International Aircrew Sleep and Wakefulness After Multiple Time Zone Flights: A Cooperative Study

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The papers in this report represent the joint efforts of an international research team of scientists and operations personnel from four different countries. These individuals, their associated airlines, and sponsoring agencies, have cooperated with the National Aeronautics and Space Administration over the past two years to carry out an extensive examination of sleep and wakefulness in international flight crews. This paper provides an overview of their collaborative endeavor, including its history and the standardization of procedures, and summarizes this center's views on the major findings of the independent laboratories. Further details concerning the methods and results of each research group are contained in their individual reports.

BACKGROUND

Optimal safety and efficiency in air carrier operations depend on flight crews being well rested and alert while performing duty in the cockpit. Consequently, significant efforts have been made to develop rest requirements to help ensure that crew members obtain adequate sleep between flights (14). For international aircrews, this requirement is complicated during layovers by the effects of multiple time zone changes. Their sleep is often disrupted because it is attempted during an inappropriate phase of the internal circadian rhythm or at times when the local population is awake and active.

Several efforts have been made to examine this problem in the operational environment. These studies have dramatically demonstrated the extent of sleep deficit which can result from flying transmeridian routes; however, most have relied on self-reported data obtained from sleep logs (8-11). Other investigators have applied standard electroencephalographic (EEG) recording techniques to examine the effects of transmeridian flight on sleep (4,5,7,13). While these few studies have provided the most objective data on sleep disruption and the concomitant changes in sleep architecture which occur in new time zones, their applicability to international flight crews is questionable. First, most subjects have been tourist volunteers unaccustomed to transmeridian flying on a regular basis. Second, upon arriving at their destination, they were restricted to sleeping at a time appropriate to local custom and were not allowed to sleep whenever they chose. Third, they were transported in the aircraft cabin, where sleeping was uncontrolled and the performance of flight duties was not required.

In light of these considerations, we initiated a comprehensive research effort to provide flight crews and operational managers with scientifically sound, useful data concerning the issue of layover sleep. International collaboration was sought in order to facilitate efficient data collection within the constraints of scheduled flight operations, and to enhance the feasibility of studying both eastward and westward flights crossing an equal number of time zones. These were the goals of an organizational meeting sponsored by NASA's Ames Research Center in October 1983. The attendees reflected a unique scientific, operational, and geographic mixture of organizations and individuals who recognized the rare opportunity to conduct such a study. Expertise in sleep research and time zone adjustment was provided by researchers from the DFVLR Institute for Aerospace Medicine (Dr. H.M. Wegmann), the Jikei University School of Medicine (Dr. M. Sasaki), and the Stanford University Medical Center (Dr. W. Dement). Operational input was provided by representatives from Lufthansa (Capt. M. Naumann), Japan Air Lines (Capt. H. Nagano and Mr. S. Nakai), and Pan American World Airways (Dr. J. McCann and Capt. W. Simons). This group, together with NASA personnel, developed an operationally feasible research plan which would provide the data necessary to obtain the first objective assessment of crew layover sleep after multiple time zone transitions.

A second planning meeting was held at NASA-Ames in February 1984 to finalize the study design, resolve technical details, and make logistical arrangements for carrying out the project. At this time, the scope of research was widened to include British participation as represented by the U.K Civil Aviation Authority (Drs. G. Bennett and R. Barnes), the Royal Air Force Institute of Aviation Medicine (Dr. A. Nicholson), and British Airways (Dr. R. Green and Capt. M. Jeffery). In addition, pilot group input and support was provided by the Air Line Pilots Associations of Great Britain (Capt. J. Fomes and Mr. D. LeBrecht) and the United States (Capt. R. Stone and Dr. R. Masters). Thus, the final cooperative effort included British, German, Japanese, and U.S. research teams, each associated with an international carrier and a source of support from their home country. While the scientific contributions of the investigators are recognized in the authorships of the following papers, much of the project's success can be attributed to the excellent advice and assistance provided by the other participants.

OBJECTIVES AND DESIGN

The overall goal of this layover (L/O) sleep study was to assess the changes in sleep quality associated with multiple time zone transitions. This objective incorporated several aims which dictated the research design. The first was to describe how sleep during a trip differs from sleep at home. The second aim was to determine how these differences are reflected in subsequent levels of "daytime" sleepiness (or alertness), and whether flight crews could subjectively assess these levels of sleepiness. Third, we sought to compare the effectiveness of different sleep-rest strategies in order to identify more successful coping techniques for recommendation to international flight crews.

