CREW FACTORS IN FLIGHT OPERATIONS VII: PSYCHOPHYSIOLOGICAL RESPONSES TO OVERNIGHT CARGO OPERATIONS.

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TABLE OF CONTENTS

SUMMARY

To document the psychophysiological effects of flying overnight cargo operations, 41 B-727 crew members (average age 38 yr) were monitored before, during, and after one of two typical 8-day trip patterns. During daytime layovers, the average sleep episode was 3hr (41%) shorter than nightime sleeps and was rated as lighter, less restorative, and poorer overall. Sleep was frequently split into several episodes and totalled 1.2 hr less per 24 hr than pretrip. Laboratory studies suggest that cumulative decreases in waketime alertness would be expected with this amount of sleep loss. The night off in the middle of a sequence of duty nights provided an important opportunity for recuperation. Its position in the sequence of night duties should be related to the sleep loss imposed by the schedules. The organization of sleep during daytime layovers reflected the interaction of duty timing with circadian physiology. The circadian temperature rhythm did not adapt completely to the inverted wake/rest schedule on duty days, delaying by about 3 hr. Highest subjective fatigue and lowest activation occurred around the time of the temperature minimum. On duty days crew members ate more snacks, and reports of headaches quadrupled, of congested nose doubled, and of burning eyes increased nine-fold. Compared to daytime short-haul air transport operations, the overnight cargo trips were less demanding in terms of duty and flight hours, and had longer layovers. Nevertheless, overnight cargo crews, who were 5.4 yr younger, lost a comparable total amount of sleep, and had shorter individual sleep episodes and more broken sleep than their daytime short-haul counterparts. Consideration should be given to relating the duration of rest periods to the time of day during which duty takes place.

1. OPERATIONAL OVERVIEW

This report is the seventh in a series on the physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects. The Operational Overview is a comprehensive review of the major findings and their significance. The rest of the volume contains the complete scientific description of the work.

To document the psychophysiological effects of flying overnight cargo operations, fourty-one B-727 crew members were monitored before, during, and after one of two typical 8-day trip patterns. On the Destination-Layover pattern, crews stayed in layover hotels between consecutive nights of flying. After three nights on duty, they deadheaded home and had about 45 hr off duty before deadheading out to begin another 3 nights of flying. On the Out-and-Back pattern, crews returned home after each night of flying. After five nights on duty, they had about 45 hr off duty before flying for two additional nights. The average duty "day" on the Destination-Layover pattern was 3.5 hr longer, with double the number of flight segments and 52 min more flight time, and the average layover was 6.1 hr shorter. All flights took place in the Eastern and Central USA, with a maximum time zone change of 1 hr per day.

Thirty-four volunteers gave sufficient data to be included in the analyses. Their average age was 37.6 yr, and they had flown for an average of 4.7 yr with their current company. Throughout their participation in the study, they wore a portable biomedical monitor which recorded average heart rate, wrist activity, and rectal temperature every two minutes. In a logbook, they rated their fatigue and mood every 2 hr while awake, and kept a detailed record of their daily activities, including duty times, sleep timing and quality, food and fluid consumption, and medical symptoms. They also completed a Background Questionnaire which included basic demographic information, sleep and lifestyle habits, and four personality inventories. They were accompanied on all flights by a NASA cockpit observer who kept a detailed log of operational events.

Flying at night obliged crews to sleep during the day. Daytime sleep episodes were about 3 hr (41%) shorter than nighttime sleep episodes, and were rated as lighter, less restorative, and poorer overall. The incidence of sleeping more than once in 24 hr tripled on days with duty, compared to days without duty. Overall, crew members averaged 1.2 hr less sleep per 24 hr on duty days than on pretrip days. This sleep restriction, combined with the poorer sleep quality, would be expected to decrease waketime alertness progressively with the number of days of reduced sleep.

The circadian temperature rhythm did not adapt completely to the inverted wake/rest schedule on duty days, delaying by about 3 hr. On average, the temperature minimum occurred at around 07:30 hr local time, about half an hour after coming off duty. Thus crew members were on duty at times in the circadian cycle when their subjective fatigue was high and when their physiological sleepiness would be expected to be high and their performance capacity low. At the same time, they were also accumulating a sleep debt. Overnight cargo crews are thus working when routine physiological factors combine to generate the greatest potential for human error.

The way that crews organized their sleep between successive nights of flying reflected the interaction of duty timing with circadian physiology. Regardless of what time they went to sleep after coming off duty in the morning, they tended to wake up around 13:10 hr local time, even after as little as 4-5 hr of sleep. This clustering of wakeup times coincides with the timing of the circadian "wakeup signal" identified in laboratory studies. Because it is difficult to sleep past the circadian wakeup signal, getting off duty earlier enables crews to sleep longer in the morning. If late off-duty times are unavoidable, then layovers need to be longer (the present data suggest at least 19 hours), in order to permit a second sleep episode in the evening. Layovers in which crew members slept twice ended 4-7 hr later (around 02:30 hr local time) than layovers in which they slept only once. Crew members need to be aware that they risk having difficulty falling asleep if they do not go to sleep again before about 04:00 hr GMT (about 22:30 hr local time), because of the evening wake maintenance zone. This is a part of the circadian cycle when it is very difficult to fall asleep, even after sleep loss.

The night off in the middle of a sequence of duty nights provides an important opportunity for recuperation. It breaks the pattern of accumulating sleep debt, with its accumulating potential for impairment of alertness and performance. Crew members averaged 41 min more sleep per 24 hr than pretrip, and 115 min more than during daytime layovers. The position of the night off in the sequence of night duties should be related to the sleep loss imposed by the schedules. On the Destination-Layover pattern, one third of all crew members had lost more than 8 hr sleep after three nights of flying. In the laboratory, reducing sleep by 2 hr per night consistently produces impaired alertness and performance. It would clearly be unwise to add a fourth consecutive night duty in this case. In contrast, on the Out-and-Back pattern, only one quarter of the crew members had lost more than 8 hr of sleep after five nights of flying. The amount of sleep lost varied greatly, even among crew members on the same trip pattern. It was not correlated with any of the individual attributes previously reported to predict adaptability to shiftwork and time zone changes, i.e., amplitude of circadian rhythms, morning/eveningness, extraversion, and neuroticism.

When they were awake at night while on duty, subjects rated their fatigue and negative affect as higher, and their activation and positive affect as lower, than when they were awake during the day pretrip. Subjective fatigue and activation have two components: one which parallels the circadian temperature cycle, and one related to the duration of wake, with minimum fatigue (peak activation) occurring 8-10 hr after wakeup. Flying at night disrupted the normal relationship between these two components. The data did not permit a precise description of these changes. However, highest fatigue and lowest activation occurred around the time of the temperature minimum, as has been reported for night workers in other industries.

On duty days, crew members ate more snacks. However, unlike the daytime short-haul air transport crews in other NASA field studies, they did not increase their consumption of caffeine. Used appropriately, caffeine can be a useful operational countermeasure for acute fatigue. Ready availability of caffeine, and of information about its use, could be beneficial in helping crew members maintain their alertness during night flights. On duty days, by comparison with pretrip days, reports of headaches quadrupled, reports of congested nose doubled, and reports of burning eyes increased nine-fold.

The responses of overnight cargo crew members to duty demands were compared with those of daytime short-haul air transport flight crews for whom the same measures were available. In both cases, crews crossed no more than one time zone per 24 hr. The overnight cargo crews had shorter duty "days" (by 3 hr), with 2 hr less flight time and fewer, shorter flight segments, and longer layovers (by 2.4 hr). They were also 5.4 yr younger on average. Neverthelss, while on duty, they lost a comparable amount of sleep per 24 hr, and had shorter individual sleep episodes and more broken sleep than their daytime short-haul counterparts. This is consistent with the finding that 62% of shiftworkers in other industries report sleep complaints by comparison with 20% of day workers, and that the daytime sleep of nightshift workers is reduced by about a third compared to a normal night of sleep at home.

Headaches were more than twice as common among overnight cargo crews than among short-haul fixed-wing crews, and were approaching the incidence reported by helicopter crews who flew daytime air transport operations in cockpits where overheating, poor ventilation, and high levels of vibration were common. Overnight cargo crews also reported a more negative effect of trips on appetite than did daytime short-haul fixed-wing crews.

These data, collected during scheduled flight operations, indicate that flight crews do not obtain the same quality of sleep during daytime rest periods as they do during nighttime rest periods. We would strongly recommend that the Federal Aviation Authority re-examine the issue of taking into account the time of day during which a crew member is on duty when determining subsequent rest requirements.

2. INTRODUCTION

This report is the seventh in a series on the physiological and psychological effects of flight operations on flight crews, and on the operational significance of these effects.

2.1 OVERNIGHT CARGO OPERATIONS

The overnight cargo industry represents a growing segment of commercial aviation operations worldwide (1). Five US companies surveyed at the time of this study employed about 4500 flight crew members in such operations. The business community has become increasingly reliant on the next-day, door-to-door delivery service provided by these companies.

2.2 NIGHT WORK AND SLEEP

Flying domestic overnight cargo operations involves an unusual combination of challenges. Like other nightshift workers (2,3), overnight cargo flight crews must adapt to a duty/rest cycle out of synchronization with a day-oriented society and with their own diurnal physiology. They are required to work at times in the circadian cycle when they are physiologically prepared for sleep, and when their performace capacity is lowest (2,4,5). Conversely, they may be trying to sleep when they are physiologically prepared for wakefulness, and also at times when disturbances (noise, light, domestic or other social demands) are maximal. The daytime sleep of nightshift workers in other sectors has been shown to be reduced by at least one third compared to normal sleep at night. The different types of sleep are not equally affected. Deep slow-wave sleep tends to be conserved at the expense of light (Stage-2) sleep and dream (Rapid Eye Movement, or REM) sleep (2). Sleepiness (measured subjectively or objectively) during night work is very common. Akerstedt (2) has recently estimated that 75% of all workers experience sleepiness on every night shift, and at least 20% experience sleepiness severe enough to cause the individual to fall asleep. This can be attributed to working during the time of maximal sleepiness (3-5 am on a diurnal routine, 6), exacerbated by the sleep loss associated with daytime sleep. A recent NASA study of preplanned cockpit rest in 3-person long-haul flight crews showed evidence of greater sleep propensity and poorer performance (on a sustained reaction time test) during eastward nightime transpacific flights, by comparison with westward daytime transpacific flights (7). The potential detrimental effects of night work on efficiency and safety have been highlighted in several recent publications (2,5,8,9).

2.3 NIGHT WORK AND CIRCADIAN RHYTHMS

Across a series of night duties, there may be some adaptation of circadian rhythms to the reversed wake/rest shedule (3). The extent of this adaptation is of interest, because it may be associated with improvements in sleep quality, sleepiness, and performance. In practise, however, it is very difficult to measure. The rhythm of core body temperature is the most commonly used indicator of circadian phase. However, changes in the level of physical activity, and sleep, cause shorter-term changes in temperature (so-called "masking effects") which are superimposed on the circadian variation.

Like other nightshift workers, overnight cargo pilots frequently revert, on days off, to sleeping at night and being active during the day. Continuously changing from a nocturnal to a diurnal rest/activity pattern can result in chronic desynchronization of the circadian system from the social factors and the day/night cycle which normally stabilize it to a 24 hr day. This can produce persistent internal desynchronization between different physiological systems, a condition which has been associated with intolerance to shiftwork (11).

2.4 INDIVIDUAL DIFFERENCES IN ADAPTATION TO SHIFTWORK

Individuals with higher amplitude circadian rhythms (11,12) and a more "evening-type" (13) circadian profile (3,14,15,16,17,18) have been reported to adapt better to shiftwork. In a group of commercial long-haul flight crew members, Sasaki et al. (19) found that evening-types showed lower levels of daytime sleepiness after an 8 h eastward flight than did morning-types. It has also been reported that individuals who score high on the extraversion and neuroticism scales of the Eysenck Personality Inventory (20) may adapt more rapidly than other personality types to schedule changes (4). In a study of Norwegian Airforce pilots, more extraverted individuals showed greater adaptation of the circadian temperature rhythm five days after a westward flight crossing 9 time zones (21,22).

2.5 FLIGHT OPERATIONS VERSUS OTHER KINDS OF SHIFTWORK

There are several characteristics of overnight cargo operations (and domestic commercial flight operations in general) which distinguish them from other types of night- or shiftwork. First, the length of the work period is variable and often unpredictable. The current Federal Aviation Regulations (FARs) for Part 121 domestic operations (FAR 121.47) and scheduled Part 135 operations (FAR 135-265) specify scheduled rest times according to the number of hours flown in the preceding duty day. These rest times can be reduced when unforeseen circumstances arise which are beyond the company's control (aircraft malfunctions, adverse weather, etc). In such cases, a mandated longer rest period must begin within 16 hours of the reduced rest period. The current requirements are summarized in Table 1.

TABLE 1: FLIGHT AND REST TIME REGULATIONS FOR DOMESTIC OPERATIONS

Flight Hours/Day	Scheduled Rest	Can Be Reduced To	Compensatory Next Rest Period
up to 8	9 h	8 h	10 h
8-9	10 h	8 h	11 h
more than 9	11 h	9 h	12 h

There is no allowance made for the time of day when duty takes place. The rest time required by the FARs begins when a crew member comes off duty and ends when he goes back on duty, i.e., it can include the time for travelling to and from home or a layover hotel. The timing of the layover with respect to the circadian cycle and to local time (meal availability, noise, light, etc) can further restrict the time available for sleep.

Second, consecutive duty periods do not necessarily start and end at the same time of day. Because duty hours are not regulated, and rest periods are related to flight hours, nothing in the regulations constrains the duty/rest cycle to a 24 hr period, as is typical in other shiftwork situations. The FARs mandate at least one 24 h period without duty in seven consecutive days. The only other restriction on the structuring of successive duty-rest periods is that a pilot may not fly more than 30 hrs in 7 consecutive days, 100 hrs in any calendar month, and 1000 hrs in a year.

Third, the amount of time off between a series of working days is much more flexible in domestic commercial flight operations, including overnight cargo operations. In general, each month crew members bid for trips which are awarded on the basis of seniority. Companies differ in the extent to which they will allow subsequent trading of trips. Many creative solutions are possible within this framework, still respecting the weekly, monthly, and annual flight time limitations. In practise, the FARs serve only as limits within which each company decides its actual scheduling policies by negotiation between management and pilots. Competition has the effect of pushing actual schedules closer to the regulated limits.

2.6 FIELD STUDIES OF FLIGHT OPERATIONS

The present study is one of a series of NASA field studies aimed at documenting the effects of different types of flight operations on fatigue, sleep, and circadian rhythms (refs 21-28). In all of these field studies, the same core set of physiological and subjective measurements was combined with detailed recordings of operational events. It is therefore possible to provide an initial comparison of the psychophysiological effects of predominantly night flying (commercial overnight cargo operations) versus predominantly daytime flying (commercial short-haul air transport operations). This comparison is of interest because both types of operations are governed by the same FARs, which do not take the time of day of flying into account. They are also similar in that each duty period contains several relatively short flight segments with considerable time spent on the ground in between segments. Thus the discrepancy between flight hours and duty hours is often large. In addition, time zone changes are minimal (a maximum of 1 hr per day for both types of operations).

2.7 ACKNOWLEDGEMENTS

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3. METHODS

3.1 SUBJECT RECRUITMENT

After the proposed study had been approved by airline management and pilot representatives, a letter and brochure explaining the study and calling for volunteers were distributed at the domicile. As in most airlines, pilots bid for monthly trip schedules which were then awarded on the basis of seniority. When NASA received copies of the monthly schedules sufficiently in advance, the trips selected for study were annotated so that crew members knew on which trips their participation would be solicited, before they decided which trips to bid. This may have introduced a bias in the sample of crew members studied. The aircraft flown were B-727s, and trips were studied only when at least two of the three flight crew members were willing to participate. The only incentives offered for participation were the possibility to review one's own physiological data, a NASA Ames Research Center Certificate of Appreciation, and a letter of recognition. The refusal rate (15%) was comparable to that in a similar previous study of flight crews in daytime short-haul air transport operations (23). Confidentiality of each subject's data was assured as in other NASA field studies (23).

3.2 TRIP PATTERNS STUDIED

The basic pattern of overnight cargo operations involves flights into and out of a hub, where pilots wait while the incoming cargo is unloaded, sorted according to its final destination, and the new cargo is loaded for delivery to the destinations of the following outward flight segments. From discussions with pilots and flight operations personnel in the participating company, the three most common types of trip patterns were identified. Informal surveys of pilots in four other overnight cargo companies indicated that these patterns are widespread throughout the industry. The first, designated "Destination-Layover" (Figure 1), began from the domicile with several flight segments arriving finally at the hub. The following outward segments from the hub ended at a third location, where the crew then had a rest period (the "destination layover"). This pattern of flying between the hub and a destination layover might be repeated several times before the crew finally returned to their domicile. In the second common trip pattern, designated "Out-and-Back" (Figure 2), crews usually returned for each rest period to their domicile. In the third category of common trip pattern, designated "Evening-Out-and-Back", duty periods began and ended earlier (around midnight) than for the usual Out-and-Back trips. They were therefore considered less challenging, in terms of their potential to disrupt sleep and circadian rhythms. Since they also represented a smaller proportion of the total flight schedules than the other two categories, they were not examined in the present study. Forty-one flight crew members (39 males, 2 females) from one company took part in the study. Of these, 23 were monitored before, during, and after the Destination-Layover pattern and 18 were monitored before, during, and after the Out-and-Back pattern. About half the trips studied took place during Daylight Savings Time, and half during Standard Time. All data were recorded on Greenwich Mean Time (GMT).

