

Sleep, Sleepiness, and Circadian Rhythmicity in Aircrews Operating on Transatlantic Routes

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ABSTRACT

This study was performed on B-747 aircrews operating on regular passenger flights between Frankfurt and the U.S. west coast (9h time difference). In an initial phase, sleep behavior was surveyed by daily logs in 38 crew members. The results for the layover period indicate congruent sleep patterns with shifts in sleep onset distinctly less than 9h. In comparison with preflight control data, sleep duration was significantly prolonged and, on average, no sleep deficits were experienced before commencing the return flight. The main part of the study consisted of polygraphic sleep recordings and multiple sleep latency tests (MSLT) applied to four complete cockpit crews (12 members total) in a baseline period, during layover, and after return to homebase. In addition, body temperature and ECG were continuously recorded. During layover, mean bed times were shifted by 4.5h at maximum. Sleep was disturbed by early and prolonged awakenings which led to a reduction of sleep efficiency. In contrast, no sleep deficits nor increases in daytime sleepiness occurred. Night duty associated with the return flight caused sleep deprivation which conversely resulted in good sleep during the first night back in Germany. However, during the second night after return, impaired sleep was observed, at least in part caused by rhythm disturbances. As predicted by our resynchronization model, ECG and rectal temperature recordings gave evidence for a desynchronization of the circadian system and an internal dissociation of different body functions.

INTRODUCTION

In principle, our investigations were performed in two major phases. In a first step (Phase I) sleep-log surveys were obtained from crews operating on the FRA-SFO and FRA-LAX routes. The latter route was included since the flight schedules of both routes are almost identical. The primary purpose of this phase was to obtain a better understanding of individual daily habits and strategies. As it subsequently turned out, these sleep surveys also provided valuable information about the quantity of sleep and its deviation from "normal".

The second phase (Phase II) served as the main part of our investigation and consisted of a battery of tests and measurements applied to a group of twelve volunteers operating as B-747 crews on scheduled passenger flights between FRA and SFO. Like the other participating research groups, our central purpose was to study sleep in aircrews exposed to a time zone considerably different from their home base. However, since multiple time zone transitions are known to affect sleep by circadian rhythm disturbances, additional

efforts were aimed at defining changes in the 24h fluctuations of selected variables. Therefore, besides studying sleep-EEG and daytime sleep latency (MSLT) in the laboratory, we continuously recorded body temperature and ECG and collected continuous urine samples. The additional measurements were conducted not only during pre-duty and layover (L/O) periods, but also during flight. Furthermore, we attempted to learn more about flight crew readjustment to home time by continuing all measurements in the laboratory for approximately two more days after return to FRA.

Fig. 1 illustrates time lines and the general experimental design. At present time, the results are limited to sleep-EEG, MSLTs, body temperature and ECG records. The chemical analysis of urinary hormones and electrolytes is still in process.

MATERIALS AND METHODS

During Phase I, 26 sleep logs were completed on the FRA-LAX route and 12 on the FRA-SFO route. The two groups were labeled "LAX" and "SF1" respectively. In Phase II, 12 additional logs were obtained from the experimental group, "SF2".

The Phase I sleep surveys extended from two days before flight duty until two days after return to home base, whereas Phase II logs extended up to 6 days before duty commenced. To obtain better comparability between Phases, the additional 4 days were omitted from the analysis. Another difference was that Phase I crew members stayed in a hotel during their L/O and at home after the return flight. The experimental, Phase II group spent both periods in sleep laboratories.

Phase II subjects were four complete cockpit crews (1 Capt, 1 F/O, 1 F/E) for a total of 12 subjects who were assembled from a group of volunteer crew members. The age for captains and flight engineers ranged from 44 to 53y and for flight officers from 32 to 40y. As Fig. 1 shows, measurements were conducted over a baseline period of 36h in our Cologne sleep laboratory, in most cases during the week before the flight. All measurements were carried out in September 1984, with each crew leaving for SFO on Wednesday and returning to FRA on Saturday. Scheduled flight times were (in GMT) FRA:0810 SFO:1935 for the outgoing and SFO:2145 FRA:0830 for the home-going flight. After arriving at SFO the crews stayed together in separate rooms at the Stanford sleep laboratory for the 48h L/O period. After returning to FRA they were transported by helicopter to the Cologne laboratory where they remained for an additional 44h (post-return).

Table I summarizes all variables and methods included in our investigations. Sleep EEG recordings were performed as described in detail in the introductory paper (Graeber, et al.). Contrary to the other research groups, respiration and leg movements were not recorded in this study, and the pretrip measurements were conducted in the sequence: adaptation night, MSLTs, baseline night, i.e., the MSLTs did not follow the baseline sleep period. Seven baseline MSLTs were administered instead of six. ECG and rectal temperature were continuously recorded by means of Oxford Medilog tape recorders. Frequency analysis for the first harmonic was carried out on the heart rate and temperature data, according to Bliss (1), by shifting a 24h window by 1h intervals over the entire experiment. The results from this analysis were compared with values predicted by a model for the estimation of resynchronization after time-zone flights (13). Urine samples were collected in approximately 2-h intervals and frozen for later chemical analysis. Subjective

TABLE I. OVERVIEW OF VARIABLES AND MEASURES.

VARIABLES				
Mood	Sleepiness	Sleep	Rhythmicity (24h)	Workload
Pre-Sleep Scales	MSLT (EEG, EOG)	EEG	Temperature	ECG
	SSS	EOG	ECG	Catecholamines
	Fatigue Card	EMG	Urine Constituents	17-OHCS
	10cm Scale	Sleep Log		
		Self-Ratings		

SSS = Stanford Sleepiness Scale

fatigue ratings (10) were obtained from the subjects at regular intervals during the awake periods.

RESULTS

Sleep log surveys. Figs. 2 to 5 present those results from the sleep log surveys which relate to the self-ratings of time and duration of sleep. Quality of sleep was also assessed by five different rating categories. These data will be published elsewhere.