The design concept centered on utilizing San Francisco (i.e., Stanford University) as a research hub where all participating airline crews would undergo either L/O or baseline EEG sleep recordings (See Fig. 1). The latter were carried out at perimeter laboratories located near the crews' home base. Each research team was responsible for collecting the baseline data for crew members from its associated airline and the L/O data for other crews arriving at that destination. These data consisted of standard polysomnographic recordings during "nocturnal" sleep followed by "daytime" multiple sleep latency tests (MSLTs) every two hours whenever the subjects were awake and not trying to sleep. The former provided objective measures of sleep quality and quantity, while the latter provided objective measures of "daytime" sleepiness for comparison with the subjects' own estimates. The MSLT measures the time a subject takes to fall asleep in a standard sleep laboratory environment. This presumably reflects the brain's physiological sleepiness and, thus, indirectly, prior sleep quality (1). By comparison, subjective estimates reflect a less stable state which can be influenced readily by environmental stimulation or voluntary muscular activity.

Throughout the study investigators attempted to minimize interference with the crew members' usual trip behavior. Although staying in a sleep laboratory precluded certain activities more easily accomplished while staying at a crew hotel, most subjects' needs were accomodated within the time limitations of the data collection schedule. Thus, crew members could implement whatever L/O coping strategies they had developed throughout their career and were encouraged to do so. No restrictions were placed on when they slept or how long they spent in bed. A variety of meals and snacks were available at any time of the day or night. Subjects could exercise moderately (e.g., walk, ride bicycles) between MSLTs, go shopping or visit local sites of interest. Although consumption of caffeinated beverages was prohibited (except in very limited amounts if withdrawal symptoms occurred), decaffeinated coffee and tea were freely available. Because alcohol can cause drowsiness and thus affect the MSLTs, alcohol consumption was prohibited except before bedtime. Then, in order to enable subjects to mimic their usual L/O behavior, they were allowed up to two glasses of beer or wine.

METHOD

In order to assure the comparability of data across laboratories, considerable effort was put into standardizing methods. As summarized in Table I, each participating laboratory carried out a core set of measurements which are described below. In addition, certain research teams collected ancillary data. Some of these latter procedures are described here, while others are described in the relevant papers.

Subjects

All subjects were active flight crew members (Captains, Co-pilots, and Flight Engineers), age 31 to 61 yrs (Fig.2), who regularly flew line trips for the participating airline. The method utilized for soliciting volunteers differed for each airline depending on operational factors related to bidding practices and labor agreements and on logistical considerations related to laboratory availability. In the case of two airlines (BA and PA), crews who had successfully bid the target trips were contacted by telephone and asked to volunteer individually. This often resulted in only one or two crew members from a particular flight staying in the L/O laboratory. In the case of the other two airlines (LH and JL), volunteers were first solicited and then assembled into crews so that two, if not three, crew members were together during the L/O recordings. Regardless of the recruitment procedure, the response was generally positive with the major reason for non-participation being the incompatibility of duty schedules with the requirements for days off before baseline or L/O recordings.

All volunteers were given a five-digit code known only to them, so that no data could be traced to a particular individual by name. Subject confidentiality was also protected by

TABLE I. PARTICIPATION SUMMARY

Airline	Measures	Flight	Time Change	Month	L/O	n
BA	P.LM.RSP MSLT RT*	LHR-SFO	-8h	Aug	48h	13
LH	P MSLT RT.HR.U	FRA-SFO SFO-FRA	-9 +9	Sept	48 48	12
JL	P.LM.RSP MSLT	NRT-SFO	+8	Oct	48	12
PA	P.LM.RSP MSLT RT*	SFO-LHR	+8	Aug-Sept	48 52 72	4 3 4
		SFO-NRT	-7	Nov	25	9

P = Polysomnography (EEG.EOG.EMG); LM = Leg movements during sleep;
RSP = Respiration during sleep; MSLT = Multiple sleep latency tests;
RT = Continuous rectal temperature; HR = Continuous heart rate;
U = 24h urine; * = Reduced n.

keeping no record of flight numbers or L/O dates. At the end of the L/O. all subjects were given the opportunity to review their recordings with a qualified researcher.

