue depends on the

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This manuscript was received for review in January 2015. It was accepted for publication in April 2015.

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DOI: 10.3357/AMHP.4268.2015

amount and quality of sleep that crewmembers are able to obtain in flight.[22] This is not only dependent on flight duration, but also on other operational factors, including local time of departure and the timing and duration of in-flight rest breaks, which will influence how well crewmembers are able to sleep at various times during the flight.[10,11,23] Compared to flight crew, cabin crew have less time available for in-flight rest due to the requirement for all cabin crew to be awake for meal services. In addition, regulatory requirements for onboard rest facilities are often less rigorous for cabin crew than for flight crew.

Additional mitigations include providing crewmembers with protected time free of duty before, during (i.e., on layover), and after the ULR trip to assist with preparation for the trip and subsequent recovery. Compared to flight crew, a larger proportion of cabin crew are women and may have greater domestic responsibilities compared to their male counterparts. This may in turn impact on their sleep at home. The rate of recovery post-trip will also vary with the degree of circadian misalignment resulting from the trip and may be slower if greater sleep loss was accumulated during the trip.

The amount and quality of sleep crewmembers are able to obtain during the layover and the extent to which they adapt to the layover time zone is influenced by layover duration and timing, as well the number of time zones crossed and flight direction. Previous research has shown that after a westward transmeridian flight, which effectively lengthens the day, circadian adaptation tends to be faster compared to after an eastward transmeridian flight.[8] Although the amount of circadian adaptation during a 2-d layover is not well documented, this will be influenced not only by the degree of light exposure, but also by social activities.[4] While retaining a home-based sleep pattern has been shown to reduce sleepiness during a 2-d layover,[16] crew often time at least some of their layover sleep to occur during the local night.[17] As a further mitigation, crew receive fatigue management training.[7] Presently, information contained in such education material is based entirely on flight crew experience due to the lack of data available for cabin crew.

The aim of this study was to evaluate the effectiveness of fatigue management for cabin crew on a westward outbound Johannesburg-New York ULR trip by monitoring their sleep, sleepiness, fatigue, and performance before, during, and after this trip. A secondary aim was to determine the appropriateness of data collection methods and measures for cabin crew.

METHODS

Subjects

The study protocol was approved by the Massey University Human Ethics Committee (application 11/74). Each crewmember provided written informed consent before participating. Participation was voluntary and confidentiality was strictly maintained. There were 55 crewmembers who participated in the study. Demographics were available for 54 crewmembers (29 women, mean age 36.5 yr; 25 men, mean age 36.6 yr) and are summarized in **Table I**.

Materials

At the start of their involvement in the study, crewmembers completed a pre-study questionnaire which was included in the sleep/duty diary. The questionnaire, which was adapted from one used for flight crew in multiple previous airline studies,[11,23] included items on cabin crew position, flying experience, age, gender, usual sleep at home on days off duty, usual sleep in onboard crew rest facilities, and in-flight fatigue.

Crewmembers completed a sleep/duty diary throughout the study. This included a look-back report to record duty periods in the week leading up to the start of participation, and 24-h timelines for recording sleep and duty information. For each study flight leg, additional pages were included to collect operational information, including scheduled and actual duty start and end time, crew position for the flight (Galley or Aisle; Premium or Economy), planned rest breaks for the flight, and how the crewmember usually manages fatigue on this flight. There was also space for recording fatigue and sleepiness at specified times.

Crewmembers wore an actigraph (Spectrum from Philips Respironics, Bend, OR) throughout their participation in the study. Actigraphy is a validated, well recognized, widely used method for recording sleep in a range of different populations[3] and has been validated for flight crew.[22] The device is the size of a wrist watch, with a functioning watch face, and is worn on the nondominant wrist. Crewmembers were asked to

Table I. Crewmember Demographics.

	CABIN CREW* MEDIAN (RANGE)	PURSERS MEDIAN (RANGE)	SENIOR PURSERS MEDIAN (RANGE)	ALL CREW MEDIAN (RANGE)
Age (yr)	35 (23-60)[†,‡]	41 (36-56)	43.5 (40-54)	36 (23-60)[‡]
Work experience (yr)	11.9 (1-38)[†,‡]	14.8 (13-21)[‡]	18.5 (17-23)	12.5 (1-38)[†,‡]
Average work hours per month	110 (55-150)	120 (90-165)	120 (80-120)[†]	110 (55-165)
Expected work hours during the month of the study flight	100 (60-150)	100 (90-165)[‡]	110 (75-120)	100 (60-165)
Long range experience (yr)	10.5 (1-19)[†]	14.7 (12-21)[‡]	16.7 (0.6-18)[†]	12.0 (0.6-21)[†]
Total number of crew	43	7	4	54

* Crewmembers who do not have management responsibilities.

Medians and range are reported for both non-normally and normally distributed data.

[†] Data not normally distributed.

[‡] Includes 1 outlier.

press a button ("event marker") on the actigraph to indicate when they began and finished trying to sleep. Data were recorded in 1-min epochs and subsequently downloaded to a computer for analysis. Actigraphy data were analyzed using the manufacturer's software (Actiware® version 5.71.0, Philips Respironics) at the medium sensitivity setting in conjunction with the sleep time information from the sleep/duty diary.

