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INTRODUCTION

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

Diverse physiological and psychological disruptions have been reported to result from rapid transmeridian travel. These "jet lag" effects are temporary and vary greatly in their severity in different individuals. The ability of aviation personnel to meet operational requirements may be compromised because of the discomfort of the physiological symptoms (gastro-intestinal upset, loss of appetite, insomnia, headaches, dizziness): the detrimental effects of sleep loss on performance; the displacement of circadian performance rhythms with respect to local time; and the subjective impression of general malaise (refs. 14,18,20).

The symptoms of jet lag are attributable to three major causes.

1. Flight-related fatigue. North-south flights, which do not involve time-zone changes, nevertheless produce a significant increase in fatigue, but without the performance decrement and physiological rhythm disruption associated with transmeridian (particularly eastward) flight (ref. 16).
2. Sleep loss resulting from the intrusion of flight-related activities into the normal sleep time.
3. The disruption to the temporal organization of the body, as the neural pacemakers of the circadian timing system resynchronize to the new local time. This (temporary) conflict between body time and environmental time is commonly experienced as desires to sleep, eat, void etc., at inappropriate times; and as an inability to sleep, a lack of appetite etc., in compliance with the local routine.

Laboratory and field studies investigating the process of resynchronization of the circadian timing system to displaced environmental time cues (zeitgebers) have revealed the following generalizations (refs. 2,7,8,10,13,18,20).

1. The time required for complete resynchronization to the new time zone depends upon the number of time zones crossed (i.e., the magnitude of the phase shift).
2. Resynchronization is usually completed more rapidly after a westward flight (phase delay) than after an eastward flight (phase advance) of the same magnitude.
3. The relative direction of flight (outbound versus homeward) and the time of departure (day versus night) have minimal effects on the process of resynchronization.
4. Circadian rhythms of different functions adjust at different rates. Thus,

during resynchronization, the normal temporal integration of physiological processes and behavior is disrupted.

5. Different phase reference points (e.g., maximum, minimum) in one rhythm may adjust at different rates (ref. 7). Interpretation of rhythm waveforms during resynchronization is complicated because rhythms adjusting at different rates may mask the expression of one another. For example, changes in gross locomotor activity associated with the sleep/wake cycle are reflected in the waveform of the core-temperature rhythm, since activity elevates core temperature.

6. The stronger the zeitgebers in a new time zone, the faster the rate of adjustment to local time.

7. In response to zeitgeber phase advances of 6 or more hours, some rhythms may adjust by advancing, while others resynchronize by undergoing the reciprocal delay (e.g., an 18 hr delay in response to a 6 hr advance). This phenomenon has been termed resynchronization by partition.

8. Mathematical modeling studies (ref. 12) suggest that the rate and direction (by phase advance or delay) of resynchronization are strongly dependent upon the period(s) of the circadian pacemaker(s).

The fact that different rhythms adjust at different rates, and the occurrence of resynchronizaton by partition, both suggest that improved understanding of the multioscillator structure of the circadian system may be a key to improved understanding of circadian-related jet-lag phenomena. The present study was designed to assess some of the physiological and psychological effects of a 9-hr phase delay and a subsequent 9-hr phase advance experienced by Norwegian Airforce Orion P-3 crews deploying from Andoya, Norway (GMT +1 hr), to Moffett Field, California (GMT -8 hr), and returning to Andoya.

We are indebted to the Andoya P-3 Squadron of the Royal Norwegian Airforce whose support was essential to this project. We also acknowledge invaluable technical assistance from Linda Connell, Carol Carrington, Bill Carson, Kevin Gregory, and Donna Miller, of Ames Research Center.

METHODS

The subjects in this study were nine P-3 Orion crew volunteers from a Norwegian Airforce squadron based at Andoya (70 ^{o} N lat.). They were drawn from four crews who experienced the deployment outlined in table 1, at 1-wk intervals beginning February 24, 1984. Two of the subjects (both training captains) were an exception to this pattern in that they did not return with their original crews, but remained at Moffett Field for an additional 2-wk, and departed on Thursday with the current crew. The protocol thus included a 9-hr phase delay over the course of two days, followed by the reciprocal 9-hr phase advance. Subjects were monitored for a maximum of 4 days prior to the day of departure from Andoya, throughout the trip, and for a maximum of 3 full days after their return to Andoya.

Rectal temperature, heart rate and activity of the nondominant wrist were recorded every 2 min with a Vitalog PMS-8 biomedical monitor. The activity detectors (a three-dimensional array of mercury switches) could not be cross-calibrated. Therefore, each subject wore the same detector throughout the study, and data on average activity during sleep have been normalized for each subject with respect to his average activity during sleep at home prior to the trip. The data on average heart rate during sleep have likewise been normalized for each subject with respect to his average heart rate during baseline sleep at home.

Subjects also kept a daily log of sleep, naps, duty times, exercise, food and fluid consumed, voidings, cigarettes smoked, and medications taken. Daily alcohol consumption was noted, with a count of 1 being equivalent to a glass of beer or wine, or one shot of spirits. Each night of sleep was rated upon awakening, on a scale from least (1) to most (5), on the questions:

Difficulty falling asleep?
Difficulty arising?
How deep was your sleep?
How rested you feel?

In addition, every even hour (Greenwich Mean Time) during waking, subjects rated themselves on a scale from 0 (not at all) to 4 (extremely) on a checklist of 26 adjectives, and estimated their fatigue by placing a mark on a 10-cm line signifying a continuum from most alert to most drowsy. Subjects also completed a background questionnaire which included questions on flying experience, health, sleep, dietary and exercise habits, and also included the Personal Attributes Questionnaire (ref. 21), the Work and Family Orientation Questionnaire (ref. 21), the Eysenck Personality Inventory (ref. 9), and the Horne and Ostberg Morningness-Eveningness Questionnaire (ref. 19). The physiological recording procedures, daily logs, and background questionnaire were the same as those being employed in an ongoing NASA study of fatigue and circadian

desynchronization in commercial and military flight crews (ref. 15). All times refer to Greenwich Mean Time.

In view of the difficulties inherent in tracking the phase of the nonstationary, nonsinusoidal waveforms of circadian rhythms during resynchronization to the new time zone, three different techniques for phase analysis were compared. First, the data were averaged in 20-min bins, and subjected to a robust, locally weighted regression smoothing (ref. 3) to identify times of the daily minima. (Since the temperature minimum normally occurs during sleep in synchronized subjects, it is less contaminated by activity masking than the daily temperature maximum.) Second, acrophases of best-fitted 24-hr sinusoids were computed every 4 hr, using a sliding 24-hr data window. Third, the 20-min averaged data were passed through a digital bandpass filter, with a Hanning window with a center frequency of 24 hr and half-power at 18 hr and 36 hr (window width 51.84 hr).

RESULTS

Fatigue and Mood Ratings

In figure 1, the 2-hourly fatigue ratings have been averaged across all subjects for each GMT day. (All pretrip baseline ratings have been combined.) One-way analysis of variance (ANOVA) indicated that fatigue did not vary significantly across days of the trip ($F = 1.35$, $p = 0.20$). On the day that crews left Andoya, however, fatigue ratings were significantly lower than on baseline days ($t = -2.58$, $p = 0.01$).

Factor analysis of the mood-adjective checklist data from 72 pilots in a previous study (ref. 15) indicated that the 26 adjectives represent three orthogonal factors, viz:

Positive (+ve) affect - friendly, pleasant, cheerful, happy, kind, considerate, relaxed, carefree.

Negative (-ve) affect - grouchy, sluggish, dull, tired, sleepy, jittery, forgetful, annoyed, defiant, tense.

Activation - efficient, clear thinking, vigilant, lively, full of pep, hard working, dependable, active.

The 2-hourly ratings on these three factors have been averaged across subjects in the present study, for each GMT day (fig. 2). One-way ANOVA indicated that positive affect varied significantly across days of the trip ($F = 1.89$, $p = 0.04$). This was primarily due to very high ratings on the day following the return to Andoya. Negative affect did not vary significantly across days of the trip ($F = 1.30$, $p = 0.22$). Activation, on the other hand, varied significantly ($F = 2.33$, $p = 0.01$) in a manner suggesting that this factor might be a useful indicator of fatigue. Thus activation decreased to levels significantly below baseline by the time crews reached Moffett, having travelled west for 2 days, crossing nine time zones. (For day 22, $t = -3.42$, $p = 0.00$). There was some indication of recovery across the days at Moffett, with a subsequent drop of activation over the 2 days of return travel. (For day 28, $t = -3.20$, $p = 0.00$). Finally, there was a rapid recovery, with activation reaching baseline levels on the first full day back at Andoya.

The Sleep/Wake Cycle

SUBJECTIVE SLEEP QUALITY. - Neither subjective sleep duration estimates ($F = 1.40$, $p = 0.18$), nor subjective sleep ratings ($F = 1.41$, $p = 0.18$) varied significantly across days of the trip. Since these subjective measures of sleep quality were reported by the subjects upon awakening, they are plotted in figure 3 with respect to the day of wakeup. For both measures, there is some indication of a decrement associated with the westward time-zone shift, followed by

recovery during the 5 days at Moffett, and a larger decrement associated with the eastward flight. (The very short average sleep duration on day 24 is largely attributable to two subjects who reported sleeping 1 hr and 1.5 hr respectively.)

OBJECTIVE SLEEP QUALITY. - The average amount of activity during sleep did not vary significantly across the days of the trip. ($F = 0.91$, $p = 0.52$). There was a tendency (fig. 4a), however, for activity to be greater in sleep episodes during and following flights (days 22, 28, and 31). (Note: the subjects did not go to bed on day 21. Rather, they delayed their sleep until early on day 22 e.g., figure 6.) On the other hand, average heart rate during sleep (fig. 4b) was significantly higher than baseline for the sleep at Brunswick, and for the first night at Moffett. (For the sleep beginning on day 22, $t = 3.06$, $p = 0.00$. For day 23, $t = 3.75$, $p = 0.00$.) Heart rate was also significantly elevated on the night preceeding the return flight from Moffett. (For day 26, $t = 2.26$, $p = 0.03$). These differences resulted in a significant variation across the days of the trip ($F = 2.47$, $p = 0.02$.) Interestingly, although the westward flight produced significant elevation in the average heart rate during sleep, the eastward flight did not. The subjective and objective measures of sleep quality were not significantly intercorrelated in this study, in contrast to a larger sample of short-haul pilots (45 subjects, 150 nights of sleep: Gander and Graeber, unpublished data). The small sample size in the present study, and the added complication of time-zone shifts, may have contributed to this discrepancy.