Core procedures

Participation schedule. Each subject was recorded polygraphically for two nights at the sleep laboratory near his homebase and during any sleep taken during the post-flight layover. This L/O lasted approximately 48h in all cases except at NRT. where operational requirements limited it to about 25h. Four LHR L/O subjects departed the laboratory after 48h and spent the remainder of the 72h L/O in the usual hotel. The first night of homebase recordings was termed the "adaptation night" since it was intended to eliminate the well known "first night" effect often seen in subjects during their initial stay in a sleep laboratory. After subjects become accustomed to the recording procedures and laboratory surroundings. their subsequent data is usually reliable. One subject experienced serious difficulty sleeping during this adaptation night and was consequently dropped from the study.

Ideally. subjects were supposed to spend two successive nights in the homebase laboratory. the second night being the baseline recording night. Furthermore. they were to have a mininmum of five non-flying days immediately before the baseline night and then commence the target trip on the day after finishing the baseline MSLT recordings. Unfortunately. due to standard duty schedules. only a few volunteers were able to fulfill this participation schedule. Therefore. a compromise schedule was adopted whereby subjects were required to complete at least the adaptation night before commencing the trip. The baseline recordings were to be completed within three weeks before or after the L/O trip, with a minimum of three non-flying days required before the baseline or L/O recordings. In the case of two airlines (LH and JL), the adaptation and baseline recordings always occurred in succession, but for one (LH) the baseline MSLTs preceded the baseline sleep recording instead of following it. Furthermore, crew members from the latter airline returned to the homebase laboratory immediately after the return flight for a 48h assessment of recovery sleep and daytime sleepiness. The procedures during this post-trip period mimicked those used during the L/O.

Sleep recordings. Crew members were asked to notify the technicians 15 min before they wished to sleep or nap so that all necessary recording preparations could be made. Time of awakening was spontaneous or by prearranged call. Standard polysomnographic techniques were used to record the following sleep related variables during all phases of the study: (a) electroencephalographic (EEG) activity from the C3-A2 or C4-A1 positions, (b) submental electromyographic (EMG) activity, and (c) bilateral electro-oculographic (EOG) activity. EEG activity from 01-A2 (or 02-A1) was also monitored until sleep onset. Recordings were made with silver or gold electrodes filled with electrode jelly and applied to the skin with collodion so that resistances of less than 10 Kohms were maintained. Chart speed was 10 mm/sec, except for some subjects from one airline (JL) who were recorded at 15 mm/sec due to differences in the available polygraphs. Polygraph calibration procedures were standardized so that the half-amplitude frequency response was 0.3-35 Hz for the EEG and EOG and 5-75 Hz for the EMG with a selective 50 or 60 Hz notch filter in each channel to eliminate interference from the local current supply. All sleep records were scored into 30 sec epochs according to the standard criteria of Rechtschaffen and Kales (12).

Multiple Sleep Latency Tests. MSLT recordings were carried out on the even GMT hour unless it occurred less than 30 min before or 15 min after a major sleep period. To minimize any unwanted influences on arousal level, alcohol consumption was prohibited between MSLTs, smoking was not permitted within 30 min before testing, and any physical exercise, showers, or meals had to be completed within 30 min before the next MSLT. Each test was preceded by 15 min of quiet indoor activity and 5 min of standard calibration procedures while the subject was in bed in a quiet darkened bedroom. He was then told to lie quietly, keep his eyes closed, and try to fall asleep. Polygraphic recording was limited to EEG activity from C3-A2 (or C4-A1) and O1-A2 (O2-A1) and bilateral EOG activity. The test was terminated when the on-line recording indicated the first three consecutive 30-sec epochs of any sleep stage or when 20 min had elapsed, whichever occurred first. The test was scored for the number of seconds that elapsed from lights-off until the first 30-sec epoch of any sleep stage. The EEG and EOG electrodes remained attached throughout the day unless there was a compelling reason to remove them.