Crewmembers were asked to rate their fatigue before and after each sleep episode and at different times in flight on the Samn-Perelli Crew Status Check (SP) on a scale from 1 = 'fully alert, wide awake' to 7 = 'completely exhausted, unable to function effectively'.[21] At the same time, sleepiness was rated on the Karolinska Sleepiness Scale, on a scale from 1 = 'extremely alert' to 9 = 'extremely sleepy, fighting sleep'.[2,13,14] Both scales have been extensively used for measuring subjective fatigue and sleepiness. The SP was developed for use with military airlift flight crew,[21] has been widely used in studies with commercial flight crew,[12,18] and has been validated in laboratory studies using forced internal desynchrony protocols.[5] The Karolinska Sleepiness Scale has been used to measure subjective sleepiness in both laboratory[2] and field studies.[13,14] After each sleep episode, crewmembers were also asked to rate their sleep quality on a scale from 1 = 'extremely good' to 7 = 'extremely poor', which has been used in previous airline studies.[12,24] At the end of each flight, crewmembers were asked to rate their workload on the raw NASA Task Load Index. These data are not included in the present analyses.

Performance was measured using a validated, 5-min version of the Psychomotor Vigilance Task (PVT)[20] (PalmPVT, Walter Reed Army Institute of Research, Silver Spring, MD) on a Palm Centro Smartphone (Palm, Inc., Sunnyvale, CA). The interstimulus interval varied randomly between 2-10 s. Crewmembers were required to attend to a display on the screen and respond as quickly as possible by pushing a button as soon as a 'bulls-eye' symbol appeared with numbers in the center that represented response time counting in milliseconds. The crewmember received immediate feedback on their reaction time each time the response button was pushed.

Procedure

Information on the study was initially advertised via the airline company's communication channels. All cabin crew scheduled on a Johannesburg-New York-Johannesburg trip during the study period (27 August 2012 to 24 June 2013) were eligible to participate. For each scheduled trip, up to 7 of the 14 crewmembers were contacted by a member of the research team and invited to participate. Since the aim was to recruit data from at least 50 cabin crew for this study, it was considered important to sample a range of flights in case conditions varied widely from one flight to the next or in the event of peculiarities on one particular flight (e.g., delays, turbulence, medical event).

At least 4 d before the study trip, participating crewmembers received an actigraph, a Palm Centro Smartphone, and a sleep/duty diary. Crewmembers were asked to wear the actigraph and complete the sleep/duty diary from 3 d prior to departure, throughout the entire ULR trip (on both flight legs and layover), and until 5 d after the ULR trip.

The company recommended that on the outbound ULR flight, the time available for rest in the bunk (between the two meal services) should be split into four rest breaks. No recommendations regarding rest break pattern were provided for the shorter, non-ULR inbound flight. The 14 cabin crew (including 1 senior purser and 2 pursers) who operate the A340-600 aircraft on the Johannesburg-New York route work as A and B crews who alternate their periods of duty and rest, with the B crew taking the first and third break on the outbound flight. In addition to the bunk rests, a 40-min seat rest can be taken on the outbound flight if needed, in one of two allocated seats in the cabin.

The crew rest facilities for cabin crew are located below the main cabin at the rear of the aircraft. Of the seven horizontal bunks, six are positioned longitudinally, with three upper and three lower bunks. The seventh bunk is transversely positioned above a storage unit. The bunks, which are separated from each other by a hard panel, each have a curtain which can be closed for privacy. Blankets and pillows are provided and the rest area is temperature and humidity controlled.

Cabin crewmembers are required to attend fatigue training before being able to fly this ULR route. As part of this training, recommendations were made to crewmembers to arrive for duty with no sleep debt by having two good nights of sleep before the start of duty. The benefits of preflight napping were also explained. In addition, crewmembers were advised to stay on domicile time during the layover to assist with recovery post-trip.

Crewmembers were rostered to be free of duty during the 48 h prior to their ULR trip and the entire crew was on standby the evening before their scheduled departure. Following the ULR trip, crewmembers were provided with four local nights at home before their next duty period.

A total of 36 return trips were studied between 27th August 2012 and 24th June 2013, with 33 having data included in the study. Daylight saving time in New York began on March 10, 2013, with 19 return trips completed prior to this and 14 return trips following this date (resulting either in a 7-h or 6-h time zone change). Details of flight departure and arrival times and duration of flights (time between blocks-off and blocks-on) and layovers are provided in **Table II**.

The westward outbound flights were scheduled to depart Johannesburg at 20:40 local time, with a local arrival time of 06:40 in New York (12:40 Johannesburg time). Following a layover of approximately 48 h, the eastward inbound flight was scheduled to depart New York at 11:15 local time (17:15 Johannesburg time), with a local arrival time of 08:00 (01:00 New York time).

On the day of each flight, crewmembers were asked to rate their fatigue and sleepiness and complete a PVT: 1) preflight, after signing on for duty; 2) around top of climb (TOC; once the seatbelt sign was turned off and within 90 min after takeoff); 3) around top of descent (TOD; at the end of the last meal service and within 90 min before landing); and 4) after landing.

Table II. Flight Details.

