

## EFFECTS OF TIME ZONE CHANGES ON SLEEP

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It is well known that, after rapid flight by a high speed jet-plane over a distance of more than 4 hour time difference, most of the passengers and jet crew suffer from so called "jet syndrome" or "jet lag". For example, if a passenger leaves Tokyo (TYO) at 1700 h, as shown in Figure 1, he arrives, after a 9 hour flight, at San Francisco (SFO) on the same date at 0900 h by the local time, that is, 0200 h by Japan time due to the time difference by 7 hours. In this case, he may stay awake and soon be busy with day-time activities, while he would still be asleep, if he were in Japan. If he goes to bed at 2300 h (at 1600 h by Japan time) in SFO on that day, his sleep, corresponds to a nap in the late afternoon continuing to evening sleep by his circadian rhythm, and consequently he may have a different type of sleep from his habitual nocturnal sleep. Seven O'clock in the morning in SFO corresponds to midnight in Japan, and the traveller is difficult to wake up, and even if he gets up, he may feel that his brain is muddled.

In this way, a rapid flight across many time zones produces desynchronization between the external or physical clock and the internal or biological clock. This desynchronization results in so called "jet syndrome", which was replaced in 1973 by "desynchronosis syndrome" (Beljan, Winget, & Rosenblatt, 1973). The desynchronosis syndrome includes:

- (a) Fatigue and psychomotor performance degradation.
- (b) Insomnia, and other sleep-wake disturbances.
- (c) Gastrointestinal dysfunction in a wide variety of forms.
- (d) Various psychosomatic manifestations in other organs.
- (e) Other symptoms which have been variously reported included headache, ophthalmocopia, dyspea, diaphoresis, nightmare, anxiety, and menstrual abnormality.

There are individual differences in susceptibility to the effects of rapid changing time zones, but all experience the above symptoms to some extent. For example, Lowell Thomas (Silverstein & Silverstein, 1974), a radio and television commentator and writer, made so many time zone transitions during a certain period of his life and worked under such a full schedule that he had no time to synchronize his biological rhythm with the local time of a new destination. In one period of about a year, he flew on a number of trips to various parts of the world crossing all twenty-four time zones at least twice. His schedule was so busy that he had very little time to rest between trips. After a while, he began to feel ill. Several times he had alarming blackouts, in which he actually lost consciousness for brief periods. Then one day, after a jet flight half way around the world, he had a frightening attack. His hands began to shake, and he found it difficult to speak and move. He was attacked by a sensation of depersonalization, feeling as if there were a thick sheet of glass separating him from the people around him. The above is an extreme case of desynchronosis syndrome.

The polygraphic study of effects of time zone transitions on sleep with civilian aircraft crews was initiated by the authors after a flight from Tokyo to San Francisco in 1967 (Endo, Sasaki, Negishi, & Suenaga, 1968). Years after, Evans, Christie, Lewis, Lewis, Daly, and Moore-Robinson (1972) reported a study on changes in sleep after flights between London and San Francisco with an 8 hour time difference. Here is an outline of the work by Evans et al. (1972).

They carried with them a portable EEG machine and flew together with the subjects to record all-night sleep EEG at the destination. On four carefully selected, healthy male subjects, all-night EEGs were recorded for seven nights in London as control nights. After trans-Atlantic flights, all-night sleep EEGs were recorded in San Francisco eight times during an eleven-day stay. After returning to London, home night recordings were again carried out on six consecutive nights.

On the first night after a London/San Francisco flight, Stage 4 sleep was enhanced, and REM sleep was decreased, although the distribution of both types of sleep during the night was not altered. Early morning awakening was a feature of the first five nights in the new time zone, particularly in the older subjects. Similar changes occurred after the return flight. There was no evidence of enhancement of REM sleep or the alteration in the distribution of REM sleep which has been noted in laboratory studies of sleep reversal. No definite evidence of circadian effects due to alteration in time zone were demonstrated.

Those who have experienced the syndrome complain that the most annoying factor is sleep disturbance, which takes place frequently, and which easily results in degradation of psychomotor performance and fatigue.

Studies on the effects of time zone changes on biological rhythms are indispensable not only for the solution of the problems in industrial hygiene, such as maintenance of health, prevention of accidents for aircraft occupants and shift workers, but also are important for the maintenance of health and the control of psychological and physical functions of diplomats and business executives who must perform important international tasks during a short stay, as well as sportsmen who participate in the Olympic games and scientists who attend international congresses. Therefore, the study on effects of time zone changes on biological rhythm will give a clue for the solution of still unsolved problems of desynchronization syndrome caused by desynchronization between physical and biological clock from the chronobiological view point.

#### Procedures and Results

The First Experiment After Flight from West to East (TYO/SFO, 1967)  
(Endo et al., 1968; Sasaki & Endo, 1977)

Subjects and procedure. The subjects were 6 male civilian aircraft crew members, aged 26-47 years. Three of them were chief pilots, two copilots, and one steward. The subjects left Tokyo at 2300 h on a non-stop flight and arrived at San Francisco at 1400 h by the local time. On that night, at a hotel in the city, all night polygraphic recordings were obtained from them by us, with an eight channel portable polygraph brought from Japan. EEG, EOG, EKG, resp. and noise were simultaneously recorded, and the results were analysed by the international classification system.

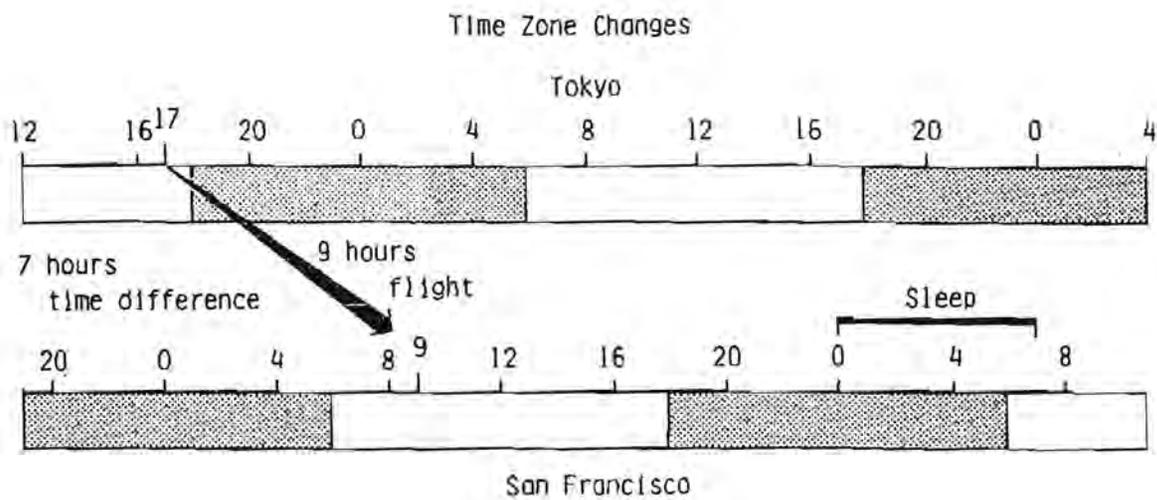


Figure 1. Changes of sleep-wake cycle due to time zone changes between TYO and SFO. If a passenger leaves TYO at 1700 h, he arrives, after a 9 hour flight, at SFO on the same day at 0900 h by local time, that is 0200 h by Japan time due to a time difference of 7 hours. In this case, he would still be asleep, if he were in Japan.

Results. Recordings were divided into three types according to the sleep time: 1) prolonged sleep time; 2) medium sleep time; and 3) shortened sleep time, which were observed in two of the subjects.

1) Cases of prolonged sleep lasted 11-12 hours until about noon of the next day. In this group, slow wave sleep (Stages 3 & 4) was enhanced, while REM sleep was depressed in the first half of sleep period, without any marked change in the percentage of Stage REM. There was a tendency toward increased awakenings in the first half of sleep. Pulse rate kept a high level during these sleep periods.

2) Cases of medium sleep lasted 8-9 hours with final awakening at 0700 h to 0900 h. They seemed to sleep according to the local time. The intrasleep cycles consisting of NREM and REM sleep were rather disturbed, NREM sleep being enhanced and REM sleep depressed in the first half of sleep period, with long latencies to REM sleep. A very impressive finding in one of these cases was a change in pulse rate. As shown in Figure 2, the pulse rate which was at a high level in the first half of the sleep period began to fall at about 0400 h by the local time. This means that the first half of the sleep period in San Francisco corresponds to the period from late afternoon to early evening in Tokyo. This is considered to be the result of the persistent home circadian rhythm of the pulse rate in Japan.

3) Cases of shortened sleep terminated after 2-3 hours of sleep, and thereafter remained awake. Their sleep seemed to correspond to an afternoon nap by Japan time. They tried to maintain stability by sleeping on their own "home time".