Subjective Data Collection. Questionnaires were used to obtain subjective information before and after various recording procedures. Before each sleep recording subjects completed a pre-sleep questionnaire which included the Stanford Sleepiness Scale (SSS), a mood assessment scale, and a self-report of prior medication. After waking, they completed a second questionnaire which included self-reports on the amount and quality of sleep in addition to the SSS. Likewise, prior to each MSLT, the subjects rated fatigue and tension on 10cm analogue scales and completed a SSS. Finally, at the end of the Baseline and L/O stays, all crew members responded to an exit questionnaire in which they characterized their activities and the rest obtained during the stay.

Daily logbooks were used document the activities and sleep of the volunteers surrounding the baseline and L/O measurements. Entries were begun at least two days before baseline or departure from homebase and continued through the laboratory stay up to several days thereafter. In addition, all subjects completed the NASA Background Information Questionnaire which provided information on lifestyle, dietary habits, exercise, personality, morning-eveningness, and sleep habits.

Ancillary Measures

Additional sleep measures. To obtain clarifying data regarding awakenings, three additional measurements were obtained from crew members from three of the participating airlines (BA, JL, and PA). These measurements consisted of heart rate, respiration, and leg movements and were polygraphically recorded only during major sleeps and not during naps or MSLTs. Respiratory data was obtained from a nasal thermistor (air flow) and an abdominal strain gauge (respiratory effort), while leg movements were detected by bipolar anterior tibialis EMG.

Body temperature, heart rate, and urine. To obtain clarifying data regarding circadian rhythmicity, crew members from two airlines (BA and PA) were asked to wear rectal temperature sensors throughout their baseline and L/O stays in the laboratory. Willingness to participate in this aspect of the study did not preclude participation in the rest of the protocol. Volunteers wore a portable solid-state recorder (PMS-8, Vitalog Corp., Redwood City, CA) which was read out through a personal computer at the end of each visit.

For a third participating airline (LH), body temperature was recorded from all subjects throughout the length of the study, including both flights and a post-return 48h laboratory stay. These data were collected on cassette via a Medilog tape recorder (Oxford Medilog Inc.) which was also used to record continuous electrocardiograms. In addition, all urinary output was collected during this time to be subsequently analyzed for catecholamines and 17-OCHS levels.

Questionnaires

In order to determine the representativeness of the laboratory L/O compared to a L/O at the crew hotel, the subjects from three airlines (PA, LH, and JL) completed daily logbooks on trips to the L/O city during the previous month. In addition, crew members from one airline (JL) were interviewed by NASA researchers during the hotel L/O to further establish any critical requirements for making the sleep laboratory stay as representative as possible.

Standardization

Standardization across laboratories for all core and common ancillary procedures was facilitated by the use of standard written protocols and the exchange of scientific staff. Following the preliminary standardization meetings, each recording site was visited by both Stanford and NASA personnel. These visits served to resolve any procedural inconsistencies regarding subject-investigator interaction, data collection and scoring.

In order to minimize scorer variability, all baseline and L/O sleep and MSLT records from a particular airline were scored by the same individual from the homebase laboratory. Furthermore, ten percent of each laboratory's sleep and MSLT data were cross-scored by a member of the paired cooperating laboratory. All data were entered into a standard matrix score sheet for input into an archival database.

OVERVIEW OF RESULTS

The results for each of the five groups of crewmembers are described in detail by the individual laboratory reports which follow. In order to facilitate comparisons across the different flight schedules, each paper includes a core set of common figures including individual summaries of each subject's sleep-wake patterns during baseline and layover. In addition, a separate Operational Summary representing a consensus view is provided for those readers specifically interested in the implications of the research for flight operations and crew training.

In the view of the NASA investigators, the basic findings are relatively straightforward and remarkably consistent among the different flight crew samples. Most crew members were able to obtain adequate sleep during L/O whether by sleeping efficiently at selected times or by sleeping less efficiently but staying in bed longer than usual. Sleep quality decreased slightly in most cases but more so after eastward flights than after westward flights. These decreases were reflected in increased daytime sleepiness (MSLT) in the new time zone; however, the mean circadian sleepiness rhythm often persisted on homebase time after the flight, so that at least part of the increase in L/O sleepiness may have included the unshifted increase usually exhibited at that GMT time. Age was another factor that significantly affected sleep quality among the various groups. In confirmation of Preston's earlier observations (10), older subjects experienced less total sleep as well as poorer quality sleep. Evidence suggests that this decrement occurs predominantly in those crew members over fifty years of age.