The means of sleep-onset and -end shown in Fig. 2 demonstrate that sleep timing under control conditions (days 1 and 2) can be considered quite normal. Thus, it can be concluded that these aircrews, when at home, go to bed at about 2200 GMT and get up at about 0600 GMT. This is true for all three groups with only minor differences in the mean values. The sleep-end preceding flight duty on day 3 is earlier by 1-2h, again in all three groups. As shown more clearly in the next figure, this results in a reduction of sleep duration, since sleep-onset on the prior evening is not adjusted correspondingly. During L/O, sleep timing is considerably shifted towards later hours, as would be expected by the time difference of -9h between FRA and SFO/LAX. However, crew members do not shift their sleep periods completely, i.e., on the average groups LAX and SF1 delayed their sleep by not more than 7 to 7.5h (onset and end of sleep respectively). Shifts of the experimental group are distinctly less ($p < 0.01$), averaging a 5h delay at the most. Thus, the experimental crews went to bed, fell asleep and got up earlier than the crews staying at the hotel. After the return flight, sleep timing was immediately shifted back towards the habitual hours of sleep at home base. The experimental group (SF2) again differs from the others in that its mean times exhibit a slower readjustment, especially sleep onset ($p < 0.001$).

In summary, Fig. 2 demonstrates similar sleep behavior patterns of the three groups before, during and after the duty period. During L/O, shifts in sleep times on average were distinctly less than the difference in local time between FRA and SFO/LAX.

Fig. 3 presents the results from the self-reports of sleep duration for the different groups. The similarity of the patterns is evident. Compared with the sleep period on day 1 (control night), there is consistently a significant reduction in sleep duration during the night immediately preceding flight duty. As demonstrated previously, these shorter sleep periods resulted primarily from the earlier wakeup times in preparation for the relatively early commencement of duty. Sleep duration is significantly extended in all groups during the first L/O, but only for the experimental group during the second night. After the return-flight, significant changes appear only twice: longer sleep on the first night for the LAX group and shorter sleep on the second night for the SF2 group. The pronounced reduction in the latter was, at least in part, caused by earlier arising at the end of the experiment due to an early pick-up time. As in the LAX group, a longer sleep duration occurred on the first post-return night for the SF1 group; however, this duration is not significantly different from control levels due to increased variance, probably caused by some substantially delayed return flights in this group. To summarize the findings of Fig. 3, it can be concluded that aircrews on the average slept less than "normal" on the night before commencing duty, but considerably more during the L/O period.

Fig. 4 illustrates what we call "sleep balance", i.e., the sum of the deviations in sleep duration from control nights. Thus, the curves reflect sleep deficit or surplus accumulated each consecutive day over the entire experimental period. Again, the three groups exhibit almost identical patterns with a moderate sleep deficit on day 3, substantial surpluses during the L/O period, and dramatic deficits after the return flight. Obviously, these deficits result from the preceding night duty when normal sleep was not possible; however, if we take into account the afternoon sleep after arrival in CGN, the sleep balance approaches zero. Although the practical implication of computing sleep balance curves may be debatable, they nevertheless demonstrate that aircrews usually attempt to get enough sleep and that they succeed.

Finally, Fig. 5 combines the three groups' sleep duration data during the three major stages of the sleep log survey. From the distribution of sleep durations it can be concluded that under control conditions about 90% of sleep episodes were between 6 and 10h. Sleep duration was 5h or less in only 5 out of 98 cases, indicating that severe sleep deficits do occur, although very rarely. This number of extremely short sleep periods remains the same throughout duty and post-duty days. In addition, for the two L/O nights the histogram clearly shows a shift to longer sleep durations with maxima of 13 and 14h in 4 cases. During the two post-return days, sleep periods show a tendency to normal length. The higher incidence in the 6-h class mainly reflects the enforced early termination of sleep during group SF2's last test night in Cologne.

Sleep recording and MSLTs. In preparing to compare sleep parameters with baseline (B2) values, we first had to check the latter for outliers. Any value deviating by more than two standard deviations (2-sigma-limit) from the group mean was defined as an outlier. Indeed, one subject exhibited REM sleep lower than this limit and wake time and time in bed (TIB) longer than this limit. In addition, his subjective sleep quality rating was below the 2-sigma-limit. He complained about a headache during the baseline night and took two aspirin. As an apparent outlier, this subject was excluded when comparisons with baseline data were made.

The beginning and end of sleep periods were calculated as mean times (N=12) of

lights-off and lights-on and summarized in Fig.6. Compared with baselines B1 and B2 when crew members went to bed at about 2200 GMT, their mean bed times shifted by 3.2h on the first L/O night (SFO1) and by 4.5h on the second (SFO2). These values generally agree with those obtained from the sleep logs for the same period. For both sleep periods the average TIB was longer than during baseline or post-return. Get-up times showed considerable interindividual variability, with a standard deviation about twice that for baseline and post-return sleep. Before leaving Stanford for the return flight, nine subjects tried to nap, seven of them fell asleep. After the return flight, which was a complete night flight according to FRA time, all crew members went to bed in the afternoon (CGN1). On the following two nights, sleep was delayed by 1.9h (CGN2) and 1.0h (CGN3) compared to baseline.

Fig. 7 shows the total sleep time (TST) as well as the percentages for different sleep stages. While TST was about 7.0h for all night-sleep periods in Cologne (except for CGN3, as explained above), it increased to almost 8.0h during L/O. The afternoon sleep following the return flight (CGN1) had a mean TST of 3.5h. REM sleep (%) was nearly constant for all sleep periods, except for a decrease during CGN1 and an increase in CGN2. While stage 2 sleep (%) was also fairly constant, slow wave sleep (stages 3+4, SWS) displayed a greater variability between sleep periods and a strikingly higher portion in CGN1. Large differences were also observed for stage 1.

Table II compares the baseline (B2) sleep parameters of our group with data reported by Williams et al. (14) for a group of males (n=10) ranging in age from 40-49y. TIB, TST as well as sleep stage percentages do not differ significantly. In addition, this table compares all sleep periods with baseline sleep B2. As might be expected, the adaptation night (B1) produced a longer mean TIB ($p<0.05$) and more stage 1 sleep. During L/O nights, TIB and TST were significantly longer with more stage 1 sleep (%) in SFO1. The afternoon sleep CGN1 had more SWS(%) and less REM sleep (%), while the following night

TABLE II. COMPARISON OF BASELINE (B2) SLEEP PARAMETERS (n=11) WITH THOSE FROM 40-49 YEAR OLD MALES (Williams) AND FROM ADAPTATION (B1), LAYOVER, AND POST-TRIP RECORDINGS.