These changes in sleep and heart rate observed after time zone transition produced by a flight from West to East can be assumed to be the desynchronization between the home circadian rhythm and physical time in the new destination. This experiment, however, was insufficient and imperfect, since polygraphic recordings for baseline nights in Tokyo and after the return home were not performed.

The Second Experiment (Flight from West to East and from East to West, 1973)  
(Endo & Sasaki, 1975)

Subjects and procedure. The subjects were 4 healthy male physicians, aged 30 to 38. All-night sleep EEGs were recorded before the flight in TYO as control nights, twice in SFO, once in Honolulu (HNL) on the way home, and three to four times after returning home. The travel schedule is represented in Figure 3. The aircraft left TYO at 1700 h, arrived at SFO at 0900 h on the same date, due to the 9-hour flight and 7-hour time difference. The subjects went to bed in SFO at 2300 h, which corresponds to 1600 h in Japan. According to their circadian rhythms in "home time", this means that they began a nap, followed by evening sleep. Because there was one night's sleep deprivation due to the flight, one day was prolonged to 41 hours. To awaken at 0800 h in SFO corresponds to 0100 h in TYO.

When it is 2300 h in HNL (time to go to bed) during the return flight, it is 1800 h in TYO and 0100 h in SFO, since there is a 2-hour difference in time between SFO and HNL. When the subjects go to bed at 2300 h on returning to TYO, it is 0400 h in HNL and 0600 h in SFO.

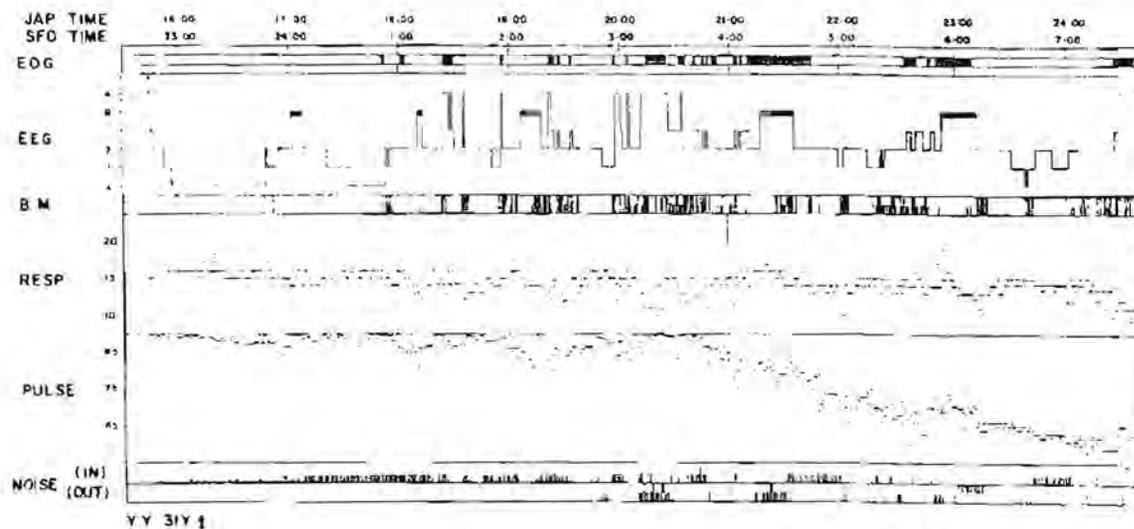


Figure 2. Polygraphic sleep diagram on the first night in SFO. A very impressive finding was the change in pulse rate. The pulse rate, which was at a high level in the first half of the sleep period, began to fall at about 0400h by local time. JAP. time: Japan time; SFO. time: San Francisco time; EOG: Electrooculogram; EEG: electroencephalographic sleep stage; RESP: Respiration. Black bar of EEG indicates REM sleep.

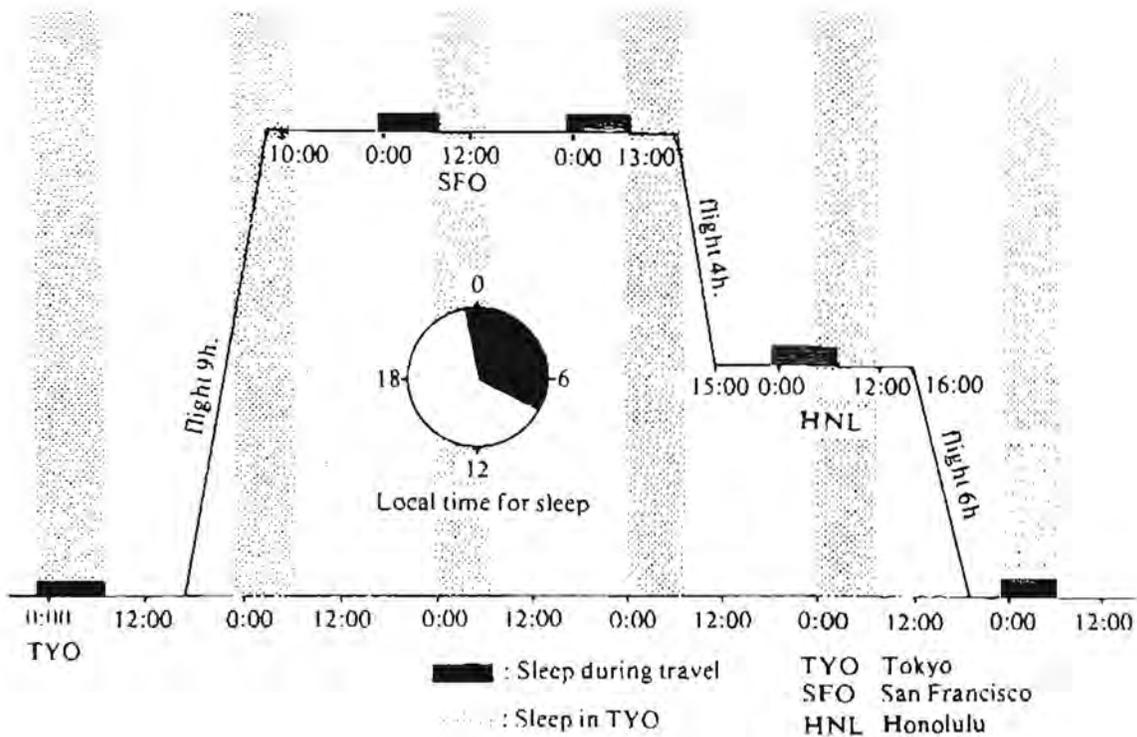


Figure 3. Flight schedule. The aircraft left TYO at 1700 h and arrived at SFO at 0900 h on the same date due to the 9-hour flight and 7-hour difference in time zone. 2300 h in SFO corresponds to 1600 h in TYO. 0800 h in SFO corresponds to 0100 h in TYO. Since there was one night's sleep deprivation due to TYO/SFO flight, one day was prolonged to 41 hours.

Results. Table 1 and Figure 4 represent sleep latency (S), REM sleep latency (R), percentage of REM sleep (%SREM) and percentage of slow wave sleep (%S3+S4). These are evidently altered by time zone transitions. Thus, sleep latency is rather short in SFO, and significantly reduced on returning home ( $p < .01$ ). REM sleep latency becomes slightly shorter in SFO but not significantly. On returning home, however, it is reduced significantly ( $p < .01$ ). It is also significantly shorter than in HNL and SFO ( $p < .05$  and  $p < .01$ , respectively). Thus, REM sleep is shown to appear rapidly after falling asleep. The %S3+S4 was significantly increased in SFO ( $p < .05$ ), while %SREM was significantly decreased in SFO ( $p < .001$ ), and significantly enhanced on returning home ( $p < .01$ ).

Table 1

Mean and Standard Deviation of Basic Data for Four Subjects Under Four Conditions

Conditions	TYO-C	SFO	HNL	TYO-H
Sleep latency (S)	8.00± 5.52	3.50± 4.95	3.25± 3.42	1.62± 1.39**
REM sleep latency (R)	111.44±52.13	105.13±39.78	104.25±38.62	*53.50±27.49** **
%S3+S4	17.61± 2.88	22.10± 3.23*	20.10± 2.26	19.73± 4.45
%SREM	23.72± 2.73	**16.48± 2.03***	21.49± 2.03	**28.66± 3.69** ***

TYO-C: Control nights in TYO

TYO-H: Home nights in TYO after return flight from SFO

\* on the upper right side of the table denotes significant difference from TYO-C, on the left, that from SFO, and on the upper left, from HNL.

\*\*\*  $p < .001$ , \*\*  $p < .01$ , \*  $p < .05$ .

Figure 5 represents the model of appearance of REM sleep in subject C.S. On the first night in SFO, there was not much change in periodic appearance of REM sleep as an intrasleep cycle, but its duration was shortened. This was especially marked in the first half of sleep. On the first night after returning home, a sleep onset REM period (SOREMP) was observed with marked increase of %SREM. The same tendency was likewise shown on the second night, and moreover REM sleep was increased in the first half of the sleep.

