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EFFECT OF CESSATION OF LATE-NIGHT LANDING NOISE ON SLEEP ELECTROPHYSIOLOGY IN THE HOME

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Prepared for:
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SUMMARY

Simultaneous measurements of noise exposure and sleep electrophysiology were made in homes before and after cessation of nighttime aircraft landing noise. Six people were tested, all of whom had been exposed to intense aircraft noise for at least two years.

Noise measurements indicated a large reduction in the hourly noise level during nighttime hours, but no change during the daytime hours. Sleep measures indicated no statistically significant changes in sleep patterns either immediately after a marked change in nocturnal noise exposure or approximately a month thereafter. Also, no strong relationship was observed between noise level and sleep disturbance over the range from 60 to 90 dB(A).

I. INTRODUCTION

A major public concern about aircraft noise is its potential effect on sleep quality. This concern is partially substantiated by inferences drawn from laboratory investigations of effects of noise on sleep. Careful evaluation of the methodology and results of such studies, however, reveals numerous grounds for questioning the application of their conclusions to aircraft noise exposure as experienced in the world at large. These grounds include dissimilarities between laboratory and realistic noise environments, familiarity and habituation of subjects to noise exposure patterns, and inadequate sample sizes. More fundamental questions may also be raised about the meaningfulness and consistency of scoring techniques for electrophysiological recordings, and the almost complete lack of information on the consequences of small amounts of sleep disturbance.

New technology for simultaneous collection of noise and sleep data in field settings has recently been introduced (Ref. 1). The current study applies this demonstrated technology to the study of changes in sleep electrophysiology in a sample of persons whose nocturnal aircraft noise exposure decreased drastically and abruptly. The goal of the current study was to determine whether relief from intense nocturnal noise exposure, when measured in the home environment, produced any immediately obvious changes in electrophysiological sleep patterns.

II. METHOD

A. Subjects

Four middle aged couples who had participated in a prior field study of sleep electrophysiology (Ref. 1) also participated in the current study. Each subject met an audiometric screening criterion for hearing acuity (within 15 dB of "normal hearing") which included an allowance for decreased sensitivity due to presbycusis (Ref. 2). All subjects were familiar with the data collection methodology from their experience in the previous study.

Due to problems in the subject group, the final experimental group contained only six people as shown in Table I. The ages of the subjects ranged from 36 to 52 years with a mean of 44.6 years. The number of years of residence in the neighborhood ranged from 2 to 11 years with a mean of 4.3 years.

TABLE I

TEST SUBJECTS

IDENTIFICATION	AGE	LENGTH OF RESIDENCE
Mr. A	50 Yrs.	2 Yrs.
Mrs. A	52 "	2 "
Mrs. B	40 "	11 "
Mr. C	44 "	3 "
Mrs. C	36 "	3 "
Mr. D	46 "	5 "

B. Site Selection and Characteristics

The residences of the subjects were located approximately one mile east of Los Angeles International Airport (LAX) underneath the approach pattern to the southern runways. All subjects lived in single family, wood frame and stucco houses on two-way residential streets in the middle of the block. The approach patterns to LAX expose the residents in this area to noise of day-night (L_{dn}) values between 80 and 85. There were no major noise sources, other than aircraft nearby that contributed to the L_{dn} values. The background noise was controlled by traffic from the nearby San Diego freeway. Figure 1 locates the residences.

On April 29, 1973 an operational change was instituted at LAX which eliminated late night aircraft landings over the subjects' residences between the hours of 2300 and 0600. This change eliminated approximately 50 overflights per night which had been heard in this community for many years.

C. Data Collection

Sleep and noise data were collected during three experimental sessions. The initial session, before cessation of night landings, was conducted during the week of April 22 to 27, 1973. The second session (immediately after cessation of nocturnal landings) was contiguous, from April 29 to May 3rd. The third experimental session was conducted about three weeks later, from May 20 to May 24.

Indoor noise exposure levels were collected concurrently with electrophysiological data. The recording equipment was