STUDY PERIOD		MEAN	MEDIAN	RANGE	*N*
Outbound flight (JNB-JFK[†])					
	Departure time (UTC[‡])	18:48	18:47	18:22-20:05	55
	Arrival time (UTC)	10:44	10:41	10:15-11:50	55
	Flight duration (hours ± SD)	15.9 ± 0.4	16.0	15.3-16.7	55
	Duty duration (hours ± SD)	18.9 ± 1.0	18.6	17.8-22.1	31
Layover					
	Duration (based on arrival and departure time, hours ± SD)*	52.6 ± 0.3	52.6	51.4-53.2	35
	Duration (based on duty end and start time, hours ± SD)*	49.3 ± 1.2	49.5	44.4-51.4	52
Inbound flight (JFK-JNB)					
	Departure time (UTC)*	15:20	15:15	15:05-15:47	52
	Arrival time (UTC)*	06:05	06:04	05:24-06:36	52
	Flight duration (hours ± SD)	14.7 ± 0.3	14.7	13.7-15.2	55
	Duty duration (hours ± SD)	18.2 ± 1.1	18.0	16.5-21.6	38

* Three crewmembers were excluded whose flight was delayed for 22 h.
[†] JNB = Johannesburg (UTC+2 h); JFK = New York (UTC-5 h; during daylight savings time, 4 h).
[‡] UTC = Coordinated Universal Time.

Sleep/duty diaries were available for all crewmembers, but four had incomplete sections and others had occasional responses missing. All data entries were cross-checked by a second independent researcher and discrepancies (0.1%) were reviewed and rectified. Data were also screened for outliers, which were cross-checked against the sleep/duty diary data. For fatigue and sleepiness ratings after nighttime sleep (i.e., sleep occurring during the local night), where nighttime sleep was split, only ratings after the final sleep episode were included.

Actigraphy recordings were available for all 55 crewmembers, however, some were incomplete. There were 11 crewmembers who had a duty period on post-trip day 5 and were therefore excluded from analyses for this day. Actigraphy records were scored using Actiware® software. To assess the reliability of the manual identification of rest intervals, 20% of files were double-scored by a second independent trained researcher. Discrepancies of more than 15 min occurred in 10.9% of rest interval start times and 7.8% of rest interval end times. These discrepancies were reviewed and any errors were corrected. An overall agreement (15 min or less difference between scorers) of 90.7% was achieved. Total sleep time per sleep period was calculated as the number of minutes of sleep from sleep onset (the first 10 consecutive minutes scored as sleep by the software algorithm) until final wake-up.[22]

A custom-built program was used to calculate the total amount of sleep across specific 24-h intervals, as follows.

- Baseline sleep: total sleep per 24 h from 72-24 h preceding noon on the day of departure. Data for Baseline day 1 included 11 crewmembers who were on duty and 4 crewmembers who were on standby, while for Baseline day 2, 1 crewmember was on duty and 1 crewmember was on standby.
- Preflight sleep: total sleep in the 24 h prior to signing on for duty for each flight.
- Layover sleep per 24 h was calculated for the first 24 h of the layover and the last 24 h of the layover (the latter being the equivalent to preflight sleep for the inbound flight).
- Post-trip sleep: total sleep obtained at home in a 24-h period from noon to noon (local time) on the 5 d post-trip, starting on the day of arrival in Johannesburg. Any sleep before noon was not included as post-trip sleep to enable comparisons between sleep on post-trip days and sleep on baseline days and evaluation of the recovery following the ULR trip (11 crewmembers took postflight naps beginning before noon).

On average, crewmembers completed five PVT tests (range 3-6). Some data were excluded from analyses due to the test not being undertaken within the required timeframe, and an additional six crewmembers had no valid PVT data (e.g., due to incorrect settings, wrong response button pressed, or malfunctioning equipment). PVT data for each crewmember were downloaded and summary statistics were generated for each test using the REACT program (Ambulatory Monitoring Inc., Ardsley, NY). Subsequent analyses were carried out in SPSS (version 21.0, IBM SPSS Statistics for Windows, Armonk, NY) and SAS (version 9.3, SAS Institute Inc., Cary, NC). Results for PVT response speed (1/reaction time × 1000), fastest 10% of responses, slowest 10% of responses, and lapses (responses exceeding 500 ms in duration) are reported here.

Statistical Analysis

Linear mixed modeling was undertaken using SAS 9.3. For the between-subject mixed models, subject ID number was included as a random effect to account for individual differences, with 'variance components' applied as covariance structure. The Kenward-Roger adjustment was applied to the degrees of freedom estimation.[15] For each model, the assumptions of normality, linearity, and constant variance were checked visually and the distribution of the residuals were tested with the Shapiro-Wilk test of normality and Levene's test for constant variance.[26] Where outlying residual values were identified, the model was rerun without the outlier(s). If removing the outlier(s) changed the findings of the model, then the reported results exclude the outlier(s). However, if the outcome of the model did not change with the outlier(s) removed, then the results reported are those including the outlier(s).

For the mixed design ANOVAs for repeated measures, where possible, each model was first run with a general covariance structure (unstructured) and the correlation matrix assessed to determine appropriate covariance structures. In the present study, subjective ratings and PVT tests were not equally spaced in time; therefore, the only appropriate covariance structures considered were compound symmetry and first-order antedependence. The Bayesian Information Criteria was used to determine which covariance structure provided the best model fit. Only compound symmetry was used in the final models.