The %SREM and %S3+S4 are represented in Figure 6. Since all the subjects exhibited similar trends, the changes in case C.S. are described below. On the baseline nights before the start from Japan, he showed normal levels of %SREM and %S3+S4, which are considered to be 20-25% and 18-22%, respectively. In SFO, %SREM was decreased, while %S3+S4 was increased. On returning home, however, the former was conversely increased while the latter was decreased.

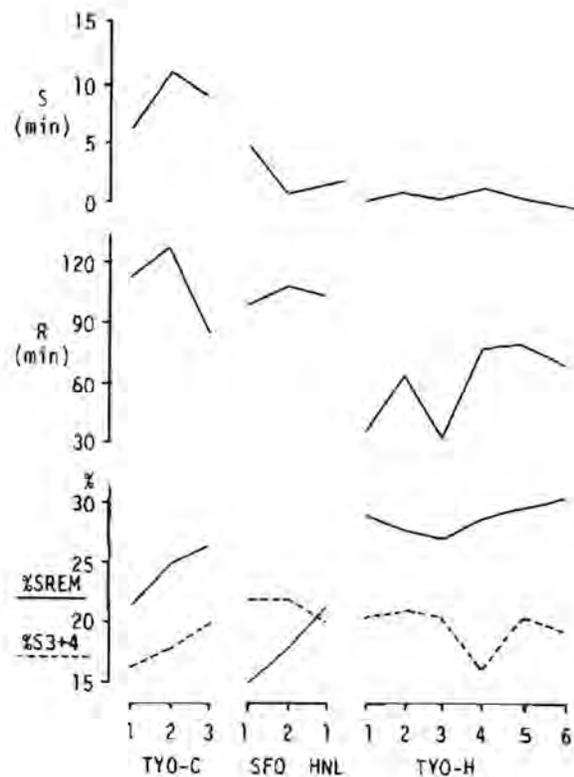


Figure 4. Mean data per night over total experiment for four subjects. Arabic numbers over experimental conditions denote experimental nights. Diagram shows shortened sleep latency (S) after each flight, decrease in %SREM and increase in %S3+4 in SFO nights. On the other hand, shortened REM sleep latency (R), increase of %SREM and decrease of %S3+4 are shown in TYO-Home nights. S: Sleep latency; R: REM sleep latency; %SREM: Percentage of stage REM in total time in bed; %S3+4: Percentage of Stage 3 and 4 in total time in bed.

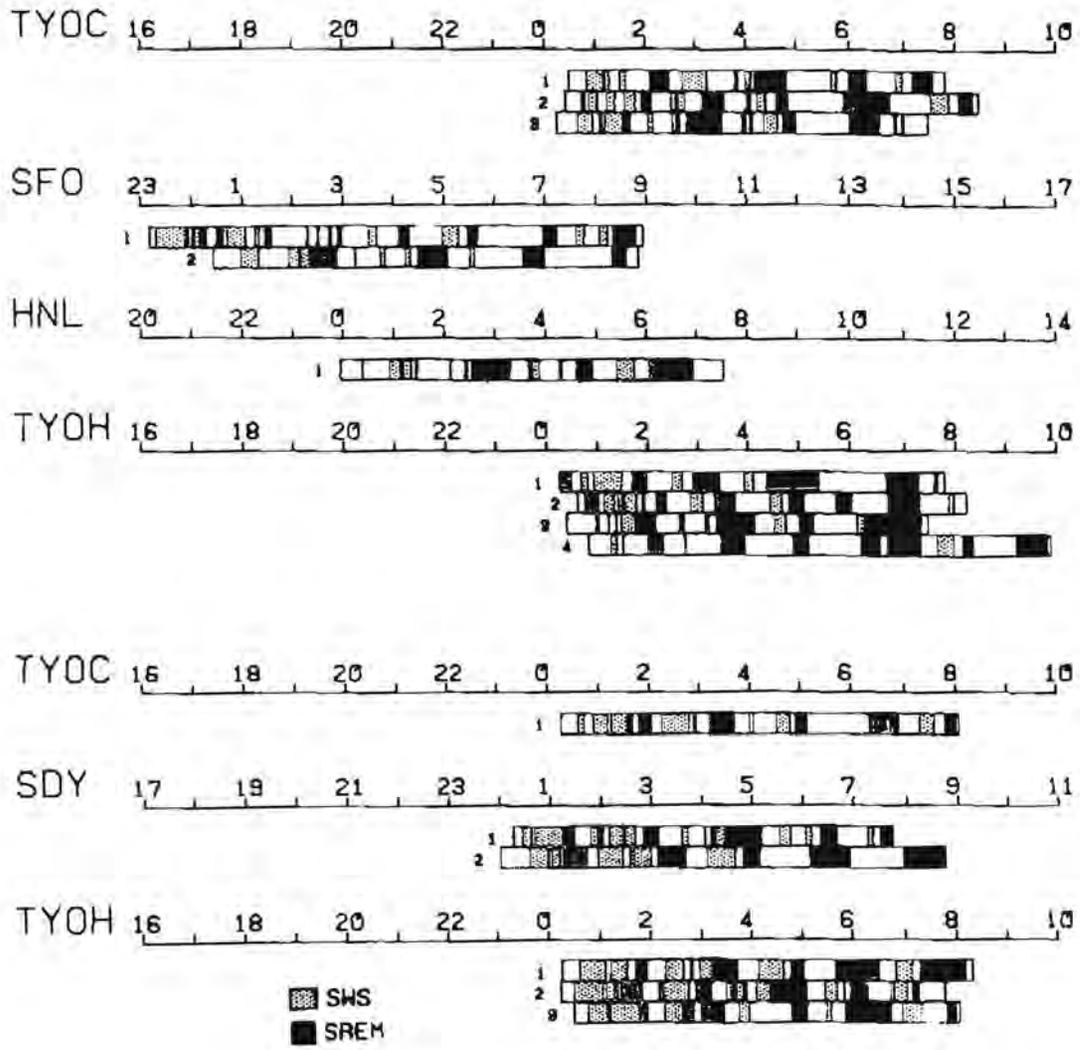


Figure 5. Distribution of REM sleep and slow wave sleep. On the first night in SFO, the durations of REM sleep periods were shortened especially in the first half of the sleep. On the first night after returning home, the sleep onset REM periods (SOREMPs) were observed with marked increase of %SREM. On the first night in SDY, scarcely any change was observed in the distributions of REM sleep periods, while SWS was increased.

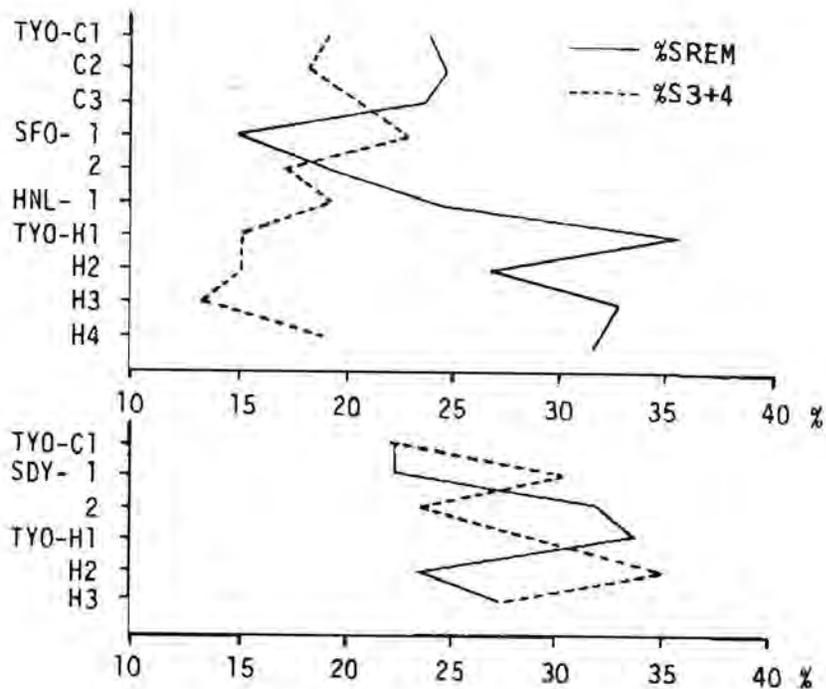


Figure 6. Percentage of Stage REM and Stage 3+4. REM sleep is markedly decreased and SWS (S3+4) increased in SFO, and vice versa on returning home. Southward and northward flight do not exhibit such phenomenon.