Source	Minutes		Percentage			
	TIB	TST	S1	S2	S3+S4	REM
B2	460.20	414.60	9.24	57.98	10.48	22.30
Williams	429.10	389.10	8.07 ^a	58.41 ^a	9.13 ^a	24.39 ^a
B1	494.50*	420.40	12.38*	57.86	6.90	22.85
SFO1	572.30**	477.50**	11.93*	55.59	10.13	22.35
SFO2	529.80**	461.90**	10.19	57.48	9.38	22.96
CGN1	219.10**	208.70**	6.67	56.23	23.47**	13.63**
CGN2	469.80	429.90	7.22	56.84	8.32	27.61**
CGN3	409.40	342.90	9.86	55.75	13.12	21.27

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

^a % SPT values given by Williams were transformed to % TST

(CGN2) showed enhanced REM sleep.

Median latencies to sleep onset, slow-wave sleep (S3), and REM sleep are shown in Fig. 8. Though the interindividual variability was rather high, the following comparisons to baseline were statistically significant: longer latencies to sleep onset and REM during adaptation, reduced latency to S3 for the CGN1 day sleep, and delayed sleep onset on the second post-return night (CGN3).

Fig. 9 presents median values of several sleep quality parameters. The number of awakenings varied between 5 (CGN1) and 11.5 (B1). In comparison with B2, sleep was less efficient during B1, SFO1, and CGN3, but more efficient during CGN1. Subjective sleep quality ratings also suggest poorer sleep during B1, SFO1, and CGN3. Computations of correlations between sleep quality parameters and age revealed significant negative coefficients ($r=-0.63$, $p<0.05$) for sleep efficiency during each L/O night, but not for total sleep time.

Individual sleep patterns and MSLT results for baseline, L/O, and post-return are presented in Fig. 10. Most of the crew members underwent one SLT after arrival at Stanford and 5-9 MSLTs between the major sleep periods. For sleep SFO1, subjects went to bed at very different times, and this rank order remained almost the same for SFO2. One subject (row 6) had relatively long naps in addition to his short sleep periods and seemed to stay on home-base time. Shifts of sleep periods were more obvious for other subjects who exhibited longer TIB. As this figure clearly indicates, reduced sleep efficiency resulted from long waking times (a) in the second half of SFO1 sleep and (b) in the beginning of CGN3 sleep.

Mean SLT values were calculated only if at least seven subjects performed the SLT at the corresponding time. In the home time zone, these mean values revealed a general pattern of long latencies immediately after sleep, short latencies in the afternoon, and longer again in the early evening (Fig. 11). During L/O, when measurements were extended until late evening, the MSLT showed the typical biphasic contour. The longest onset latencies were always found after the main sleep periods (B1, SFO1, SFO2, CGN2), regardless of how far they were shifted. Comparison of MSLT latencies revealed the following significant differences (Wilcoxon test): (a) increase between 1600 and 1800 GMT for baseline ($p<0.05$) and L/O ($p<0.10$); (b) increase between 1600 and 2000 GMT for baseline ($p<0.05$), L/O ($p<0.01$), and post-return ($p<0.05$); and a decrease between 2000 and 2400 GMT for L/O ($p<0.05$). In addition, latencies of the MSLTs at 1800 GMT were significantly different ($p<0.05$) between L/O and post-return.

Temperature and ECG. As compared with baseline data, temperature and heart rate curves revealed distinct phase shifts during L/O and after return to FRA. The curves in Fig. 12 represent mean values from all experimental subjects. Computed minima (Bliss [1]), as well as minima predicted by our model (13), are marked differently in the figure. Vertical lines illustrate where the minima would be expected if subjects had completely adapted to SFO time.

The temperature rhythm was shifted by 3.75h on the first and by 5h on the second day of the L/O period (both relative to baseline), while after return to home base the shift was 3.25h relative to the last day in SFO (or 2.75h relative to baseline). The rhythm of heart rate was shifted even more: 6.25h on the first day in SFO and 7.0h on the second;

after return to FRA a shift of 6.0h relative to SFO2 occurred, which corresponds to a time difference of 1h relative to the baseline rhythm.

As a consequence of the different adjustment speeds, internal dissociation can be observed. The phase difference between heart rate and temperature rhythms was -1h during baseline periods and changed to +1.5h during the first and +1.0h during the second day in SFO. Due to the faster readaptation of the heart rate, the phase difference became -2.75h after return to home base. No actual minima from harmonic analysis are given for the return-flight day, because of the irregularities in the sleep-wake cycle. According to FRA time this flight was a total night flight. Even if related to the shifted circadian rhythm (delay by 5h), it must still be considered as night duty, at least in part. Inspection of the curves demonstrates that, though the first circadian trough occurred in the second part of the duty period, heart rate and temperature already increased again about 2h before landing.

The periodical decrease of heart rate and temperature every 2h during awake time in Fig. 12 was most likely caused by the reduction of activity during MSLTs. Compared with the heart rate oscillations, the temperature fluctuations were delayed by 20-30 min.

While the 24-h means of the circadian rhythms show only minor variation, the amplitudes are considerably higher during L/O as compared with baseline and post-return periods (Table III). In our view, this is mainly caused by a masking effect. From the longer sleep durations one could expect an increase in amplitude since longer periods of inactivity result in longer sections of lower values in heart rate and temperature rhythms. At the same time this would also lead to a decrease in the 24-h mean, but in our case such an effect is compensated by the higher physical activity of most subjects during the day at Stanford (e.g., bicycling and jogging). Of course, these activities enhance the rhythm amplitudes even more by adding sections of values higher than normal to the rhythm curves.

In order to interpret the circadian results in more detail, shifts in acrophases of temperature and heart rate as well as those predicted by our model are presented in Fig. 13, along with the subjects' mean daily bedtimes. All parameters indicate a clear shift towards the corresponding hours of the new time-zone (by a delay during L/O and by an advance after return to CGN). However, heart rate adapts faster, mainly due to the simultaneous shift of the rest-activity cycle. Temperature acrophases shift more slowly, and their

TABLE III. ESTIMATED 24H MEANS AND AMPLITUDES OF HEART RATE AND TEMPERATURE COMPUTED FROM AVERAGE CURVES (After Bliss (1))

SOURCE	HEART RATE (1/min)		TEMPERATURE (°C)	
	Mean	Amplitude	Mean	Amplitude
B1/B2	68.5	13.0	36.8	0.55
SF01	71.5	19.5	36.75	1.00
SF02	72.5	17.5	36.8	0.60

adjustment pattern corresponds well with the bedtimes, except for day CGN3. Fig. 13 also demonstrates that changes in temperature rhythm acrophase, after either westward or eastward flight, can be correctly predicted by our model of resynchronization.