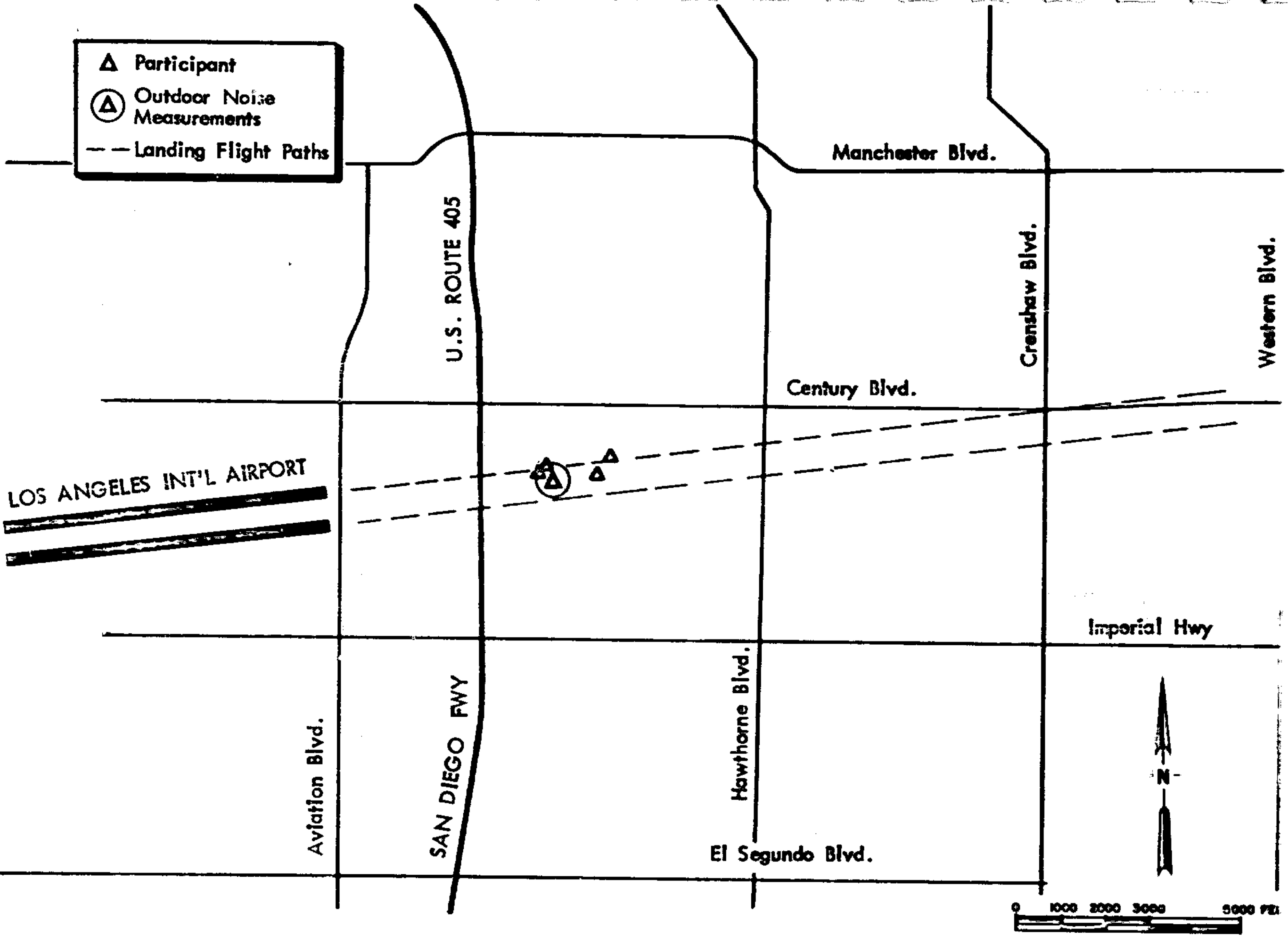


FIGURE 1. LOCATION OF THE RESIDENCES OF TEST PARTICIPANTS

placed in a room adjacent to the bedroom, with the microphone situated one to two meters from the subjects' heads. Two research assistants calibrated the noise monitoring equipment and applied the electrodes to the subjects' heads approximately one hour prior to retiring each night. The subjects were requested to avoid major changes in their daily life style during the testing period. They were also asked to refrain from consumption of alchohol and new medication at least one hour before retiring. No explicit mention was made of the imminent change in aircraft landing procedure unless the subject raised the issue.

D. Equipment

A modified analog tape recorder and sound system and a compact biodata monitor were used for indoor collection of both noise and sleep data. The outdoor noise data were recorded by a portable digital system. A schematic representation of the test monitoring equipment is shown in Figures 2 and 3.

A specially modified four track analog recorder was used indoors as the storage medium for both sleep and noise data. The tape recorder was modified to record at a speed of 1-7/8 inches per second. A further adjustment to playback equalization was made to allow data readout at four times the recording speed. A Bruel and Kjaer precision sound level meter with a 1 inch condenser microphone was used for continuous analog recording of the indoor noise environment on one channel of the tape system. A WWV receiver produced timing information on a second tape channel.