REM sleep, which has a circadian rhythm as later described, was investigated to determine whether the change was elicited in the first or last part of sleep. The proportion of REM and NREM sleep, especially S3+S4, are represented in Figure 7 for case C.S. In the first 120 min of sleep, NREM sleep, especially slow wave sleep, was increased and REM sleep decreased and the later was markedly increased in TYO-H. In the last 120 min., REM sleep was decreased and NREM sleep was increased in SFO; whereas, after returning home, REM sleep became less than in baseline nights in TYO and more than in SFO.

As for the change in the autonomic functions, an investigation was made on pulse rate as an example. As seen in Figure 8, the mean pulse rate was elevated on the first night in SFO, and the distribution curve of pulse became double peaked on the second night, indicating the coexistence of both Japan's and SFO's rhythm in one record. In HNL on the return trip, the pulse distribution curve exhibited three peaks. On home nights the pulse rate was elevated, but it failed to reach the level of the pulse rate during baseline nights even on the third home night.

The results mentioned above conspicuously demonstrate how sleep after time zone transitions is, in many respects, altered in comparison to usual nocturnal sleep. It is, however, necessary to eliminate effects of flight itself and sleep deprivation to confirm the effects of time displacement alone on sleep. So it is necessary for us to attempt a flight, which takes as long as that to SFO, with similar sleep deprivation, and without any time zone differences. Accordingly, the following experiment was undertaken.

#### The Third Experiment (Southward and Northward Flight 1974) (Endo & Sasaki, 1975)

Subjects and procedure. On one of the subjects mentioned above, after baseline nights in Tokyo, all-night sleep EEGs were recorded in two consecutive nights in Sydney (SDY) and in three consecutive nights after returning to TYO. The aircraft started from TYO at 1800 h and via Manila arrived at SDY at 0800 h on the next day. Thus one day was prolonged to 49 hours for this subject because of the sleep deprivation of one night and a one hour time displacement. On the return flight, on day was prolonged to 47 hours.

Results. On the first night in SDY, scarcely any change was observed in the distributions of REM sleep periods (as on the lower part of Figure 5). On the second night, REM sleep was increased especially in the last half of sleep. On the first night after returning home, REM sleep was increased in the last half of sleep, but a sleep onset REM period as seen in the westward flight was not observed.

%SREM and %S3+S4 are presented in the lower part of Figure 6. On the first night in SDY, %SREM was scarcely changed, while %S3+S4 was increased. These were evidently different from the result on the first night in SFO. On the second night in SDY, %SREM was increased, while %S3+S4 was decreased from that on the first night.

The proportions of REM and NREM sleep in the first and the last part of sleep were presented in Figure 9. %SREM was not altered at all, while %S3+S4 was increased in the first half of sleep in SDY, and both %SREM and %S3+S4 re-

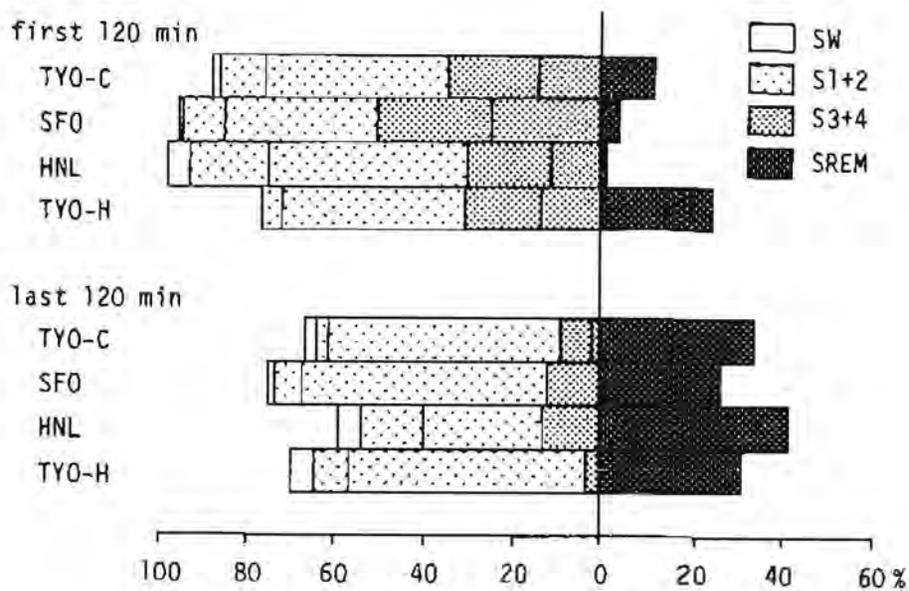


Figure 7. Percentage of sleep in each stage during the first and last 120 min. In the first 120 minutes of sleep SWS (S3+4) was increased and REM sleep decreased in SFO, whereas SWS was slightly decreased and REM sleep markedly increased in TYO-H. In the last part of sleep, REM sleep was decreased and SWS was slightly increased in SFO, whereas in TYO-H REM sleep became less than in TYO-C and more than in SFO.

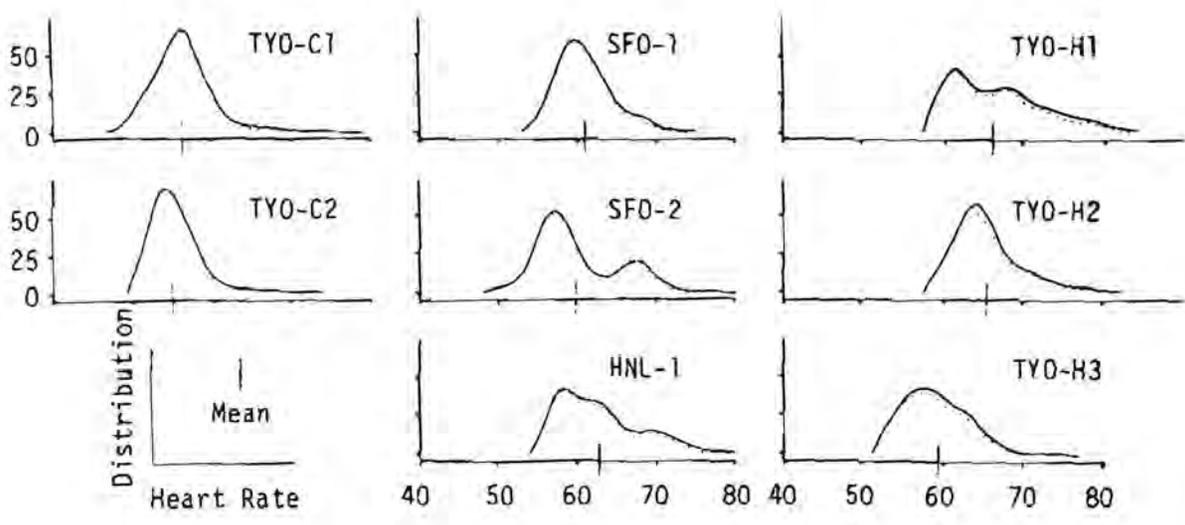


Figure 8. Distribution curve of heart rate during whole night of sleep. Heart rate rises on the first night in SFO, exhibits two peaks on the second night, and three peaks in HNL on the return trip. On the first night after returning home, it again rises exhibiting two peaks.

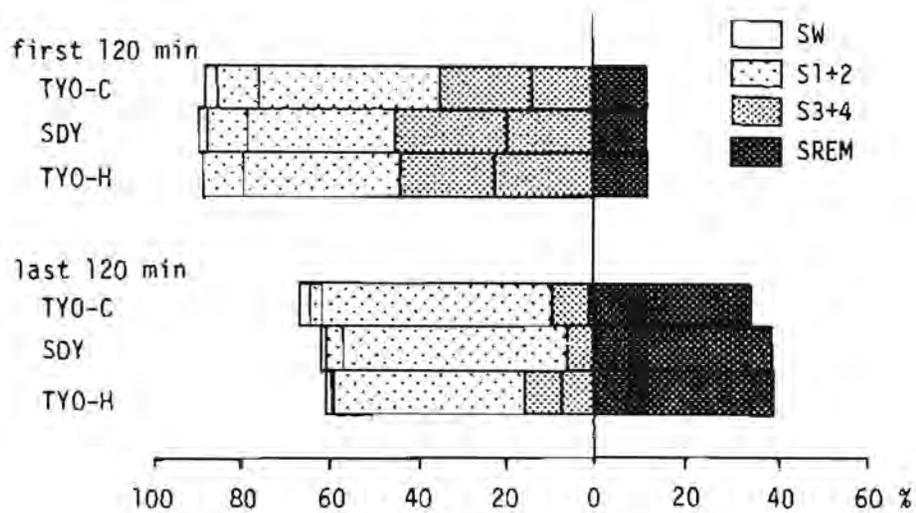


Figure 9. Percentage of sleep in each stage during the first and last 120 min of sleep after flights to and from SDY. In the first part of sleep %SRRM was not altered at all, while %SWS was increased in SDY and both %SREM and %SWS remained unaltered in TYO-H. In the last part of sleep %SWS was decreased while %SREM was increased in SDY.

mained unaltered after returning home. In the last part of sleep in SDY, however, %S3+S4 was decreased while %SREM was increased.