DISCUSSION

Our experimental design was based initially on the following hypothesis: Due to the considerable time difference between FRA and SFO, aircrews performing duty on this route would suffer from rhythm disturbance of their circadian system. As a direct consequence, they would also experience sleep difficulties, a problem which has repeatedly been a matter of serious concern among aircrews and safety researchers (5,7,8). Furthermore, sleep difficulties would be manifested by sleep loss and reduced sleep quality, both in terms of subjective ratings and objective EEG recordings.

Sleep log analysis. Clearly, the results from our sleep-log surveys do not support the above hypothesis. In contrast, there is convincing evidence that our pilots slept significantly more during the L/O period and did not suffer at all from sleep loss, as compared with their normal sleep habits at home base. It is not possible to determine whether this was achieved by conscious attempts or by efforts and conditions beyond the subjects' direct control. From personal communications, however, we are inclined to conclude that the majority of the pilot population is well aware of this problem and takes serious measures to get enough sleep. No doubt, the results from the sleep-log surveys demonstrate that they succeed; however, the findings presented in this paper do not rule out the possibility that sleep deficits may occur in individual cases. The presented results deal only with computed means and thus merely reflect average behavior. There are already indications that severe sleep deficits may be experienced by some crew members. In at least five cases, sleep was 5h or less during L/O as well as during control and post-return periods (with a 3h minimum in one case). A more detailed analysis is planned to settle this question of individual problems.

There is another, more general, but also quite unexpected result that the sleep-log surveys are disclosing. Initially, all participating research groups were concerned about whether the sleep laboratory would be an adequate setting to obtain realistic information about "true" L/O behavior in the hotel environment. Comparison of the three sleep-log groups reveals strong evidence that we were well "on the safe side", in essence for two reasons: (a) The patterns of sleep timing and duration were almost identical; in fact, statistical analysis (Kruksal-Wallis test) did not detect any general difference when the data sets (entities of 8 days) as a whole were compared. (b) During the first L/O, night sleep duration in the laboratory was significantly shorter than in the hotel environment (U-test); again, this was in contrast to what had been expected. Despite the quiet, isolated surroundings of the sleep facility, our subject group did not sleep longer than aircrew staying in the commercial atmosphere of the city hotel. In addition, during both post-return nights the laboratory group reported distinctly shorter sleep durations than the other groups sleeping at home. Thus, the data clearly refute the argument that sleep deficits could be anticipated in the realistic world even though they had not been observed in the laboratory.

Of course, conclusions drawn from subjective ratings may give cause for criticism. However, subjective estimates of sleep duration, i.e., time between onset and end, correlate well with objective measurements. This is not necessarily true for the amount of sleep, since number and time of awakenings are frequently misjudged thus leading to major

discrepancies between subjective and objective assessments of total sleep time. Theoretically, our sleep-log data could have indicated longer sleep periods despite a decrease in the amount of sleep, if our subjects had suffered from longer awakenings than accounted for by the surplus in sleep duration. In fact, the sleep-EEG recordings in our experimental group disclosed considerably prolonged awake periods during L/O sleep. Nevertheless, total sleep time was distinctly longer than under baseline conditions. To us, there appears to be not much evidence that this should be different in the two other groups. In particular, the impressive and consistent similarities between the three groups in almost all sleep-log results support this view.

Sleep recording and MSLT analysis. As a prerequisite for discussing details of the sleep-EEG and MSLT results it is important to know whether there are any differences between crew members' usual habits and their behavior in the laboratory, and how such differences may influence final conclusions about the study.

Each time subjects left the sleep laboratories, questionnaires were administered asking for general sleep quality and a comparison between their usual sleeping conditions and those of the laboratory. In general, the answers to each question were equivalent after the baseline, L/O, and post-return periods. On a 5-point-scale from "very poor" to "very good" the subjects consistently rated their sleep quality as being good. Quantity of sleep, daytime drowsiness, and quantity of meals were judged as comparable with the usual conditions. Upon leaving the Cologne laboratory after the post-return phase, all crew members were interviewed. Six claimed that their sleep was better than at home, and six reported no difference. The improved sleep was attributed to the darkness and silence of the laboratory and to the absence of family disturbances. In contrast to what we inferred from the sleep-log surveys, these findings could mean that conclusions regarding sleep quality drawn from the experimental results should be rather conservative with regard to sleep in the usual world where flight crews are sometimes faced with a more disturbing environment.

The experimental part of the sleep investigations revealed a clear pattern of sleep periods with only minor individual differences. During L/O, the onset of the two main sleep periods was shifted ahead by 3.2 and 4.5h, respectively, as compared with baseline data. Our results cannot distinguish whether these shifts were due to a phase shift of an autonomous circadian sleep rhythm, or whether they reflect a conscious compromise between increased fatigue and an adjustment to the social environment of the new time zone. If the crew members delayed sleep completely by 9h, they would be much more tired during the pre-sleep hours. Even with only a partial sleep delay, Stanford Sleepiness Scale (SSS) ratings and MSLT results indicate that the subjects were more tired before L/O sleep than before baseline or post-return sleep.

After the return flight, which according to FRA local time was a complete night flight, crew members retired in the afternoon for a recovery sleep of several hours. For the night-sleep periods, they went to bed more than 1h later than during baseline. As there was no social need, this behavior may be explained by a circadian phase delay resulting from the preceding adjustment to the SFO time zone. However, another reason is also conceivable: it might be assumed that recovery sleep in the afternoon leads to delayed tiredness in the evening and consequently to a later sleep time.

Objective sleep quality may be conceived as a matter of the amount and continuity of

sleep. Accordingly, the typical disturbance of sleep during the adaptation night was manifested by decreased sleep efficiency, a higher number of awakenings, a longer sleep-onset latency, and a longer latency to REM sleep. Despite this impaired sleep quality, there was no increase of overall sleepiness during the day. In fact, the MSLT results provided no indication of an abnormal increase in sleep tendency during any phase of the study.

On the first L/O night subjects slept less efficiently and rated their sleep subjectively worse. The efficiency was reduced by relatively long awakenings during the second half of the night. Probably, the circadian system forced them to awake too early, e.g., because they felt hungry or had to use the bathroom. Possibly due to training or experience, they were able to fall asleep again and to compensate somewhat for the effects of shifted sleep by staying in bed longer. Thus, at the end they got even more total sleep than during the baseline night. The sleep disturbances seen during SFO1 were not as pronounced for SFO2.

However, from correlational analysis, we found that difficulties in sleep continuity during L/O increased with age, so that older crew members had to stay in bed longer than younger ones in order to get enough sleep.