The sleep physiology data, consisting of multiplexed FM recordings of electroencephalograms (EEG) and electro-oculograms (EOG) for each person were recorded on the remaining two tape

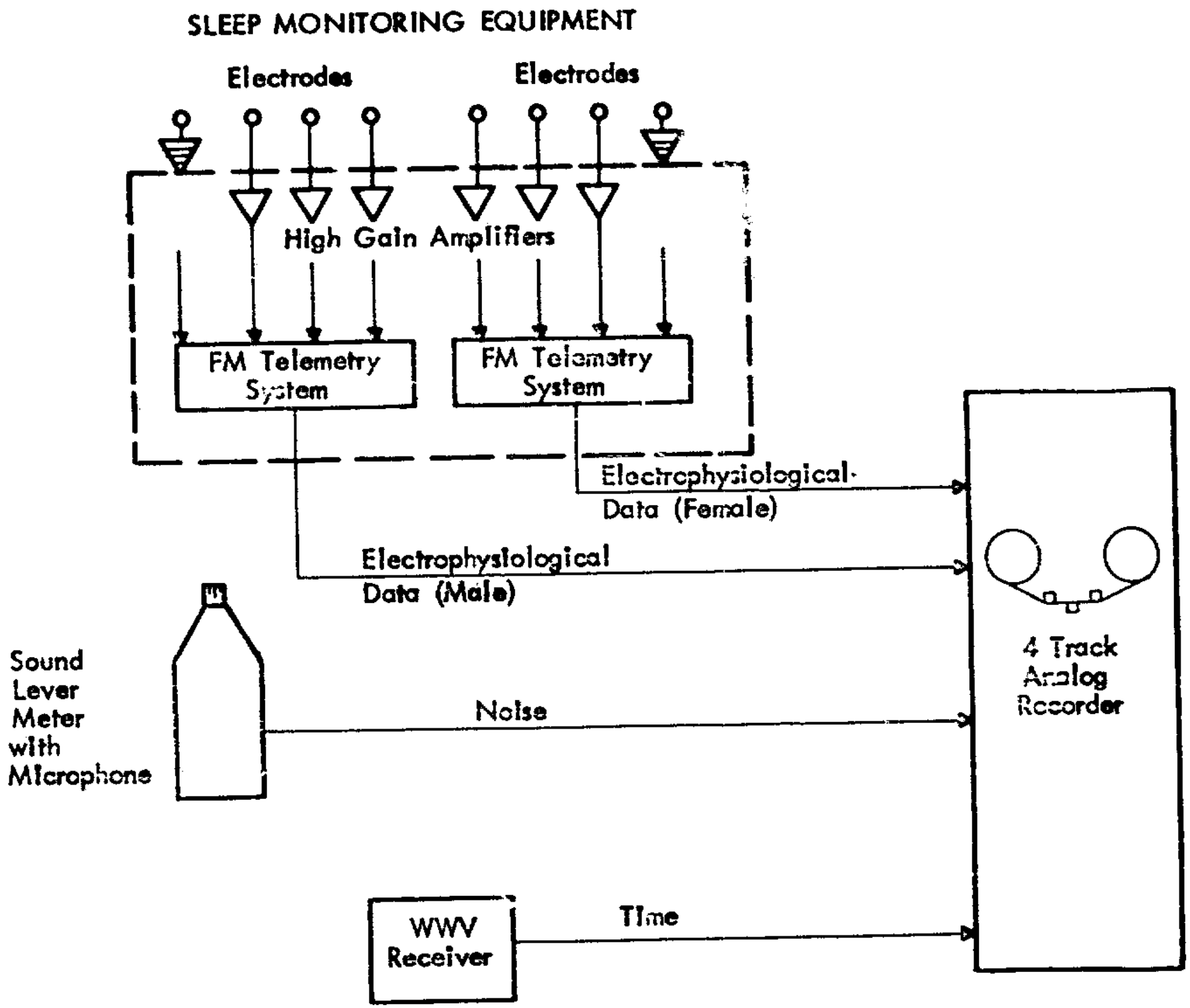


FIGURE 2. SCHEMATIC REPRESENTATION OF HOME MONITORING EQUIPMENT

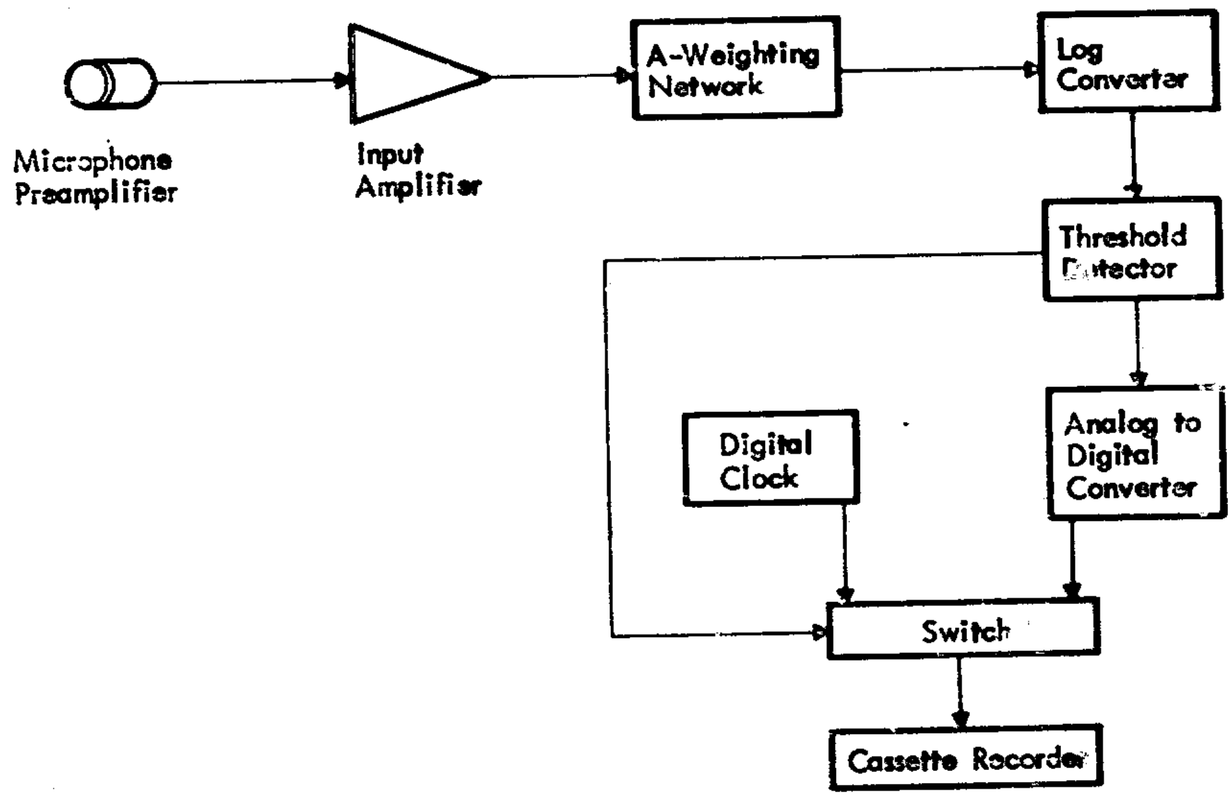


FIGURE 3. SCHEMATIC REPRESENTATION OF OUTDOOR MONITORING EQUIPMENT

channels. Three separate carrier frequencies were used on each channel to differentiate right and left EOG and EEG data.

Outdoor noise data were collected by a portable digital system. The portable noise unit contained a microphone, an input amplifier, an A-weighting network, a threshold detector, a logarithmic converter, an analog to digital converter, a digital clock and a cassette tape recorder. The system operated unattended, sampling noise levels every half second throughout the night. Noise levels which exceeded a preset threshold were recorded on a magnetic tape cassette.

E. Data Reduction Procedures

The indoor acoustic data and the physiological data were reduced simultaneously as shown in Figure 4. The indoor noise data recorded on magnetic tape were analyzed by the portable monitoring unit that was used for outdoor noise measurement. This unit automatically provided event marking information on the physiological channels when the noise level exceeded 60 dB(A). At the same time, the noise exposure was recorded on paper by a logarithmic graphic level recorder.

The outdoor noise data were computer processed to obtain the Equivalent Sound Level (L_{eq}). The software detected the number of events that exceeded the threshold by at least 5 dB, the event durations, and the peak levels of all events exceeding the threshold.