These changes mentioned above were evidently different from those after the flights from East to West and vice versa, which were accompanied by many time zone changes. The changes in sleep after southward and northward flights were similar to those after total sleep deprivation which are described later. One should refrain from drawing any definite conclusion from the above experiment performed on a single subject, and it is necessary to repeat this experiment to corroborate the above results.

It is, however, considered likely from the third experiment that changes in sleep in the first and second experiment may be caused by time zone changes. Therefore, the authors carried out the fourth experiment in order to investigate the length of time and physiological changes necessary for recovery from desynchronization of sleep with the local time.

The Fourth Experiment (Eastward and Westward Flights and Synchronization 1975) (Endo, Sasaki, Nishihara, Sekiguchi, Murasaki, Bono, & Suenaga, 1975)

Subjects and procedure. The subject was the same physician as in the third experiment. All-night sleep EEGs were recorded twice as baseline nights in TYO, 7 times during a 10-day stay in SFO and 5 times during an 8-day period following the return home.

Results. The appearance pattern of REM sleep in SFO coincided with that on baseline nights in TYO on about the 8th day. After returning home, the coincidence was also realized in the 8th day (Figure 10). It was evident from this figure that the REM sleep in SFO synchronized with the local time in about 8 days after the arrival, and that, on returning home, the sleep onset REM periods were again observed in spite of accomplishment of synchronization of sleep.

Figure 11 represents %SREM and %S3+S4 on baseline nights in TYO, on nights in SFO and on home nights in TYO. In SFO, lowered %SREM was gradually elevated with lapse of day until it returned to the level of %SREM on baseline nights in TYO in 7 to 8 days. On the other hand, increased %S3+S4 was gradually reduced to restore the baseline level again 7 to 8 days.

After the accomplishment of synchronization of sleep to the local time in SFO, enhancement of REM sleep did not take place on home nights. However, REM sleep latencies were much shortened, and it appeared without passing through Stages 3 and 4. It took 8 days for REM sleep to restore the usual pattern of its appearance.

In order to study the rhythmicity of REM sleep periods, a binary autocorrelation test by Globus was performed (Figure 12). Minimum agreement levels in baseline nights were at a lag time 45-50 minutes followed by peak agreement levels at 90 to 100 minutes. In SFO, the curve was flattened and minimum agreement occurred earlier with a peak agreement at around 50 minutes in 1 to 5 days, and the disturbances with a decreased peak agreement level was remaining as late as 7 to 10 days in spite of the peak agreement at 90-100 minutes. Tokyo home nights (home nights 5 to 8) showed a return to rhythmicity compati-

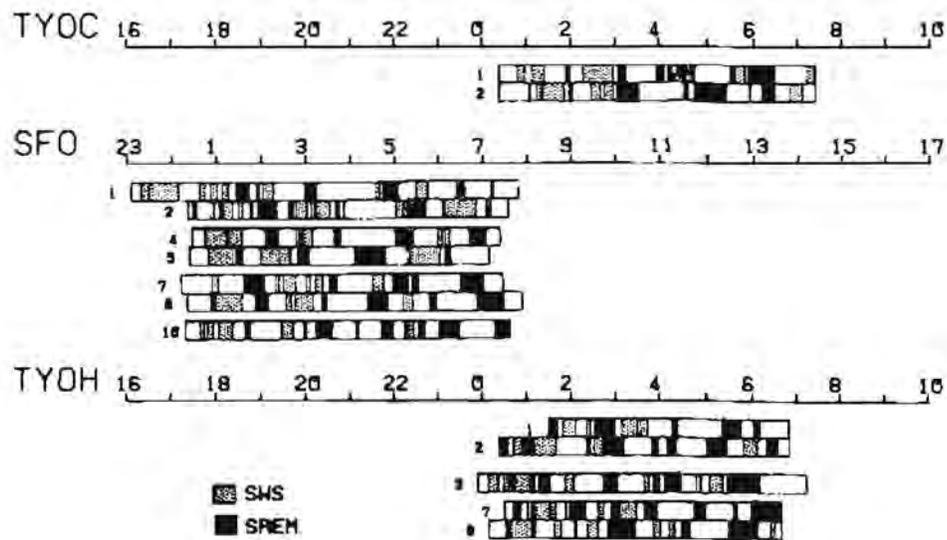


Figure 10. Appearance patterns of REM sleep and SWS before, during, and after 10-day stay in SFO. Synchronization of appearance patterns of REM sleep and SWS in SFO and TYOH with those in TYOC becomes clear in about 8 days both after arriving at SFO and after returning home.

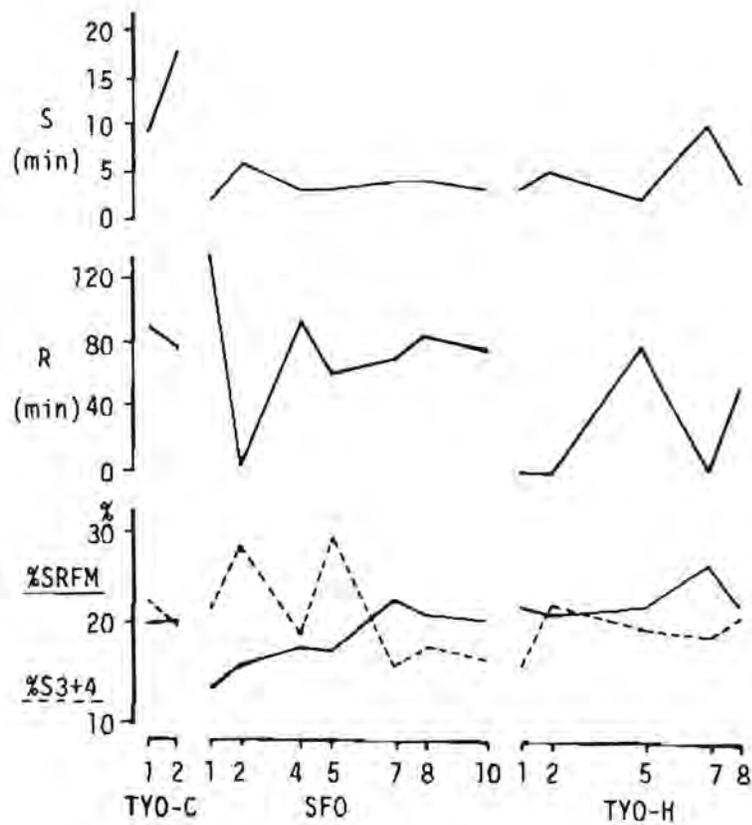


Figure 11. Sleep latency (S), REM sleep latency (R), %SREM, and %S3+4 before, during, and after 10-day stay in SFO.

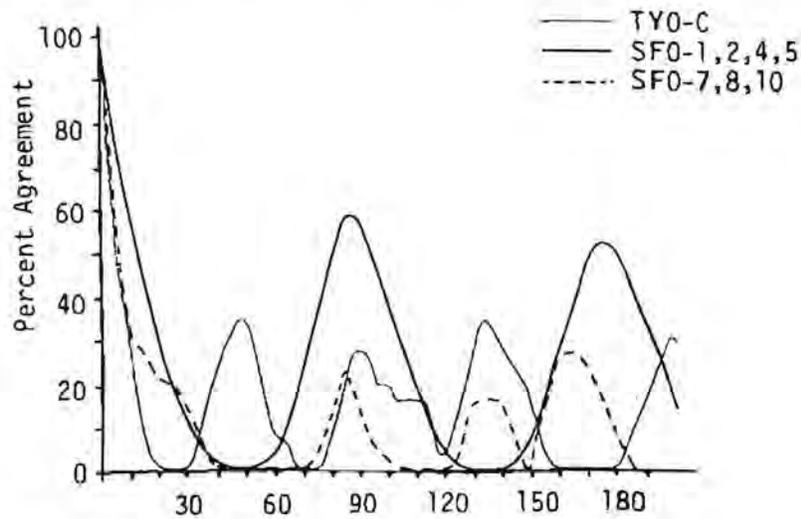
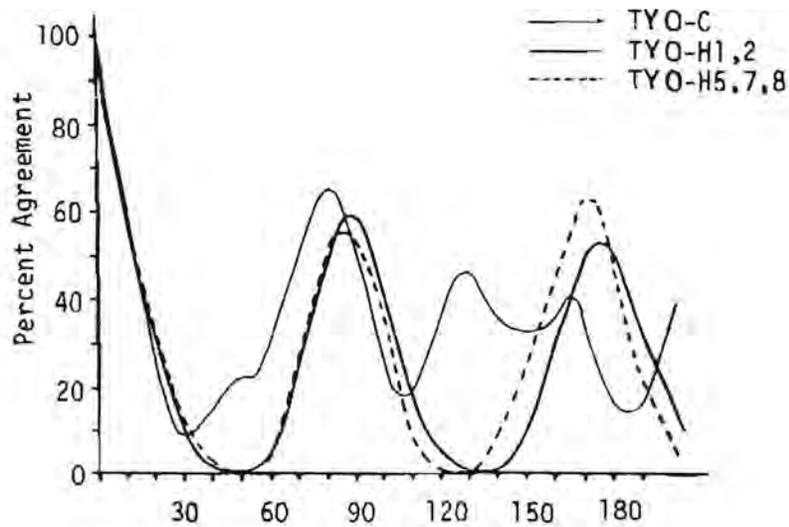


Figure 12. Results of binary autocorrelation test. Minimum agreement level in baseline nights was at a lag time 45-50 minutes followed by peak agreement level at 90 to 100 minutes. In SFO the curve was flattened and minimum agreement occurred earlier with a peak agreement at around 50 minutes in 1 to 5 days and disturbance was remaining as late as 7 to 10 days. TYO-home nights 5 to 8 showed a return to rhythmicity compatible with baseline nights in TYO.

ble with baseline nights in TYO. Though desynchronization in sleep is generally greater in the case of a flight from West to East, synchronization in sleep seems to occur approximately in 8 days as a whole.