The majority of the crew members took a nap before the return flight home. This short extra sleep most likely improved alertness for the following night shift (6.9). During the return flight the subjects incurred a sleep loss which may account for the good sleep experienced during the afternoon and first night after arrival in Germany. The afternoon sleep was characterized by a rebound of SWS, i.e., a short latency to stage 3 sleep and more SWS(%) than observed during baseline. During the following night a rebound of REM sleep was observed. These effects are well known as consequences of sleep deprivation. During the second night, objective as well as subjective sleep quality was reduced, very likely due to rhythm disturbances, some of which were detected in MSLT and body temperature.

The MSLT results closely reflect the 24-h profiles reported by Richardson et al (11). Nevertheless, the interpretation of MSLT results turned out to be more complicated. At least two factors seem to influence daytime sleepiness. The first is related to the time since the preceding sleep. Thus, long sleep latencies were observed whenever subjects had recently awakened from a major sleep regardless of time of day. After pilots awoke, they were unlikely to fall asleep during the following SLT. A second factor reflects a circadian influence on sleep tendency. It is characterized by relatively high sleepiness around midday and an increase in sleep latency in the late afternoon. The increase occurred at the same time (GMT) during the baseline and L/O periods. Consequently, we conclude that the underlying sleepiness rhythm might have shifted too slowly to be disclosed after the westbound flight. The observation of an SLT-rhythm delay after the return flight supports the view that the delayed nocturnal sleep in Cologne is related to the observed delay in the circadian rhythmicity of other physiological functions.

Rhythm disturbances. As expected, our results provided evidence that the time-zone transition associated with flight duty on the FRA-SFO route leads to (a) desynchronization of internal body time from the external timing system and (b) to an internal dissociation between the circadian rhythms of different body functions. Both effects influence sleep behavior. This was most clearly shown by the early and prolonged awakenings of the first L/O sleep period. Most likely these awakenings were triggered by the circadian system, which was out of phase with the new local time by an advance of more than 5h (according

to the acrophase of the temperature rhythm). Due to progressive synchronization, awakenings occurred at later hours and became shorter or disappeared during the second nocturnal sleep period. In contrast to awakenings, sleep-onset time is influenced by other factors in addition to circadian rhythmicity, e.g., activation, conscious efforts, and in particular the duration of the preceding awake period. Therefore, the advance of sleep onset during L/O may not reflect the "true" shift of the underlying rhythm, but more probably is the result of several influences. This could also explain our findings from the sleep surveys that sleep-onset time in the laboratory was earlier than in the hotel.

For the post-return period we were also able to demonstrate a desynchronization of circadian rhythms from local time. In contrast to the SFO L/O, however, it was a delay and the extent was less pronounced (ca. 2h). Theoretically, this again should affect sleep; but awakenings would be expected at the beginning of the sleep period, or a delayed onset of sleep should occur. As already mentioned, our EEG data confirmed this assumption for the second night, whereas the findings for the first nocturnal sleep were confounded by the effects of sleep deprivation and the preceding afternoon sleep.

Our rhythm results reveal one other important operationally relevant fact. Due to the relatively short L/O period, synchronization with SFO time was not completed. In fact, the circadian system had only shifted by about 5h before the return flight commenced. Thus, readaptation to home-base time would be comparable to conditions after the transition of five time zones. As a result, desynchronization on the second post-return day was not more than about 2.5h, which is below the limit (3h) that is accepted as critical in terms of operational significance (13,15).

CONCLUSIONS

We were able to show that the time zone transition associated with FRA-SFO flight duty leads to a desynchronization of the circadian system. According to our hypothesis, rhythm disturbances would cause major difficulties for sleep quality and quantity. However, from our subjective and objective sleep data we must conclude that the observed desynchronization produced only moderate effects upon sleep. During L/O, early and extended awakenings led to a reduction of sleep efficiency, but did not cause sleep deficits. Sleepiness during the diurnal phase was not elevated, but quite normal. Night duty during the return flight caused sleep deprivation which in turn resulted in good sleep during the first night at homebase; however, impaired sleep occurred on the second night, at least in part caused by desynchronization. Nevertheless, resynchronization to homebase time appears fast enough that pilots can achieve a reasonable re-adjustment before commencing flight duty again.

Obviously, these conclusions cannot be generalized. In the present form, our results consider only mean values and do not address individual cases where the situation may be far less favorable than on the average. Finally, our conclusions apply only to a duty schedule that is relatively short and not especially complex. There are other duty patterns that require operations with much more complex schedules involving many more days away from home base and more transit stops in different time zones. From these we may anticipate a quite different picture as to sleep problems and rhythm disturbances. Finally, it should be mentioned that the present results fit well into the line of our previous studies in aircrews and complement the results that have been obtained from short-haul (4) as well as from

long-haul flight schedules (2.3.12).

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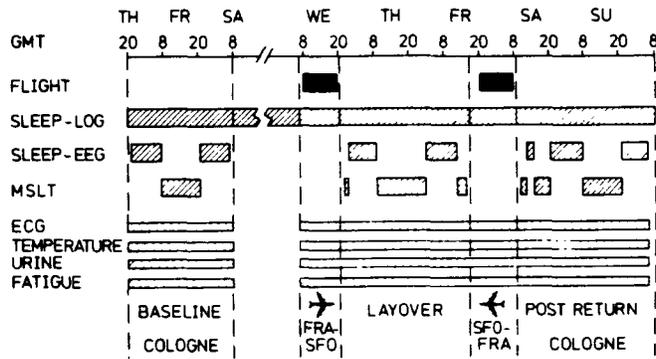


Figure 1.- Overview of time lines for the data collection of the flight schedule Frankfurt-San Francisco.