3.3 DATA COLLECTED

Subjects were monitored for a maximum of 3 days before the trip, throughout the trip (8 days), and for up to 4 days after the trip. They were accompanied during all flights by a NASA cockpit observer who held at least a private pilot's license and was familiar with air transport operations. The observers instructed subjects in the use of equipment and kept a log of operationally significant events for each trip segment flown.

Throughout his/her participation in the study, each subject wore a Vitalog PMS-8 biomedical monitor (Vitalog Monitoring Inc., Redwood City, CA) which recorded rectal temperature, average heart rate, and average activity of the non-dominant wrist every 2 minutes around the clock. To estimate the effects of duty demands on the circadian timing system, the temperature data were examined in two different ways. First, the temperature data for individual crew members were averaged in 20 min bins and then subjected to multiple complex demodulation (29). Second, a constant (0.28°C) was added to the raw temperature data for each subject whenever he was alseep. This mathematical "unmasking" procedure was based on the reported 0.28 °C difference between the temperature rhythm during sleep and wake in internally desynchronized subjects (30). The "unmasked" data for each subject were then averaged in 20min bins and subjected to multiple complex demodulation, as before. (See Appendix I for a more detailed description of the unmasking technique). For both masked and unmasked data, the cycle-by-cycle temperature minimum was taken as the computer-selected lowest value within 12 h in the remodulated waveform. In a few instances, this procedure identified two minima in 24 hours. When this occurred, the raw data and multiple complex demodulated waveform were superimposed on the sleep and nap times and, if there was no clear way of discriminating between the minima (circadian or masking), the data for that cycle were discarded. Missing data points in the raw data were replaced by linear interpolation, and all fitted waveforms were overlayed with the original data to check that the interpolations did not introduce spurious estimates of the minima.

Subjects also kept a daily log of sleep and nap timing, showers or baths, exercise, duty times, food, caffeine, and alcohol consumption, bowel movements, urinations, cigarettes, medications and medical symptoms. The logbook provided space for recording up to two sleeps and two naps per 24 hr. Although the durations of short sleeps and long naps may overlap, we have retained the designations given by the subjects in all the analyses. The quality of each subject-designated sleep episode was rated from 1-5 on the following four questions: difficulty falling asleep?; how deep was your sleep?; difficulty rising?; how rested do you feel?. Ratings were converted so that higher values indicated better sleep, and added to give an overall sleep rating. Every 2 hr during the waking day, subjects completed a 26-adjective mood checklist, and estimated their fatigue by placing a mark on a 10-cm line signifying a continuum from most alert to most drowsy. They also completed a Background

Questionnaire compiled to obtain information on demographic and lifestyle variables, sleep and nutritional habits, and personality profiles. These measures are described in detail in reference 23.

Every 3-4 days, the cockpit observers offered each subject the opportunity to examine his/her own physiological data (during the downloading of this data onto computer diskettes), and to compare this data with his/her logbook entries. This feedback was intended to help maintain compliance with protocol requirements and to improve the accuracy of logbook recordings.

3.4 DATA MANAGEMENT

Background Questionnaire, daily log and observer log data were coded and entered into a specially modified Relational Information (RIM) database on a VAX 11/750 computer. The Vitalog data were initially read out to an Apple II Plus computer and stored on diskettes. The original binary files were converted to text files and transferred to the VAX. After editing, the physiological data were entered into the same database as the questionnaire, daily log, and observer log data.

4. RESULTS

4.1 TRIP STATISTICS

Both trip patterns studied included a rest day at home interrupting a series of nights of flying in a duty pattern lasting 8 days in total. In the Destination-Layover pattern (Figure 1), crews deadheaded home (flew as passengers, but were on duty) after 3 nights of flying, and had about 45 hr off duty before deadheading from their domicile to begin another 3 nights of flying. In the Out-and-Back pattern (Figure 2), crews arrived home after 5 nights of flying, then had about 45 hr off duty before beginning another 2 nights of flying. The 8 trip days were therefore subdivided into duty and no-duty days in the analyses.

To be included in the analyses, crew members had to have provided at least one night of pretrip sleep data and two nights of posttrip sleep data. Twenty subjects (87%) on the Destination-Layover pattern and 14 subjects (78%) on the Out-and-Back pattern met these criteria. The duty variables for the trips flown by these subjects were compared by 2-group t-tests (Table 1).

TABLE 2: COMPARISON OF THE DUTY CHARACTERISTICS FOR THE TWO TRIP PATTERNS

	Mean (S.D.) Destination-Layover	Mean (S.D.) Out-and-Back	t
On-duty time (hr)	3.29 (4.34)	6.71 (2.23)	7.83***
Off-duty time (hr)	11.86 (3.42)	11.83 (1.99)	0.09
Duty duration (hr)	8.57 (3.96)	5.11 (1.96)	8.72***
†Layover duration (hr)	12.36 (2.34)	18.49 (2.13)	17.03***
Home day duration (hr)	44.82 (1.90)	45.13 (2.99)	0.29
# Segments/night	3.65 (1.16)	1.84 (0.60)	10.64***
Segment duration (hr)	0.80 (0.41)	1.13 (0.35)	9.18***
Flight hrs/24 hr	2.93 (1.04)	2.07 (0.72)	7.17***
# Segments/trip	21.90 (2.23)	12.63 (0.92)	10.98***
# of hub turns	4	1	
	n=20	n=14	

†Layovers between successive nights of flying. Does not include the "no-duty" day.
***p<0.001
number of

Crew members flying the Destination-Layover pattern went on duty about 3.4 hr earlier, and consequently had duty days about 3.5 hr longer than did crew members flying the Out-and-Back pattern. The Destination-Layover pattern averaged double the number of flight segments, and 52 min more flight time per night. Layovers between duty nights were also more than 6 hr shorter on the Destination-Layover pattern. Destination-Layover crews flew in and out of the hub four times during the eight day pattern, whereas Out-and-Back crews had only one hub turn.

4.2 PILOT STATISTICS

The characteristics of the crew members on the two trip patterns were compared by 2-group t-tests (Table 3). These data are from the Backgound Questionnaires. There were no significant ($p<0.05$) differences.

TABLE 3: COMPARISON OF THE SUBJECT POPULATIONS FOR THE TWO TRIP PATTERNS

	Mean (S.D.) Destination-Layover	Mean (S.D.) Out-and-Back	t
age (yrs)	37.8 (4.8)	37.4 (4.9)	0.19
experience (yrs)	12.8 (4.4)	12.8 (3.3)	0.01
height (inches)	70.0 (3.0)	70.5 (2.6)	0.50
weight (lbs)	181.2 (27.8)	174.4 (29.5)	0.68
Eysenck Personality Inventory			
neuroticism	4.5 (4.2)	5.2 (3.7)	0.51
extraversion	11.2 (4.0)	10.7 (3.9)	0.35
lie	3.6 (1.7)	3.5 (2.4)	0.15
Morning/Eveningness Questionnaire			
	55.0 (6.9)	53.7 (9.3)	0.45
Personal Attributes Questionnaire			
instrumentality	25.3 (3.8)	23.4 (4.1)	1.43
expressivity	23.5 (3.8)	22.2 (4.0)	0.92
i+e	3.3 (0.9)	3.0 (1.1)	0.86
Work and Family Orientation			
mastery	21.5 (3.9)	21.0 (3.3)	0.41
competitiveness	13.4 (4.4)	12.9 (3.8)	0.34
work	18.5 (1.3)	17.9 (2.0)	1.13

The number of years of experience was taken as the largest value from among the following categories: years with the present airline; years of military experience; years of airline experience; years of general aviation experience; other. The Destination-Layover crew members had been with the participating airline slightly longer on average (5.1 yr) than had the Out-and-Back crew members (4.3 yr).

4.3 EFFECTS OF TRIPS ON PHYSIOLOGICAL AND PSYCHOLOGICAL VARIABLES

4.3.1 Sleep

Being on duty at night obliged subjects to displace their sleep to the daytime hours. As a first comparison, the characteristics of individual daytime sleep episodes were compared with nightime sleep episodes on pretrip, no-duty and posttrip days (Table 4). For each subject, mean heart rate, temperature, and activity levels during each sleep episode were calculated from 20 minutes after the reported sleep onset time until 10 min before the reported wakeup time. This trimming minimized contamination of the estimates of mean heart rate, temperature, and activity levels during sleep by the comparatively high values which occur immediately before and after sleep (23). Variability in heart rate and activity during sleep was estimated as the standard deviation of the raw scores for each sleep episode for each subject. Sleep ratings in Table 4 have been converted so that higher values indicate better sleep.

TABLE 4: COMPARISONS OF SLEEP MEASURES BEFORE, DURING, AND AFTER TRIPS

	Pretrip	Duty	No-Duty	Post	p(F)
Sleep onset (GMT)	5.05	10.22	5.19	5.06	92.90***
Wakeup (GMT)	12.71	14.79	13.33	12.44	15.74***
Sleep latency (min)	14.11	17.81	25.04	21.89	1.99
Sleep duration (hr)	7.46	4.56	8.09	7.21	40.90***
Total sleep/ 24 hr	7.54	6.31	8.23	7.65	10.62***
Difficulty falling asleep?	4.21	4.12	4.23	4.04	0.35
How deep was your sleep?	3.65	3.39	4.06	3.76	5.54**
Difficulty rising?	3.48	3.31	3.38	3.69	1.60
How rested do you feel?	3.27	2.66	3.28	3.40	5.40**
Sleep rating	14.60	13.43	14.97	14.88	3.84*
# awakenings	1.68	0.81	1.15	1.13	10.98***
Mean heart rate (beats/min)	62.78	63.23	60.98	61.56	1.18
S.D. heart rate	6.89	6.55	6.41	6.88	0.55
Mean activity (counts/min)	2.77	2.62	1.31	1.70	1.19
S.D. activity	7.06	6.11	5.18	6.31	0.81
Mean temperature (°C)	36.74	36.81	36.66	36.72	3.92*
S.D. temperature	0.12	0.11	0.14	0.14	1.75

p(F) from 1-way ANOVAs (Table 5)
* 0.05>p>0.01, **0.01>p>0.001, ***p<0.001

To test if sleep differed significantly among pretrip, duty, no-duty and posttrip days, 1-way ANOVAs were performed, with subjects treated as a random variable. These analyses are summarized in Table 5, and are the source of the significance levels indicated in Table 4. Where the ANOVA revealed significant pretrip/duty/no-duty/posttrip differences, the values for pretrip, duty, no-duty, and posttrip sleeps were intercompared by posthoc t-tests. As expected, sleep episodes occurred significantly later on duty days than on pretrip days (for sleep onset, $t=-12.93$, $p<0.0001$; for wakeup, $t=-4.37$, $p<0.0001$), or on the no-duty day (for sleep onset, $t=11.45$ $p<0.0001$; for wakeup, $t=2.87$, $0.01>p>0.001$), or on posttrip days (for sleep onset, $t=12.39$, $p<0.0001$; for wakeup, $t=4.99$, $p<0.0001$). These differences in sleep timing are emphasized in the distributions in Figures 3 and 4.

TABLE 5: CHARACTERISTICS OF INDIVIDUAL SLEEP EPISODES BEFORE, DURING, AND AFTER TRIPS.

	F (pre/Duty/No-Duty/Post
Sleep onset (GMT)	92.90***
Wakeup (GMT)	15.74***
Sleep latency (min)	1.99
Sleep duration (hr)	40.90***
Total sleep/ 24 hr	10.62***
Difficulty falling asleep?	0.35
How deep was your sleep?	5.54**
Difficulty rising?	1.60
How rested do you feel?	5.40**
Sleep rating	3.84*
# awakenings	10.98***
Mean heart rate (beats/min)	1.81
S.D. heart rate	0.56
Mean activity (counts/min)	1.19
S.D. activity	0.81
Mean temperature (^{o}C)	3.92*
S.D. temperature	1.75

*0.05>p(F)>0.01, **0.01>p(F)>0.001, ***p(F)>0.001

Individual sleep episodes on duty days were significantly shorter than sleep episodes pretrip (t=10.17, p<0.0001), or on the no-duty day (t=-10.76, p<0.0001), or on posttrip days (t=-8.77, p<0.0001). The total sleep per 24 hr was significantly shorter on duty days than on pretrip days (t=4.22, p<0.0001), or on the no-duty day (t=-5.65, p<0.0001), or on posttrip days (t=-5.09, p<0.0001). Sleeps on duty days were rated as less deep than sleeps on the no-duty day (t=-3.80, 0.001>p>0.0001), or on posttrip days (t=-2.06, p<0.05). Pretrip sleeps were also rated as less deep than sleeps on the no-duty day (t=-2.11, 0.05>p>0.01). Subjects reported feeling less rested after sleeps on duty days than after pretrip sleeps (t=3.20, 0.01>p>0.001), or after sleeps on the no-duty day (t=-3.02, 0.01>p>0.001) or after posttrip sleeps (t=-4.16, p<0.0001). Overall, sleeps on duty days were rated as significantly worse than those either pretrip (t=2.57, 0.05>p>0.01), or on the no-duty day (t-2.55, 0.05>p>0.01) or posttrip (t=-2.73, 0.01>p>0.001). Subjects reported significantly more awakenings during pretrip sleep episodes than for either duty sleeps (t=6.63, p<0.0001), or no-duty sleeps (t=2.61, 0.05>p>0.01), or posttrip sleeps (t=3.13, 0.01>p>0.001). They also reported fewer awakenings during duty sleeps than during posttrip sleeps (t=-2.25, 0.05>p>0.01). However, sleep episodes on trip days were about 40% (3 hr) shorter than sleep episodes at other times (i.e., combining pretrip, no-duty and posttrip). If the number of awakenings per hour of sleep is considered, the difference between trip sleeps and posttrip sleeps disappears. The average numbers of awakenings per hour of sleep were: 0.23 for pretrip sleeps; 0.18 for trip sleeps, 0.14 for sleeps on the no-duty day; and 0.17 for posttrip sleeps. The average temperature during sleep was higher for duty sleeps than for no-duty sleeps (t=2.26, 0.05>p>0.01).

While individual daytime sleep episodes were 3.1 hr shorter than average nighttime sleep episodes (combining pretrip, no-duty, and posttrip days), the total sleep per 24 hr on duty days averaged only 1.2 hr less than on pretrip days without duty (combining pretrip, no-duty, and posttrip days; see Table 4). This was because, on average, 53% of subjects reported multiple sleeps or naps on days containing duty, whereas only 17% reported multiple sleeps or naps on days without duty (Figure 5). However, the incidence of multiple sleeps or naps per 24 h varied markedly among duty days, and between the two trip patterns. This observation prompted further analyses of the relationships between duty factors and sleep patterns during layovers. Only layovers between consecutive nights of flying were considered. Within these layovers, only subject-designated sleep episodes were considered, since subject-designated naps accounted for only 2.6% of the total sleep time on the Destination-Layover pattern, and 3.5% on the Out-and-Back pattern.

Examination of individual sleep/wake records revealed three basic patterns of sleep on the days between night duties. Subjects either: a) slept twice in the layover; or b) slept once, going to sleep in the morning; or c) slept once in the evening. The frequency of occurrence of these different sleep patterns is summarized in Table 6. On the Destination-Layover trip pattern, crew members normally slept only once in the morning (96% of all layovers). In contrast, on the Out-and Back pattern, they were frequently able to sleep a second time (58% of all layovers) before going back on duty in the evening.

TABLE 6. BASIC SLEEP PATTERNS DURING DAYTIME LAYOVERS

	% of Destination-Layover Layovers	% of Out-and-Back Layovers
Two sleeps per layover	4	58
One morning sleep	96	37
One evening sleep	-	5
	n=84 layovers	n=78 layovers

One way ANOVAs were performed to test whether the timing and duration of the sleep episodes in these categories differed significantly among the categories, or between the two trip patterns (Table 7).

TABLE 7: COMPARISON OF DIFFERENT CATEGORIES OF SLEEP EPISODES ON THE TWO TRIP PATTERNS

	Destination-Layover				Out-and-Back				
	1st of 2	2nd of 2	AM Single	PM Single	1st of 2	2nd of 2	AM Single	PM Single	F
Asleep (GMT)	11.86	9.33	13.69	-	14.23	3.32	12.60	2.27	299.09***
Wakeup (GMT)	16.94	11.78	19.21	-	18.44	6.58	18.51	6.21	333.77***
Sleep duration (hrs)	4.91	2.33	5.44	-	4.30	3.29	5.79	4.02	14.06***

***p<0.001

Posthoc Tukey tests with Bonferroni correction were used to compare each sleep category with every other category. Rather than describing all the comparisons, the following discussion is restricted to comparisons among the major categories (excluding paired sleeps on the Destination-Layover pattern and late single sleeps on the Out-and-Back pattern - see Table 6). The major sleep categories are summarized in Figure 6. Early single sleeps on the two patterns were indistinguishable in timing and duration. They were significantly longer than either of the sleeps of a pair. On the Out-and-Back pattern, single early sleeps also began earlier than first sleeps of a pair. Wakeup times were indistinguishable for early single sleeps and first sleeps of a pair on both trip patterns, i.e., when crew members went to sleep in the morning, they tended to wake up around the same time (combined average, 18.72 hr GMT).