EFFECTS OF ALCOHOL ON SLEEP QUALITY. - Six of the eight subjects for whom complete log data were available, consumed alcohol during the study. Consumption was much greater during the trip than either before or after (fig. 5). Evidently alcohol was not used as a countermeasure for the effects of the eastward flight. The low alcohol consumption in Norway may reflect, in part, the large price differential between Norway and California. Since there were considerable intersubject differences in the amount of alcohol consumed, daily intake for each subject was converted to a percentage of his total intake over the study. These normalized daily values were then compared (by two-way ANOVA; subject, by alcohol/no alcohol, by sleep quality) with each of the sleep-quality measures for the subsequent night's sleep. None of the sleep-quality measures was significantly different on nights following alcohol consumption versus nights without prior alcohol consumption. (For sleep ratings, $F = 0.02$, $p = 0.88$. For sleep durations, $F = 0.03$, $p = 0.86$. For average activity during sleep, $F = 0.03$, $p = 0.86$. For average heart rate during sleep, $F = 0.78$, $p = 0.38$.) For nights following alcohol consumption, however, there was a significant positive correlation between the amount of alcohol consumed and sleep duration ($r = 0.57$, $p < 0.05$).

SUBJECTIVE SLEEP TIMING. - All subjects showed a clear phase delay in the times of sleep onset and wake onset following the westward flight. This is evident (fig. 6) in the small standard errors on the averages across subjects during the

phase delay. To estimate the magnitude of the delay shift for each subject, the times of sleep onset and the subsequent wake onset on day 27 were compared with the average sleep times at home. The resulting average shifts of -9.38 hr +/- 1.95 hr (standard deviation) for sleep onset, and -8.89 +/- 0.84 hr for wake onset were not significantly different (one-way ANOVA F = 0.43, p = 0.52).

There was greater intersubject variability in the timing of sleep following eastward flight. The data contributing to figure 6 are the sleep times designated by the subjects as a night's sleep, however five of the eight subjects also took naps during adjustment to the zeitgeber advance. (Daily log data for the return to Andoya were missing for one subject.) Three patterns of adjustment of the sleep wake cycle are shown in figure 7. The subject in figure 7a completed the standard protocol and showed a clear phase delay followed by a clear phase advance. Similarly, in figure 7b, the sleep/wake cycle underwent straightforward phase shifts, but in this case the subject remained at Moffett for the 3 wk, so that presumably he was fully synchronized to local time before the return (eastward) flight. The subject in figure 7c also stayed at Moffett for 3 wk, however he adopted a different sleep strategy during the flight back to Norway. He took a nap from 1910 hr to 2330 hr during the second leg of the flight, a brief nap (1400 hr to 1600 hr) the following afternoon, and then finally went to bed at 2330 hr. This sleep pattern had a major effect on the adjustment of his other rhythms (see below).

The Temperature Rhythm

Adequate baseline temperature data to permit estimates of phase shifts were available for seven of the nine subjects. Four hourly estimates of the cycle-by-cycle acrophases for these subjects have been averaged in figure 8. All seven subjects showed an unambiguous phase delay in response to the 9-hr westward time-zone displacement. In contrast, there was considerable variability among subjects in their responses to the 9-hr phase advance, particularly in the extent of waveform disruption. In addition, one subject apparently underwent a phase delay of the temperature rhythm in response to the zeitgeber advance. This variability of response is reflected in the magnitude of the standard error bars in figure 8. The average baseline acrophase of the temperature rhythm, estimated by this technique, was 15.2 hr. During the final 24 hr shown in figure 8, the average acrophase had only returned to 19.3 hr; i.e., the phase advance was incomplete.

A small reduction in temperature rhythm amplitude typically accompanied adjustment to the zeitgeber delay (fig. 9). To measure the magnitude of the delay shift accomplished by the temperature rhythm, average phase estimates for the final 24 hr at Moffett were subtracted from average baseline phase estimates, for each subject. The results for the three phase-

estimating techniques employed are shown in table 2, together with the average phase shifts measured in the sleep/wake cycle. One-way ANOVA indicated that the estimates of the temperature-rhythm phase delay by the three techniques were not significantly different ($F = 1.93$, $p = 0.17$). These analyses suggest that the 9-hr phase shift was essentially complete before the subjects left Moffett. Interestingly, the phase delay measured by the temperature minimum was significantly correlated with the phase delay in the time of sleep onset ($r = 0.84$, $p < 0.05$). There were no other significant correlations between estimates of the phase shifts of the two rhythms.

Three types of response of the temperature rhythm to the zeitgeber advance are shown in figure 10. (These are the same subjects whose sleep/wake cycles are shown in figure 7.) The subjects in figure 10a and 10b both showed phase advances in their temperature rhythms: however, the subject in figure 10c had a disrupted sleep/wake cycle and was apparently undergoing a 15-hr phase delay in the temperature rhythm, at least until the time that data collection ceased.

Interactions Between Mood, Personality, and Age

Correlation analyses were performed to test whether age or subjects' scores on any of the personality scales were significant predictors of their average mood ratings during the pretrip baseline days (table 3).

Age was the only subject attribute which correlated significantly with positive affect in this study. Thus older subjects tended to rate themselves more friendly, pleasant, cheerful, kind, etc., during the pretrip baseline days in Andoya.

Scores on the expressivity index of the Personal Attributes Questionnaire (ref. 21) showed significant negative correlation with baseline ratings on the negative affect mood axis. A high score on the expressivity scale indicates a subject who is expressive of his own emotions and aware of the feelings of others. Such subjects scored themselves low on the adjectives grouchy, sluggish, dull, tired, etc., during baseline. The significant negative correlation between androgeny and negative affect is due to the fact that the androgeny score is a combination of the instrumentality and expressivity scores (ref. 21).

The significant negative correlation between the neuroticism scale of the Eysenck Personality Inventory (ref. 9) and negative affect is counter-intuitive. This highlights a potential problem in the mood and personality data in this study, i.e., asking subjects, who are not native English speakers, to differentiate subtle shades of meaning on questionnaires in English.

Scores on the work index of the Work and Family Orientation

Questionnaire were significantly correlated with baseline ratings on the "activation" mood axis. A high score on the work orientation scale is exemplified by statements like "once I undertake a task, I dislike goofing up and not doing the best job I can" (ref 21, pg 89).

Because the activation mood factor varied in a manner which could have been fatigue-related (fig. 2), correlation analyses were performed to see whether the degredation in activation on day 22 was related to age or personality. There were no significant correlations, either with the subjects' average activation ratings on day 22, or with the difference between this value and the baseline score (table 3).

Interactions Between Rates of Phase Shift, Personality and Age

Table 4 summarizes correlations between age, subjects' scores on the personality scales, and the magnitude of the phase delays in the temperature rhythm and the timing of sleep.

Scores on the competitiveness scale of the Work and Family Orientation Questionnaire (ref. 21) correlated significantly with the phase shifts in both the temperature minimum and the timing of sleep onset. (Wake onset was probably controlled largely by alarm clocks.) A high score on competitiveness is exemplified by, e.g., "I really enjoy working in situations involving skill and competition" (ref. 21, pg 89), and was correlated, in this study, with greater phase-delay shifts.

The extraversion scale of the Eysenck Personality Inventory (ref. 9) was significantly correlated with the magnitude of the delay shift of the filtered temperature waveform. Because of the window width of the filter (about 52 hr), this measure reflects the shifting of the entire waveform, as opposed to the minimum alone. A high score on the extraversion scale is interpreted as indicating that "individuals tend to be outgoing, impulsive, and uninhibited, having many social contacts and frequently taking part in group activities" (ref. 9). In the present study, high extraversion scores were correlated with greater delays of the temperature rhythm.

The correlation between morningness/eveningness scores and delays of the temperature minimum, just failed to reach significance at the 95% level. The correlation coefficient was negative, i.e., more "evening" types tended to show greater phase delays. In the present study, however, scores on the morningness/eveningness questionnaire were not significantly correlated with the phase of the temperature rhythm at home, as measured by any of the 3 techniques. Nor was there a significant correlation between the phase of the temperature rhythm at home and the magnitude of the phase delay observed.

Similarly, although the correlations of phase shifts with age were all negative, they failed to reach significance.

DISCUSSION

The present study was designed to assess, under field conditions, the effects of 9-hr time-zone shifts on fatigue and the circadian rhythms of sleep/wake and core temperature.

Effects on Fatigue

Ten measures of fatigue were collected, which fell into two categories:

1. two-hourly fatigue and mood ratings;
2. estimates of sleep quality (including subjective ratings of sleep duration and quality, and objective measures of sleep quality, i.e., average heart rate and activity during sleep).

Of the 2-hourly ratings, only the "activation" mood index showed significant variation across the days of the trip, which could be interpreted as fatigue-related (fig. 2). Average baseline ratings on this cluster of adjectives were significantly correlated with scores on the work orientation scale of the Work and Family Orientation Questionnaire. This relationship was also found in a much larger sample (n = 64) of commercial airline pilots flying short-haul operations on the east coast of the United States (Gander et al., unpublished observations). It is not particularly surprising that subjects who rate themselves high in orientation toward work should also rate themselves high on the adjectives of the activation index (efficient, clear thinking, vigilant, lively, full of pep, hard working, dependable, active). It is interesting, however, that one-time answers on a questionnaire correlated with repeated mood ratings made over several days during which a variety of activities were undertaken.

Subjectively estimated sleep durations did not appear to be affected in any systematic way by the time-zone shifts (fig. 3a). On the other hand, subjectively rated sleep quality was significantly poorer than baseline on the first night following the eastward flight, but not following the westward flight (fig. 3b).

Average activity during sleep tended to be highest on the nights that the subjects slept in Brunswick, i.e., between the two westward flight segments (fig. 4a, day 22), and again between the two eastward flight segments (day 28). Activity also remained high during the first night's sleep back in Andoya (day 31). While these patterns are suggestive of a detrimental effect of the flights on restlessness during sleep, the differences were not statistically significant.

Average heart rate during sleep was significantly elevated over baseline levels for the first 2 nights at Moffett (fig. 4b, days 22 and 23), and again on the night preceeding the return flight to Andoya (day 26). This finding would seem

to suggest that the westward flight was more disruptive than the eastward flight, in contrast to the trends in the other sleep-quality measures and the rates of adjustment of the circadian rhythms (see below). Possibly, factors unrelated to the time-zone shifts had greater effects on heart rate during sleep than on the other variables; however, the present data do not provide resolution of this apparent contradiction.

Alcohol consumption did not adversely affect the sleep quality measures employed in this study. In fact, when subjects consumed alcohol during the day, their subsequent night's sleep duration was positively correlated with the amount they had drunk.

Effects on Circadian Rhythms

The average sleep onset and wake onset times appeared to be fully adapted to local time by the first night's sleep at Moffett (fig. 6). In contrast, following the eastward flight, these variables took until the third night in Andoya to return to complete adjustment to within one standard error. The individual patterns of sleeping and napping during adjustment to the time-zone shifts may have been an important factor in the rate of resynchronization of other circadian rhythms (see below).

The core temperature rhythm had evidently completed the 9-hr phase delay by the final 24 hr at Moffett (table 2), however, figure 8 indicates that, on average, the acrophase took several days to come to within one standard error of complete resynchronization. The average acrophase over the final 24 hr of temperature recording at Andoya was still 4.1 hr later than the average baseline acrophase, suggesting that the phase advance was not yet complete.

These pooled results conform to generalizations from previous studies, namely that adjustment takes longer after a phase advance than after an equivalent phase delay, and that the sleep/wake cycle adjusts more rapidly than the core temperature rhythm. There were, however, a number of striking individual differences in the present study.