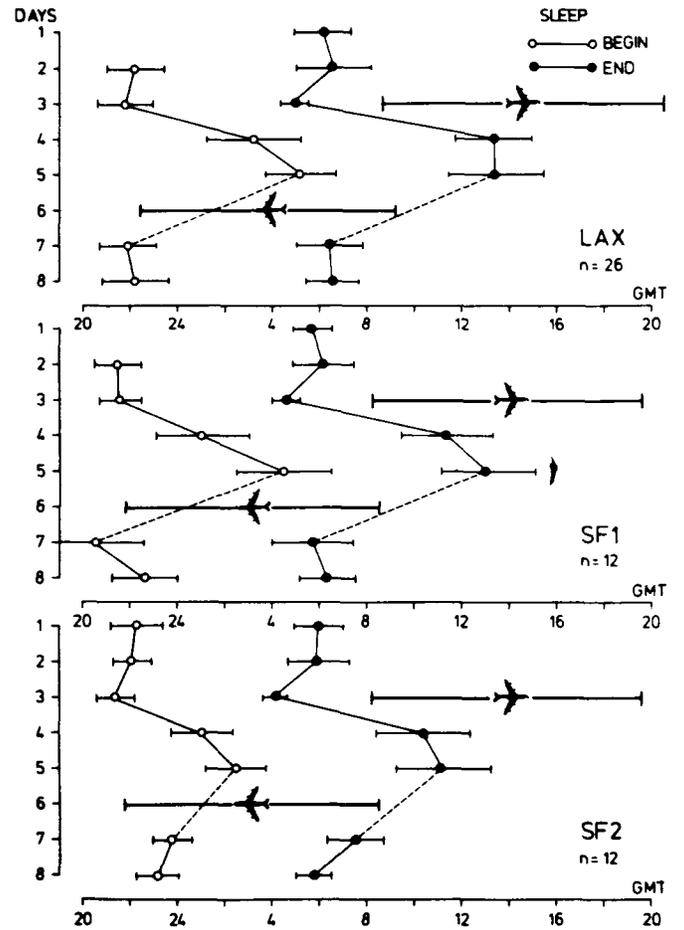


Figure 2. Subjective ratings of beginning and end of sleep during control, layover and post-return nights. Presented are means (\pm S.D.) of the three different groups. (Numbers of days at the vertical axis refer to days beginning at 2400 GMT.)

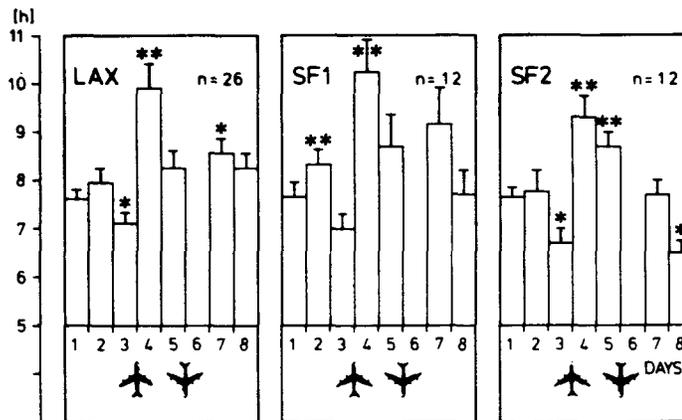


Figure 3. Subjective ratings of sleep duration during control, layover, and post-return nights (means \pm S.E.). * $p < 0.05$; ** $p < 0.01$ for differences from sleep period of day 1.

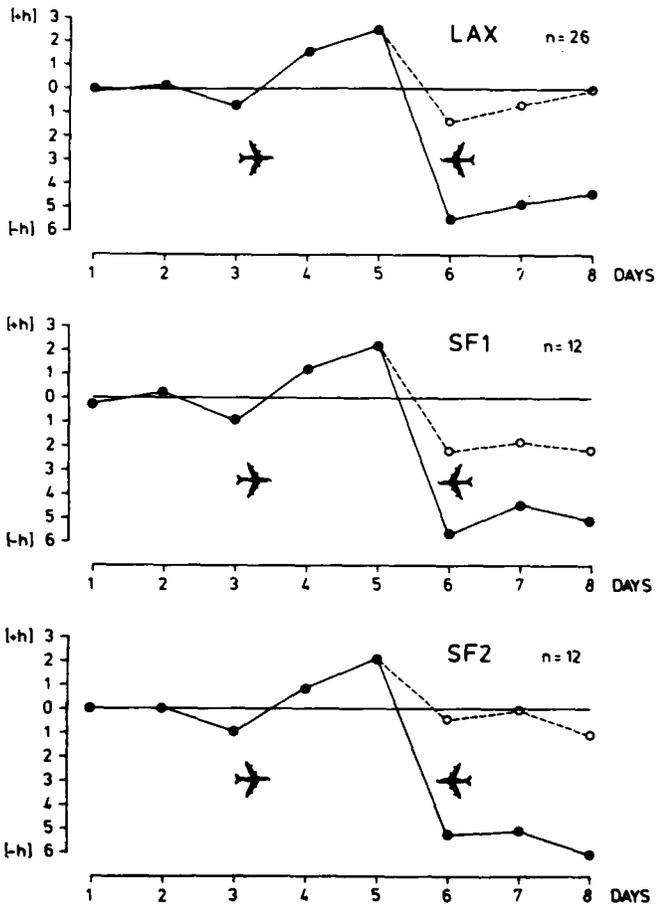


Figure 4. Sleep balance: accumulated deviations of subjectively rated sleep duration from control nights (day 1 and day 2). Values do not include short extra sleep periods (naps). Open circles and dashed lines represent sleep balance including sleep in the afternoon following return flight.

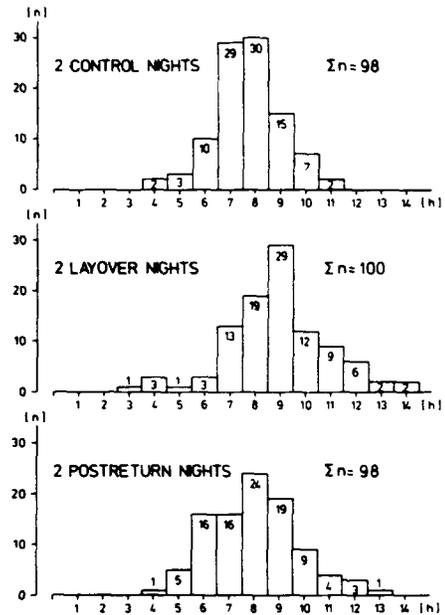


Figure 5. Histogram of subjectively rated sleep duration of all three groups together. Combined are two nights each from the control, layover and post-return period. (Note: sleep period immediately preceding flight schedule not included).