The sleep data were analyzed according to the international scoring criteria of the Association for the Psychophysiological Study of Sleep, with two exceptions. Electrode placement (over the left eye, below the hairline) deviated from the above criteria

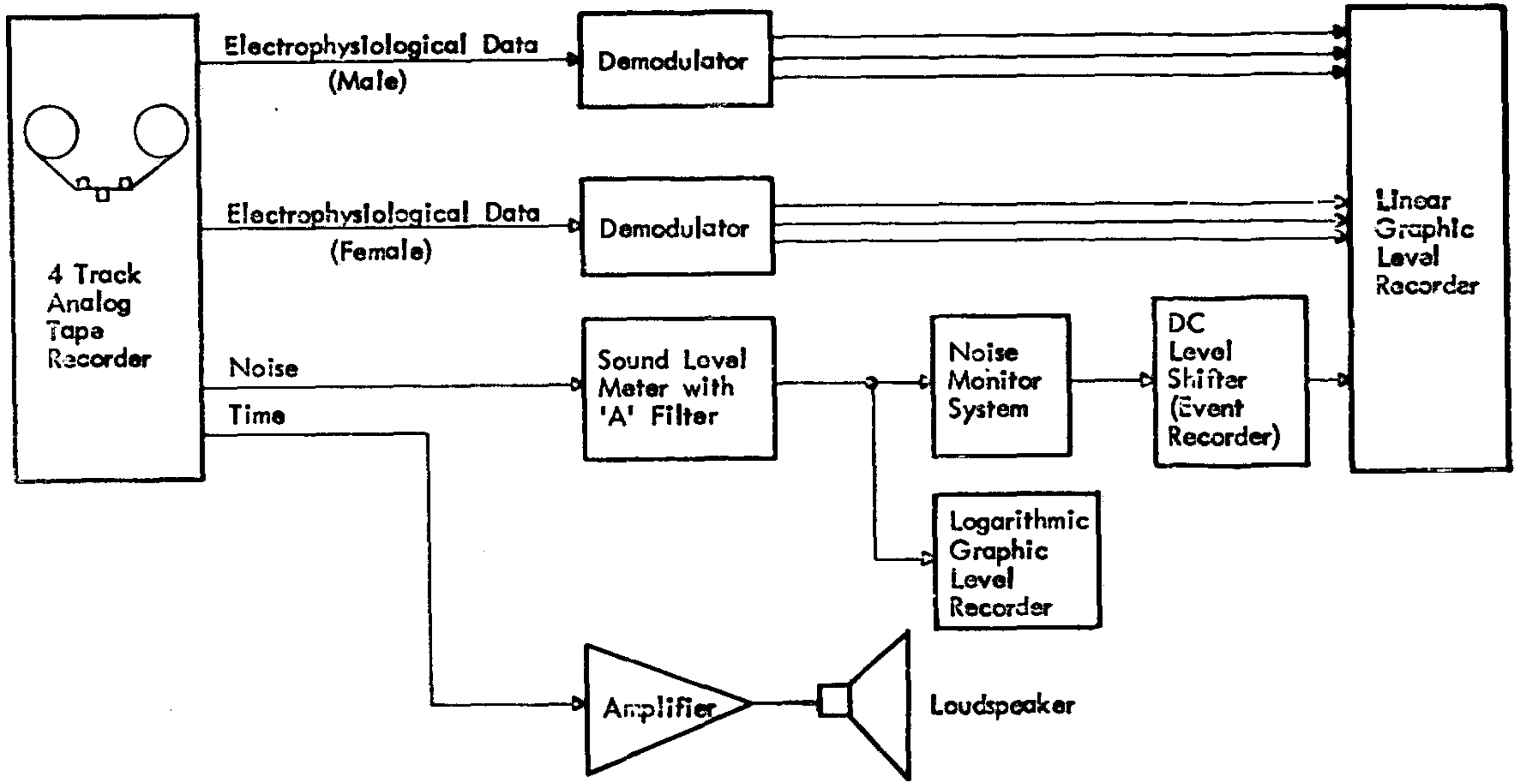


FIGURE 4. SCHEMATIC REPRESENTATION OF DATA ANALYSIS EQUIPMENT

(yielding a more frontal derivation); and a 100 microvolt criterion was adopted for delta waves in place of the recommended 75 microvolt criterion.

The FM recordings of the sleep physiology data were demodulated and written on a linear polygraph level recorder. The biodata were screened automatically to detect delta activity, defining sleep Stages 3 and 4. The delta detector output was written out along with continuous EEG and EOG data and noise event marks on the sleep records. Two human scorers checked the automatic data analysis and classified the remaining sleep information into sleep stage categories. The scorers assigned each twenty second epoch of a sleep record to one of the following stages.

LIGHT SLEEP

1. Movement (M) - gross body movements
2. Waking (W)
3. Stage 1

DEEP SLEEP

1. Stage 2
2. Stage 3
3. Stage 4
4. Rapid Eye Movements (REM)

The distinctions between *light* and *deep* sleep time were based on a number of considerations. For example, *light* sleep includes the category of *movement* which is generally associated with an EEG pattern of waking and Stage 1 which is characterized by drowsiness and partial awareness. Since Stage 1 exhibits alpha wave activity and does not show typical sleep spindles and K complexes, it also was placed with the former two classifications under *light* sleep. *Deep* sleep is characterized by the delta wave activity of Stages 3 and 4 and the sleep spindles and K complexes of Stage 2. The REM stage was also included in *deep* sleep although some REM characteristics are present in Stage 1.