The subject (83002) whose data are shown in figures 7c and 10c, was exceptional in his responses to the eastward flight, both in his temperature rhythm, which appeared to adjust to the phase advance by undergoing a phase delay, and in his sleep/wake cycle. This subject took a 4.33-hr nap during the final leg of the flight to Andoya and then a short nap the following afternoon. Of the remaining six subjects for whom complete data are available for the phase advance, three took in-flight naps of which the longest was 2.0 hr. Five of the six also went to bed for a "night's" sleep shortly after arrival in Andoya.

A phase delay in the temperature rhythm in response to a 6-hr zeitgeber

advance has been reported for a subject in a temporal isolation experiment (Wever, 1979, figure 77). Since this subject simultaneously phase-advanced his sleep/wake cycle, this was an example of resynchronization by partition. It is unclear whether subject 83002 advanced or delayed his sleep/wake cycle in response to the 9-hr phase advance (fig. 7c). The picture is further confused by the fact that he was on an all-night mission from the evening of day 29 through until the morning of day 30. (Temperature recording ceased on the morning of day 29.)

There are several possible interpretations of the exceptional responses of subject 83002. First, model simulation studies (ref. 12) suggest that the inability of the temperature rhythm to phase advance by 9 hr might be due to an unusually long period of the circadian pacemaker regulating temperature. (In the two-pacemaker model, this would correspond to pacemaker x. In the single pacemaker "somnostat" model (ref. 6), this would correspond to the circadian process). The long in-flight nap could be interpreted as a very advanced night sleep. (In terms of the two-pacemaker model, this would suggest a relatively short period of the sleep/wake pacemaker. In the somnostat model, it would presumably be attributed to a conscious decision by the subject to go to sleep, which effectively lowered the upper threshold of the somnostat, but did not influence the time course of the circadian pacemaker process.) On the other hand, the atypical sleep/wake pattern may itself have been a factor in the response of the temperature rhythm. Recent studies by Czeisler et al. (ref. 5) suggest that sleep per se may constitute an "internal" zeitgeber for the circadian system. It is not presently possible to resolve whether the long in-flight nap was an indicator of unusual characteristics of the circadian system of subject 83002, and/or a cause of his atypical response to the zeitgeber advance.

The only personality scale which correlated significantly with phase delays in both the temperature rhythm (temperature minimum) and the sleep/wake cycle (sleep onset) was the competitiveness rating from the Work and Family Orientation Questionnaire. All of the personality correlations in this study should be interpreted with some caution, given that the subjects were responding to questionnaires which were not in their native language, and in view of the small sample size. Nevertheless the data do suggest that individuals with high achievement need may adapt their circadian rhythms more quickly following westward flight. Subjects who scored high on the extraversion scale of the Eysenck personality inventory also showed greater phase delays in their temperature-rhythm waveforms. It seems likely that such subjects would be more exposed to social zeitgebers in the new time zone, which would tend to enhance their rate of resynchronization (ref. 20).

The phase delays in the core temperature rhythm tended to be larger in "evening" types and in younger subjects; however, these trends did not reach statistical significance. It would be interesting to see whether these effects were

significant in a larger sample. Previous findings from European studies (refs. 1.11.17) have suggested that "evening" types adapt better to shiftwork. Calquhoun (ref. 4) has also reported that subjects with late-peaking temperature rhythms adjust more rapidly to an 8-hr eastward transmeridian flight, than subjects with early peaking temperature rhythms. In the present study, however, there was no significant correlation between the phase of the temperature rhythm at home (as measured by any of the three techniques) and either the magnitude of the phase delay, or the morningness/eveningness score.

Summary

In this study, sleep-quality indices (with the exception of average heart rate during sleep) tended to be more disrupted following eastward flight (phase advance) than following westward flight (phase delay); however, these effects were not very major. Alcohol consumption did not have marked effects on sleep quality. Subjective fatigue and mood ratings were not greatly compromised by the time-zone transitions; however, activation appeared to take several days to recover following westward flight. The rapid recovery after eastward flight may be a response, in part, to returning home.

The data presented here confirm that the circadian rhythms of sleep/wake and core temperature adjust more rapidly following a phase delay than following a phase advance. For either direction of shift, the core temperature rhythm adjusted, on average, more slowly than the sleep/wake cycle. An example is presented of a subject whose core temperature rhythm appeared to undergo a 15-hr delay in response to the 9-hr zeitgeber advance. The pattern of sleeping and napping during and after the eastward flight was evidently a key factor in this unusual response; however, whether it was correlated and/or possibly causal remains unclear. In this small sample, subjects who were extroverts and/or had high achievement need, achieved greater phase delays over the 5 days at Moffett.

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TABLE 1.- TIME LINE OF EACH DEPLOYMENT

Weekday	Day	Location
Friday	21	Andoya, Norway (GMT +1 hr)--Brunswick, Maine (GMT -5 hr)
Saturday	22	Brunswick--Moffett Field, California (GMT -8 hr)
Sunday	23	Moffett Field
Monday	24	Moffett Field
Tuesday	25	Moffett Field
Wednesday	26	Moffett Field
Thursday	27	Moffett Field--Brunswick
Friday	28	Brunswick--Andoya

TABLE 2.- MEAN PHASE DELAYS

Variables	Techniques for Temperature			Sleep	
	Smoothed temp min	Acrophase sinusoid fit	Acrophase, filtered waveform	Sleep onset	Wake onset
Mean phase delay Standard deviation	-9.60 ±1.47 hr	-8.08 ±1.83 hr	-8.43 ±1.19 hr	-9.49 ±1.92 hr	-8.89 ±0.84 hr

TABLE 3.- CORRELATION COEFFICIENTS FOR PERSONALITY AND AGE AS PREDICTORS OF MOOD

Variable	Baseline positive affect	Baseline negative affect	Baseline activation	Activation on day 22	Change in activation
Instrumentality	-0.11	-0.64	-0.06	0.54	-0.50
Expressivity	-0.36	-0.85**	0.23	0.14	-0.09
Androgeny	-0.42	-0.81*	0.33	0.25	-0.17
Mastery	-0.61	0.11	0.24	-0.31	0.32
Competitiveness	-0.41	-0.38	0.48	-0.29	0.34
Work	-0.55	-0.59	0.84**	-0.29	0.39
Extraversion	0.08	-0.02	0.19	0.51	-0.44
Neuroticism	-0.33	-0.87*	0.24	0.64	-0.56
Morning/evening	-0.53	0.03	0.07	-0.40	0.38
Age	0.75*	0.62	-0.54	0.19	-0.26

*$p < 0.05$
**$p < 0.01$

TABLE 4.- CORRELATION COEFFICIENTS FOR PERSONALITY AND AGE AS PREDICTORS OF PHASE DELAY SHIFTS

Variable	Smoothed temp min	Acrophase, sinusoid fit	Acrophase, filtered waveform	Sleep onset	Wake onset
Instrumentality	-0.03	0.04	0.08	-0.45	-0.69
Expressivity	-0.18	-0.03	-0.00	-0.45	-0.72
Androgeny	-0.08	-0.10	-0.17	-0.37	-0.57
Mastery	-0.73	0.19	0.18	-0.38	-0.03
Competitiveness	0.87*	0.21	0.35	0.94**	0.67
Work	0.29	0.75	0.30	0.42	0.16
Extraversion	0.07	0.57	0.79*	0.20	0.43
Neuroticism	-0.12	0.47	0.69	-0.18	0.02
Morning/evening	-0.75	-0.29	-0.08	-0.35	0.02
Age	-0.48	-0.70	-0.51	-0.41	-0.14

*$p < 0.05$
**$p < 0.01$

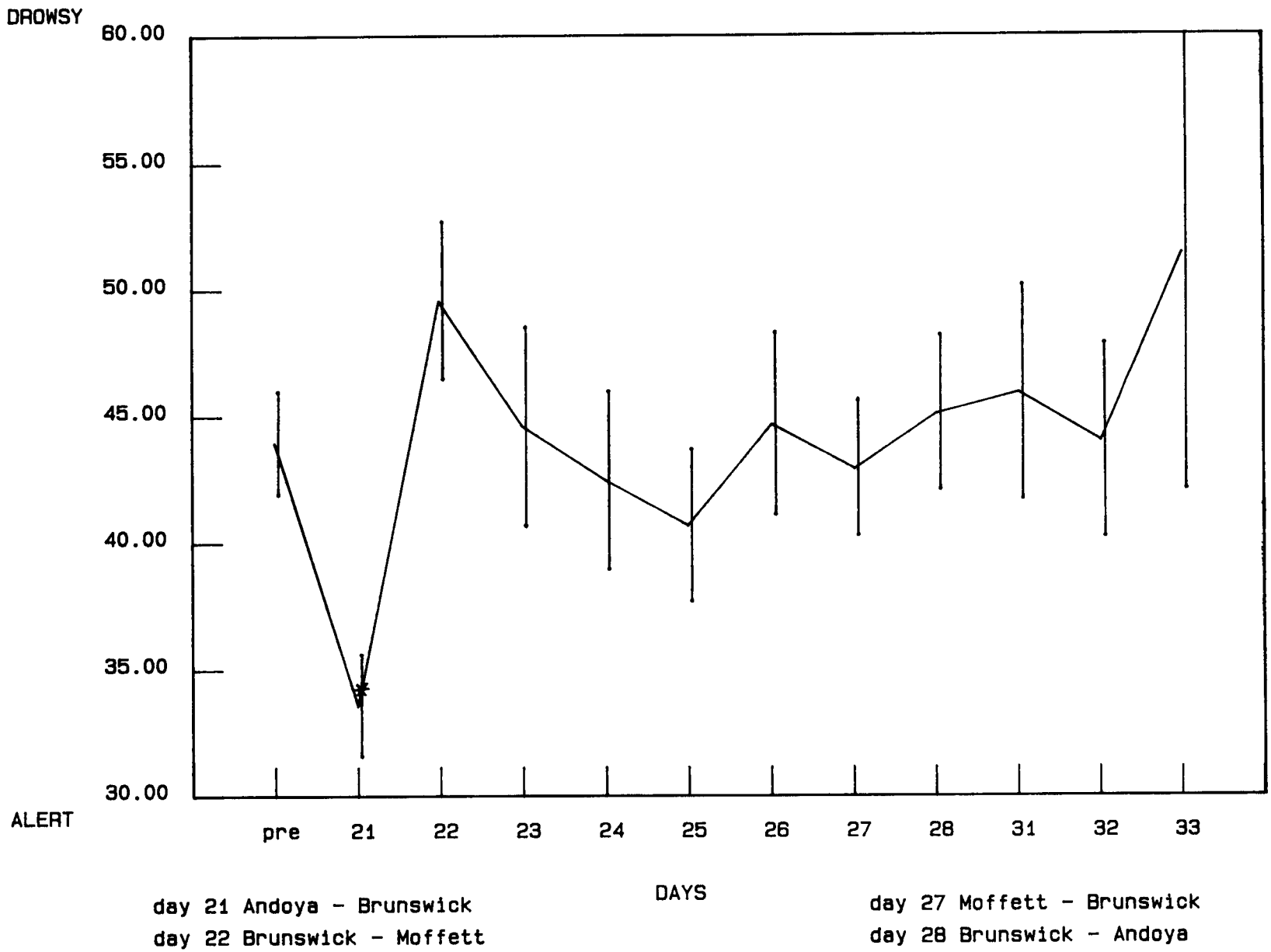


Figure 1.- Subjective fatigue ratings (100-mm analog scale) averaged across all subjects for each day of the study. (Baseline days have been averaged together). Asterisk indicates a value significantly different from baseline.