To test whether the timing and duration of the layover had a consistent effect on the way crew members organized their sleep, 1-way ANOVAs were performed comparing layovers containing two sleeps with layovers containing one early sleep or one late sleep (Table 8).

TABLE 8: COMPARISON OF LAYOVERS CONTAINING ONE SLEEP VERSUS TWO SLEEPS

	Destination-Layover			Out-and-Back			
	Two Sleeps	Early Single	Late Single	Two Sleeps	Early Single	Late Single	F
Off-duty (GMT)	10.77	11.92	_____	12.49	10.97	12.76	14.11***
On-duty (GMT)	5.76	0.78	_____	7.97	3.75	7.64	377.13***
Layover duration (hrs)	18.99	12.86	_____	19.48	16.78	18.88	164.07***

***p<0.001

Posthoc Tukey tests with Bonferroni correction were used to compare each layover category with every other category. As before, only the comparisons among the major categories are discussed here. Layovers containing one early sleep on both trip patterns began earlier, finished earlier, and were shorter than layovers containing two sleep episodes. Destination-Layover layovers containing one early sleep (92% of all layovers between consecutive nights of flying on this pattern) were shorter than all other categories of layovers. These analyses indicate that the decision to sleep once or twice in a layover is largely determined by the timing and duration of the layover.

To test whether sleep durations were comparable on the two trip patterns, the total sleep (including naps) for each 24 hr period for each subject was converted to a z score (compared to the mean for all 24 hr periods for all subjects). A 2-way ANOVA was then performed (Table 9) comparing the two trip patterns for pretrip, duty, no-duty and posttrip days. The two trip patterns did not differ significantly in the amount of sleep subjects were able to obtain per 24 hr, either on days with duty, or on days without duty. For both trip patterns, crew members slept significantly less on duty days.

TABLE 8: TOTAL SLEEP/24 hr ON THE DESTINATION-LAYOVER VERSUS THE OUT-AND-BACK PATTERN

	F Trip Pattern	F Pre/Duty/No-duty/Post	F Interaction
Total daily sleep	0.47	17.43****	1.95

****$p<0.0001$

For each subject, his total sleep per 24 h (including naps) was subtracted from his mean total baseline sleep per 24 h (including naps), giving a daily measure of sleep loss (Figure 7). As expected, from Table 9, the total cummulative sleep loss by the end of the two trip patterns (compared to pretrip baseline) was not significantly different (9.8 hr for the Destination-Layover pattern, 9.9 hr for the Out-and-Back pattern; 2-group t-test on the z scores calculated with respect to the combined mean, $t=-0.49$, $p=0.62$).

4.3.2 Sleep Loss and Individual Attributes

For each subject, his daily sleep loss was expressed as a percentage of his total baseline sleep per 24 h, and then his average daily percentage sleep loss was calculated for all trip days. Average daily percentage sleep loss on duty days has previously been shown to increase with age among long-haul flight crew members (31). In the present study, correlation analyses were performed to see if this measure was related to any of the individual attributes reported to predict adaptation to shiftwork in other industries (see Introduction). The amplitude of the temperature rhythm was calculated as the difference between the minimum and maximum of the multiple complex demodulated waveform fitted to the pretrip baseline temperature data (see Methods). The correlations in Table 10 include data from the 25 crew members who gave at least one cycle of baseline data. None of these relationships was significant at the 0.05 level.

TABLE 10: INDIVIDUAL DIFFERENCES IN MEAN DAILY PERCENTAGE SLEEP LOSS

	correlation coefficient
temperature amplitude (masked)	-0.00
temperature amplitude (unmasked)	-0.16
neuroticism	-0.04
extraversion	0.08
morning/eveningness	0.27

4.3.3 Circadian Phase

The average times of the daily temperature minima for crew members on the Destination/Layover pattern are shown in Figure 8a (n=10, i.e. 44% of subjects), and for crew members on the Out-and-Back pattern in Figure 8b (n=4, i.e., 22% of subjects). In general, the effect of flying at night was to move the subsequent temperature minimum several hours later, with the exception of the second trip day on the Out-and-Back pattern (Figure 8 b). For both patterns, on the no-duty day (trip day 4 for Destination-Layover crews, trip day 6 for Out-and-Back crews) the time of the temperature minimum returned towards its earlier pretrip position.

To test whether the unmasking technique (adding 0.28^{o}C to the raw temperature data for each subject whenever he was alseep) altered the estimated times of the temperature minima, a 2-way within subjects ANOVA was performed for each trip pattern (Table 11). This compared masked and unmasked minima estimates across the days of the study.

TABLE 11: MASKED VERSUS UNMASKED ESTIMATES OF THE CYCLE-BY-CYCLE TEMPERATURE MINIMA

	F Days	F Masked/Unmasked	F Interaction
Destination-Layover	7.98***	1.57	3.90***
Out-and-Back	2.23*	0.08	1.41

* 0.05>p>0.01, ***p<0.001

Overall, the masked and unmasked estimates of the timing of the daily temperature minima were not significantly different. However, the significant interaction for the Destination-Layover pattern suggests that the masked and unmasked estimates did not change in a similar way across the days of the study. Significant differences (post-hoc t-tests) between the masked and unmasked estimates on a given day are indicated by asterisks in Figure 8a. In general, when subjects flew at night, the masked estimate of the time of the temperature minimum was later than the unmasked estimate. Conversely, when they slept at night, the masked estimate was earlier than the unmasked estimate. This pattern was not seen in the Out-and-Back data (Figure 8b). However, it may have been obscured by the small sample size (n=4). A significant progressive adaptation of the temperature rhythm across successive nights of flying was not observed in either trip pattern. Therefore, the data were grouped into pretrip, duty, no-duty, and posttrip days.

To test whether the timing of the daily temperature minimum was affected differently by the two trip patterns, for both masked and unmasked estimates a 2-way ANOVA was performed comparing the trip patterns across pretrip, duty, no-duty, and posttrip days (Table 12). Two additional subjects from each trip pattern were included in these analyses (for a total of 12 subjects (52%) on the Destination-Layover pattern, and 6 subjects (33%) on the Out-and-Back pattern). Each of these subjects had one trip day on which it was not possible to identify a clear temperature minimum, and they were therefore not included in Figure 8 and in the analyses in Table 11.

TABLE 12: COMPARISON OF THE TWO TRIP PATTERNS FOR PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS (2-WAY ANOVA)

	F Trip Type	F Pre/Duty/No-duty-Post	F Interaction
Masked	1.03	30.34***	0.49
Unmasked	1.36	11.29***	0.36

***p<0.001

These analyses suggest that, overall, the two trip patterns did not have different effects on the timing of the daily temperature minimum. However, for both masked and unmasked estimates, the timing of the temperature minimum varied significantly across pretrip, duty, no-duty, and posttrip days. These differences were further evaluated by post hoc t-tests. The significant differences are summarized in Table 13.

TABLE 13: SIGNIFICANT POST HOC T-TESTS FOR THE ANOVAS IN TABLE 11

	t Duty vs Pretrip	t Duty vs No-Duty	t Duty vs Posttrip
Masked	-6.23****	4.91****	4.77****
Unmasked	-4.53****	2.89**	3.28**

**0.01>p>0.001, ****p<0.0001

For both masked and unmasked estimates, the temperature minimum occurred later on duty days than at any other time (Figure 9). For both types of estimates, the timing of the temperature minimum was not significantly different among pretrip, no-duty, and post-trip days. The average times of the daily temperature minima across pretrip, duty, no-duty, and posttrip days are summarized in Table 14.

TABLE 14: MEAN TIMES (GMT) OF THE DAILY TEMPERATURE MINIMUM

	Pretrip	Duty	No-Duty	Post
masked	9.56	13.06	10.07	9.94
unmasked	9.83	12.63	10.63	10.55

The masked estimates suggest that the temperature minimum delayed 3.5 hrs on duty days by comparison with pretrip, while the unmasked estimates suggest that the delay was 2.8 hrs. However, these two measurements of the shift in the temperature minimum were not significantly different (paired t-test, t=-0.62, p=0.54).

4.3.4 Subjective Fatigue and Mood

Every 2 hr while they were awake, subjects rated their fatigue level on a 10 cm line from "drowsy" to "alert". They also rated their current mood from 1 (not at all) to 4 (extremely) on 26 adjectives that have been shown to load on three orthogonal factors, designated positive affect, negative affect and activation (23). There are three issues that complicate the analysis of these fatigue and mood data. First, in other NASA field studies, these measures have been found to differ significantly between individuals and to exhibit marked time-of-day variation (23,27). In the present study, when they were on-duty, crew members gave ratings during the night, and slept during the day. Conversely, when they were off duty (pretrip, the no-duty day, and posttrip) they gave ratings during the day and slept at night. Thus, the data sample different times of day. Second, the temperature data suggest that the circadian clock shifted about 3 hr when crew members were flying at night, by comparison with pretrip. Even with this shift, ratings made during different stages of the study (pretrip, duty, no-duty, posttrip) sampled different parts of the circadian cycle. Third, most subjects did not provide complete data for the times that they were awake.

To obtain a first indication as to whether duty demands altered the time-of-day variation in fatigue and mood, pretrip, duty, no-duty and posttrip data were analyzed separately by 1-way ANOVA (time-of-day) with subjects treated as a random variable (Table 15 and Figure 10). Only 2 subjects provided data for 20 h per day across pretrip, duty, no-duty, and posttrip days. Only 4 subjects provided data for 16 h per day across pretrip, duty, no-duty, and posttrip days. Thus, for the analyses in Table 15, each subject included for each study stage provided data for all (4 hr) time bins, but different groups of subjects, and times of day, were included in the analysis for each study stage. The numbers in parentheses indicate the number of subjects included in each analysis.

TABLE 15: TIME-OF-DAY VARIATIONS IN FATIGUE AND MOOD RATINGS ACROSS PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS

	Pretrip F (n)	Duty F (n)	No-duty F (n)	Posttrip F (n)
Fatigue	7.57(11)***	13.01(36)***	2.05(6)	6.97(8)***
Positive affect	1.54(12)	11.46(37)***	1.22(8)	3.15(8)*
Negative affect	1.62(12)	19.57(37)***	3.25(8)*	5.36(8)**
Activation	7.90(12)***	12.28(37)***	2.26(8)	4.80(8)**

*0.05>p>0.01, **0.01>p>0.001,***p<0.001

On pretrip and posttrip days, fatigue was rated highest at 0700 GMT (about 01:30 local time) and lowest at 1900 GMT (about 13:30 local time). This replicates the pretrip pattern seen in helicopter pilots (27). When they were on duty, overnight cargo crew members reported feeling most fatigued at 1500 GMT (about 09:30 local time). Conversely, they felt least fatigued at 2300 GMT (about 17:30 local time). Because of the reduction of the data into 4 hr time bins, it is impossible to establish with precision the amount of shift in the fatigue rhythm from pretrip to trip days.

Positive affect did not show a significant time-of-day variation pretrip, which is consistent with comparable data from helicopter and short-haul fixed-wing pilots (23,27). On duty days, it was lowest in the early hours of the morning (0700 to 1500 GMT, about 01:30 to 09:30 local time) and highest at 2300 GMT (about 17:30 local time), i.e., when fatigue was lowest. Negative affect did not show a significant time-of-day variation pretrip, in contrast to other studies (23,27). On duty days, it was highest when fatigue was highest (1500 GMT) and lowest when fatigue was lowest (2300 GMT). Activation showed a pattern of variation which was the mirror image of fatigue, as in other studies (23,27). The timing of the pretrip maxima at 1900 GMT (about 13:30 local time) and minima at 0700 GMT (01:30 local time) replicates that seen in other studies (27).

To examine the combined effects of duty demands and the reversed activity-rest schedule on subjective fatigue and mood, 1-way ANOVAs were performed, with subjects treated as a random variable (Table 16). Ratings made pretrip during daytime wakefulness (1400-2200 h GMT) were compared with ratings made while on duty at night (0600-1200 h GMT). Thirty-six subjects provided sufficient data to be included in these analyses. During duty nights, fatigue and negative affect were higher, and positive affect and activation were lower, than during pretrip days.

TABLE 16. FATIGUE AND MOOD DURING DAYTIME VERSUS NIGHTTIME WAKE

	Pretrip Mean	Duty Mean	F
Fatigue	33.46	51.05	53.28***
Positive affect	2.35	1.98	30.65***
Negative Affect	0.49	0.68	13.26***
Activation	2.34	1.85	49.13***

***p<0.001

4.3.5 Caffeine Consumption

Although there were no cabin crew, every flight was provided with a large cooler of drinks (bottled water, fruit juices, soda, etc) and crews often collected a thermos of coffee from operations. Coffee and snack foods were available at most en route airports, and a full cafeteria service was available at the hub. Some crew members, particularly on the Out-and-Back pattern, brought their own food and beverages on duty with them. The number of cups of caffeinated beverages, and the time of day at which caffeine was consumed, were recorded in the daily logbook. All of the 34 subjects included in the sleep analyses consumed caffeine at some time during the study. To test whether caffeine consumption was different across pretrip, duty, no-duty, and posttrip days, a 1-way ANOVA was performed, with subjects treated as a random variable. No significant difference was found in consumption across the study period. Caffeine consumption was highest on duty days (average 2.4 cups per day), however this was not significantly different from consumption on the non-duty day (2.21), pretrip (2.06) or posttrip (1.75).

4.3.6 Meals and Snacks

The time of eating and the general content of meals (breakfast, lunch, dinner) and snacks was recorded in the daily logbook. To test whether consumption of meals and snacks was different across pretrip, duty, no-duty, and posttrip days, 1-way ANOVAs were performed, with subjects treated as a random variable (Table 17).

TABLE 17: CONSUMPTION OF MEALS AND SNACKS ON PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS

	F
Meals	9.02***
Snacks	10.17***

***p<0.001

Subjects reported fewer meals per day posttrip (mean=2.01) than either pretrip (mean=2.67, t=3.67, 0.001>p>0.0001), or on duty days (mean=2.48, t=2.22, 0.05>p>0.01), or on the no-duty day (mean=2.76, t=3.34, 0.01>p>0.001). More snacks were reported during duty days (mean 1.36 per day) than either pretrip (mean=0.78, t=-3.46, p=0.001), or on the no-duty day (mean=0.94, t=2.03, 0.05>p>0.01), or posttrip (mean=0.61, t=4.68, p<0.0001). The low consumption of caffeine, meals, and snacks reported posttrip probably reflects incomplete reporting posttrip.

4.3.7 Medical Symptoms

Subjects also noted when they experienced medical symptoms which were classified into 20 categories (23). Twenty-eight of the 34 subjects included in the sleep analyses (82%) reported symptoms at some time during the study. The three most common symptoms were: headaches (42% of all reports, reported by 59% of subjects at some time during the study), congested nose (19% of all reports, reported by 26% of subjects at some time during the study), and burning eyes (9% of all reports, reported by 18% of subjects at some time during the study). The percentage of these reports which occurred on pretrip, trip, and posttrip days is shown in Table 18.

TABLE 18: REPORTS OF COMMON MEDICAL SYMPTOMS ON PRETRIP, DUTY, NO-DUTY, AND POSTTRIP DAYS

Symptom	% Pretrip	% Duty	% No-duty	% Posttrip
Headache	16.67	72.2	1.9	9.3
Congested nose	16.0	32.0	8.0	44.0
Burning eyes	8.3	75.0	16.7	0.0

The incidence of headaches quadrupled on duty days, by comparison with pretrip, while the incidence of congested nose doubled, and of burning eyes increased ninefold.

4.4 COMPARISON WITH DAYTIME SHORTHAUL FIXED-WING OPERATIONS

4.4.1 Comparison of the Duty Demands

Table 19 compares (2-group t-tests) the average duty characteristics of the overnight cargo trips studied with those of the daytime short-haul trips flown by the 44 subjects included in the sleep analyses in reference 23.

TABLE 19: COMPARISON OF DUTY CHARACTERISTICS, OVERNIGHT CARGO VERSUS DAYTIME SHORTHAUL TRIPS.

	Mean (S.D.) Overnight Cargo	Mean (S.D.) Short-Haul	t
local time on duty (hr)	23.71 (3.53)	8.73 (2.96)	27.11***
local time off-duty (hr)	6.87 (3.01)	19.37 (2.94)	40.54***
daily duty duration (hr)	7.14 (3.69)	10.64 (2.19)	11.67***
layover duration (hr)	14.87 (3.79)	12.52 (2.52)	6.31***
flight hours/day	2.55 (1.00)	4.50 (1.39)	14.93***
flight segments/day	2.78 (1.30)	5.12 (1.34)	14.34***
flight segment duration	0.90 (0.42)	1.07 (0.47)	7.26***

***$p<0.001$

The information for Table 19 came from the daily logbooks kept by the crew members and from the cockpit observer logs. As expected, the timing of the duty periods was inverted between the two types of operations. The overnight cargo crew members had duty "days" about 3.5 hr shorter and layovers about 2.4 hr longer than did the short-haul crew members. The overnight cargo duty periods averaged 2.0 hr less flight time, with fewer (2.3), shorter (by 10 min) flight segments.