Counters recorded percentages of delta activity when certain criteria were met; these percentages were used to indicate sleep stages. From 20 percent to 51 percent delta activity was regarded as Stage 3; 51 percent or more delta activity was regarded as Stage 4 sleep. Less than 20 percent delta wave activity was taken to indicate some other sleep stage which was hand scored.

III. RESULTS

Three principal analyses of the noise and sleep data were conducted. The three analyses treated the noise data separately, the sleep data separately, and the noise and sleep data together.

A. Analysis of Noise Data

The change in nocturnal noise exposure was in fact abrupt and dramatic. Figure 5 displays the change in outdoor Hourly Noise Level (HNL) (the *energy averaged* hourly A-weighted sound level) for typical 24 hour periods before and after cessation of night overflights. The L_{dn} outside values before and after cessation are 85 and 83. The marked decrease in level from 77 to 51 dB(A) or 26 dB(A) between the hours of 2300 and 0600 is a direct result of the rerouting of night operations. Typical inside noise levels during the same period were 52 dB(A) before cessation and 39 dB(A) after cessation of night overflights. Recordings of daytime noises inside the houses were not made, however, estimates of L_{dn} values were 60 dB(A) before cessation and 59 dB(A) after cessation.

Figure 6 shows a similar trend in decreased noise levels inside homes after cessation of nocturnal flyovers. The measured noise events included flyovers, traffic and interior residential noises before the cessation, but mostly "people noises" (i.e., movement or coughing) generated inside the house after the cessation. As may be seen in Figure 6 the mean number of events per hour in the 5 dB interval centered at 80 dB(A) before cessation of flyovers was 1.2, or 8.4 events during the time period 2300-0600. The average duration 10 dB down from the maximum level was 8 seconds. After cessation of flyovers, the mean number of events in that interval declined to 0.2 events