Post hoc tests were used to investigate comparisons of interest where main and interaction effects were statistically significant in the mixed design ANOVAs for repeated measures. Holm's sequentially rejective procedure was employed to adjust the level of significance.[1] Bonferroni adjusted *P*-values were calculated for post hoc tests for significant interactions and fixed effects with more than two levels of comparisons in the mixed design ANOVAs and ANCOVAs.

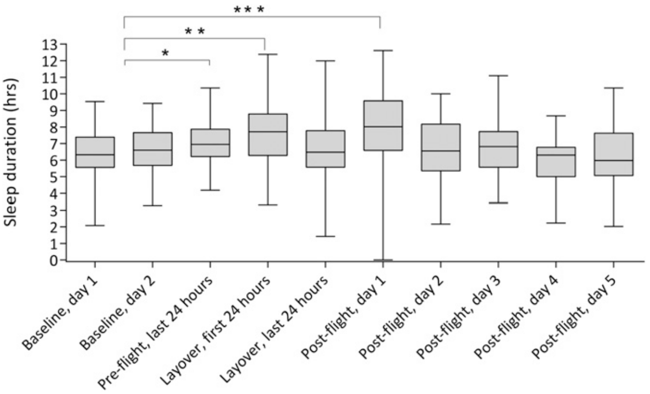

Fig. 1. Total sleep (hours) per 24 h at home and on layover. Each boxplot displays the middle 50% of data as a gray box, with the median value indicated by the horizontal line inside the box. The whiskers represent the minimum and maximum values. Statistically significant post hoc pairwise comparisons (from three linear mixed models) are denoted by * for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.0001$.

RESULTS

A total of 183 cabin crew were approached to participate in the study. Of these, 134 (73%) agreed to participate. Of those who agreed to participate, 28 (21%) did not undertake data collection for various reasons (e.g., change of mind, sick leave, forgot to collect study pack) and 25 (19%) stopped collecting data during their participation. Data collection was completed by 81 crewmembers (60% of those who agreed to participate; 44% of those invited to participate). Of these, 11 datasets (14%) were excluded due to equipment failure and 15 datasets (19%) were excluded due to too much missing actigraphy data. Datasets from 55 cabin crew (41% of those who agreed to participate; 30% of those invited to participate) were of sufficient quality to be included in the final analyses.

Performance on the preflight PVT test prior to the outbound flight was much slower and included more lapses than at TOC or preflight prior to the inbound flight. The most likely explanation is that this was a result of distractions in the testing environment, so preflight tests were not included in subsequent analyses. The total amount of sleep obtained per 24 h at home pre-trip, on layover, and post-trip is shown in **Fig. 1**.

On baseline days, crewmembers obtained on average 6.5 h sleep per 24 h (range 2.1–9.5 h). They obtained on average 33 min more sleep in the 24 h before departure compared to baseline [$F(1, 106) = 6.80, P = 0.01$]. Almost half of the crewmembers (22/55) had a preflight nap on the day of departure. More crewmembers (13/24) assigned the 2nd and 4th scheduled bunk rests (i.e., the A crew) took a preflight nap in comparison to crewmembers (7/29) who were given the 1st and 3rd scheduled bunk rests (the B crew) [$\chi^2(1) = 5.04, P = 0.02$]. Crewmembers who in the pre-study questionnaire reported napping often or always at home on days off were not more likely to take a preflight nap in comparison to crewmembers who reported to never, seldom, or sometimes nap at home [$\chi^2(1) = 1.73, P = 0.19$].

On the outbound flight, the usual pattern for in-flight rest was 3 h-3 h-2 h-2 h or 2 h-2 h-3 h-3 h with each crewmember scheduled for two rest breaks in the crew rest facility (i.e., bunk), except for two crewmembers who each had one 5-h rest break in the bunk. On the shorter inbound flight, more than half of the crewmembers (32/55) had one single, 4-h bunk rest break, occurring either in the first or second half of the flight. Three crewmembers followed a different in-flight rest pattern (2 h-4 h-2 h), while the remainder had a rest break pattern similar to that employed on the outbound flight, with each crewmember scheduled for two 2-h rest breaks.

On the outbound flight, an additional seat rest was taken by almost 50% of crewmembers. On the inbound flight, only four crewmembers took an additional seat rest, since on this flight leg, a seat for this purpose was not usually provided. On each flight, all crewmembers attempted sleep during each scheduled bunk rest break and all crewmembers obtained some sleep during at least one of their breaks, averaging 216 min (range 98–303 min) on the outbound flight and 175 min (range 40–255 min) on the inbound flight.

A mixed model ANCOVA was run to determine whether flight leg (outbound/inbound) and crewmember age influenced the total amount of in-flight sleep, irrespective of scheduled bunk rest break pattern. Crewmembers obtained on average 41 min more sleep on the outbound flight than the inbound flight [$F(1, 53) = 25.89, P < 0.001$] and age was not associated with the amount of sleep obtained in flight [$F(1, 52) = 0.26, P = 0.61$]. A further ANOVA showed that the total amount of in-flight sleep on the outbound flight did not differ between crew who had the 1st and 3rd break and crew who had the 2nd and 4th break [$F(1, 51) = 0.01, P = 0.93$; mean estimated total sleep time of 216 and 215 min, respectively].