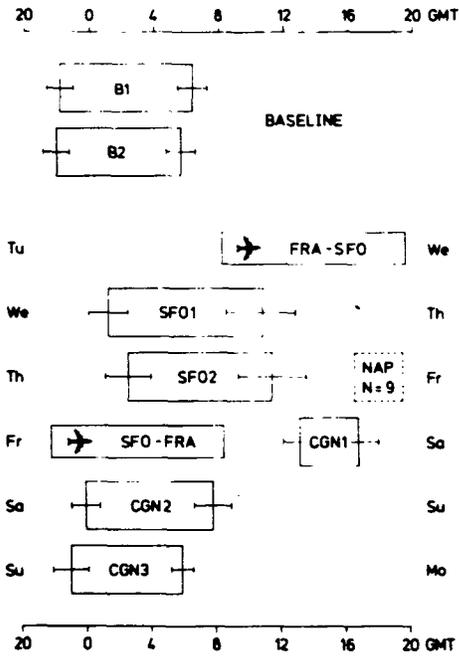


Figure 6. Time schedule of sleep periods and flights. Time axis is chosen from 2000 to 2000 GMT. Bars for sleep periods show standard deviation for light off and on. Baseline recordings were taken several days before flight to SFO.

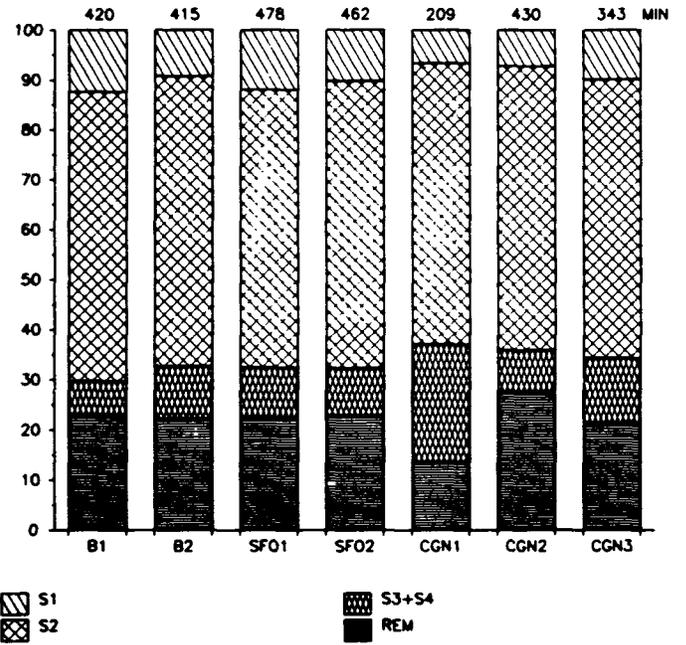


Figure 7. Mean percentage of total sleep time (TST) for sleep stages. Means (N = 12) are shown for seven sleep periods. Absolute TST values (min) are given on top of the bars.

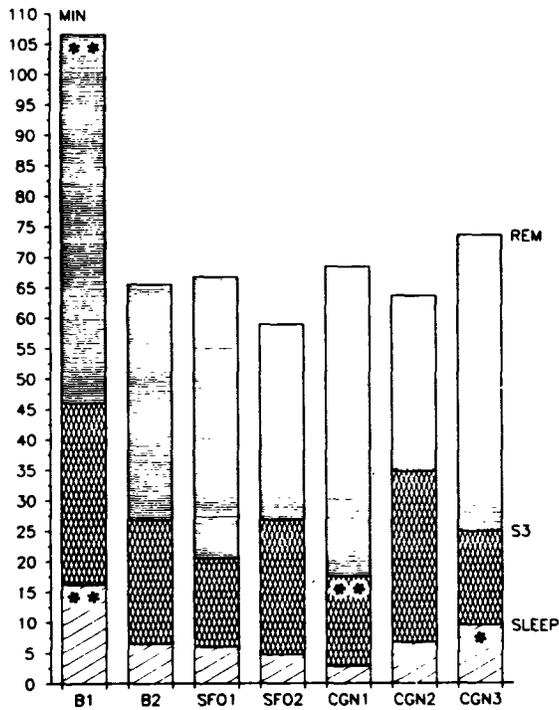
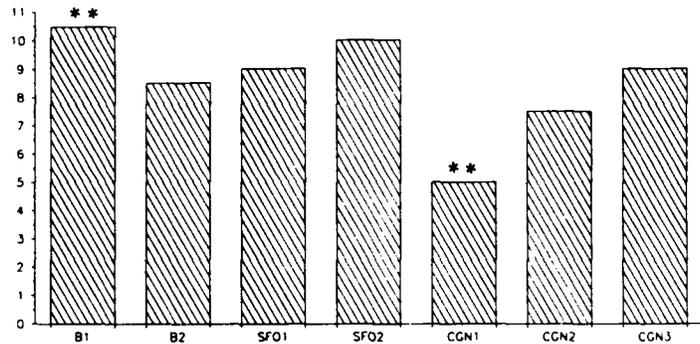
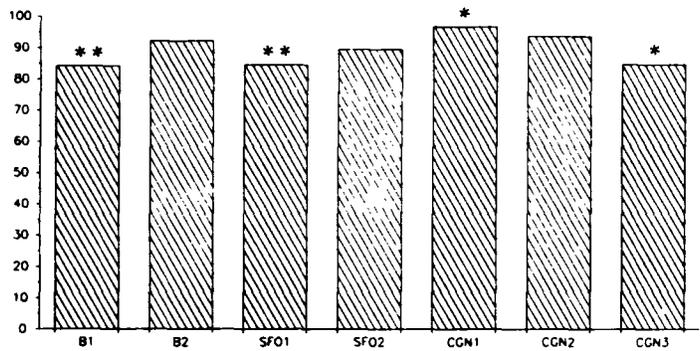


Figure 8. Median (N=12) latencies to the first ten minutes of persistent sleep, to slow-wave sleep (S3), and to REM sleep. Significant differences from baseline values (B2) are indicated (* $p < 0.05$, ** $p \leq 0.01$, Wilcoxon-matched-pairs-signed-rank test).



MEDIAN SLEEP EFFICIENCY (%)



MEDIAN SUBJECTIVE SLEEP QUALITY

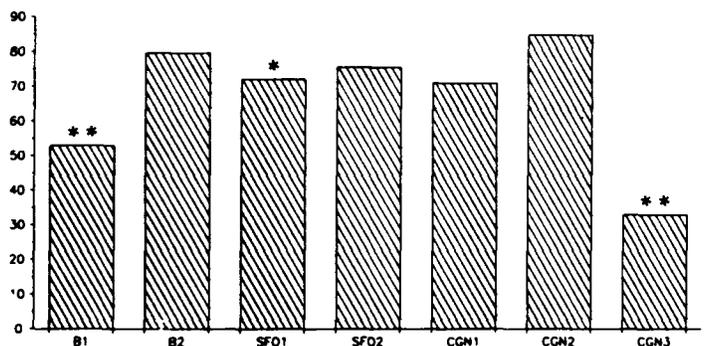


Figure 9. Sleep efficiency, number of awakenings, and subjective ratings of sleep quality for seven sleep periods. Significant differences from baseline (B2) are indicated (* $p < 0.05$, ** $p \leq 0.01$).