Pulse rate, taken as an index of the autonomic functions, failed to recover synchronization over the 10 days after arrival in SFO as seen in Figure 13. Its restoration is acquired on the 5th day after returning home. Thus, there are differences in time needed for synchronization of physiological functions between eastward and westward flights.

#### The Fifth Experiment (Flight From East to West 1976)

Subjects and procedures. The same physician as in the fourth experiment served as the subject. After baseline nights in TYO, all-night sleep EEGs were recorded on four consecutive nights in London (LDN).

The aircraft left TYO at 2130 h and via Anchorage arrived at LDN at 0605 h on next day due to a 17-hour flight and the 8-hour difference in time zone. The subject went to bed in LDN at 2300 h, which corresponded to 0700 h in TYO. According to his circadian rhythm in "home time", this means that he began to take a morning nap followed by an afternoon nap. To wake up at 0700 h in LDN corresponds to 1500 h. As there was one night's sleep deprivation due to the flight and 8 hour difference in time zone, his one day was prolonged to 54 hours.

Results. The appearance pattern of REM sleep is represented in Figure 14. On the first night in LDN, increased numbers of REM sleep periods were noted. On the first and second nights in LDN, early appearances of REM sleep periods were observed with marked increase of REM sleep which was predominantly in the first part of the sleep period.

Sleep latencies and REM sleep latencies were reduced on the nights in LDN and gradually increased to those of baseline nights. %SREM was increased, while %S3+S4 was reduced on the nights in LDN (Figure 15). The findings mentioned above are similar to those on the home nights after returning from SFO.

The proportions of REM sleep and slow wave sleep (S3+S4) within 120 minutes of sleep onset (the first part) and within 120 minutes before waking up on the next morning are represented in Figure 16. In the first part, REM sleep was increased and gradually decreased, but by the fourth night in LDN did not return to the REM sleep levels on the baseline night. Slow wave sleep was markedly increased on the first night in LDN but was decreased from the second to fourth nights in LDN. In the last 120 minutes of sleep, REM sleep was also increased and slow wave sleep was decreased and on the fourth night in LDN these tendencies continued.

As for the change in autonomic function, examination of pulse rate data was taken as an example. As seen in Figure 17, the mean pulse rate was elevated by the third night in LDN and its restoration was acquired on the fourth night in LDN.

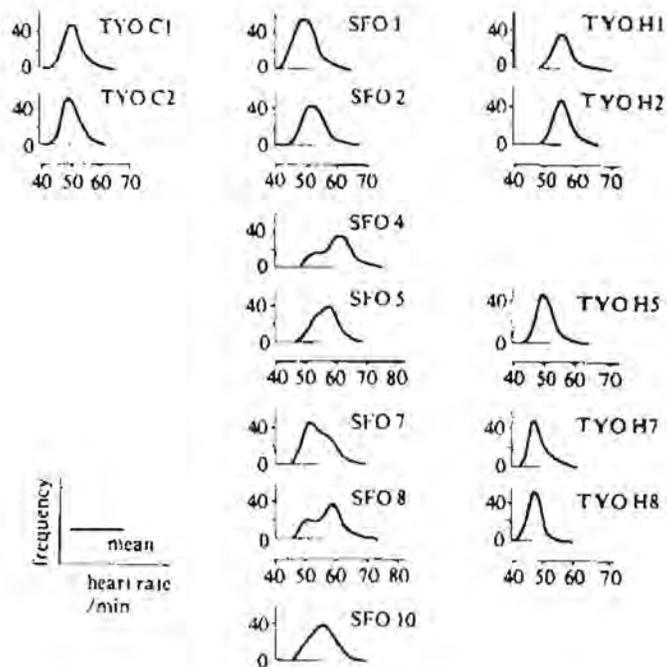


Figure 13. Frequency distribution of heart rate in nocturnal sleep before, during, and after 10-day stay in SFO. Heart rate failed to restore synchronization with that in baseline nights even on the 10th day after arrival at SFO and its restoration is acquired on the 5th day after returning home.

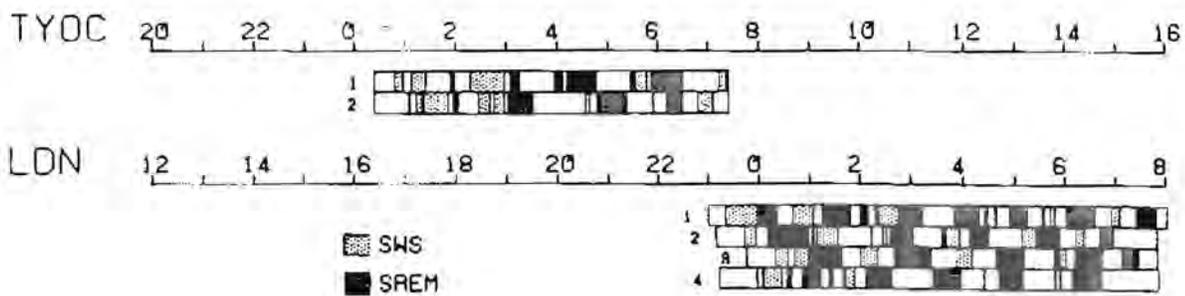


Figure 14. The appearance patterns of REM sleep and SWS in the nights in TYOC and LDN. The Figure shows increased numbers of REM sleep periods on the first night in LDN and early appearances of REM sleep periods on the first and second nights in LDN

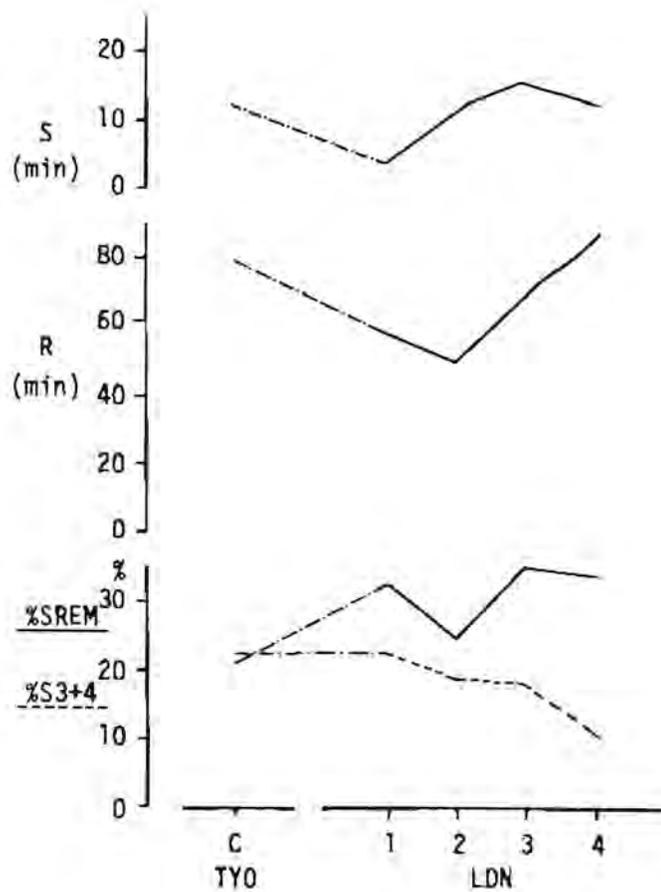


Figure 15. Sleep latency (S), REM sleep latency (R), %SREM and %S3+4 at nights in LDN. The Figure shows shortened sleep latency, shortened REM sleep latency, and increase in REM sleep after TYO/LDN flight.