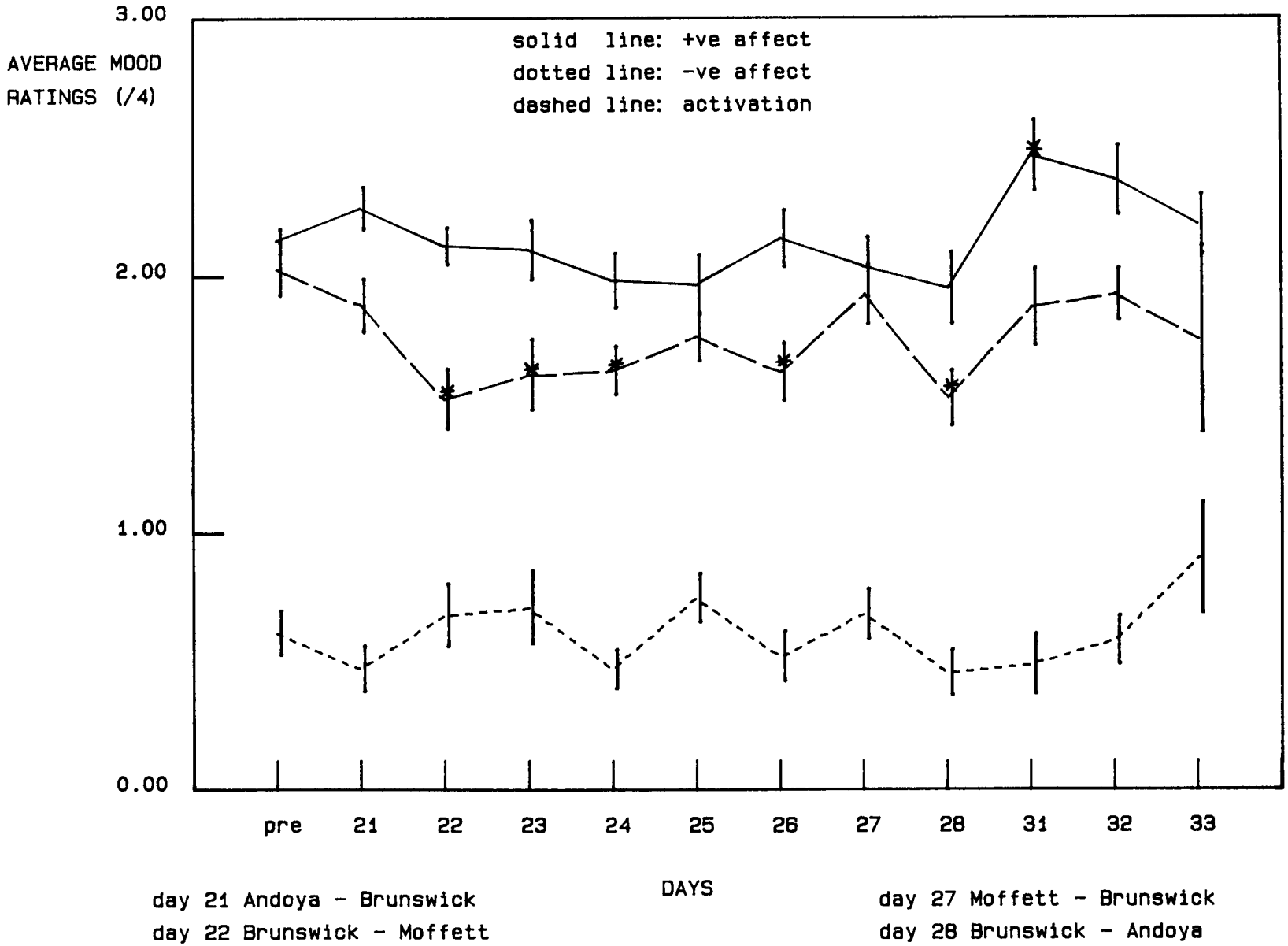


Figure 2.- Subjective mood ratings on each of the three mood factors (0 means "not at all," 4 means "extremely") averaged across all subjects for each day of the study. (Baseline days have been averaged together.) Asterisks indicate values significantly different from baseline for that factor.

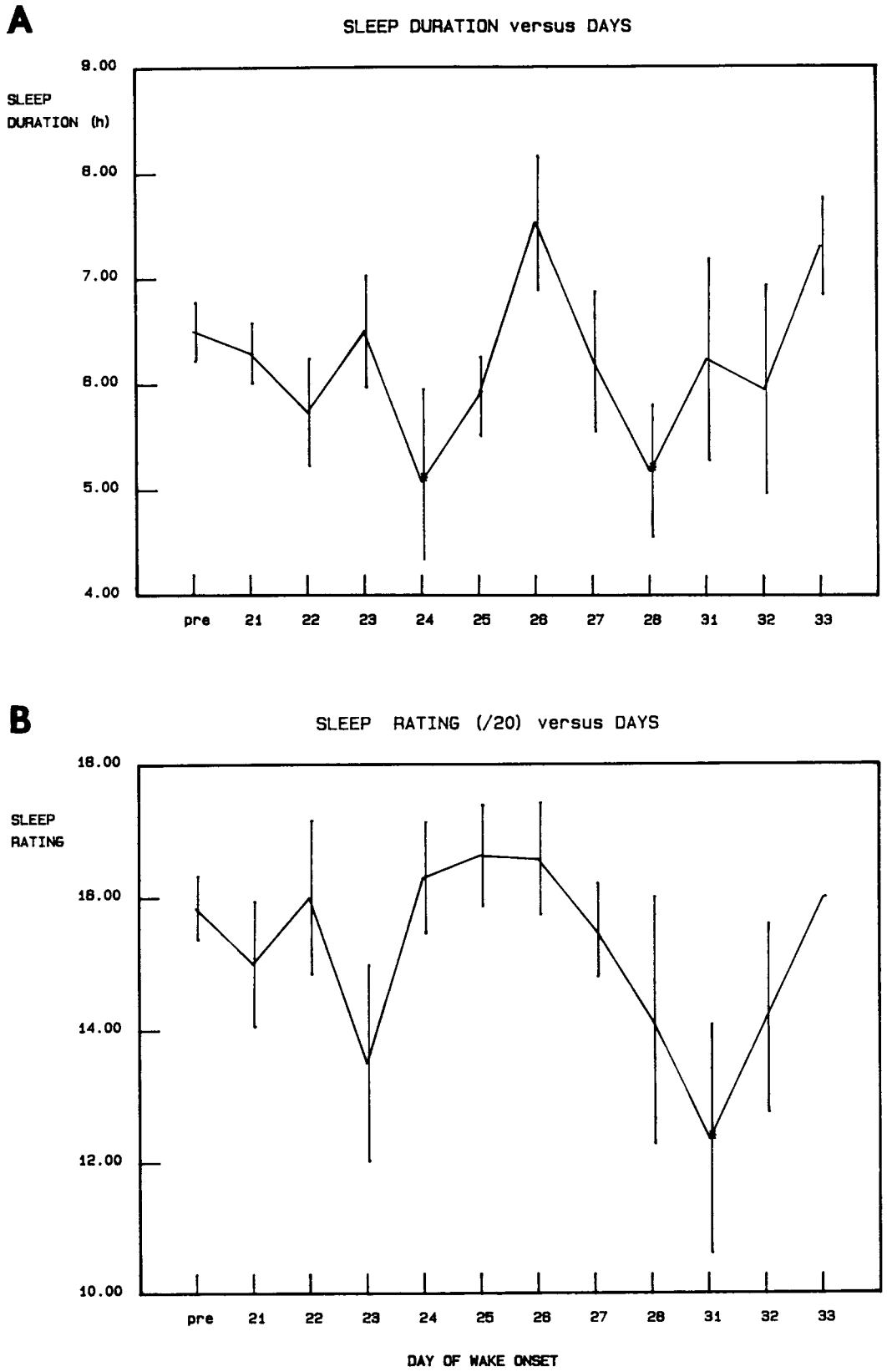


Figure 3.- Subjectively estimated sleep duration and quality. (a) Subjectively estimated sleep durations averaged across all subjects for each day of the study. (Baseline days have been averaged together.) Asterisks indicate sleeps significantly shorter than baseline. (b) Subjective ratings of sleep quality averaged across all subjects for each day of the study. (Baseline days have been averaged together.) The maximum possible score of 20 represents "perfect" sleep. Asterisk indicates a value significantly different from baseline.