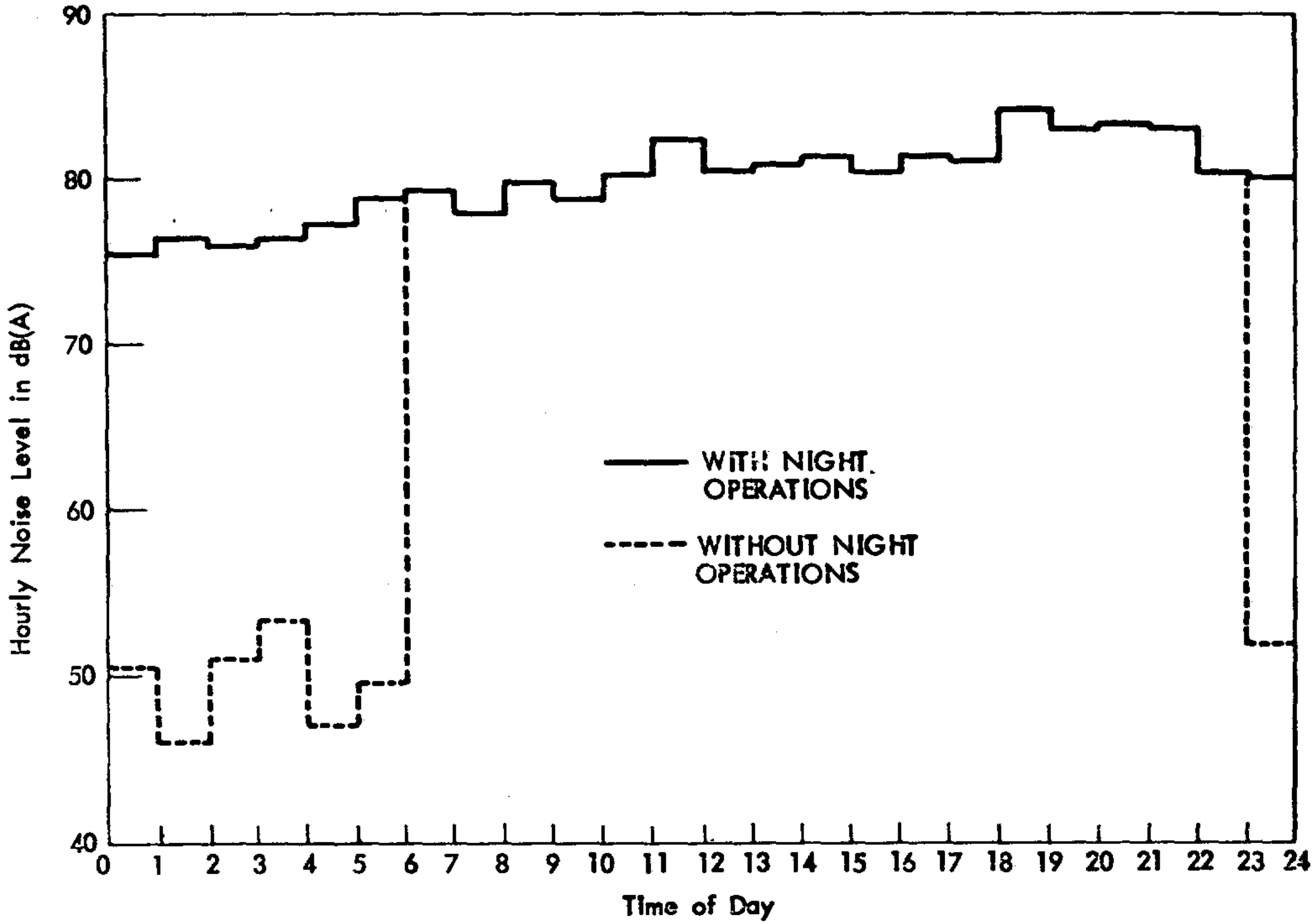


FIGURE 5. OUTDOOR HOURLY NOISE LEVELS FOR A TWENTY-FOUR HOUR PERIOD

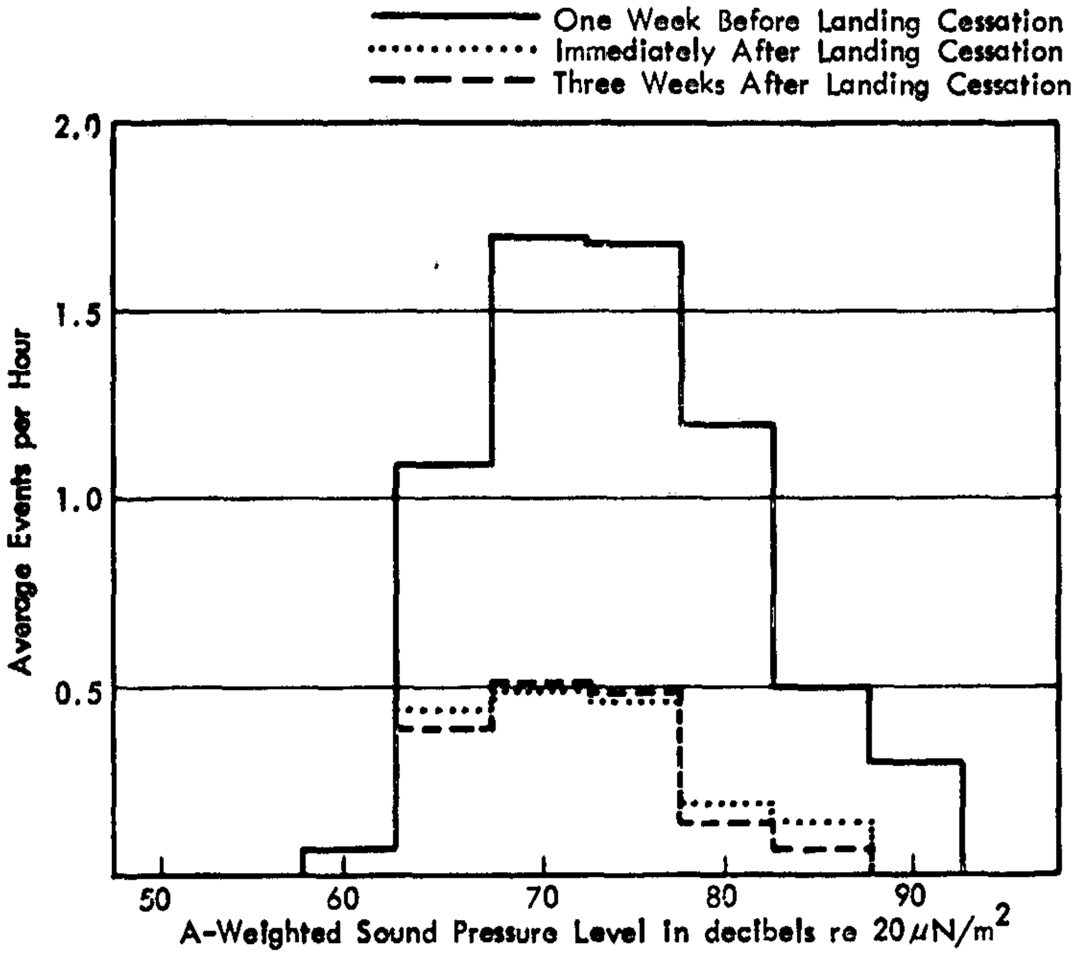


FIGURE 6. NIGHTTIME NOISE LEVELS INSIDE HOMES BEFORE AND AFTER CESSATION