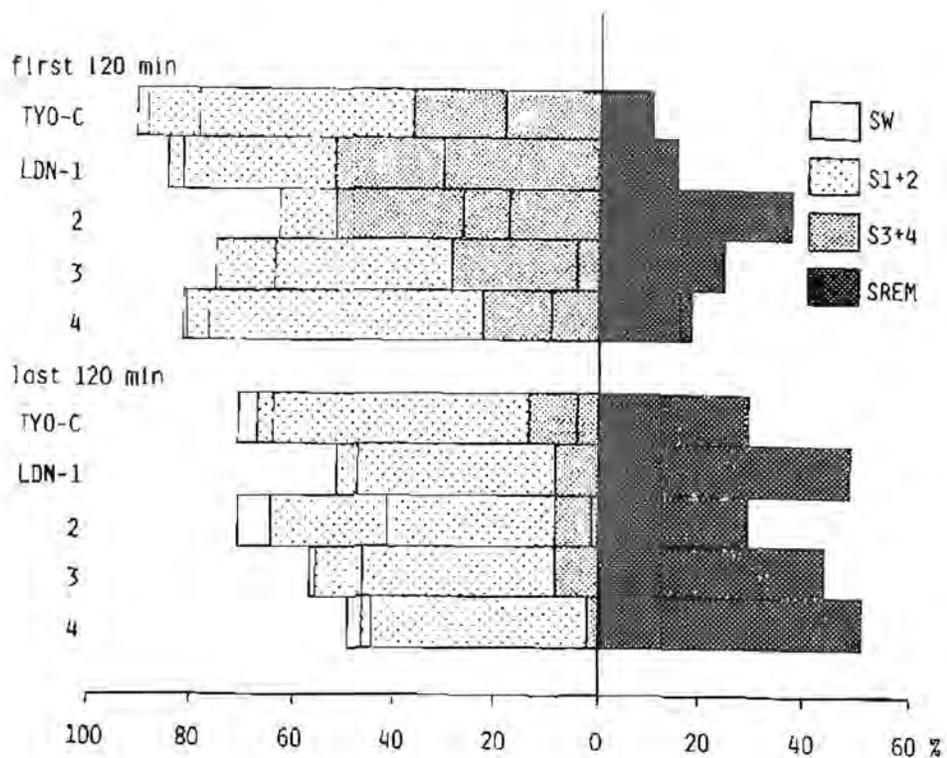


Figure 16. The proportions of REM sleep and slow wave sleep within the first and last 120 minutes of sleep. In the first part REM sleep and SWS were increased and gradually decreased at nights in LDN. In the last part REM sleep was increased and SWS was decreased at nights in LDN.

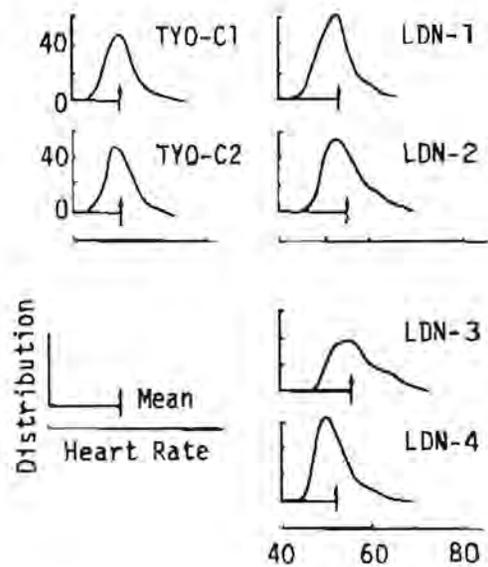


Figure 17. Frequency distribution of heart rate in nocturnal sleep on nights in LDN. The mean heart rate was elevated by the third night in LDN and its restoration was on the fourth night in LDN.

## Discussion

The described changes in sleep after time zone changes are thought to be the result of a complicated summation of sleep deprivation, sleep reversal, naps, shifts in sleep onset time and changes in circadian rhythm. As mentioned before, Evans reported that no definite evidence of circadian effects due to alteration in time zone were demonstrated. According to the author's findings however, sleep as a circadian rhythm can not be free from the effect of time zone changes.

### Changes in Sleep After Eastward Flight (Flight from TYO to SFO)

In SFO, as compared with baseline nights in TYO, both the amount and proportion of Stage REM (TSREM and %SREM) were decreased. NREM sleep, especially slow wave sleep, was increased in both amount and proportion. It is not considered unreasonable to assume that these changes in sleep may have resulted from the maintenance of the home circadian rhythm to a new destination. To go to bed at 2300 h in SFO, which corresponds to 1600 h in TYO, means that a traveller from TYO starts his sleep from evening nap in TYO if he was in TYO. In evening naps, NREM sleep is increased and REM sleep is decreased (Maron, Rechtschaffen, & Wolpert, 1964; Webb, Agnew, & Sternthal, 1966; Webb & Agnew, 1967; Webb, 1966). Endo, Nishihara, Aizawa, and Oda (1976) and Endo, Koga, and Fukuda (1978), who made detailed studies of naps, confirmed that in evening naps, REM sleep was decreased and slow wave sleep was increased as seen in Figure 18. In the flight from West to East, however, the subjects experienced one night total sleep deprivation. Consequently, it is necessary to do research on naps after total sleep deprivation.

Changes of REM and NREM sleep after total sleep deprivation are represented in the lower part of Figure 18. REM sleep is clearly increased in the morning and decreased in the evening in spite of one night of total sleep deprivation. These findings indicate that the distribution of REM sleep is not affected by total sleep deprivation, but has a clear circadian rhythm, that is, clock dependency. By contrast, slow wave sleep is increased in the morning, afternoon, and evening naps after total sleep deprivation. Thus, slow wave sleep is more independent of circadian effects and responsive to the length of prior wakefulness.

From the findings mentioned above, it is assumed that the decrease of REM sleep and the increase of slow wave sleep in the first part of the sleep in SFO may be caused by effects of one night total sleep deprivation and circadian rhythm of REM Sleep. Seven o'clock in the morning in SFO, when the subjects wake up, corresponds 0000 h in TYO, when REM sleep is usually decreased and SWS increased (Taub & Berger, 1973). This may be the reason that in the last half of sleep on the first night in SFO, REM sleep was decreased.

The effects of one night total sleep deprivation during the flight from TYO to SFO must be taken into consideration. In the first recovery night after sleep deprivation, NREM sleep is markedly increased, while REM sleep remains unchanged (Berger & Oswald, 1962; Williams, Hammack, Daly, Dement, & Lubin, 1964). Therefore, a decrease in REM sleep on the first night in SFO can not be explained only by the effect of sleep deprivation. Globus (1966) and Globus, Gardner, and Williams (1969) stated that the occurrence of REM sleep is

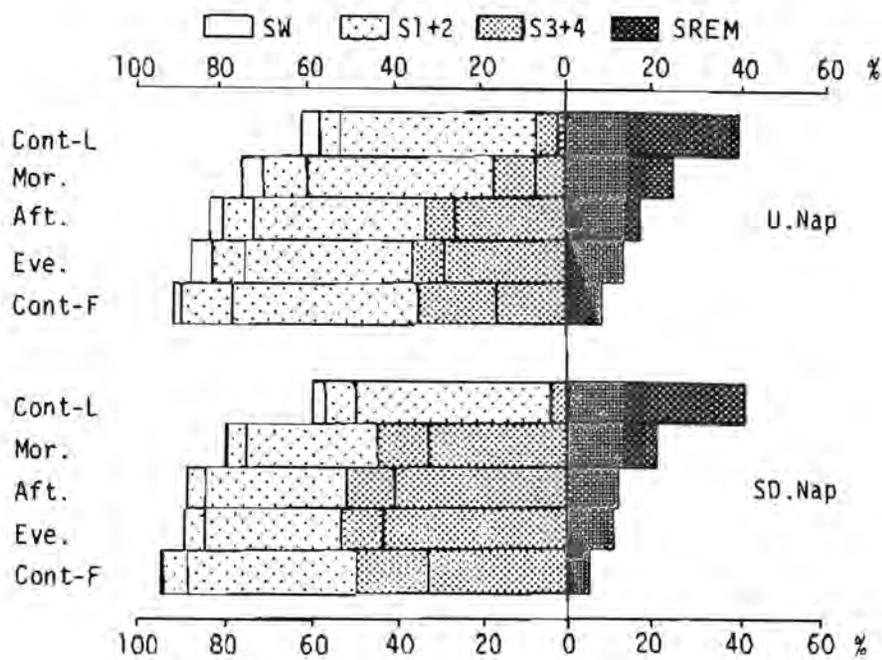


Figure 18. Percentage of sleep in each stage during 120 min after sleep onset in usual nap (U.Nap) and after one night total sleep deprivation (SD. Nap). Mor: morning nap; Aft: afternoon nap; Eve: evening nap; Cont-L: 120 min of sleep before awaking from nocturnal sleep; Cont-F: 120 min of sleep after falling asleep in nocturnal sleep.