To determine if the total amount of sleep on the inbound flight was affected by the number or timing of the rest breaks, comparisons were made between crewmembers who had the 1st and 3rd break, 2nd and 4th break, first single break, and second single break. The distribution of total in-flight sleep for each of these break patterns is illustrated in **Fig. 2**. The results from the mixed model ANOVA showed a significant difference between rest break patterns [$F(3, 48) = 8.11$, $P < 0.001$]. Post hoc pairwise comparisons indicated that crewmembers who had the 1st and 3rd break obtained on average less sleep than those with the 2nd and 4th break ($P = 0.005$) and less sleep compared to crewmembers with the first single break ($P = 0.009$) or those with the second single break ($P < 0.001$).

Two sets of ANOVAs were run to determine if a preflight nap affected the amount of sleep obtained in flight on the outbound flight (no crewmembers napped prior to the inbound flight due to the earlier departure time). The first model investigated whether there was an effect of having a nap or not on the total amount of sleep obtained in flight (all rest breaks combined). The second model investigated the effect on the amount of sleep obtained in the crewmembers' first rest break only. A preflight nap had no significant effect on the amount of sleep during the first scheduled break [$F(1, 53) = 1.07$, $P = 0.31$], or on the total amount of in-flight sleep [$F(1, 53) = 0.04$, $P = 0.84$].

Ratings of fatigue and sleepiness were made eight times in association with each flight leg: preflight, at TOC, prior to the first break, after the first break, prior to the second break, after the second break, at TOD, and after landing. However, because of the variable pattern of rest breaks, the timing of the pre- and post-break ratings were not identical for crewmembers. Therefore the linear mixed model ANOVAs for repeated measures only considered the four common time points (preflight, TOC, TOD, and after landing) and flight leg (outbound; inbound) as well as the interaction of these factors. As shown in **Fig. 3**, subjective fatigue changed significantly across the flight [$F(3, 315) = 89.23$, $P < 0.001$], with crewmembers feeling least fatigued preflight and getting progressively more fatigued during the flight. Crewmembers also felt significantly more fatigued on the inbound flight than the outbound flight [$F(1, 317) = 20.83$, $P < 0.001$].

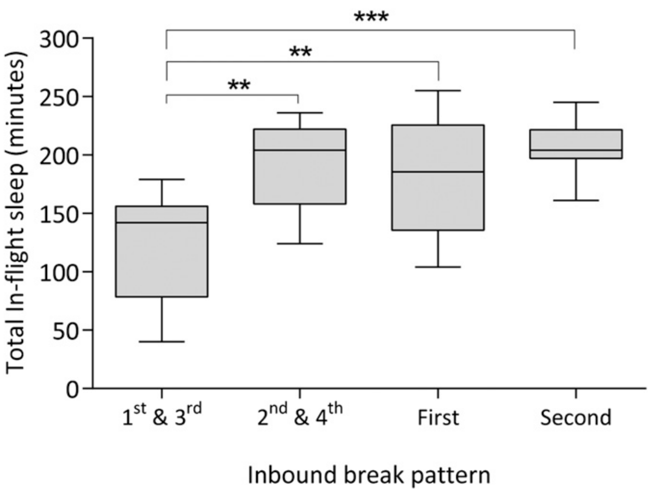

Fig. 2. Total in-flight sleep (minutes) by rest break pattern on inbound flight. 1st & 3rd = first and third break; 2nd & 4th = second and fourth break; first = single break during first half of flight; second = single break during second half of flight. Each boxplot displays the middle 50% of data as a gray box, with the median value indicated by the horizontal line inside the box. The whiskers represent the minimum and maximum values. Statistically significant post hoc pairwise comparisons are denoted by ** for $P < 0.01$ and *** for $P < 0.0001$.

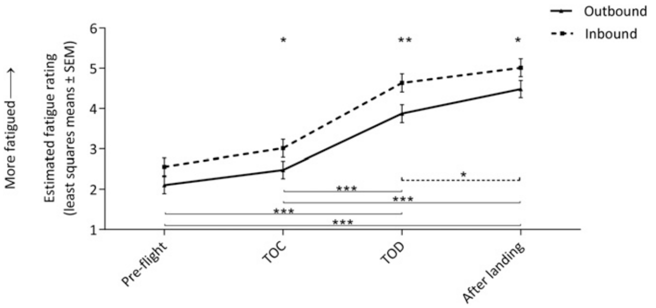

Fig. 3. Mean estimated SP fatigue ratings across the outbound and inbound flights. Statistically significant post hoc pairwise comparisons are denoted by * for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$. Asterisks in top of figure denote differences between outbound and inbound. Solid connector lines indicate differences between rating times which were observed on both flight legs; the dashed connector line indicates a difference between ratings on the outbound flight only.

The same pattern was seen for subjective sleepiness, which changed significantly across the flight [$F(3, 311) = 94.40$, $P < 0.001$], with crewmembers feeling least sleepy preflight and progressively more sleepy during the flight. Crewmembers also felt significantly more sleepy on the inbound flight than on the outbound flight [$F(1, 313) = 14.32$, $P < 0.001$].

For PVT performance, linear mixed model ANOVAs considered two common time points (TOC and TOD) and flight leg as well as the interaction of these factors. On both flight legs, PVT response speed declined from TOC to TOD [$F(1, 96) = 11.97$, $P < 0.001$] and was slower on the inbound flight than the outbound flight [$F(1, 95) = 5.97$, $P = 0.02$], as shown in **Fig. 4**. The same pattern of performance decline across the flight (from TOC to TOD) was seen for the fastest 10% of responses [$F(1,91) = 5.35$, $P = 0.02$], slowest 10% of responses [$F(1,97) = 12.44$, $P < 0.001$], and lapses [$F(1,96) = 15.79$, $P < 0.001$]. In addition, the fastest 10% of responses were faster on the outbound leg than on the inbound leg [$F(1, 89) = 10.60$, $P = 0.002$].