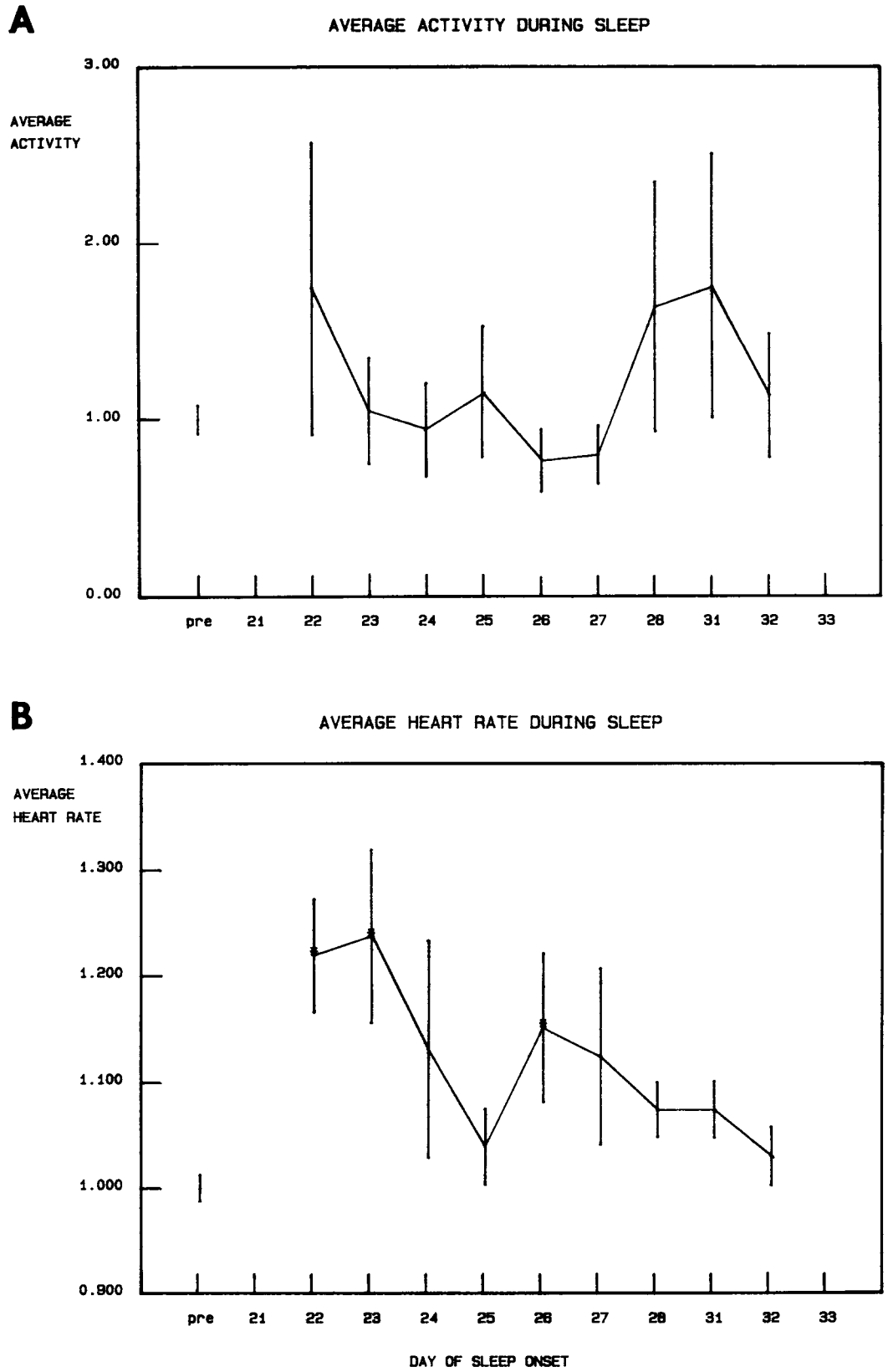


Figure 4.- Average activity and heart rate during sleep. (a) Activity during sleep averaged across all subjects for each day of the study. Data for each subject are normalized with respect to his average activity on baseline nights. (b) Heart rate during sleep averaged across all subjects for each day of the study. Data for each subject have been normalized as in (a).

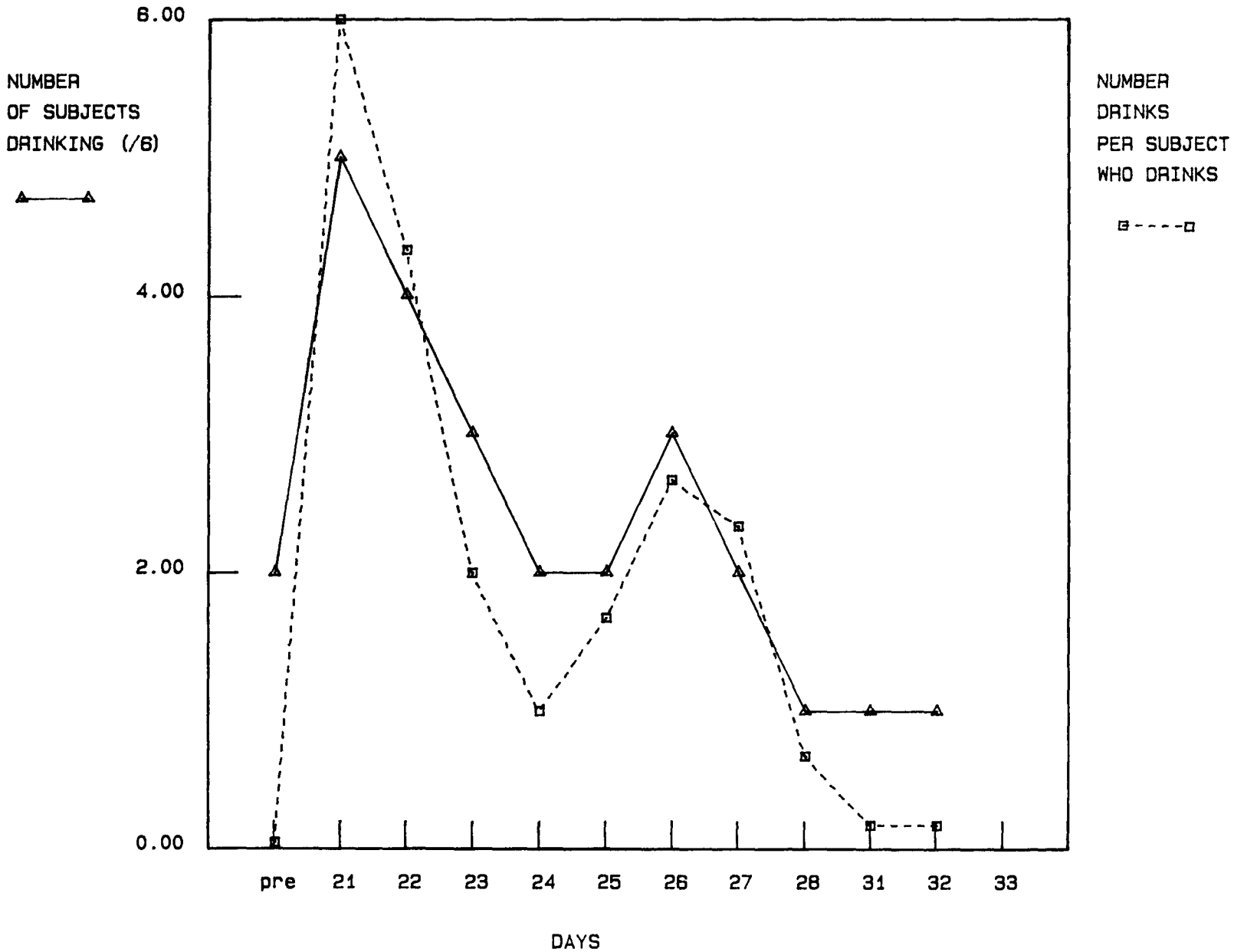


Figure 5.- Alcohol consumption averaged for the six subjects who drank, for each day of the study. Days on which most subjects drank were also days on which subjects tended to drink most.

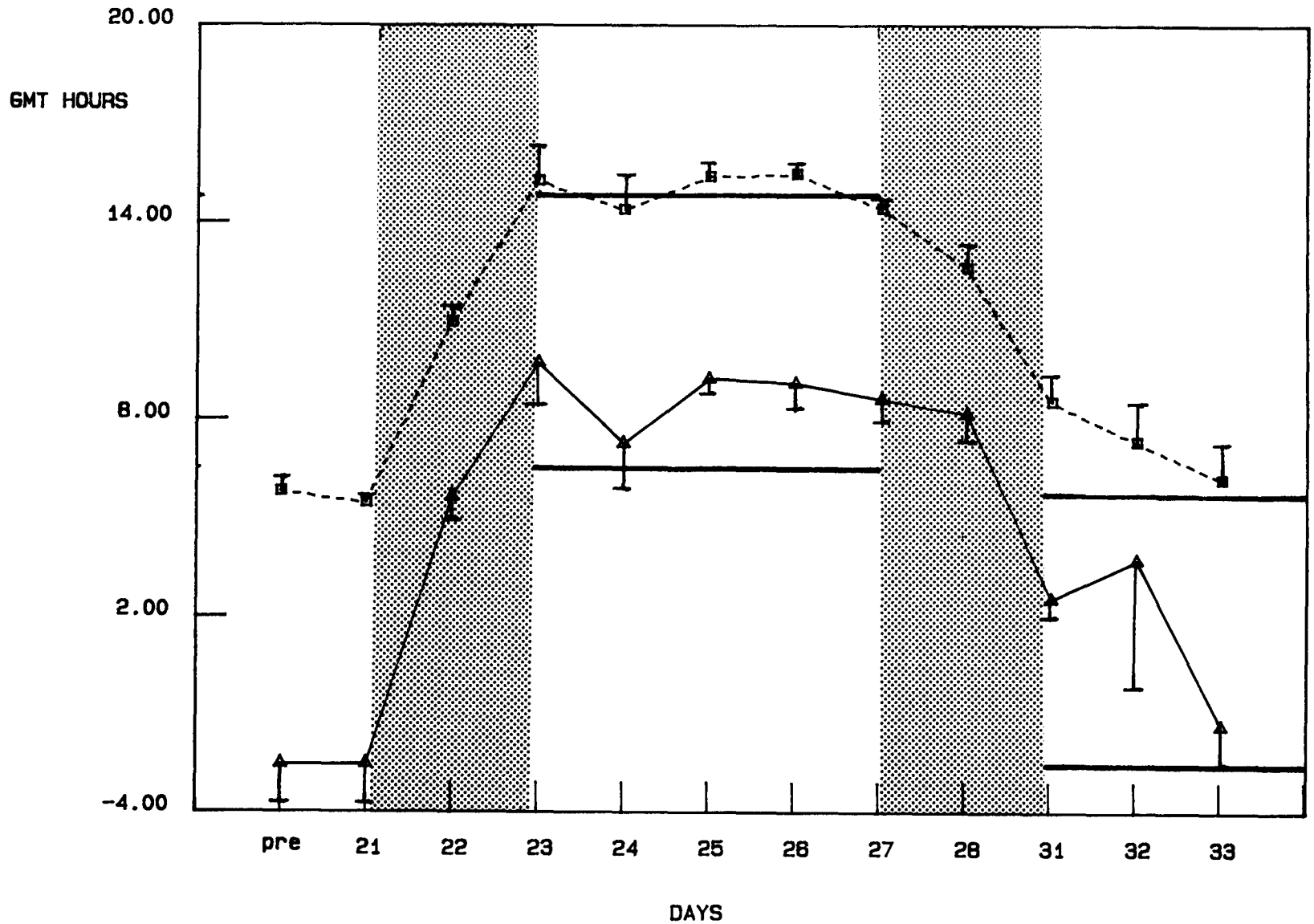


Figure 6.- Times of sleep onset (triangles) and wake onset (squares) averaged across subjects for each day of the study. Stippling indicates days of transmeridian flights. Heavy horizontal lines indicate expected times of sleep onset and wake onset for the completed phase shifts. Vertical bars indicate standard errors (S.E.). The delay shift is evidently complete by the first night's sleep back in Andoya (day 33).