4.4.2 Comparison of the Subject Populations

Demographic and personality measures for the crew members included in the overnight cargo and daytime short-haul analyses are compared by 2-group t-tests in Table 20. This information came from the Background Questionnaires.

TABLE 20: COMPARISON OF PILOT CHARACTERISTICS, OVERNIGHT CARGO VERSUS DAYTIME SHORTHAUL STUDIES.

	Overnight Cargo Mean (S.D.)	Short-Haul Mean (S.D.)	t
age (yrs)	37.62 (4.76)	43.02 (7.65)	3.82***
experience (yrs)	12.79 (4.35)	17.07 (6.56)	3.57***
present airline (yrs)	4.74 (4.17)	14.41 (8.49)	6.60***
height (inches)	70.21 (2.82)	70.59 (1.86)	0.73
weight (lbs)	178.40 (28.29)	174.84 (16.84)	0.69
Eysenck Personality Inventory			
neuroticism	4.79 (3.98)	6.58 (4.51)	1.82
extraversion	11.00 (3.89)	10.91 (3.46)	0.11
lie	3.56 (1.94)	3.41 (1.92)	0.34
Morning/Eveningness Questionnaire			
	54.44 (7.86)	57.64 (8.67)	1.68
Personal Attributes Questionnaire			
instrumentality	24.50 (3.96)	23.27 (3.94)	1.36
expressivity	22.94 (3.85)	22.34 (4.40)	0.63
i+e	3.18 (0.99)	2.84 (1.01)	1.46
Work and Family Orientation			
mastery	21.30 (3.64)	19.95 (4.10)	1.50
competitiveness	13.15 (4.08)	12.57 (3.49)	0.67
work	18.24 (1.63)	17.66 (2.09)	1.32

***$p<0.001$

The years of experience was taken as the largest value from among the following categories: years with the present airline; years of military experience; years of airline experience; years of general aviation experience; other. The overnight cargo crew members were 5.4 yr younger on average and had 9.4 yr less experience in their present airline. There were no significant differences between the two groups in their height or weight, or in their scores on the personality inventories.

4.4.3 Comparison of the Responses to Trips

To compare the effects of overnight cargo and daytime short-haul fixed-wing operations on overall sleep loss, the average daily percentage sleep loss was compared (by 2-group t-test on the z scores calculated with respect to the combined mean). This comparison included data from 33 pilots from each type of operation (total 66 pilots), and did not reveal a significant difference between the two groups ($t=-0.24$, $p=0.81$).

The average daily percentage sleep loss tends to underestimate the sleep disruption resulting from duty demands because it considers only the total sleep per 24 h, ie., it ignores the breaking up of sleep into several shorter episodes which is characteristic of daytime sleep. In Figure 11, the percentage of subjects reporting more than one sleep episode (including naps) per 24 hr is compared for overnight cargo operations versus two daytime short-haul operations which were studied using the same measures (23,27). Multiple sleep episodes were 17 times more common during overnight cargo operations than during daytime short-haul fixed-wing operations, and 2.5 times more common than during daytime short-haul helicopter operations. The incidence of multiple sleep episodes per 24 h was particularly low during short-haul fixed-wing operations because long duty days and short layovers seldom allowed sufficient time for second sleeps or naps. Another way to examine sleep disruption is to look at the percentage of the total sleep per 24 hr which comes from sleep episodes other than the longest (Figure 12). On this measure, overnight cargo crews gained 9.5 times more sleep from secondary sleep episodes than did short-haul fixed-wing crews, and 5.0 times more than helicopter crews.

Table 21 compares the incidences of the three most commonly reported symptoms among crew members flying overnight cargo, daytime short-haul fixed-wing, and daytime helicopter operations.

TABLE 21: PERCENTAGE OF SUBJECTS REPORTING
THE 3 MOST COMMON MEDICAL SYMPTOMS IN DIFFERENT FLIGHT OPERATIONS

	1st Symptom	2nd Symptom	3rd Symptom
Overnight Cargo	headache (59%)	congested nose (26%)	burning eyes (18%)
Short-Haul	headache (25%)	congested nose (16%)	back pain (7%)
Helicopter	headache (73%)	back pain (32%)	burning eyes (18%)

Shiftworkers are often considered to have higher levels of domestic stress, and have higher incidences of gastro-intestinal complaints, than day workers (9). Several questions in the Background Questionnaire addressed these issues. The responses of 41 overnight cargo crew members were compared with those of 90 daytime fixed-wing short-haul crew members on the following questions.

What is your marital status? Circle all appropriate answers.

a. married   b. single   c. divorced   d.living with someone

Circle the response which best describes your general health.
A..........B..........C..........D..........E
fair excellent

How often do you experience stomach or intestinal problems on trips that you do not usually experience at home?
A..........B..........C..........D..........E
never frequently

How would you describe your appetite on trips as compared to its level at home?
A..........B..........C..........D..........E
decreases increases

Is your diet better or worse while on trips?
A..........B..........C..........D..........E
worse better

The groups were also compared on two questions which addressed the issue of fatigue and performance.

To what extent does fatigue affect your performance?
A..........B..........C..........D..........E
none very much

During a typical trip, how often do you feel that fatigue is affecting your performance?
A..........B..........C..........D..........E
never frequently

Because of the potential confound with age, the groups were compared by 2-way ANOVAs (operation by age) with 5 year age bins from 30-50, and over-50-year-olds. These results are summarized in Table 22.

TABLE 22: EFFECTS OF DAYTIME VERSUS NIGHTTIME FLYING ON DOMESTIC STRESS AND GASTRO-INTESTINAL PROBLEMS

	F Operation Type	F Age	F Interaction
Marital status	0.91	1.57	0.13
General health	2.13	1.76	0.73
Stomach/intestinal problems	0.89	0.92	1.22
Appetite on trips	5.84*	0.57	0.51
Diet on trips	2.23	0.8	1.41
Extent of fatigue effects	0.50	0.60	1.42
How often fatigue affects	0.05	1.88	1.09

* $0.05>p>0.01$

The only significant difference between the two groups was that overnight cargo crews reported a more negative effect of trips on appetite than did daytime short-haul fixed-wing crews.

5. DISCUSSION

The data gathering procedures used in this study were designed to cause minimum disruption to the normal flow of scheduled overnight cargo operations. The investigators aimed to observe situations without influencing them. This approach has face validity for the operational community. On the other hand, it lacks the rigour of scientific experimentation in which some variables are controlled while others are systematically manipulated in an attempt to reveal causal links. To exploit both approaches - observational and experimental - findings from laboratory experiments were used to guide data analysis and interpretation, for example in the effects of sleep loss and in the circadian control of sleep.

5.2 EFFECTS OF TRIPS ON SLEEP

It should be noted that all of the sleep data in the present study are from subjective reports, which are known to be less reliable than physiological sleep measures obtained from polygraphic recordings. Within subjects designs were used in the ANOVAs to compensate for the large interindividual variability in these measures. The changes in sleep timing and duration after night duty were sufficiently great that the lower reliability of the subjective data would not be expected to alter the major findings. The consistent relationships between sleep timing and layover timing also support the validity of the measures used. The changes in subjective sleep quality were less marked. Crew members reporting their daytime sleep as lighter, whereas polygraphic studies indicate that the daytime sleep of other night workers contains proportionally more deep sleep that normal nighttime sleep (2).

Flying at night obliged crews to try to sleep during the day. Daytime sleep episodes were about 3 hr shorter than nighttime sleep episodes, and were rated as lighter, less restorative and of poorer quality overall. Core temperature was also higher during daytime sleep episodes, as a result of the incomplete circadian adaptation to night work, i.e., daytime sleeps and nighttime sleeps occurred during different parts of the circadian temperature cycle.

When duty schedules permitted (see below), crew members often slept more than once during a daytime layover. The incidence of multiple sleeps or naps per 24 hr tripled on duty days compared to days without duty (53% versus 17%). Consequently, crew members lost an average of 1.2 hr of sleep per 24 hr on duty days, by comparison with pretrip. In the laboratory, reducing nightime sleep by this amount results in daytime sleepiness which increases progressively with the number of days of reduced sleep (32,33). However, restriction of nighttime sleep in the laboratory also results in shorter sleep latencies and deeper sleep with fewer awakenings. The fact that the daytime sleep of crew members was also rated as lighter, lest restorative, and poorer overall, suggests that their sleep loss may well have had an even greater effect on subsequent alertness and performance than comparable sleep restriction in the laboratory.

The loss of 1.2 hr of sleep per 24 hr represents a reduction in total sleep duration on duty days of about 16% compared to pretrip baseline. Nightshift workers in other industries report reductions in sleep duration of a least one third for daytime sleep compared to nighttime sleep (2). However, there are several reasons why this comparison may be misleading. First, the individual daytime sleep episodes of overnight cargo crews were 41% shorter than their pretrip nighttime sleep episodes. Second, their work/rest schedules were much more variable on a day-to-day basis than those of other night workers, and daily sleep loss varied greatly depending on the timing and duration of the layovers (Figure 6). Averaging the sleep loss across all duty days thus hides some layovers during which crew members lost much more sleep.

The night off in the middle of the sequence of duty nights clearly provided an important opportunity for recuperation. Crews averaged 41 min more sleep per 24 hr than pretrip and 115 min more than during daytime layovers. On the Destination-Layover pattern, this opportunity occurred after three nights of flying, by which time a third of the crew members had already lost the equivalent of a full night of sleep (8 hr). In the laboratory, this rate of sleep loss would consistently produce impaired performance and alertness (33). On the Out-and-Back pattern, the night off occurred after 5 nights of flying, by which time a quarter of the crew members had lost more than 8 hr of sleep. The average duty "day" on the Destination-Layover pattern was 3.5 hr longer, with double the number of flight segments and 52 min more flight time, and the average layover was 6.1 hr shorter. Nevertheless, the average sleep debt accumulated by the end of the two 8-day patterns was not significantly different (about 10 hr). This is due, at least in part, to the considerable variability in sleep loss among individuals within each of the trip patterns. This variability was not correlated with any of the individual attributes reported by others (refs 3,4,11-22) to predict adaptability to shiftwork and time zone changes, i.e., amplitude of circadian rhythms, morning/eveningness, extraversion, and neuroticism.

Layover timing and duration had a major influence on the sleep that crew members were able to obtain between consecutive nights of flying. Layovers containing one sleep episode early in the layover (96% of Destination-Layover layovers, 37% of Out-and-Back layovers) began earlier and were shorter than layovers containing 2 shorter sleep episodes (4% of Destination-Layover layovers, 58% of Out-and-Back layovers). A third sleep organization, sleeping once late in the layover , was observed in only 5% of Out-and-Back layovers.

There was a remarkable coincidence of wakeup times for early single sleeps and first sleep episodes of a pair in layovers between consecutive nights of flying. On the Out-and-Back pattern, early single sleeps ended, on average, at 18:31 GMT and first sleeps of a pair ended at 18:26 GMT. On the Destination-layover pattern, the average wakeup time for early single sleeps was 19:13 GMT. This is about 6.0 hr after the average temperature minimum on duty days (13:04 GMT for the masked estimate, 12:38 GMT for the unmasked estimate). When isolated subjects in time-free environments have a sleep/wake cycle which does not match the period of the circadian temperature rhythm, they wake up spontaneously most often about 6 hr after the temperature minimum (10). This observation has given rise to the notion of a circadian "wakeup signal". The present data suggest that crew members had difficulty sleeping past the circadian wakeup signal, even although they had slept considerably less than on baseline nights (7.5 hr). On the Out-and-Back pattern, early single sleeps averaged 5.8 hr, while first sleeps of a pair averaged 4.3 hr. On the Destination-Layover pattern, early single sleeps averaged 5.4 hr.

Studies of sleep in a variety of experimental protocols (10) have revealed the existence of a "wake maintenance zone" of several hours duration and centered about 8 hr before the circadian temperature minimum in a time-free environment, or shortly before the habitual bedtime. While traversing this zone, subjects have difficulty falling asleep even when they are suffering from major sleep loss. In the present data, 8 hr before the average temperature minimum corresponds to about 05:00 GMT after a night of flying. The average time of sleep onset pretrip was also about 05:00 GMT. On the Out-and-Back pattern, the average sleep onset time for second sleeps in a layover was around 03:20 GMT, i.e., just before the predicted evening wake maintenance zone. Layovers containing 2 sleep episodes ended 4-7 hr later (07:58 GMT) than layovers in which crew members slept only once.

5.3 EFFECTS OF TRIPS ON CIRCADIAN PHASE

The analyses suggest that the daily temperature minimum occurred about 3 hr later when crews flew at night than during the pretrip baseline period when they slept at night. This would suggest incomplete circadian adaptation to the reversed work/rest schedule, comparable with findings from studies of night workers in other industries (e.g., 3,9,11).

To compensate for the masking of the circadian variation in temperature by changes in the level of physical activity, 0.28^{o}C was added to the raw temperature data for each subject whenever he was alseep. Overall, this mathematical "unmasking" did not significantly change the magnitude of the delay associated with night duty (3.5 hr in the masked data, 2.8 hr in the unmasked data). However, on the Destination-Layover pattern, the masked and unmasked estimates of the temperature minima were significantly different on certain days. In general, when subjects flew at night, the masked estimate of the time of the temperature minimum tended to be later than the unmasked estimate. Conversely, when they slept at night, the masked estimate tended to be earlier than the unmasked estimate. A more detailed discussion of the unmasking technique can be found in Appendix I.

5.4 EFFECTS OF TRIPS ON SUBJECTIVE FATIGUE AND MOOD

On pretrip days, fatigue was lowest, and activation highest, several hours after wakeup. Conversely, fatigue was highest, and activation lowest, in the last rating before nighttime sleep. This concurs with the pretrip time-of-day variation observed in North Sea helicopter crews (23), and with the time-of-day variation in similar variables in the laboratory (34). Rhythms in subjective fatigue and activation do not parallel the objective variations in physiological sleepiness measured by the multiple sleep latency test (19,34). Monk (34) proposes the useful conceptualization of these subjective rhythms as "interfaces" between the physiological variations regulated by the circadian clock and the behavior that they are intended to elicit, i.e., the circadian cycling of restful sleep and active wakefulness.

Several experimental protocols have demonstrated two separate components in subjective fatigue (or alertness) and activation: 1) a circadian variation which parallels the circadian temperature cycle; and 2) a component associated with the sleep/wake cycle, with minimum fatigue (peak activation) occuring 8-10 hrs after waking (34). For crews in the present study, flying at night delayed the circadian temperature rhythm about 3 hr and altered the sleep/wake pattern, i.e, it disrupted the normal relationship between these two components. As, expected, it also altered the time-of-day variation in subjective fatigue and activation (Figure 10). However, because of the reduction of the data into 4 hr time bins, it is impossible to establish with precision the amount of shift in these rhythms from pretrip to duty days. Studies of night workers in other industries have found lowest subjective alertness coinciding with the minimum in body temperature (34). In the present study, when crew members were flying at night, highest fatigue and lowest activation were observed in the time bin from 1300 hr to 1700 hr GMT, i.e., just after the time of the temperature minimum (about 1300 hr GMT). Because of the variability in layover sleep patterns, it is difficult to make generalizations about the relationship between the sleep/wake cycle on duty days, and fatigue and activation ratings.

Positive and negative affect did not show significant time-of-day variations pretrip. This contrasts with the significant pretrip time-of-day variation in negative affect shown by the helicopter crews (27). In general, in normal healthy subjects, measures of affect show weak circadian variation at most (34). On the other hand, in the present study, positive and negative affect both showed significant time-of-day variation on duty days, when they varied as mirror images. Positive affect was highest, and negative affect lowest, when fatigue was lowest, i.e. in the time bin from 2100 hr to 0100 hr GMT. Both affect variables continued to show significant time-of-day variation posttrip, maintaining the same relationship to the subjective fatigue rhythm as was observed on duty days.

Average fatigue and mood ratings during nightime wakefulness while on duty were compared with average ratings during pretrip daytime wakefulness. During duty, fatigue and negative affect were higher, and activation and positive affect were lower than during pretrip days.

5.5 EFFECTS OF TRIPS ON CAFFEINE AND FOOD CONSUMPTION

In contrast to crew members flying daytime short-haul operations (23,27), overnight cargo crew members did not significantly increase their caffeine consumption on duty days.

Snacking increased significantly on trips, although the number of meals consumed daily did not change. The meals eaten on duty days may have been less filling and/or snacking may have served as a countermeasure to help stay awake.

5.6 EFFECTS OF TRIPS ON MEDICAL SYMPTOMS

Fifty-nine per cent of subjects reported headaches at some time during the study, while 26% reported congested nose, and 18% reported burning eyes. The incidence of headaches quadrupled on duty days, by comparison with pretrip, while the incidence of congested nose doubled, and of burning eyes increased ninefold.

5.7 DAY VERSUS NIGHT FLYING

By comparison with the daytime short-haul fixed-wing operations studied, the overnight cargo operations had shorter duty days (by an average of 3 hr), with 2hr less flight time and fewer, shorter flight segments, and had layovers between duty "days" that averaged 2.4 hr longer. The overnight cargo crews averaged 5.4 yrs younger than their daytime short-haul counterparts. This may confer some advantage in terms of adaptability to shiftwork (31). However, overnight cargo crews were also less experienced overall, and averaged 9.4 yr less experience in their present airline. This represents a minimum estimate of how long they had been flying overnight cargo operations (average of 4.7 yr).