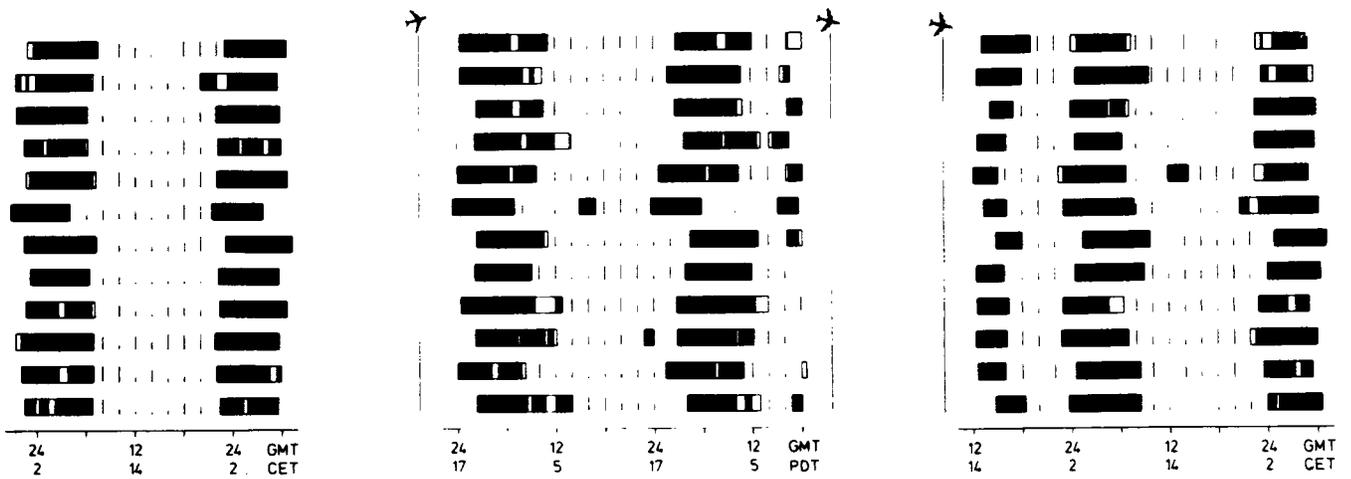


Figure 10. Sleep pattern and multiple sleep latency test (MSLT). Sleep periods in black, wake times in white. Vertical lines between sleep periods represent MSLT; their height is sleep latency in minutes.

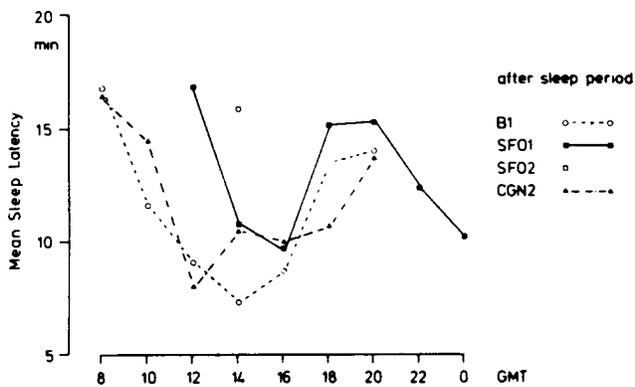


Figure 11. Mean MSLT after sleep periods B1, SF01, SF02, CGN2.

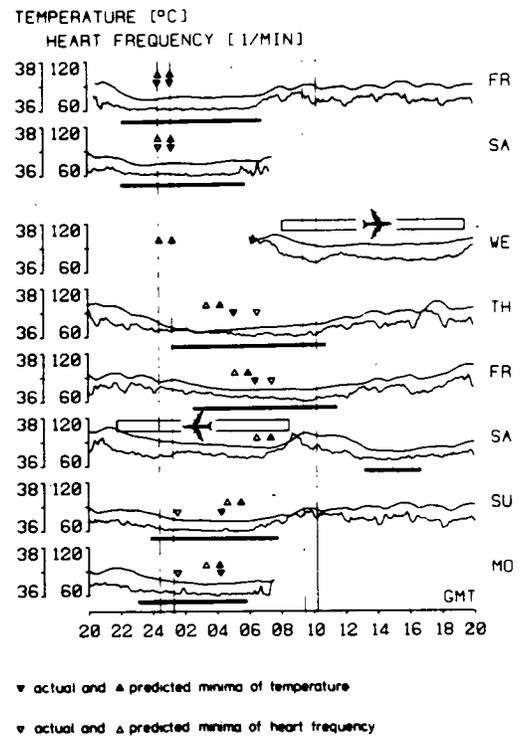


Figure 12. Means for temperature (upper curves) and heart rate (lower curves) before, during and after flights. Vertical lines indicate position of minima during baseline and after complete shift by 9h (solid lines: temperature; dashed lines: heart rate).

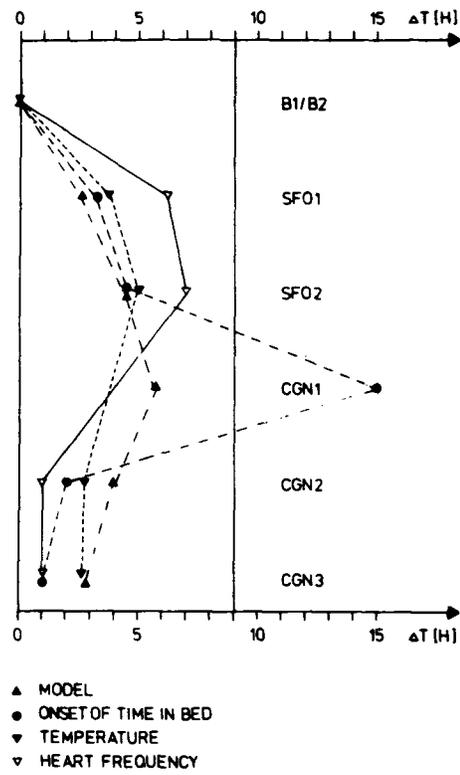


Figure 13. Shifts in acrophases relative to baseline position.