Subjective measures led to less consistent conclusions. While certain groups rated their L/O sleep quality as better than baseline in contrast to their polysomnographic data, other groups' ratings reflected the poor sleep quality seen in the recordings. Crew members were even less able to predict their own daytime sleepiness, in that the subjective sleepiness ratings typically did not correlate with the more objective, MSLT measures.

In addition to the basic findings, we feel that several issues are raised by the overall results. Numerous studies have shown that the human circadian system is disrupted more by eastward than westward time zone shifts and takes longer to resynchronize after the former (6). Thus, it is not surprising that sleep patterns were more disturbed in crews flying eastward routes. Other research (2,3,15) has recently shown that sleep duration varies as a function of the phase of the circadian temperature rhythm, with longer sleeps occurring when temperature is decreasing and shorter sleeps occurring when subjects go to sleep near the time of the temperature trough. REM sleep is more concentrated near the time of this trough, so that the amount and timing of REM during sleep depends on when the subject sleeps in relation to his circadian temperature rhythm. Conversely, slow-wave sleep is more influenced by the length of prior wakefulness than by circadian phase position (4). These findings would predict (4,13) some of the observed alterations in sleep stages and quality (e.g., decreased amounts of REM sleep following eastward flights). However, most of the changes in sleep quality were not as extensive as one might expect from the literature. For some groups, there were no statistically significant changes in sleep stage percentages or latencies despite the substantial time zone shift. It is difficult to determine whether these relatively mild effects were due to some type of adaptation developed in response to repeated time zone shifts by flight crews. A partial explanation may lie in some subjects' relatively low baseline sleep durations used for comparison to L/O sleep.

There was a wide range of individual differences observed in sleep quality and efficiency. In addition to age, there is evidence from the Japanese crews to suggest that some of these differences may be due to individual variations in circadian type, i.e., morningness-eveningness preferences in lifestyle. Regardless, it is still not clear why certain individuals exhibited consistently poor sleep quality and excessive daytime sleepiness during baseline, L/O, or both. A detailed analysis of their data, including respiratory disturbances and periodic leg movements, in comparison to that of a similar age, non-pilot control group is currently underway.

One of the most striking findings was the similarity of the baseline daytime sleep latency curves (i.e., MSLT) among the different airline groups. Their average curves all exhibited a gradual increase in sleepiness throughout the day reaching a maximum during the late afternoon followed by a gradual decline into the evening. Despite the sampling limits imposed by irregular L/O sleep/wake patterns, it appears that these sleepiness rhythms persisted on homebase time after the time zone shift. Thus, it may be possible for crews to predict when it would be easier to fall asleep and thereby develop better strategies for sleeping or napping while away from home.

It is our belief that the clearest implications for L/O sleep strategies come from the data obtained after eastward night flights. As explained in the Operational Summary, adhering to more structured sleep schedules and limiting initial post-flight sleep would appear to facilitate the acquisition of adequate sleep during the L/O. The use of other strategies, e.g., maintaining a homebase sleep pattern, can be evaluated less readily because of the statistical limitations imposed by the relatively few crew members who chose a consistent alternative to sleeping at the local customary time. Further analyses will have to be conducted concerning the potential importance of other types of activities observed in these subjects (e.g., meal patterns, exercise).

These studies provide the first physiological documentation of the sleep problems associated with international flight operations. While there may always be some doubt regarding the ability to generalize from sleep in a laboratory to sleep in hotels, both the German and Japanese sleep log data strongly suggest that crew members' sleep-wake patterns are not very different under the two conditions Furthermore, it is likely that less ideal conditions for sleep often exist in the hotel environment, so that the results obtained here may represent a "best case". Similarly, the L/O recordings were made after the initial outbound flight of a trip and therefore do not represent the vast majority of long-haul L/Os which typically occur in the less ideal context of a series of multiple time zone flight segments. Nevertheless, we believe that these findings provide an operationally sound framework for addressing the issue of long-haul crew rest and for developing more effective ways to study sleep-related problems in human performance. This was the mandate placed upon us by NASA with respect to the issues of fatigue and circadian desynchronization in flight crews. The reader is referred to the individual laboratory papers for the views and opinions of the other participating investigators.