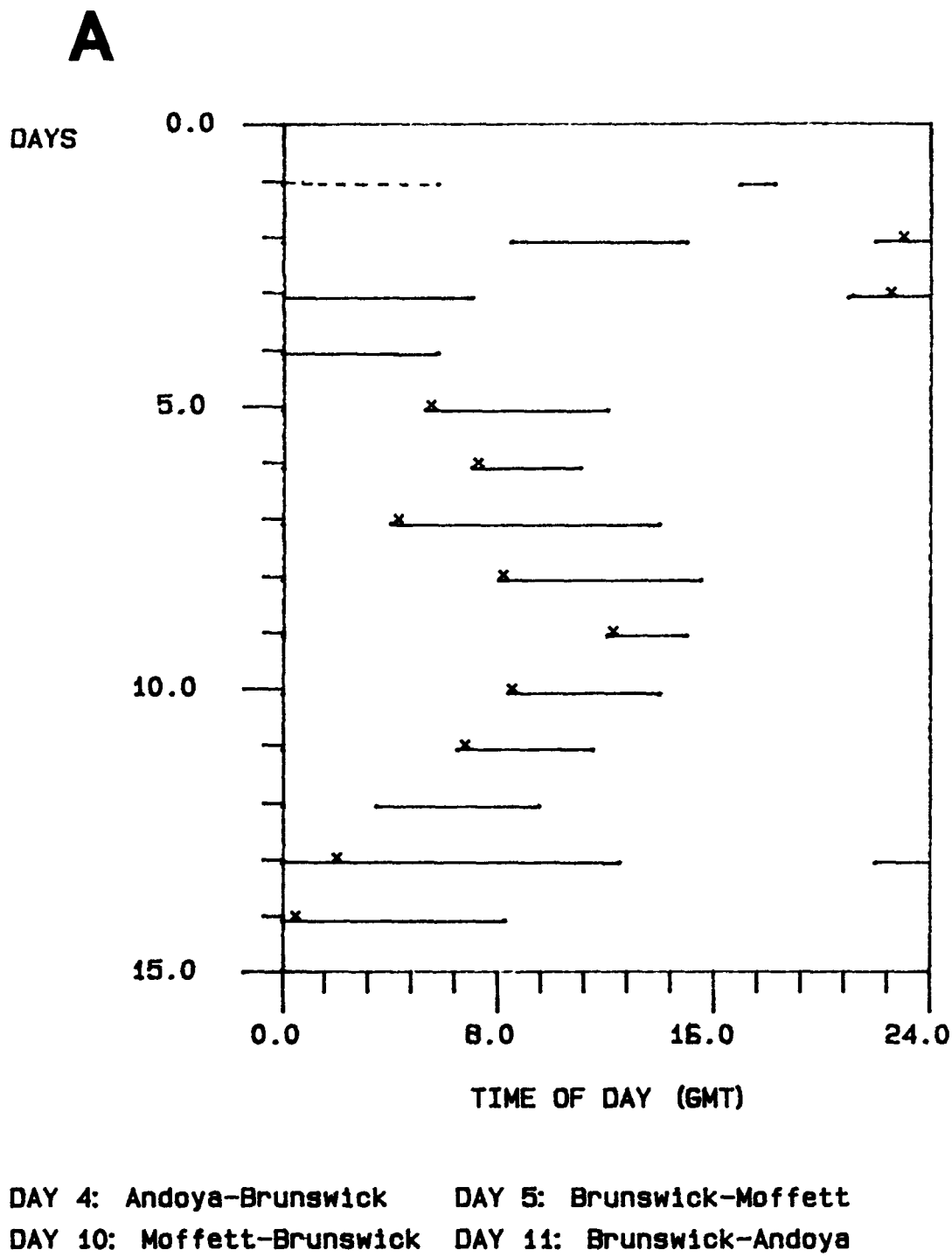
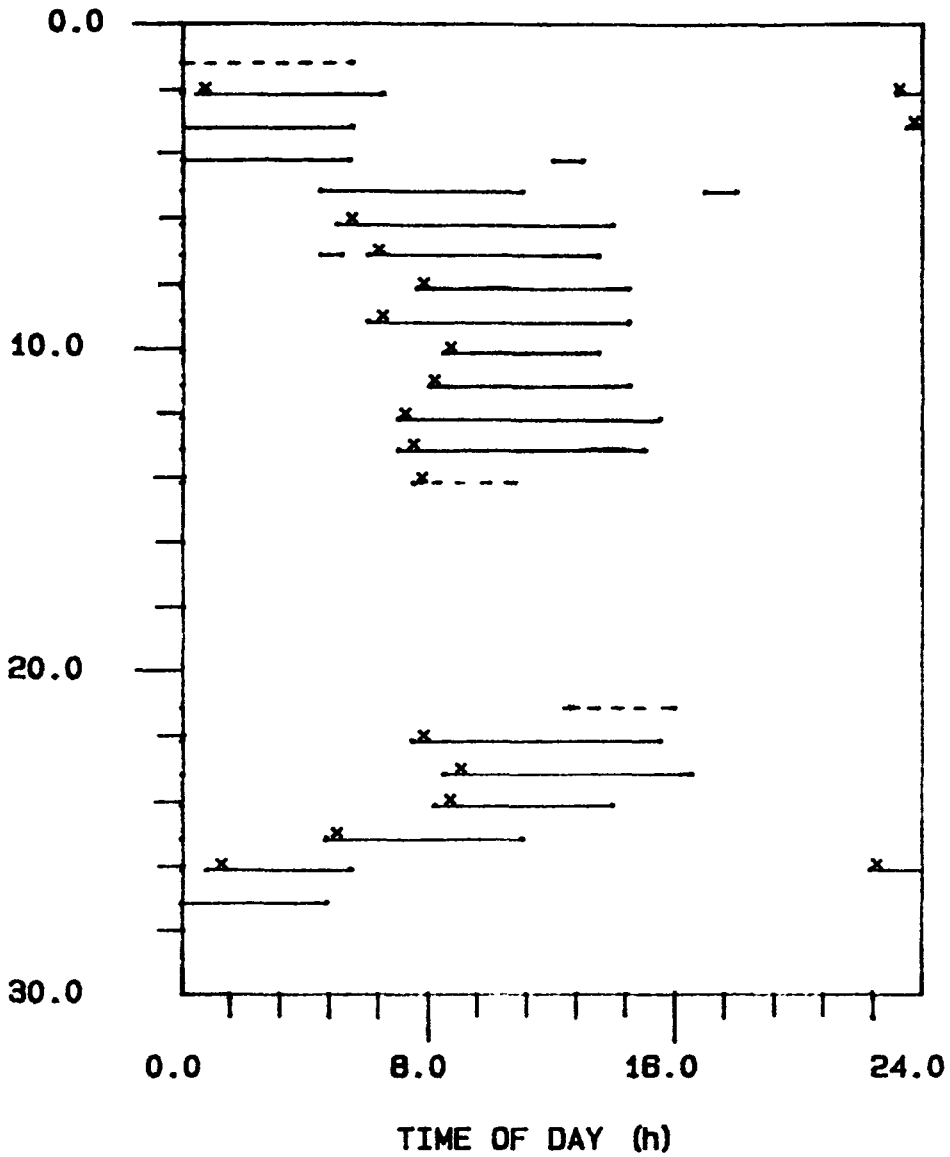


Figure 7.- Patterns of sleep/wake cycle adjustment. (a) Sleep/wake cycle of a subject who experienced the standard protocol (see Methods). Horizontal lines indicate times in bed, asleep (x), and awake. Dotted line indicates a sleep episode for which only wakeup time was reported. Days are numbered sequentially from the beginning of the subject's participation in the study. The subject flew an all-night mission from the evening of day 1 to the morning of day 2.

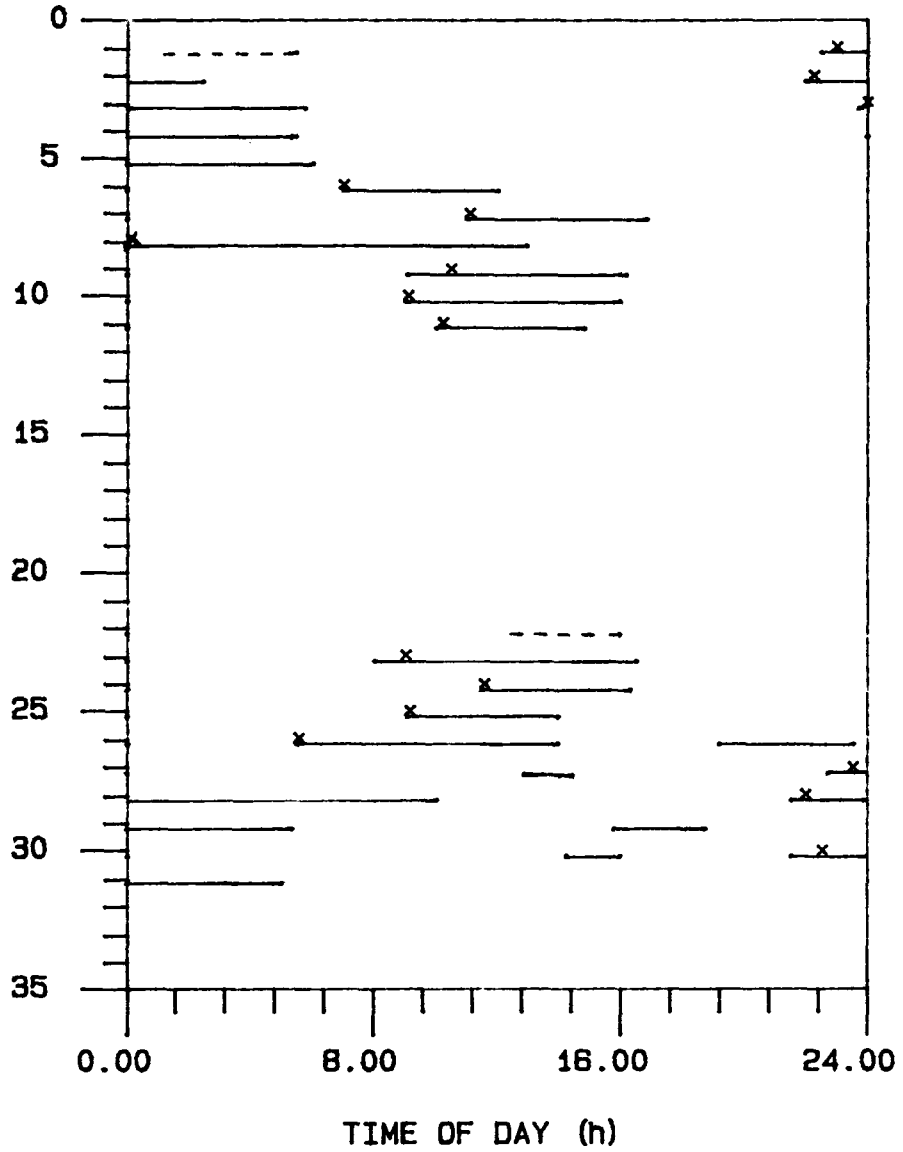
B



DAY 4: Andoya-Brunswick DAY 5: Brunswick-Moffett
DAY 24: Moffett-Brunswick DAY 25: Brunswick-Andoya

Figure 7.- Continued. (b) Sleep/wake cycle for one of the subjects who stayed at Moffett Field for 3 wk. Symbols as in (a), except that dotted lines indicate sleep episodes for which either in bed (asleep) or wakeup times were not reported.

C



DAY 5: Andoya-Brunswick DAY 6: Brunswick-Moffett
DAY 25: Moffett-Brunswick DAY 26: Brunswick-Andoya

Figure 7.- Concluded. (c) Sleep/wake cycle of the second subject who stayed at Moffett for 3 wk. Symbols as in (b). This subject had an exceptional pattern of sleeping and napping during and after the eastward flight (see text). The subject flew an all-night mission from the evening of day 29 through to the morning of day 30.