Two sets of linear mixed model ANCOVAs investigated factors influencing fatigue, sleepiness, and PVT response speed at TOD. The first set included the amount of in-flight sleep obtained, the duration of time awake at TOD, and flight leg. The

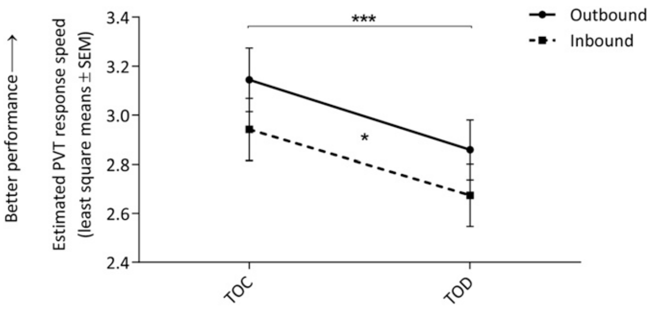

Fig. 4. Mean estimated PVT response speed across the outbound and inbound flights. Statistically significant post hoc pairwise comparisons are denoted by * for $P < 0.05$ and *** for $P < 0.0001$.

second set was similar, but included total sleep in the 24 h prior to TOD instead of the amount of sleep obtained in flight.

With longer time awake at TOD, crewmembers felt more fatigued [$F(1,56) = 6.58$, $P = 0.01$] and sleepy [$F(1,75) = 5.06$, $P = 0.03$]. No association was found between PVT response speed and prior wakefulness [$F(1, 48) = 2.39$, $P = 0.13$]. No associations were found between fatigue, sleepiness, or PVT response speed and total in-flight sleep or total sleep in the 24 h prior to TOD.

The majority (85.3%) of crewmembers had more than one sleep episode in the first 24 h of the layover, while in the last 24 h of the layover, most (61.8%) only slept once, and for nearly all crewmembers (73%), this was during the local night (defined as at least 80% of sleep occurring between 22:00 and 08:00 local New York time). Crewmembers obtained significantly more sleep per 24 h on layover than on baseline days [$F(2, 158) = 11.93$, $P < 0.001$]. Post hoc pairwise comparisons indicated that estimated mean total sleep was 69 min longer in the first 24 h of the layover than on baseline ($P < 0.001$), but did not differ from baseline in the last 24 h of the layover ($P = 1.000$). Crewmembers obtained almost 1.5 h more sleep in the first 24 h post-trip when compared to baseline days [$F(5, 281) = 8.64$, $P < 0.001$] and 58% took a postflight nap. From post-trip day 2 onwards, the total amount of sleep did not differ from baseline days.

Fatigue and sleepiness ratings after nighttime sleep (i.e., sleep occurring during the local night) on baseline days were compared to fatigue and sleepiness ratings after nighttime sleep on post-trip days. Crewmembers were no more fatigued [$F(5, 237) = 1.07$, $P = 0.38$] or sleepier after waking on any of the postflight days compared to baseline [$F(5, 237) = 0.57$, $P = 0.72$].

DISCUSSION

The present study demonstrates that data collection is feasible for cabin crew on ULR trips. However, the response rate and completion rate tended to be lower compared to a recent study involving flight crew.[25] Of the cabin crew invited, 27% declined to participate and the reasons for this are unknown. Of those who agreed to participate, 60% completed data collection and 41% provided data of suitable quality. Methods for improving recruitment and completion rates are therefore worthy of investigation.

In the present study, cabin crew generally prepared well for the ULR trip by obtaining on average more sleep in the 24 h preflight compared to baseline days and almost half took a preflight nap. Baseline sleep averaged 6.5 h per night, although this varied greatly between individuals. Not all crewmembers were free from duty on baseline days, but this was the best available estimate of normal sleep at home. In comparison, flight crew flying this same ULR route obtained on average 7.5 h of sleep on baseline days.[25] The reasons for this difference deserve further investigation, but may be due to differences in the demographics and domestic responsibilities between the two occupational groups. Almost half of the cabin crew were women and may have had a disproportionate level of domestic responsibilities, which could impact on their nighttime sleep. Recurrent training that includes education on the importance of recovery sleep at home may be valuable for cabin crew.

Taking a preflight nap before the outbound flight did not influence the amount of sleep during cabin crews' first scheduled in-flight rest break or the total amount of in-flight sleep, as was also found for flight crew flying this same route.[25] This finding reinforces that a preflight nap before an evening departure is feasible and does not appear to adversely influence subsequent in-flight sleep.

Crewmembers obtained on average more sleep on the ULR outbound flight (3.6 h) than the non-ULR inbound flight (2.9 h), which was in part facilitated by the longer flight duration and local evening departure of the outbound flight. However, the amount of in-flight sleep varied greatly between individuals. Age-related changes in sleep[19] were not evident in the in-flight sleep duration, but it is possible that actigraphy is not sensitive for detecting age-related changes in short in-flight sleep periods. The high interindividual variability suggests that other personal, environmental, and/or work-related factors may influence in-flight sleep and this warrants further investigation to develop recommendations for improving in-flight sleep.