The average daily percentage sleep loss was not significantly different between the two groups, despite the difference in layover duration. Multiple sleep episodes per 24 hr were 17 times more common on overnight cargo trips than on daytime short-haul fixed-wing trips. The long duty days and short nighttime layovers in the latter operations resulted in a particularly low incidence of multiple sleep episodes on trip days. On the other hand, daytime short-haul helicopter crews had average layovers 2.1 hr longer than the overnight cargo crews (27), but reported multiple sleep episodes 2.5 times less often during trips. On trips, overnight cargo crews gained 9.5 times more sleep from secondary sleep episodes than did short-haul fixed-wing crews, and 5.0 times more than did helicopter crews. (Secondary sleep episodes were defined as those sleep episodes other than the longest in each GMT day)

At first glance, since overnight cargo crews were not losing more sleep per 24 hrs than their daytime short-haul counterparts, it might be argued that there is no reason to allow extra rest time for overnight cargo crews. However, the potential operational impact of that sleep loss is greater for overnight cargo crews, for the following reasons. First, because the circadian cycle does not adapt completely to the inverted duty-rest schedule, overnight cargo crews are working around the time of peak physiological sleepiness (around 2:00-06:00 for people sleeping at night, or around the time of the circadian temperature minimum). Thus, even without sleep loss, they would be expected to be sleepier on the job than their day-flying short-haul counterparts.

Second, performance on a number of laboratory tasks (e.g., signal detection, reaction time, simple arithmetic; ref 36), and the performance of experienced fighter pilots in an F-104G simulator (37), parallels the circadian temperature rhythm, and is thus poorest in the early morning hours. In other 24 hr operations, performance is consistently poorer on the night shift (9,38). Thus, even without sleep loss, overnight cargo crews would be expected to have greater difficulty maintaining satisfactory on-the-job performance than their day-flying short-haul counterparts.

Third, there are several observations which suggest that the quality of the daytime sleep obtained by overnight cargo crew members is not comparable to that obtained by short-haul crew members sleeping at night. The daytime sleep of overnight cargo crews was often split into several episodes across the 24 hr day. There are no laboratory data addressing the effects of splitting sleep on subsequent alertness and performance. However, it seems reasonable to assume that the pattern of consolidated sleep at night, favoured during human evolution to the present, confers some advantage. The daytime sleep of overnight cargo crews was also displaced in the circadian cycle, compared to a normal night of sleep. It is well-established that sleep quantity and quality vary across the circadian cycle.

In summary, the safety margin is already reduced for overnight cargo pilots because they are working through the daily times of peak sleepiness and poorest performance on a number of tasks. The same amount of sleep loss brings them closer to a critical minimum of alertness and performance than their day-flying short-haul counterparts. In addition, the sleep that they obtain in several episodes across the day is probably not as restorative as the equivalent amount of consolidated nighttime sleep.

Headaches were more than twice as common among overnight cargo crews as among short-haul fixed-wing crews, and were approaching the incidence reported by helicopter crew members who flew in cockpits where overheating, poor ventilation, and high levels of vibration were common (27). Overnight cargo crews complained more frequently of congested nose than short-haul fixed-wing crews, and reported a comparable incidence of burning eyes to that of helicopter crews. Overnight cargo crews also reported a more negative effect of trips on appetite than did daytime short-haul fixed-wing crews. This may have been due, at least in part, to duty coinciding with the part of the circadian cycle not normally associated with meals (late evening through early morning).

5.8 CONCLUSIONS

Flying at night imposes a number of physiological challenges which are not present in comparable daytime operations. As this study demonstrates, circadian adaptation to night duty is incomplete. On average crew members came off duty around 07:00 local time, which is about half an hour before the average time of the temperature minimum after a night of flying. Therefore they were on duty at times in the circadian cycle when their subjective alertness was low, and when their physiological sleepiness would be expected to be high, and their performance capacity low (36,37,38). Their daytime sleep was truncated in many instances by the circadian wakeup signal. Depending on the duration of the layover, they were often unable to sleep again before going back on duty. In addition, their day time sleep was reported as lighter and less restorative than nighttime sleep. Thus crew members were working around the circadian low point with an accumulating sleep debt. In laboratory studies, this combination produces poorest performance (36). Field data from other 24 hour shiftwork operations, and accident rates in other modes of transport, also consistently indicate poorer performance at night (2,9,38). Overnight cargo crews are working when routine physiological factors combine to generate the greatest potential for human error.

From this study, a number of recommendations can be made to address these problems. The first two are scheduling manipulations. The third addresses nutritional issues, while the fourth proposes possible regulatory action.

1. The timing and duration of layovers had consistent effects on sleep. Getting off duty earlier permitted a longer sleep episode before the circadian wakeup signal. Going back on duty later allowed a second sleep episode closer to duty time, thus reducing the duration of wakefulness for the next duty period. The balance of these two effects needs to be considered when determining the timing and duration of layovers. For example, crew members finishing duty after 06:00 local time are unlikely to obtain 7 hr of sleep before the circadian wakeup signal (about 13:10 local time after a night of flying). The layover should therefore be at least 19 hr long, to allow suficient time for a second sleep episode. Crew members need to be aware that they risk having difficulty falling asleep if they do not go to sleep again before about 22:30 local time, because of the evening wake maintenance zone.
2. The night off represents an important opportunity for recuperation. It breaks the pattern of accumulating sleep debt, with its accumulating impairment of alertness and performance. Its position in the sequence of night duties needs to be related to the rate of sleep loss imposed by the schedules. On the Destination-Layover pattern, for example, it would clearly have been unwise to add a fourth consecutive night of

flying when a third of the crew members had already lost more than 8hr of sleep after three nights of flying. In contrast, on the Out-and-Back pattern, only a quarter of crew members had lost more than 8 hr sleep after 5 nights of flying. The use of naps as a fatigue countermeasure in overnight cargo operations deserves further attention (39).

3. Gastro-intestinal problems frequently accompany incomplete circadian adaptation to a work schedule or a new time zone. The Background Questionnaire did not identify major differences between the effects of daytime and nighttime flying, except that overnight cargo crews reported a more negative effect of trips on appetite. However, it would be premature to conclude on this basis that there are no differences over a long period of time. Both groups reported more snacking on trips. The availability of better quality food on trips should be considered. In contrast to daytime short-haul fixed-wing crews, overnight cargo crews did not increase their caffeine consumption on trips. Used appropriately, caffeine can be a useful operational countermeasure for acute fatigue (39). Ready availability of caffeine, and of information about its use, could be beneficial in helping crew members maintain their alertness during night flights.
4. Based on the prevalence of split sleeps during daytime layovers, and the displacement of sleep to a different part of the circadian cycle, we argue that flight crews do not obtain the same quality of sleep during daytime rest periods as they do during nighttime rest periods. We would strongly recommend that the Federal Aviation Authority re-examine the issue of taking into account the time of day during which a crew member is on duty when determining subsequent rest requirements.

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FIGURE LEGENDS

Figure 1

The Destination-Layover trip pattern. SAV- Savannah (Eastern Time), CHS - Charlston (Eastern Time), MEM - Memphis (Central Time). DH - deadhaed, i.e. crew members flew as passengers.

Figure 2

The Out-and-Back trip pattern. MEM - Memphis (Central Time), SAT - San Antonio (Central Time).

Figure 3

Distributions of the times of falling asleep at home (i.e., combining pretrip, no-duty, and posttrip days) and on duty days.

Figure 4

Distributions of the times of waking up at home (i.e., combining pretrip, no-duty, and posttrip days) and on duty days.

Figure 5

Percentage of subjects reporting more than one sleep or nap episode per 24 hr on different days of the study. Note that the first and fifth duty days on the Destination-Layover pattern followed an off-duty period (Figure 1) and included one sleep episode before going back on duty, and one after the night of flying. Only sleep episodes during layovers between successive nights of flying were included in the analyses in Tables 6,7,8.

Figure 6

Average layover and sleep timing on the two trip patterns. Percentages on the left indicate the percentage of layovers in each trip pattern during which early single or split sleep episodes occurred.

Figure 7

Average daily sleep loss (hrs) across the two trip patterns. Vertical bars indicate standard errors. Since sleep loss is calculated with respect to the pretrip sleep duration, the average pretrip sleep loss is zero.

Figure 8

Average times of the daily temperature minima across the two trip patterns. Vertical bars indicate standard errors. Asterisks indicate days on which the masked estimate was significantly different from the unmasked estimate.

Figure 9

Average times of the temperature minima on pretrip, duty, no-duty, and posttrip days, for the two trip patterns. Vertical bars indicate standard errors.

Figure 10

Average fatigue and mood ratings at different times of day on pretrip, duty, no-duty and posttrip days. The GMT times represent the midpoints of the 4 hr data bins.

Figure 11

Percentage of subjects reporting more than one sleep or nap episode per 24 hr on pretrip, trip, and posttrip days. Comparison of the sleep disruption caused by nighttime flying (overnight cargo operations) and daytime flying (short-haul fixed-wing and helicopter operations).

Figure 12

Percentage of daily sleep coming from sleep episodes other than the longest, on pretrip, trip, and posttrip days. Comparison of the sleep disruption caused by nighttime flying (overnight cargo operations) and daytime flying (short-haul fixed-wing and helicopter operations).

Figure 13

Effect of the unmasking technique on the estimated time of the temperature minimum. The fitted curve is a robust locally weighted regression smooth, with f=0.67 (ref. 40).

Figure 14

Comparison of the masked and unmasked estimates of the times of the temperature minima on pretrip, duty, no-duty, and posttrip days.

7. APPENDIX 1: CIRCADIAN PHASE ESTIMATION

In this study, the extent to which the circadian clock adapted to a series of night duties was estimated from the shift in the time of the daily temperature minimum from pretrip days to duty days. The validity of this approach needs to be considered in detail, because of the problem of the changes in temperature produced by physical activity (masking) which are superimposed on the circadian variation in temperature.

The mathematical "unmasking" technique used here (adding 0.28^{o}C to the raw temperature data for each subject whenever he was alseep), is clearly very simplistic. However, its effect on the estimated times of the cycle-by-cycle temperature minima is not so straight forward as it might seem at first glance. Some smoothing also occurs in the fitting of the multiple complex demodulated waveform. When the mid-point of the sleep episode occurs close to the masked temperature minimum, the unmasking technique (adding a constant during sleep) has minimal effect on the estimated time of the temperature minimum. When the mid-point of the sleep episode is displaced from the masked temperature minimum, the unmasking technique alters the estimated time of the temperature minimum, but in a complex way. This relationship is illustrated in Figure 13. The displacement of the mid-point of sleep from the masked temperature minimum is plotted on the x axis, while the difference between the masked and unmasked estimates of the time of the temperature minimum is plotted on the y axis. When the mid-point of sleep occurs up to about 4 hrs before the masked temperature minimum ($-4<x<0$ in Figure 13), then the unmasking technique gives a later estimate of the time of the temperature minimum. Conversely, when the mid-point of sleep occurs up to about 4 hrs after the masked temperature minimum ($0<x<4$ in Figure 13), then the unmasking technique gives an earlier estimate of the time of the temperature minimum. Across this relative phase range ($-4<x<4$ in Figure 13), there is a significant linear correlation between the displacement of the mid-point of sleep from the masked temperature minimum, and the difference between the masked and unmasked estimates of the temperature minimum ($r=.63$, $p<0.01$). Although there are fewer data points, it also appears that the unmasking technique affects the estimated time of the temperature minimum even when the mid-point of the sleep episode is close to the temperature maximum. When the mid-point of sleep occurs in the hours after the temperature maximum ($-12<x<-8$ in Figure 13), then the unmasking technique gives an earlier estimate of the time of the temperature minimum. Conversely, when the mid-point of sleep occurs in the hours before the temperature maximum ($8<x<12$ in Figure 13), then the unmasking technique gives a later estimate of the time of the temperature minimum. In summary, the effect of the unmasking technique on the estimated time of the temperature minimum is dependent on where in the temperature cycle sleep occurs.

When crew members went to sleep in the morning after a night of flying, they were sleeping later in the temperature cycle than when they slept at night. A 2-way ANOVA was performed (Table 23) to compare the masked and unmasked estimates of the temperature minima across the phases of the study (pretrip/duty/no-duty/postrip). This analysis included data from 18 subjects.

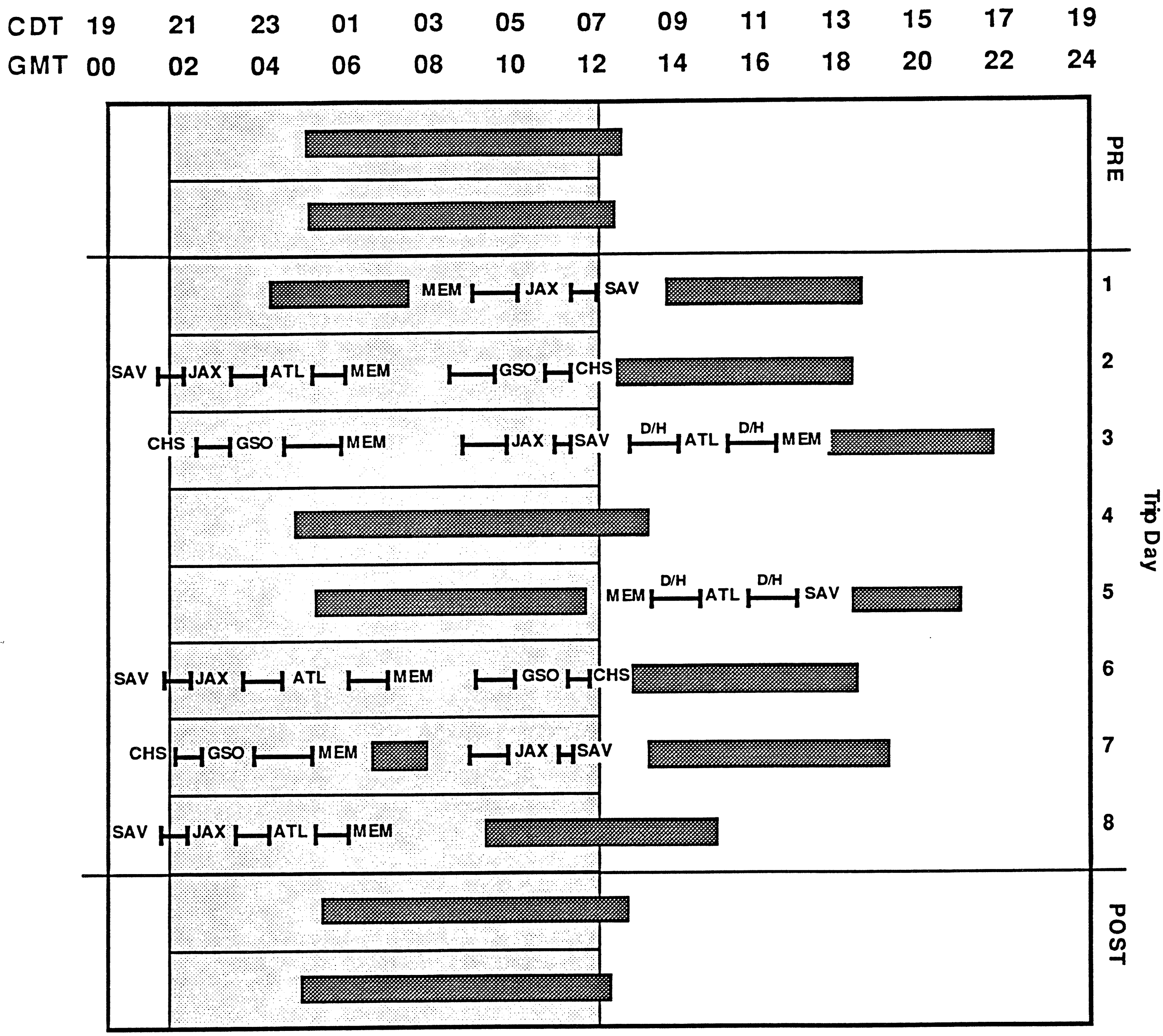
TABLE 23: EFFECTS OF THE UNMASKING TECHNIQUE ON THE ESTIMATED TIME OF THE TEMPERATURE MINIMUM

	F mask/unmask	F pre/duty/no-duty/post	F interaction
estimated time of the temperature minimum	3.57	21.63***	4.62**

0.01>p>0.001,*p<0.001

Overall, the masked and unmasked estimates were not significantly different (p=0.08). However, the significant interaction indicates that the masked and unmasked estimates did not change similarly across all phases of the study. This is illustrated in Figure 14. Post hoc tests indicated that the masked estimates were significantly earlier than the unmasked estimates on the no-duty day (F=7.33, p=0.015) and on posttrip days (F=6.62, p=0.020). Sleep onset and wakeup times (GMT) were not significantly different among pretrip, no-duty, and posttrip days. Thus, the significant differences between the masked and unmasked estimates of the time of the temperature minimum on no-duty and posttrip days suggests that the circadian system had shifted by comparison with pretrip. The extent of this small shift cannot be measured with great precision because these data are from a real-world setting which does not permit fine control of all the potential contaminating variables. On the other hand, it is clear that the circadian system did not invert to match the reversed rest-activity cycle on duty days. This is the most relevant point from an operational perspective, because it indicates that crew members were being required to work around the circadian times of lowest alertness and performance.