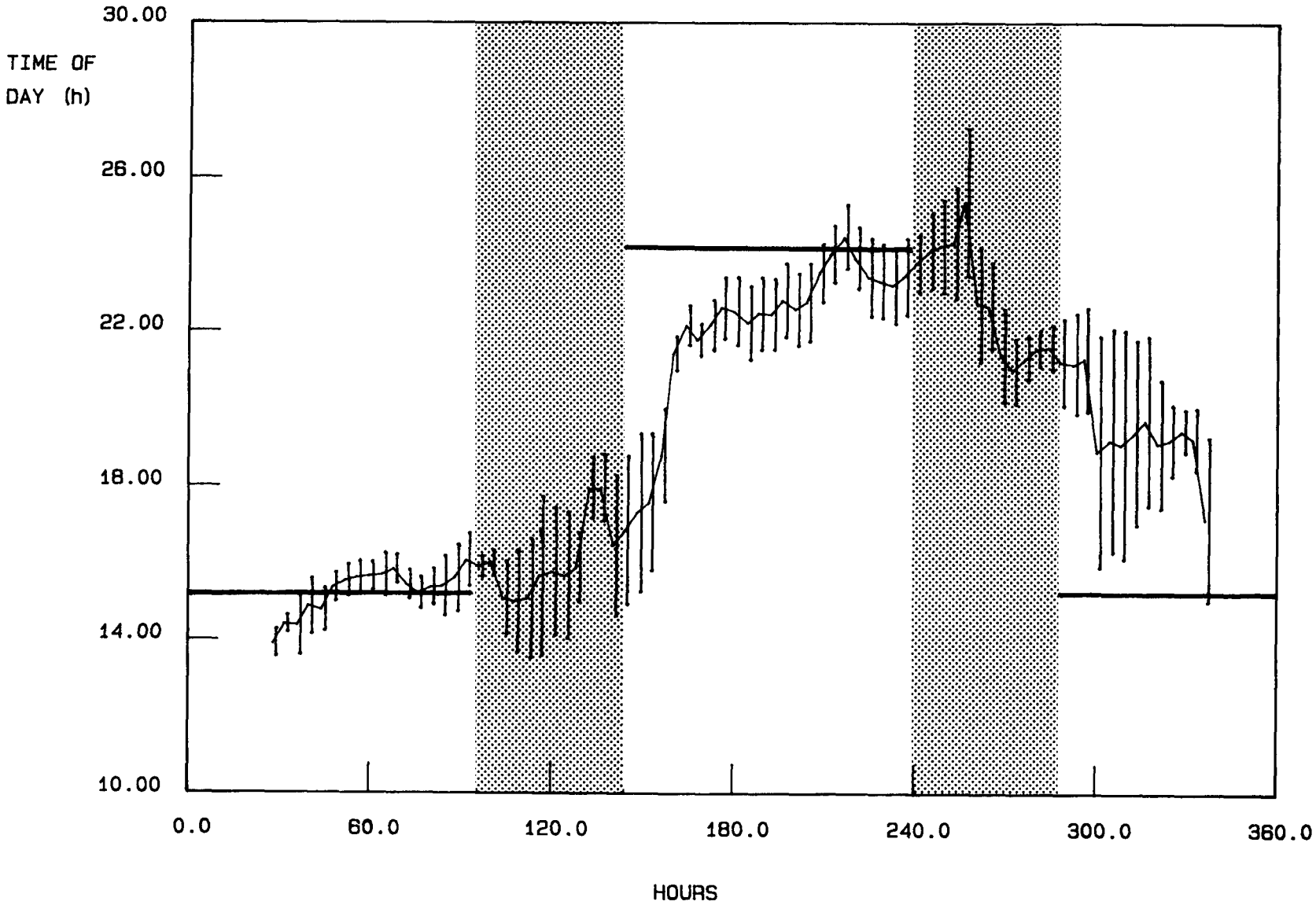


Figure 8.- Times of temperature maximum, estimated as the acrophase of the best-fit 24-hr sinusoid for 24-hr windows of data, calculated at 4-hr intervals. Equivalent time points have been averaged across subjects for consecutive 4-hr intervals throughout the study. Stippling indicates days of transmeridian flights. Heavy horizontal lines indicate estimated times of acrophase for the completed phase shifts. The phase delay is evidently completed by the final day at Moffett (hrs 216-240), while the phase advance is still in progress at the end of the study.

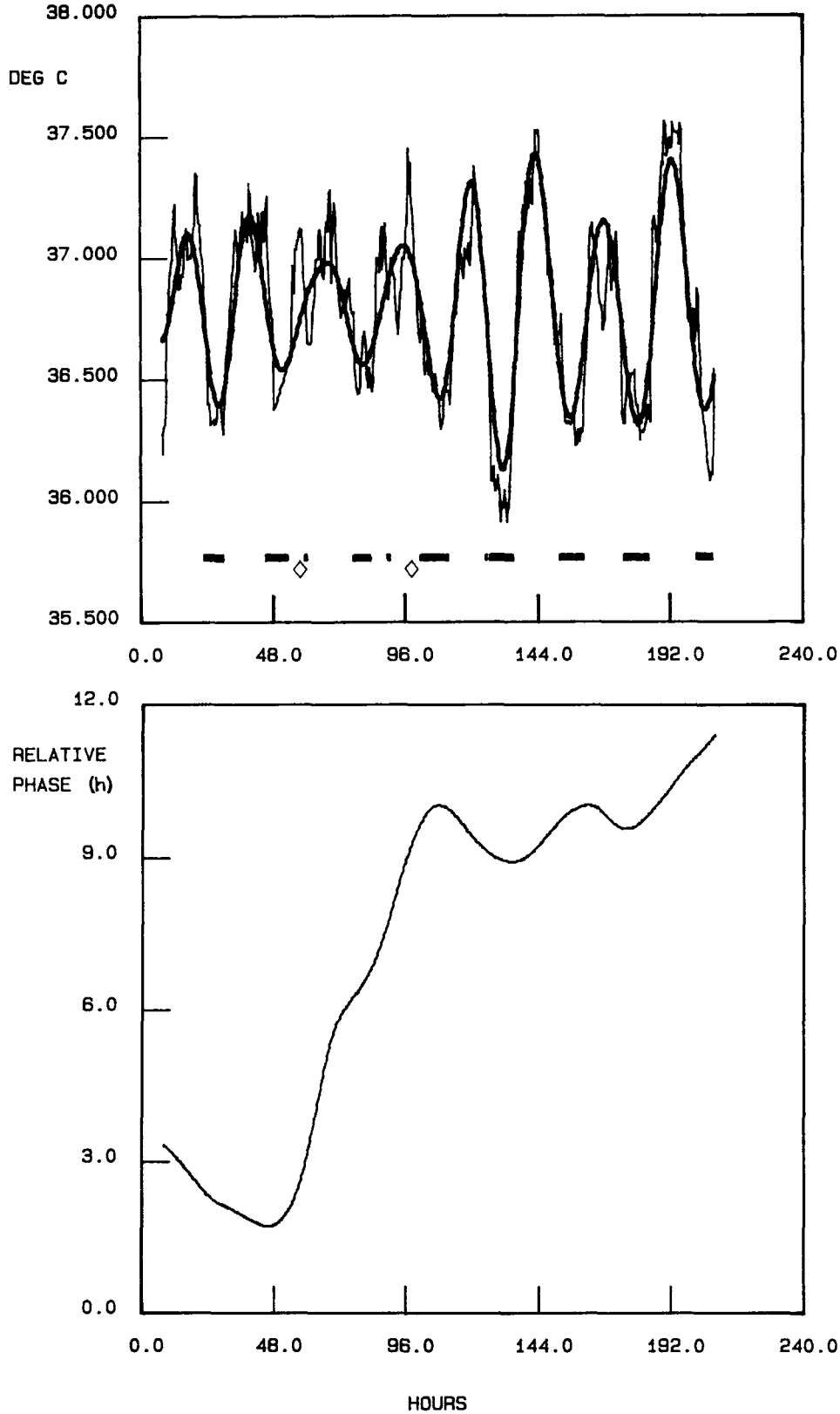


Figure 9.- Upper panel – Temperature data (20-min bins) and Hanning filtered waveform for the baseline days at Andoya, the 2 days of westward flight, and the first 5 days at Moffett, for the subject whose sleep/wake cycle is shown in figure 7(b). Black bars indicate self-reported times of sleep and naps. Diamonds indicate times of take-off from Andoya and final landing at Moffett. Lower panel – Acrophase of the filtered temperature waveform, showing a clear phase delay of about 9 hr. Note: The first and last 26 hr of the filtered data are unreliable, as the first complete 52-hr data window is centered 26 hr into the data, and similarly the final complete 52-hr data window is centered 26 hr from the end of the data.

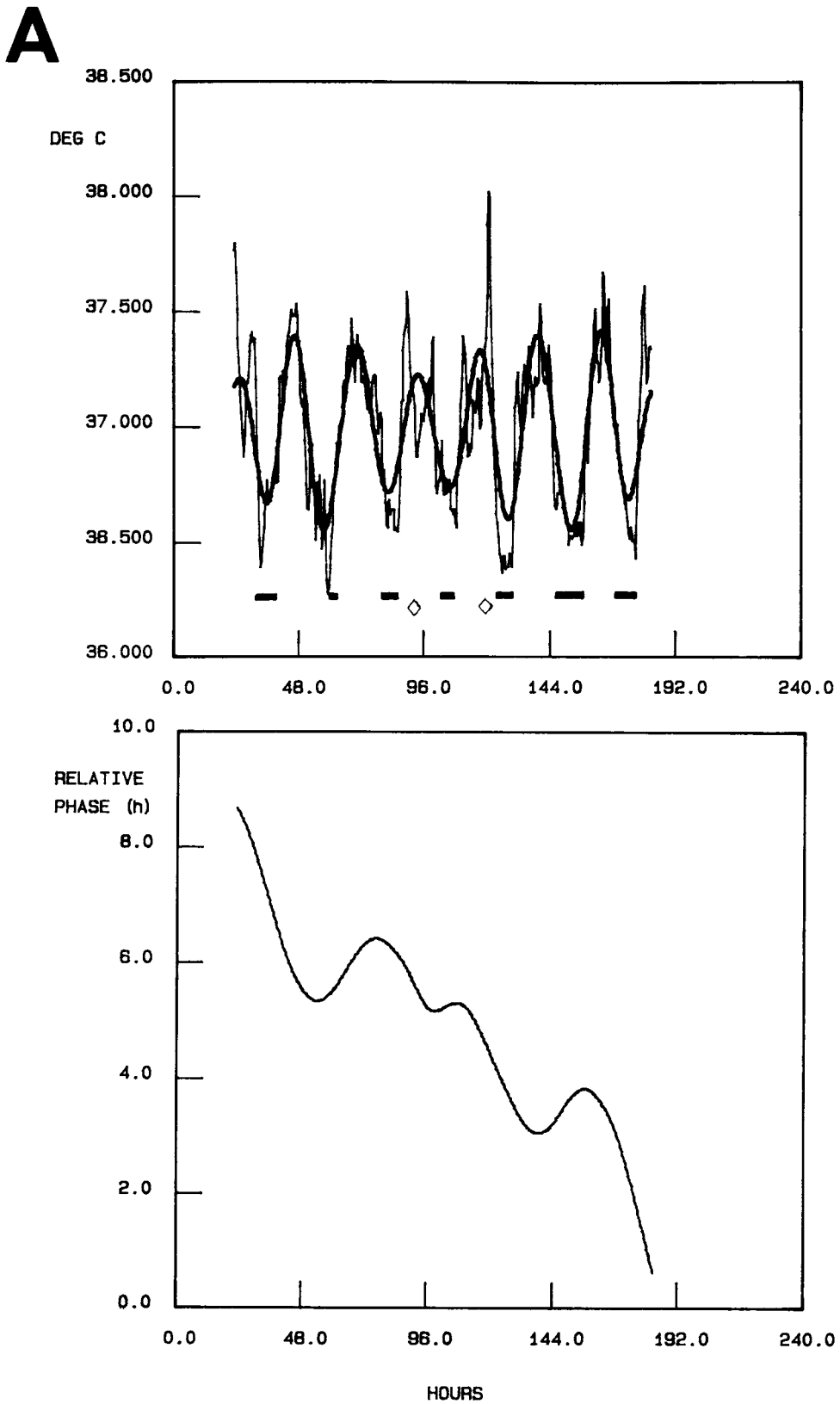


Figure 10.- Three types of response of the temperature rhythm to the zeitgeber advance. (a) Upper panel – Temperature data and filtered waveform for the final 3 days at Moffett and the return to Andoya, for the subject whose sleep/wake cycle is shown in figure 7(a). Black bars indicate self-reported times of sleeps and naps. Diamonds indicate times of take-off from Moffett and final landing at Andoya. Lower panel – Acrophase of the filtered waveform, showing a clear phase advance of about 9 hr.