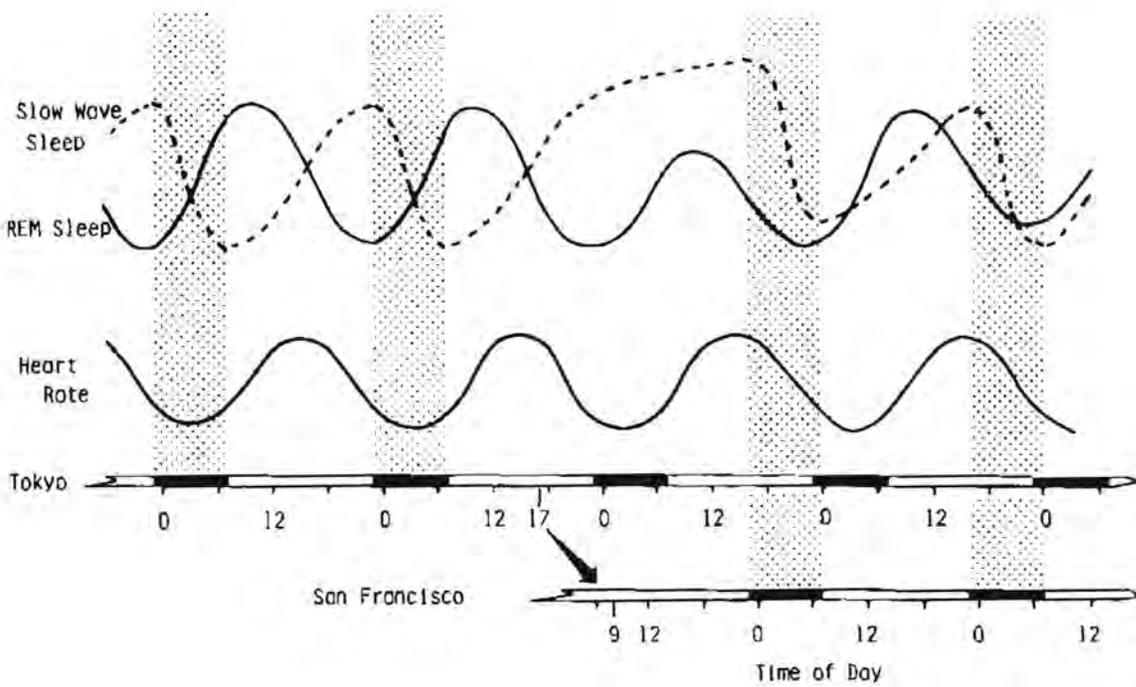


Figure 19. Schematic relationship between a shift of sleeping time and changes of biological rhythms after eastward flight.

a function of real time, occurring at the same time from day to day. Endo et al. (1976,1978) elucidated the circadian rhythm of REM sleep, that is, clock dependency of REM sleep. The changes of REM sleep in SFO mentioned above, are considered to be the result of having brought the circadian rhythm of REM sleep in TYO to SFO.

A schematic relationship between a shift of sleeping time due to time zone changes and changes of biological rhythms is represented in Figure 19. From the results of temporal distributions of REM sleep and changes of slow wave sleep based on the research of naps after usual nocturnal sleep and after one night total sleep deprivation, we can represent circadian rhythm of REM sleep and increase of slow wave sleep as the results of summation of prior wakefulness in the upper part of this Figure. As the sleep in SFO corresponds to that in the late afternoon to the evening in TYO, the decrease of REM sleep in SFO is considered to be the result of having brought the home circadian rhythm of REM sleep into SFO. The increase of slow wave sleep appears to be the result of prior wakefulness due to one night sleep deprivation. The circadian rhythm of heart rate is represented in the middle of Figure 19. The increase of heart rate during nocturnal sleep in SFO may be caused by the persistence of the home circadian rhythm of the heart rate.

As the sleep onset time is almost the same in SDY as in TYO after a southward flight to SDY, only the effects of one night sleep deprivation were found on the first night in SDY. Thus, the first night sleep after arrival at SFO was evidently different from that in SDY.

Changes in Sleep After Westward Flight (Flights from SFO to TYO and from TYO to LDN)

The sleep after returning home was different from that in baseline nights in TYO, with decreased REM sleep latency, appearance of SOREMPs and increased REM sleep in the first part of sleep. The sleep after the flight from TYO to LDN was also different from that on baseline nights in TYO, with decreased REM sleep latency and increased REM sleep especially in the first part of the sleep.

Since the sleep after returning home and in LDN corresponds to that in the early morning to forenoon in the place before the flight, it is necessary to investigate the effect of sleep reversal and naps in daytime.

Weitzman, Kripke, Goldmacher, McGregor, and Nogueira (1970) and Jovanovic (1971) reported that in sleep reversal, REM sleep was increased in the first half of sleep and REM sleep latency was reduced. Nakagawa and Nakagawa (1970) reported that in daytime naps REM sleep occurred without passing through Stage 3 or Stage 4. Endo et al. (1978) elucidated that in both usual naps and naps after one night total sleep deprivation, morning naps had shortened REM sleep latency, increased REM sleep and frequent SOREMPs.

From the findings mentioned above, it is suggested that the nocturnal sleep after returning home and in LDN may reflect the circadian rhythm of sleep in the place before the start of the flight. It is, however, impossible to give sufficient explanation as to why the increase of REM sleep in the fourth experiment was only vestigial, whereas that in the second experiment was marked. Elucidation of this point must wait future study.

Synchronization of sleep as a circadian rhythm to new time zone is attained nearly in 8 days either after eastward or westward flight. This seems to suggest that sleep, which to a certain degree is voluntarily changeable, may not be influenced by advanced shift or by delayed shift. By contrast, the circadian rhythm of autonomic functions such as pulse rate, which is involuntary, takes 10 days for synchronization after eastward flight, and only 5 days after westward flight. The findings mentioned above indicate that there may be varying synchronization in different physiological rhythms.

In the southward and northward flights, the changes in sleep mentioned above were unobservable except the effect of total sleep deprivation. It can therefore be assumed that the changes in sleep elicited by the transmeridian flights may chiefly be attributed to time zone changes.

#### Summary

Studies on alterations in circadian rhythms due to time zone changes were discussed with emphasis placed on sleep. On the basis of five experiments; 1) changes in sleep after TYO/SFO flight (Eastward flight), 2) changes in sleep after TYO/SFO and SFO/TYO flights (Eastward and Westward flights), 3) control study on changes in sleep after TYO/SDY and SDY/TYO flights (Southward and Northward flights), 4) synchronization of sleep with the local time after eastward and westward flights, and 5) changes in sleep after TYO/LDN (Westward Flight). Changes in sleep after time zone changes were summarized as follows:

1. Changes in sleep after eastward flight (from TYO to SFO). After TYO/SFO flight, the amount of SWS was significantly elevated and REM sleep was markedly depressed especially during the first and last parts of nocturnal sleep, although the distribution of both types of sleep was not altered. The sleep latency was short and REM sleep latency did not change. The mean pulse rate was elevated. It took 8 days for the sleep rhythm to synchronize with the local time in SFO, and more than 10 days for pulse rate. Thus, there was a difference in synchronization between different physiological phenomena.

2. Changes in sleep after westward flight (from SFO to TYO and from TYO to LDN). After SFO/TYO flight, there was enhancement of REM sleep especially in the first part of the nocturnal sleep, but SWS did not change. Sleep latency and REM sleep latency were significantly abbreviated. Also there was clear evidence of alteration in the distribution of REM sleep with SOREMP on the nights after SFO/TYO flight. After TYO/LDN flight as the westward flight, sleep latency and REM sleep latency were also abbreviated and REM sleep was increased. It took 8 days for the sleep rhythm after SFO/TYO flight to synchronize with Japan time, and about 5 days for pulse rate. Thus, there was a difference in the number of days prior to synchronization for different physiological functions, and more days were needed for synchronization after the eastward than after the westward flight.

3. Changes in sleep after southward and northward flights. After the TYO/SDY flight without a time zone change, there was no change of REM sleep but marked enhancement of SWS on the first night in SDY. On the first night after the return flight SDY/TYO, there was enhancement of SWS

but no change of REM sleep. This supports the assumption that desynchronization syndrome including sleep disturbance may be attributable to time zone changes.

The utilization of time zone changes for the study of desynchronization of circadian rhythms and of the chronobiology of desynchronization is not only possible, but also contributes to the pathophysiological elucidation of sleep disturbance and to the study of shift workers.

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES  
Public Health Service  
Centers for Disease Control  
National Institute for Occupational Safety and Health

THE TWENTY-FOUR HOUR WORKDAY: PROCEEDINGS OF A SYMPOSIUM  
ON VARIATIONS IN WORK-SLEEP SCHEDULES

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