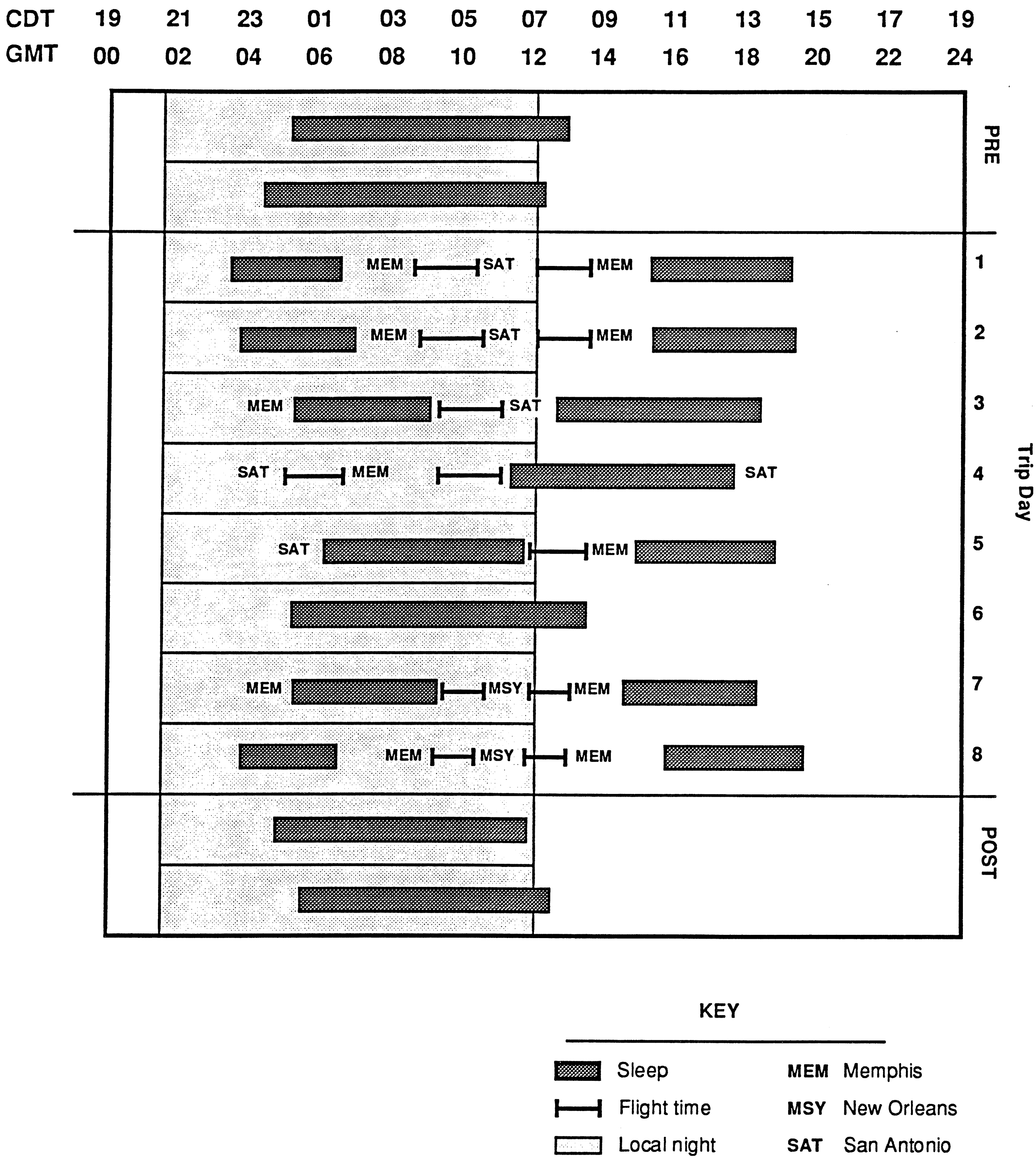
Figure 1



KEY

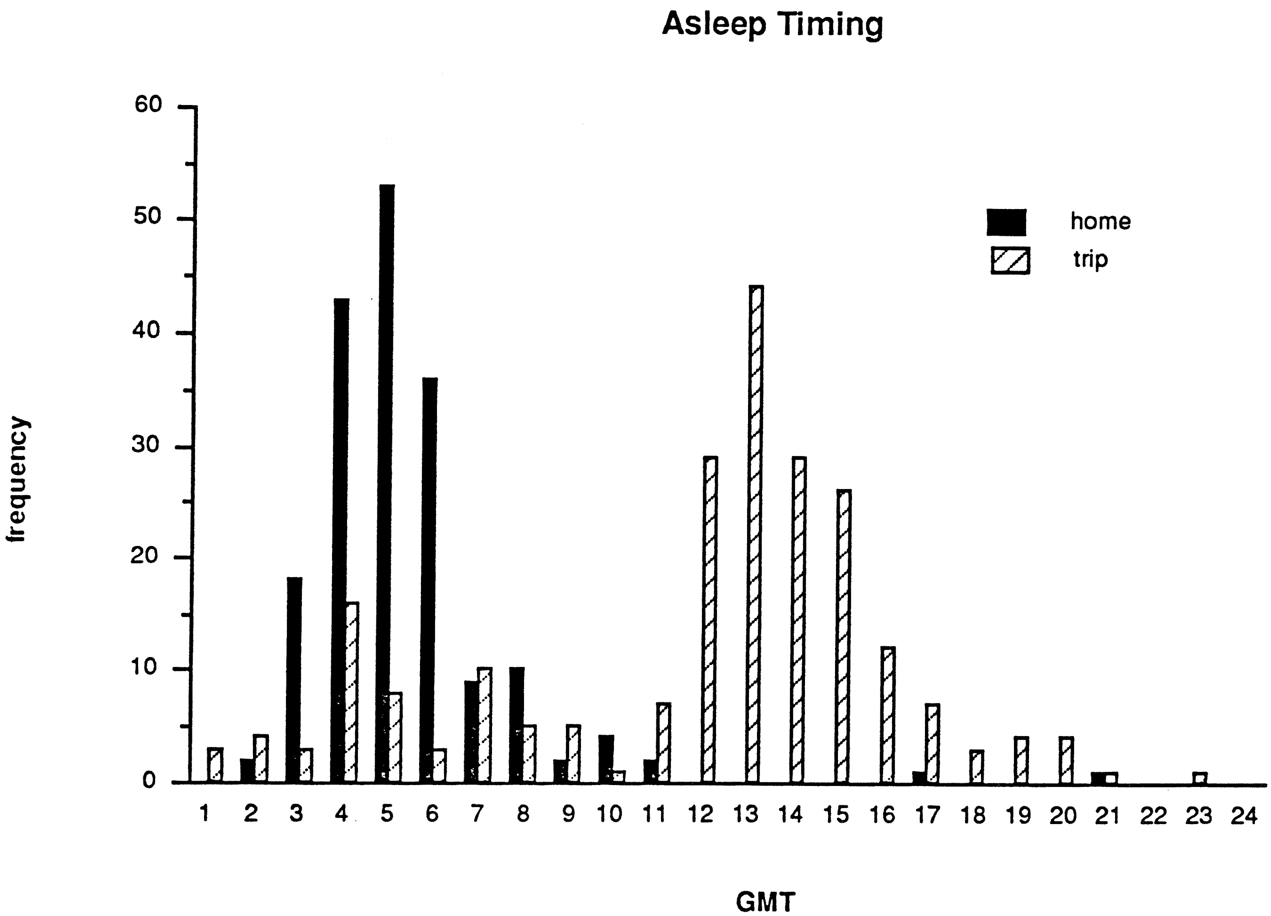
(shaded box)	Sleep	ATL	Atlanta
(bar)	Flight time	GSO	Greensboro
(open box)	Local night	JAX	Jacksonville
D/H	Deadhead	MEM	Memphis
		SAV	Savannah

Figure 2



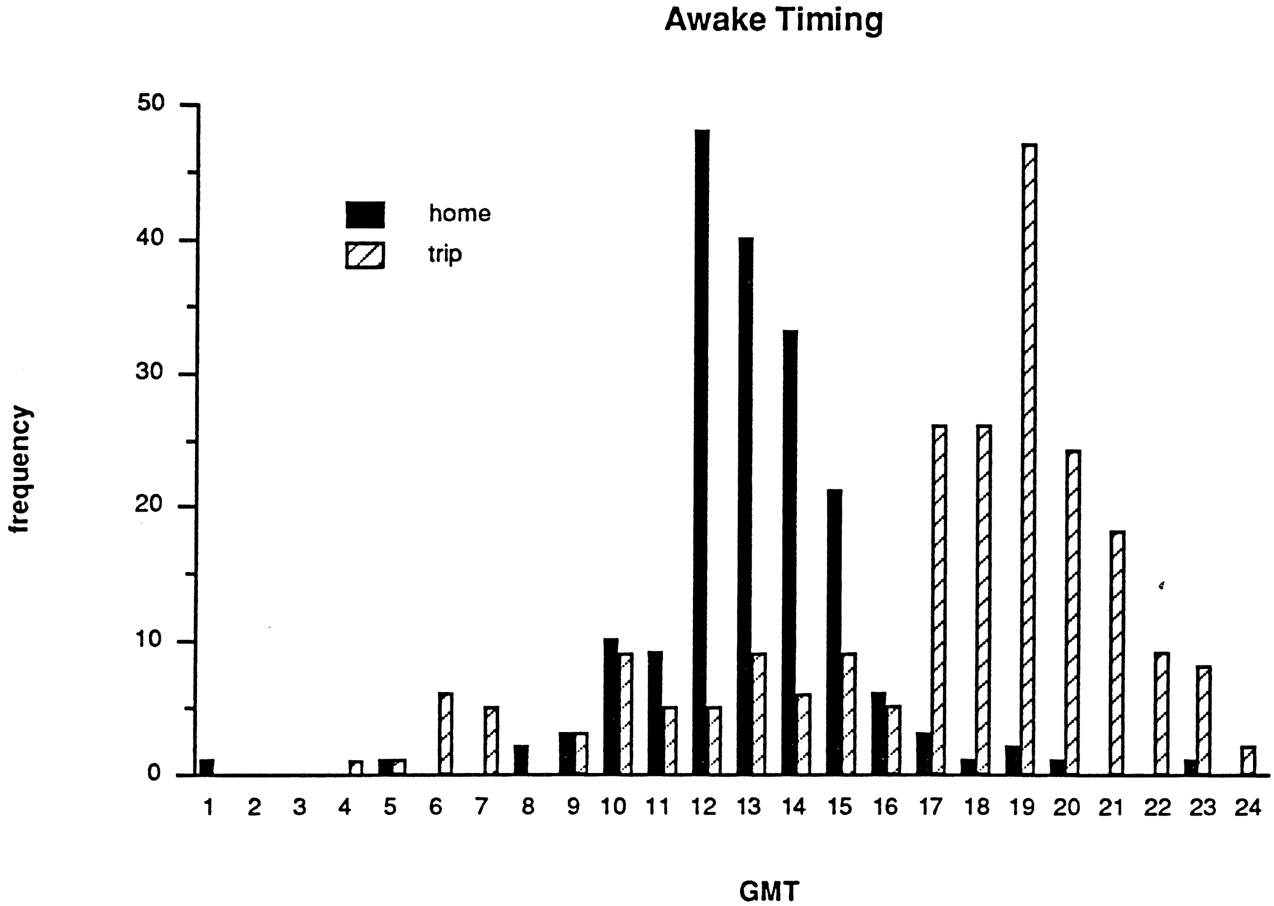
CDT 19 21 23 01 03 05 07 09 11 13 15 17 19
GMT 00 02 04 06 08 10 12 14 16 18 20 22 24
PRE
1 MEM SAT MEM
2 MEM SAT MEM
3 MEM SAT
4 SAT MEM SAT
5 SAT MEM
6
7 MEM MSY MEM
8 MEM MSY MEM
POST
Trip Day
KEY
Sleep
Flight time
Local night
MEM Memphis
MSY New Orleans
SAT San Antonio

Figure 3



Asleep Timing
frequency
60
50
40
30
20
10
0
home
trip
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
GMT

Figure 4



Awake Timing
50
40
30
20
10
0
frequency
home
trip
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
GMT

Figure 5

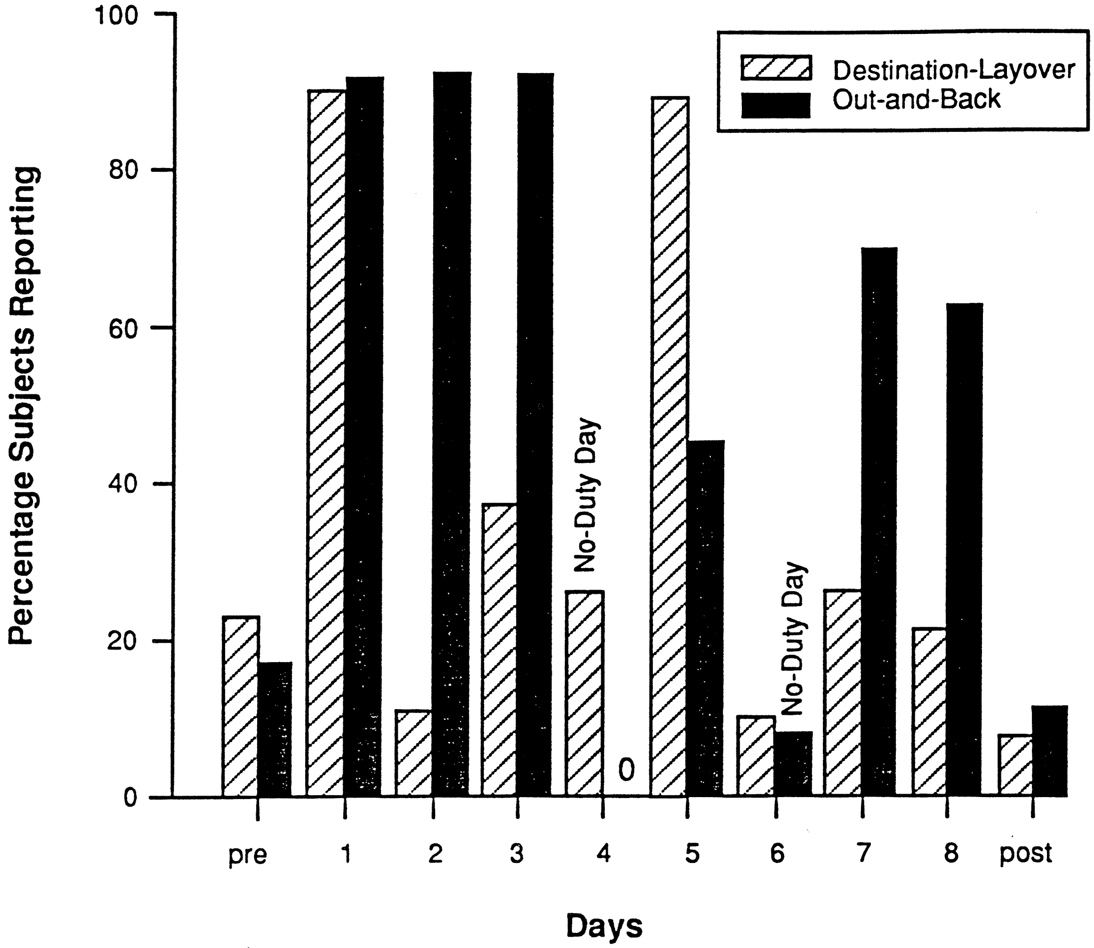

Destination-Layover
Out-and-Back
Percentage Subjects Reporting
100
80
60
40
20
0
No-Duty Day
No-Duty Day
0
pre
1
2
3
4
5
6
7
8
post
Days