As per company recommendations, the time available for rest in the bunk on the outbound flight was split into four rest breaks on almost all occasions. There are presently no company recommendations regarding in-flight rest patterns on the inbound flight. The findings do not indicate that splitting the available rest time into four rest breaks is better or worse than splitting the available time into two rest breaks. However, the timing of the scheduled bunk rest breaks affected the amount of total in-flight sleep obtained on the inbound flight, with crew taking the 1st and 3rd break obtaining significantly less in-flight sleep compared to all other crew. Assuming minimal circadian adaptation during the layover, the 1st rest break would have fallen in the circadian evening wake maintenance zone (a few hours before a person's normal bedtime when sleep is difficult to initiate and maintain) on Johannesburg time, whereas the longer single break during the first half of the flight would have extended past the evening wake maintenance zone, allowing more sleep to be obtained. However, crewmembers taking the first long break would also have been awake longer at TOD than all other crewmembers, and a longer duration of time awake at TOD (but not prior sleep) was associated with increased fatigue and sleepiness at TOD. On other ULR routes,[6] a number of different break patterns have been used and preference is in part determined by the flight's departure window. Providing crew with two breaks each has the advantage of minimizing the risk of not obtaining any sleep if one of the breaks occurs during a less favorable time in the circadian body clock cycle for sleep.[6]

In the last 24 h of the layover, most crewmembers slept during the local night, despite being advised to stay on domicile time. This caused sleep to be truncated on the morning of departure, due to the local morning sign-on time and/or due to the crewmember's inability to stay asleep due to the circadian drive for wake. A preflight nap was not possible for most crewmembers due to the relatively short period of time between waking and sign-on, coupled with an adverse circadian phase for sleep (late afternoon Johannesburg time/morning New York time), during which initiating or maintaining sleep is difficult.

The context in which a PVT test is completed can differ greatly between workplace settings, as is the case for cabin crew in comparison to flight crew as well as for cabin crew at different phases of the flight. Although we cannot be certain, the poor performance on the outbound preflight PVT test may have been a result of distractions in the testing environment. Completion of the PVT in a busy cabin is expected to have contributed to the large variability observed in the subsequent tests, which in turn may also have contributed to the lack of a statistically significant association between sleep history and performance. On the other hand, a study using combined datasets from four field studies which included data from 237 pilots on 730 long range and ultra-long range flights also found no association between PVT performance and sleep/wake history at TOD.[9] Despite the more challenging context in which the PVT was completed, the PVT showed the expected changes in cabin crew's performance across the flight (from TOC to TOD) and between flight legs. Compared to flight crew, however,[9,25] cabin crew's PVT performance was overall slower and resembled more closely the performance of populations in other research studies.[27] In future studies the timing and/or location for completing PVTs should be carefully considered in consultation with the cabin crew.

Fatigue and sleepiness ratings were overall higher and PVT response speed was slower on the shorter non-ULR inbound flight in comparison to the outbound ULR flight, even though both flights spanned the local Johannesburg night, assuming minimal adaptation during the layover. These findings indicate that longer flights do not necessarily result in greater declines in performance and increases in fatigue, especially if sufficient in-flight sleep is obtained. The greater fatigue experienced on the inbound flight may instead be a consequence of the accumulated sleep loss across the trip and suggests adequate recovery following such patterns of work is important.

The present findings suggest that four local nights off duty following the ULR trip is, on average, sufficient to enable crewmembers to recover from the trip. However, sleep duration varied greatly among individuals, as did the postsleep sleepiness and fatigue ratings, which suggests that some crewmembers recover more slowly than others. Education on the importance of recovery sleep at home, including a consideration for individual differences in sleep need and recovery, would therefore be beneficial for cabin crew.

In conclusion, this study of cabin crew flying a ULR trip between Johannesburg and New York used recommended measures and methods for collection and analysis of data,[7] allowing a robust scientific assessment of changes in sleep, sleepiness, fatigue, and performance across the ULR trip. To our knowledge, this is the first ULR validation study involving cabin crew. It demonstrates that cabin crew fatigue was managed effectively on the outbound ULR flight. It also demonstrates that this type of data collection is feasible for cabin crew, although operational differences between cabin crew and flight crew need to be considered in these data collection processes and a large number of cabin crew may need to be approached to obtain sufficient data. Multiple factors may influence the motivation of cabin crew to take part in the data collection and this warrants further investigation. It is important to note that the findings from the present study cannot be generalized to operations with different flight durations, departure times, and/or arrival times.

ACKNOWLEDGMENTS

We would like to acknowledge the significant contribution of the participating cabin crewmembers and their diligence in completing the study requirements. We would also like to acknowledge the involvement of the research assistants at South African Airways, namely Barbie Moonsamy, Carol Myaluza, Ayanda Toti, Beverly Seabi, Heather Marule, Samantha Narisamulu, Carey Bouwer, and Masilo Matseke, and at the Sleep/Wake Research Centre, Rosie Gibson, Sophie McCashin, and Hannah Timms for their assistance with the data processing. This study was funded by South African Airways.