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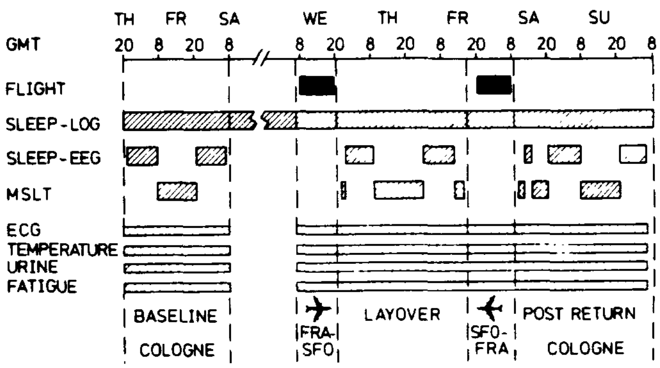

Figure 1.- Overview of time lines for the data collection of the flight schedule Frankfurt-San Francisco.

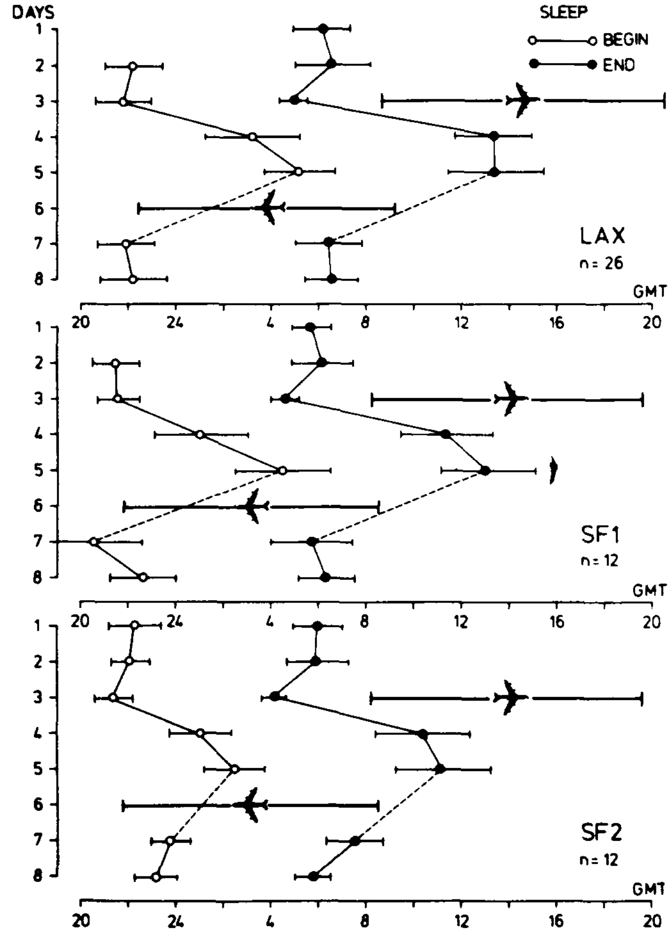

Figure 2. Subjective ratings of beginning and end of sleep during control, layover and post-return nights. Presented are means (±S.D.) of the three different groups. (Numbers of days at the vertical axis refer to days beginning at 2400 GMT.)

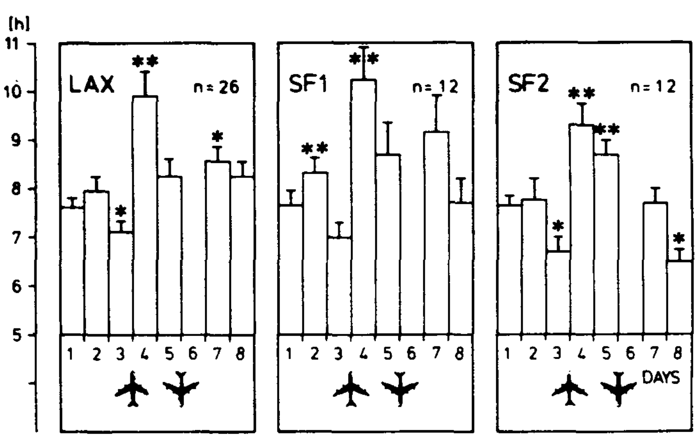

Figure 3. Subjective ratings of sleep duration during control, layover, and post-return nights (means +/- S.E.). * p<=0.05; ** p<=0.01 for differences from sleep period of day 1.