Figure 6

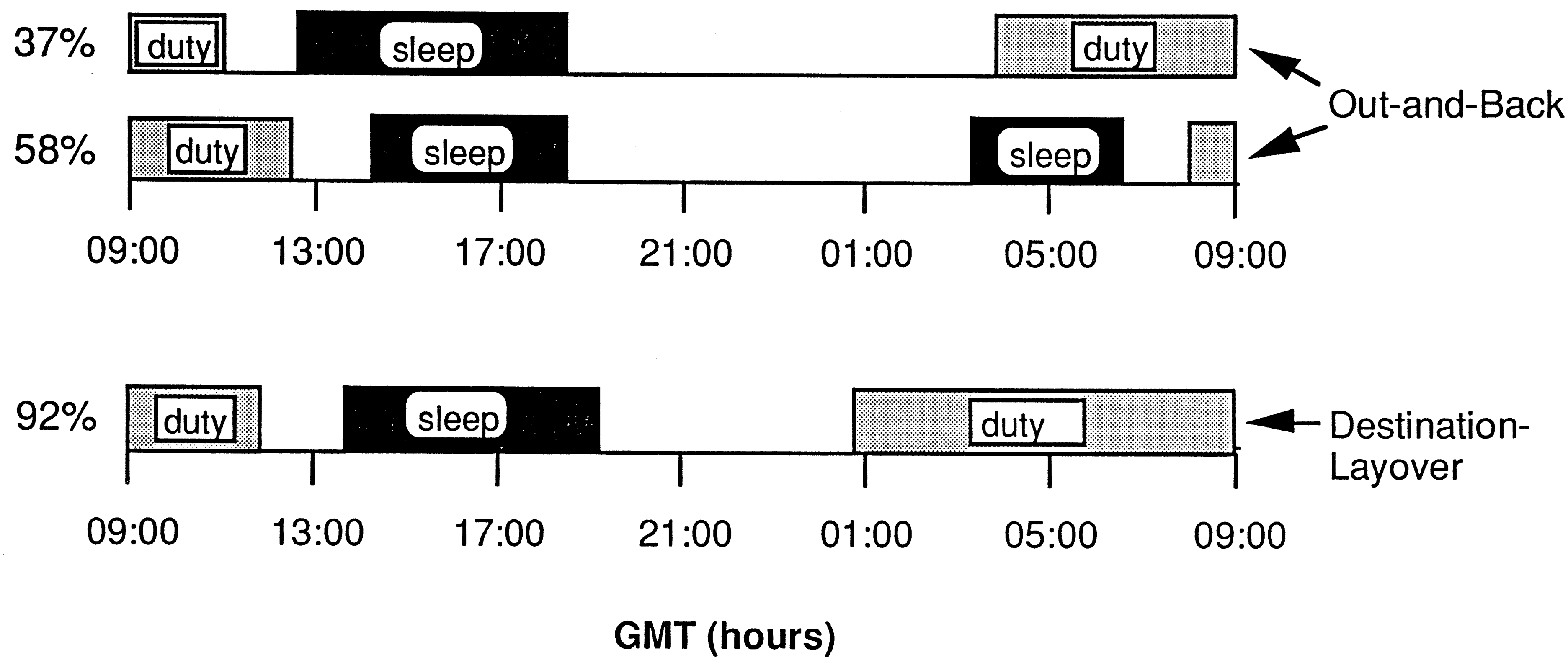
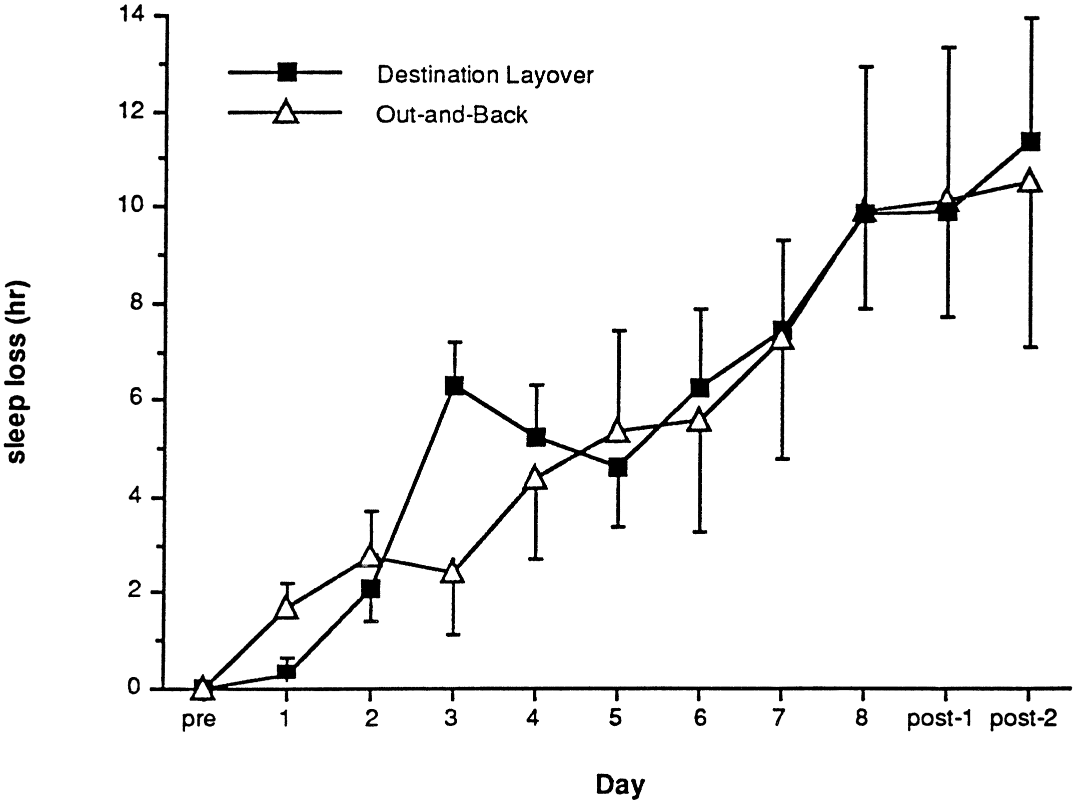
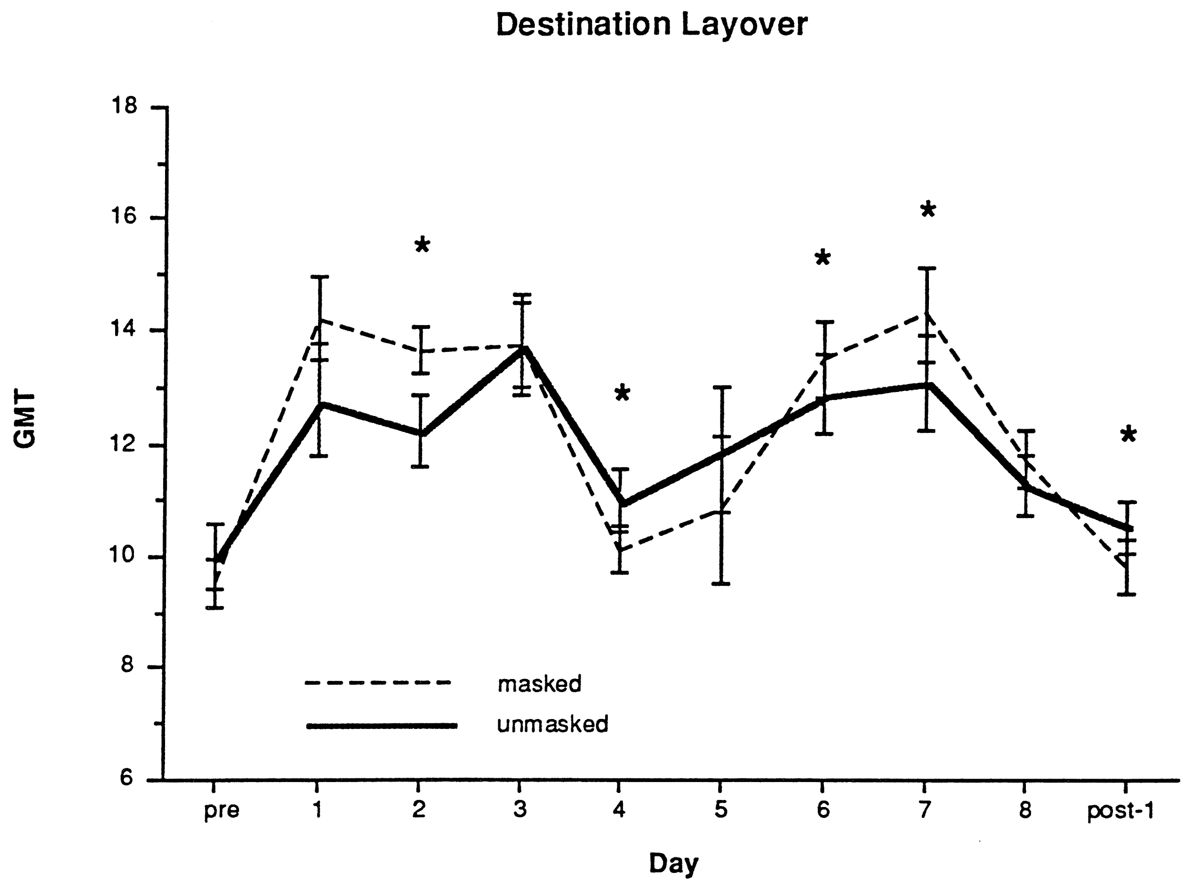

37%
duty
sleep
duty
58%
duty
sleep
sleep
Out-and-Back
09:00
13:00
17:00
21:00
01:00
05:00
09:00
92%
duty
sleep
duty
Destination-
Layover
09:00
13:00
17:00
21:00
01:00
05:00
09:00
GMT (hours)

Figure 7



14
12
10
8
6
4
2
0
sleep loss (hr)
Destination Layover
Out-and-Back
pre
1
2
3
4
5
6
7
8
post-1
post-2
Day

Figure 8


Destination Layover
GMT
18
16
14
12
10
8
6
*
*
*
*
*
masked
unmasked
pre
1
2
3
4
5
6
7
8
post-1
Day