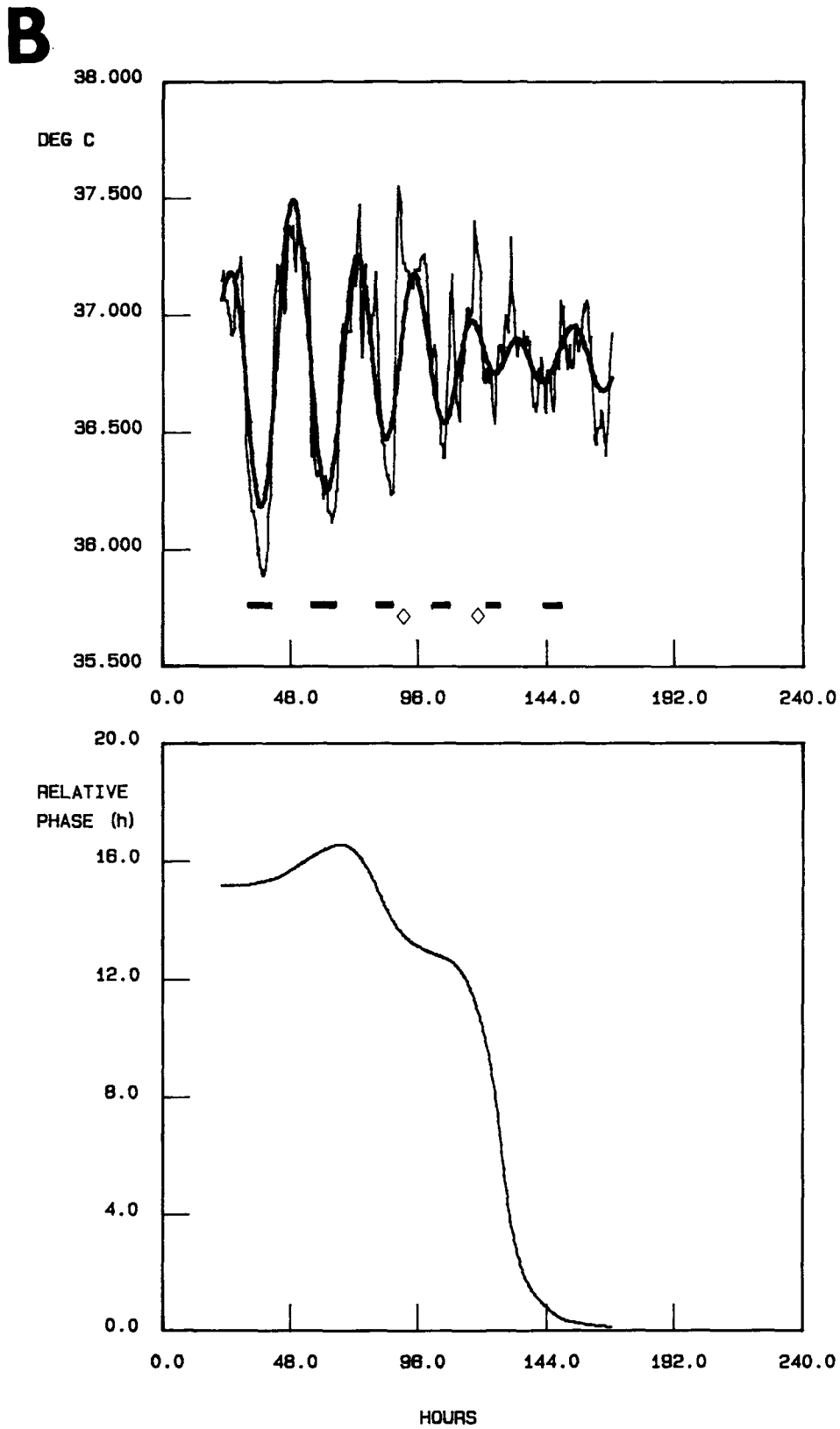


Figure 10.- Continued. (b) Upper panel – Temperature data and filtered waveform as in 10 (a), for the subject whose sleep/wake cycle is shown in figure 7(b). Symbols as in 10(a). Lower panel – Acrophase of the filtered waveform, showing a clear phase advance with indication of overshoot of the 9-hr shift.

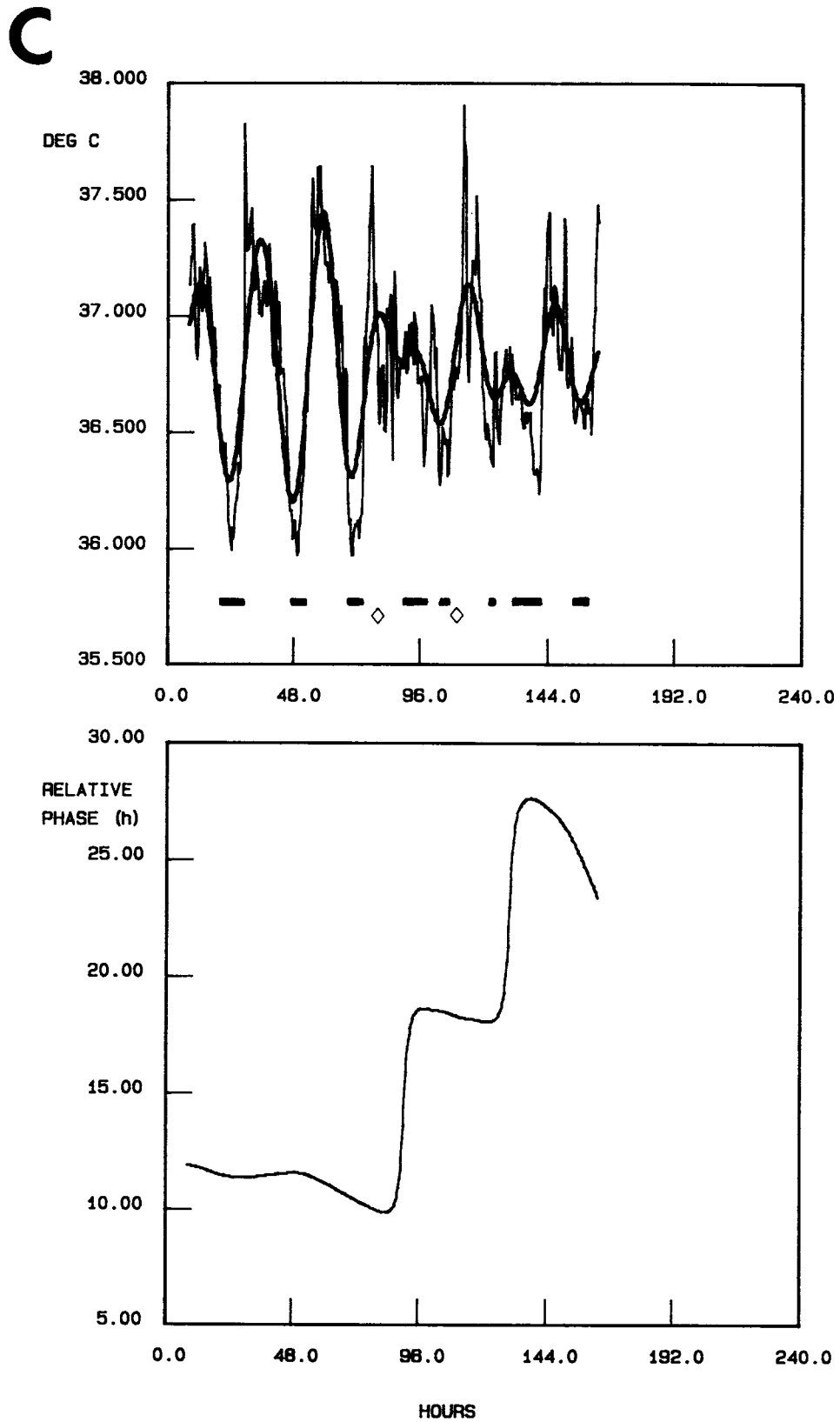


Figure 10.- Concluded. (c) Upper panel – Temperature data and filtered waveform as in 10(a), for the subject whose sleep/wake cycle is shown in figure 7(c). The atypical pattern of sleeping and napping in this subject clearly affected his temperature waveform. Lower panel – Acrophase of the filtered waveform, indicating a phase delay of the temperature rhythm in response to the 9 hr advance of the zeitgeber.

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16. Abstract

Physiological and psychological disruptions caused by transmeridian flights may affect the ability of flight crews to meet operational demands. To study these effects, 9 Royal Norwegian Airforce P3-Orion crewmembers flew from Norway to California (-9 hr), and back (+9 hr). Rectal temperature, heart rate and wrist activity were recorded every 2 min, fatigue and mood were rated every 2 hr during the waking day, and logs were kept of sleep times and ratings. Subjects also completed 4 personality inventories.

The time-zone shifts produced negative changes in mood which persisted longer after westward flights. Sleep quality (subjective and objective) and duration were slightly disrupted (more after eastward flights). The circadian rhythms of sleep/wake and temperature both completed the 9-hr delay by day 5 in California, although temperature adjusted more slowly. The size of the delay shift was significantly correlated with scores on extraversion and achievement need personality scales. Responses to the 9-hr advance were more variable. One subject exhibited a 15-hr delay in his temperature rhythm, and an atypical sleep/nap pattern. On average, the sleep/wake cycle (but not the temperature rhythm), completed the 9-hr advance by the end of the study. Both rhythms adapted more slowly after the eastward flight.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Jet lag Time zone changes Circadian core temperature rhythm Circadian sleep/wake cycle	Unlimited Subject category - 52

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