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REFERENCES

1. Aickin M, Gensler H. Adjusting for multiple testing when reporting research results: the Bonferroni vs. Holm methods. Am J Public Health. 1996; 86(5):726–728.
2. Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci. 1990; 52(1-2):29–37.
3. Ancoli-Israel S, Cole R, Alessi C, Chambers M, Moorcroft W, Pollak CP. The role of actigraphy in the study of sleep and circadian rhythms. Sleep. 2003; 26(3):342–392.
4. Czeisler C, Buxton OM. The human circadian timing system and sleep–wake regulation. In: Kryger MH, Roth T, Dement WC, editors. Principles and practice of sleep medicine, 5th ed. St. Louis (MO): Saunders Elsevier; 2011:402–419.
5. Ferguson SA, Paech GM, Sargent C, Darwent D, Kennaway DJ, Roach GD. The influence of circadian time and sleep dose on subjective fatigue ratings. Accid Anal Prev. 2012; 45(Suppl.):50–54.
6. Flight Safety Foundation. Cabin crews adapt readily to challenges of ultra-long-range flight. Flight Saf Dig. 2005; 24(8-9):41–45.
7. Flight Safety Foundation. Fourth workshop yields insights into early ultra-long-range operations. Flight Saf Dig. 2005; 24(8-9):1–15.
8. Gander PH, Gregory KB, Miller DL, Graeber RC, Connell LJ, Rosekind MR. Flight crew fatigue V: long-haul air transport operations. Aviat Space Environ Med. 1998; 69(9, Suppl.):B37–B48.
9. Gander PH, Mulrine HM, van den Berg MJ, Smith AA, Signal TL, et al. Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. J Sleep Res. 2015; −÷(1):110-119.
10. Gander PH, Mulrine HM, van den Berg MJ, Smith AAT, Signal TL, et al. Pilot fatigue: relationships with departure and arrival times, flight duration and direction. Aviat Space Environ Med. 2014; 85(8):833–840.

11. Gander PH, Signal TL, van den Berg MJ, Mulrine HM, Jay SM, Mangie J. In-flight sleep, pilot fatigue and psychomotor vigilance task performance on ultra-long range versus long range flights. J Sleep Res. 2013; 22(6):697–706.
12. Gander PH, van den Berg MJ, Jay SM, Signal TL. Comparison of flight crew sleep and fatigue during Delta Airlines long range and ultra-long range operations. Wellington (New Zealand): Massey University; 2012.
13. Gillberg M, Kecklund G, Åkerstedt T. Relations between performance and subjective ratings of sleepiness during a night awake. Sleep. 1994; 17(3):236–241.
14. Härmä M, Sallinen M, Ranta R, Mutanen P, Muller K. The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. J Sleep Res. 2002; 11(2):141–151.
15. Littel RC, Milliken G, Stroup W, Woldfinger R, Schabenberger O, editors. SAS for mixed models. Cary (NC): SAS Institute; 2006.
16. Lowden A, Åkerstedt T. Retaining home-base sleep hours to prevent jet lag in connection with a westward flight across nine time zones. Chronobiol Int. 1998; 15(4):365–376.
17. Lowden A, Åkerstedt T. Eastward long distance flights, sleep and wake patterns in air crews in connection with a two-day layover. J Sleep Res. 1999; 8(1):15–24.
18. Pascoe PA, Johnson MK, Roberston KA, Spencer MB. Sleep in rest facilities on board aircraft: field studies. Farnborough (UK): DERA; 1995. Report No.: DERA/CHS/A&N/CR/95/002.
19. Redline S, Kirchner L, Quan SF, Gottlieb DJ, Kapur V, Newman A. The effects of age, sex, ethnicity, and sleep-disordered breathing on sleep architecture. Arch Intern Med. 2004; 164(4):406–418.
20. Roach GD, Dawson D, Lamond N. Can a shorter psychomotor vigilance task be used as a reasonable substitute for the ten-minute psychomotor vigilance task? Chronobiol Int. 2006; 23(6):1379–1387.
21. Samn SW, Perelli LP. Estimating aircrew fatigue: a technique with implications to airlift operations. Brooks AFB (TX): USAF School of Aerospace Medicine; 1982. Report No.: SAM-TR-82-21.
22. Signal TL, Gale J, Gander PH. Sleep measurement in flight crew: comparing actigraphic and subjective estimates to polysomnography. Aviat Space Environ Med. 2005; 76(11):1058–1063.
23. Signal TL, Gander PH, van den Berg MJ, Graeber RC. In-flight sleep of flight crew during a 7-hour rest break: implications for research and flight safety. Sleep. 2013; 36(1):109–115.
24. Signal TL, Mulrine HM, van den Berg MJ, Smith AAT, Gander PH. Evaluation of the sleep and performance of South African Airways flight crew on the Johannesburg-New York ultra-long range flight. Technical Report. Wellington (New Zealand): Massey University; 2013.
25. Signal TL, Mulrine HM, van den Berg MJ, Smith AAT, Gander PH. Mitigating and monitoring flight crew fatigue on a westward ultra-long-range flight. Aviat Space Environ Med. 2014; 85(12):1199–1208.
26. Tabachnick B, Fidell L. Using multivariate statistics, 4th ed. Boston (MA): Allyn & Bacon; 2000.
27. Wesensten NJ, Belenky G, Thorne DR, Kautz MA, Balkin TJ. Modafinil vs. caffeine: effects on fatigue during sleep deprivation. Aviat Space Environ Med. 2004; 75(6):520–525.