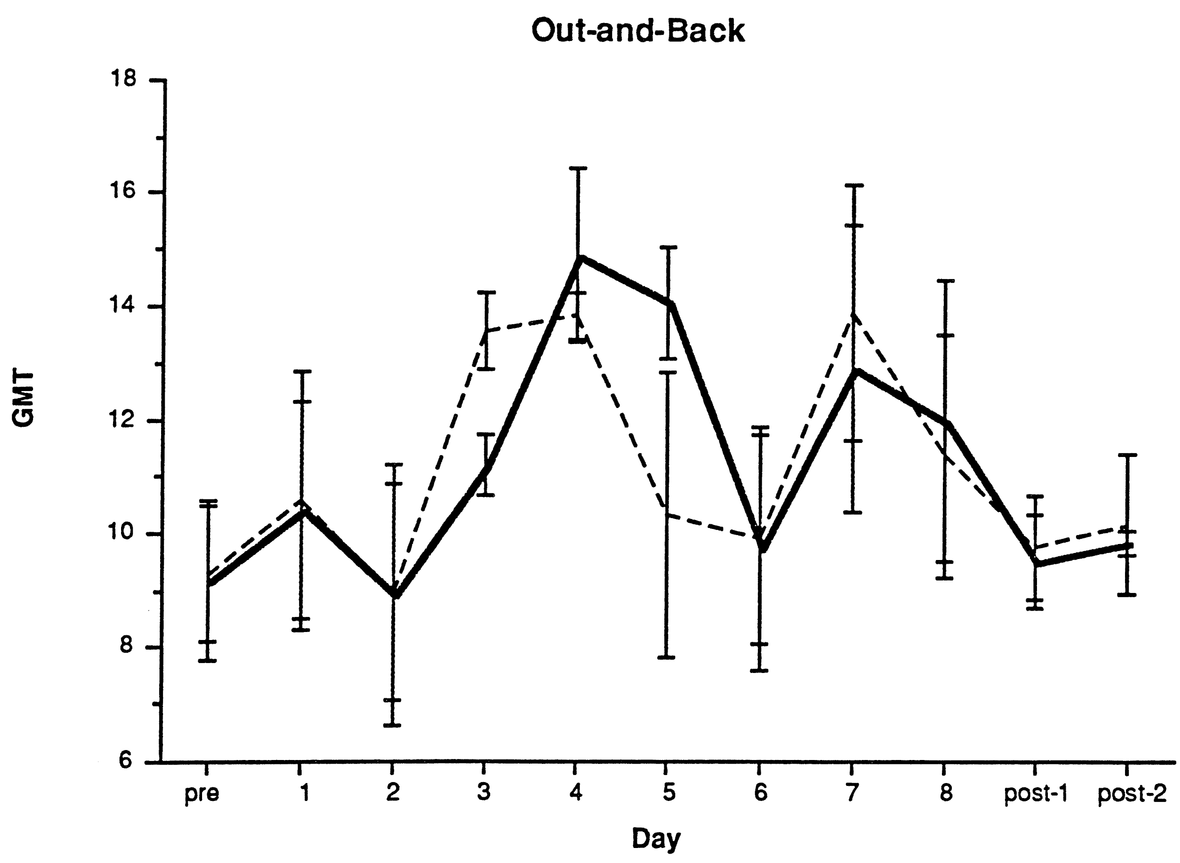

Out-and-Back
GMT
18
16
14
12
10
8
6
pre
1
2
3
4
5
6
7
8
post-1
post-2
Day

Figure 9

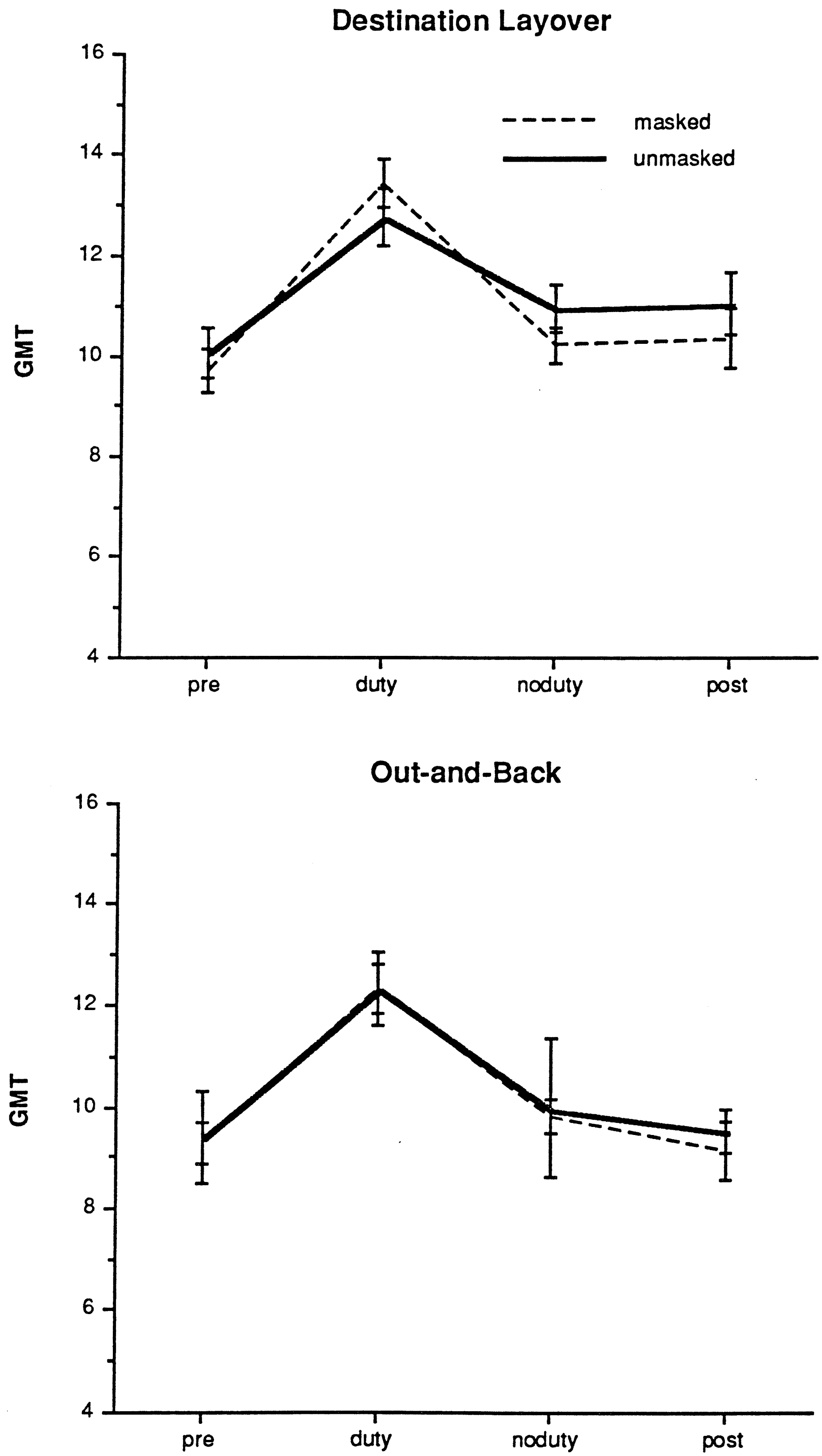
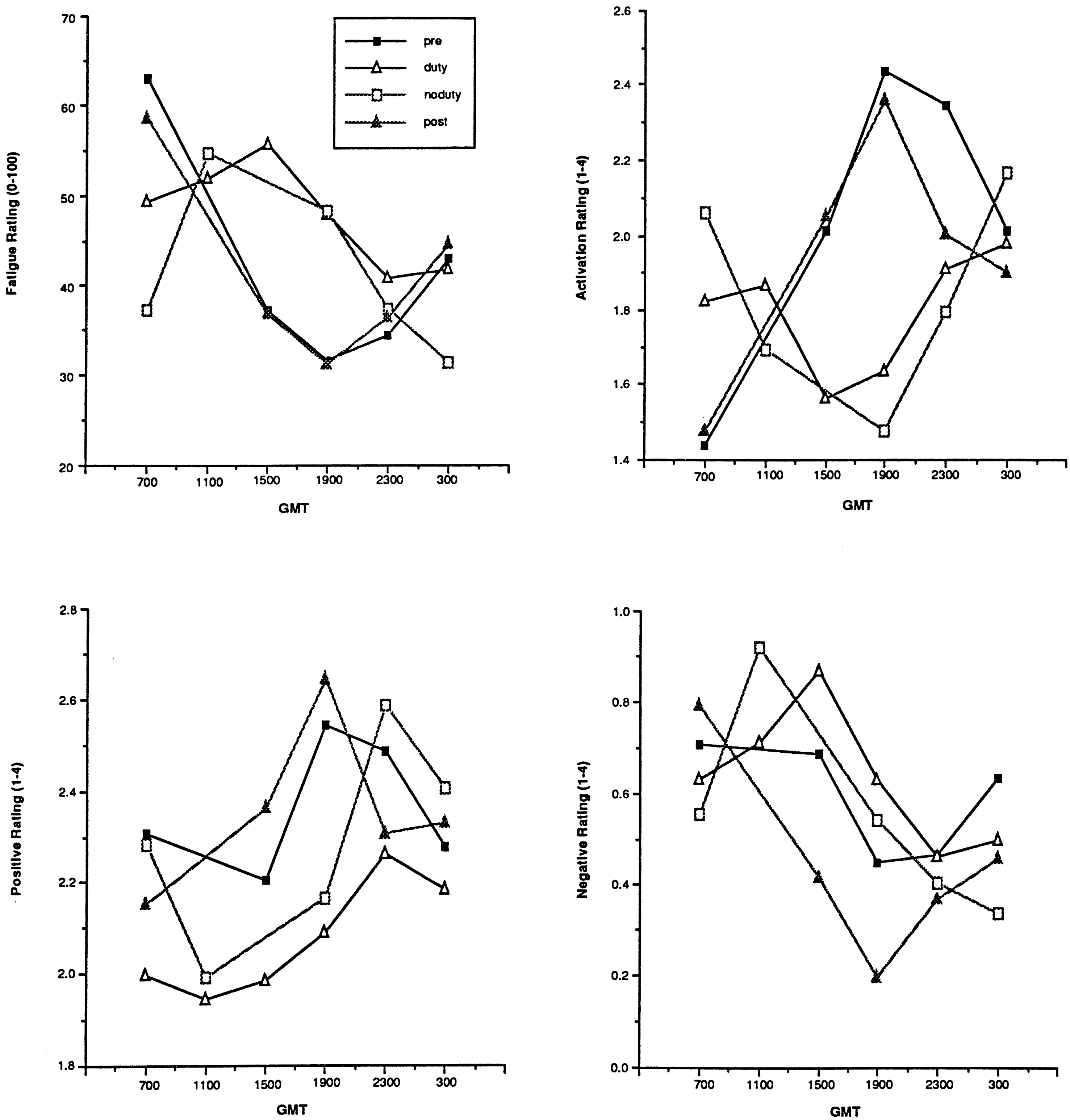
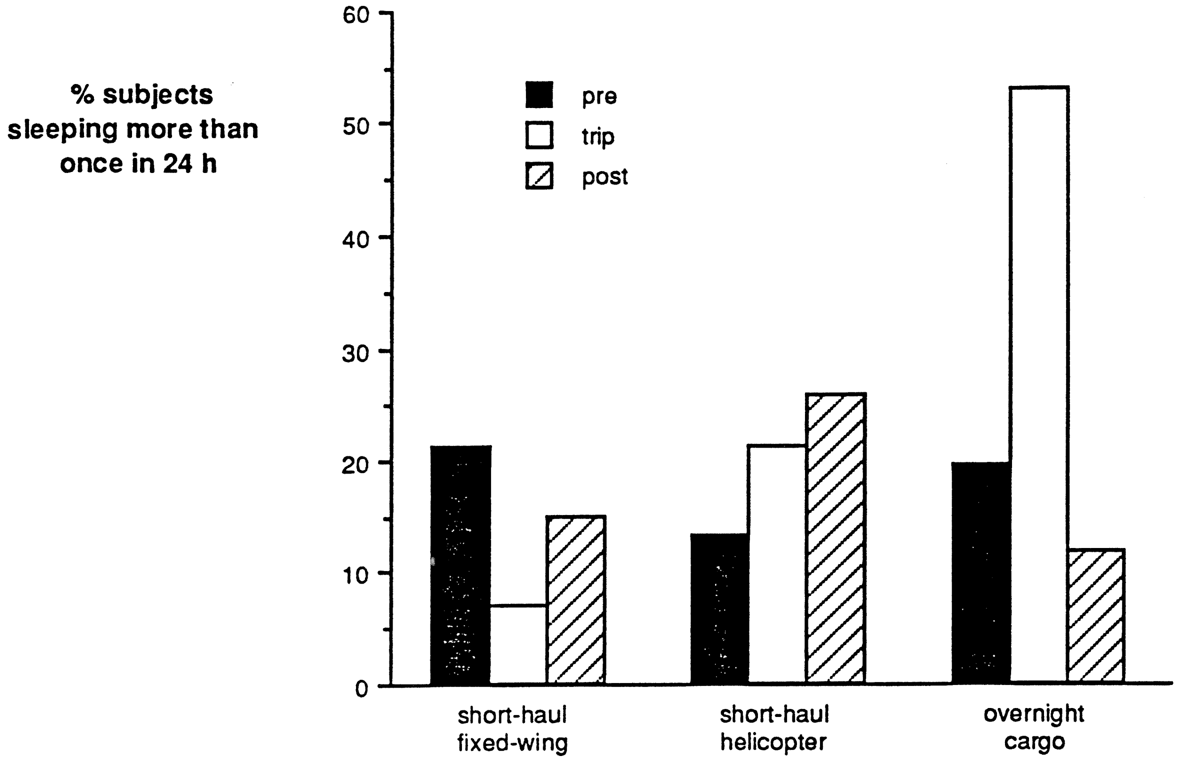

Destination Layover
16
14
12
10
8
6
4
GMT
masked
unmasked
pre
duty
noduty
post
Out-and-Back
16
14
12
10
8
6
4
GMT
pre
duty
noduty
post

Figure 10



pre
duty
noduty
post
Fatigue Rating (0-100)
70
60
50
40
30
20
700
1100
1500
1900
2300
300
GMT
Activation Rating (1-4)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
Positive Rating (1-4)
2.8
2.6
2.4
2.2
2.0
1.8
Negative Rating (1-4)
1.0
0.8
0.6
0.4
0.2
0.0

Figure 11



% subjects
sleeping more than
once in 24 h
60
50
40
30
20
10
0
pre
trip
post
short-haul
fixed-wing
short-haul
helicopter
overnight
cargo

Figure 12

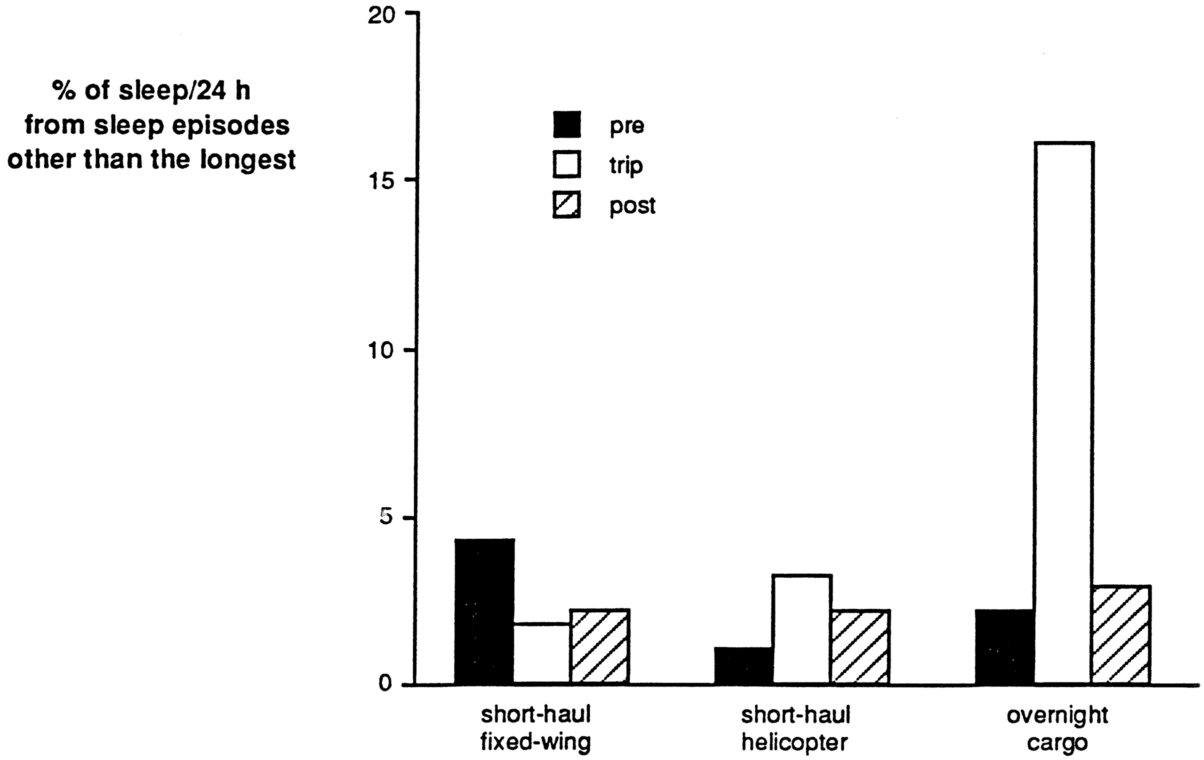

% of sleep/24 h
from sleep episodes
other than the longest
20
15
10
5
0
pre
trip
post
short-haul
fixed-wing
short-haul
helicopter
overnight
cargo

Figure 13

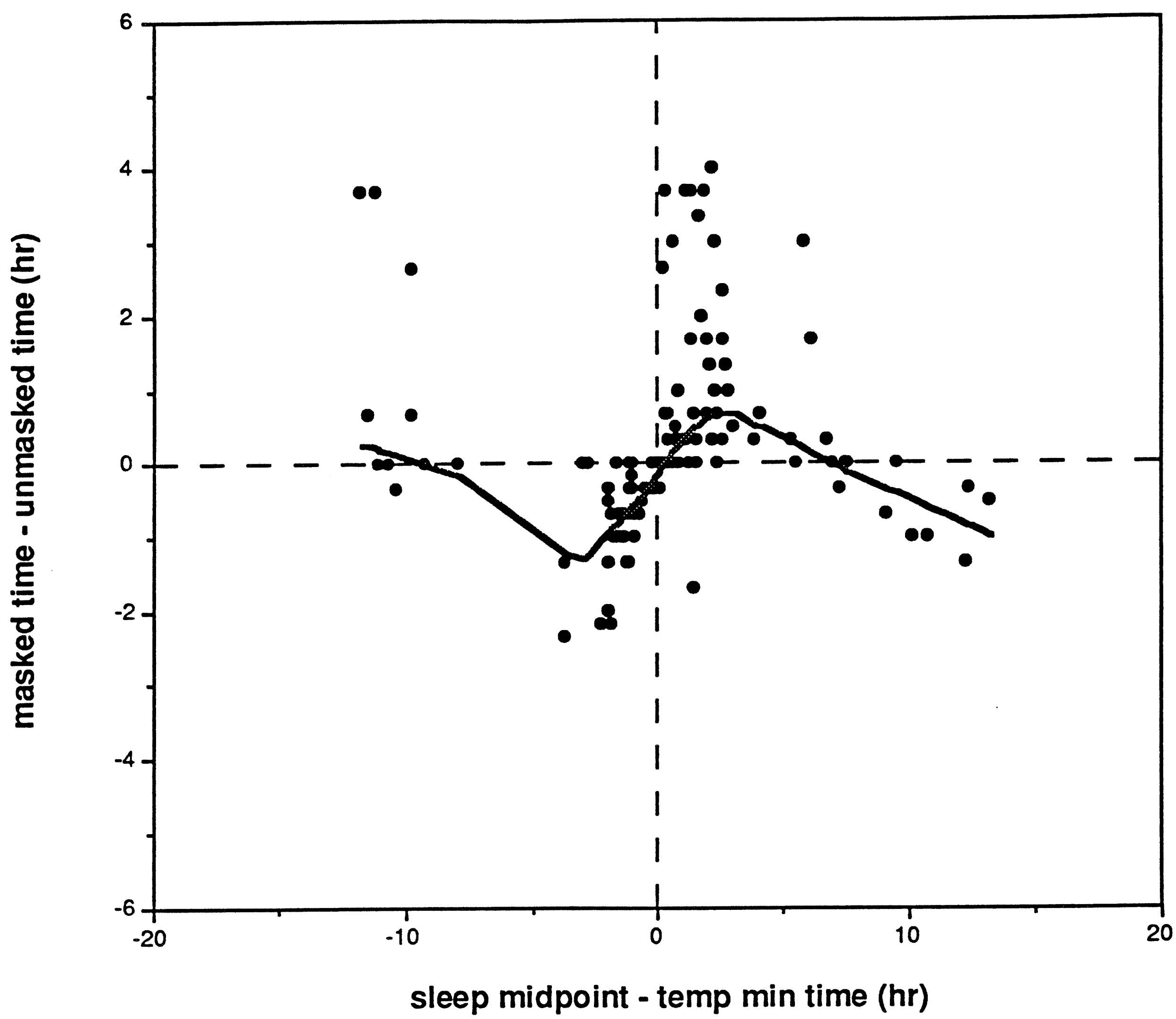
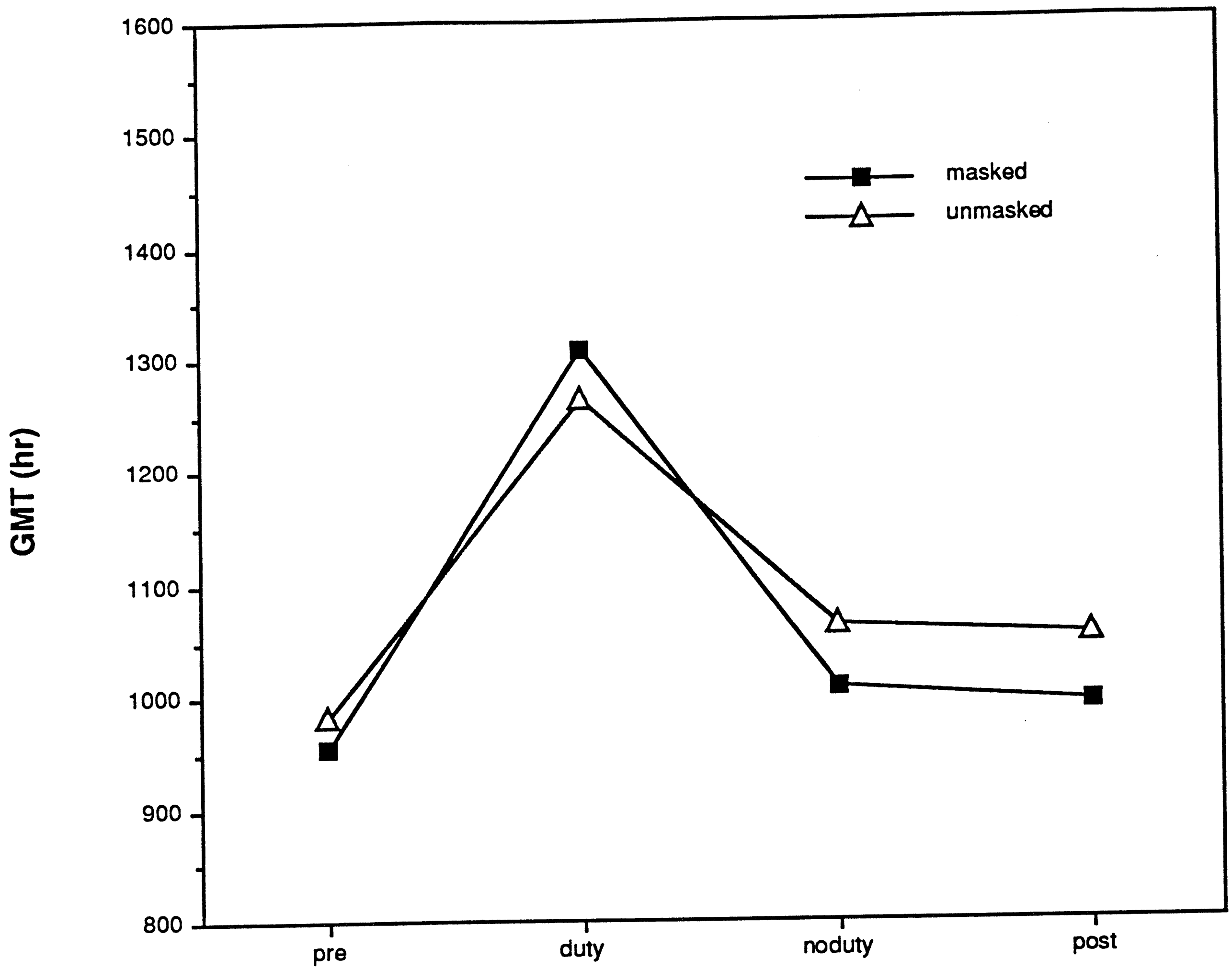

masked time - unmasked time (hr)
6
4
2
0
-2
-4
-6
-20
-10
0
10
20
sleep midpoint - temp min time (hr)

Figure 14



1600
1500
1400
1300
1200
1100
1000
900
800
GMT (hr)
masked
unmasked
pre
duty
noduty
post