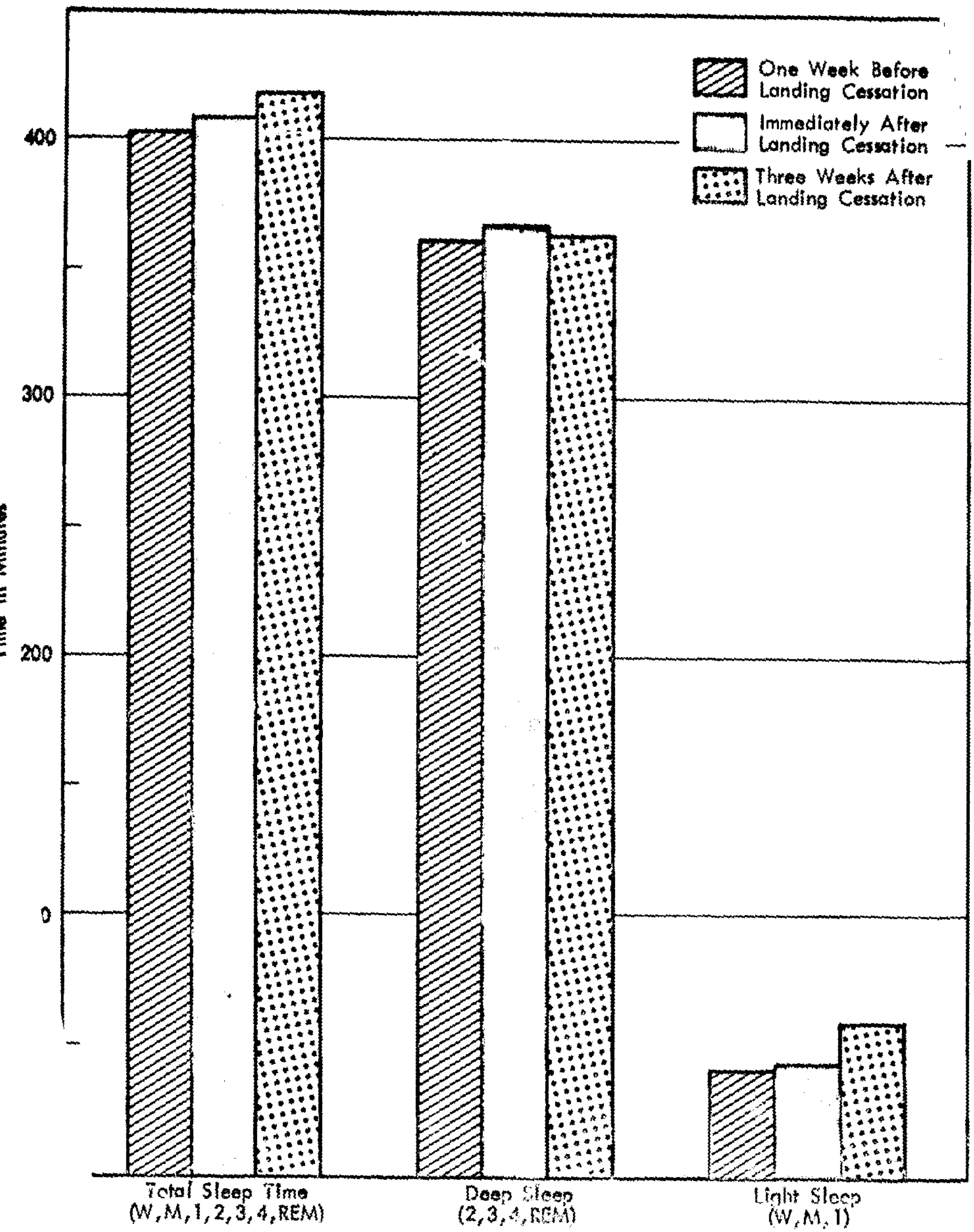
per hour, or 1.4 events over seven hours. The average duration of these events was less than one second. Two weeks later, the hourly average number of events was 0.14, or .98 per night. Again, the events had an average duration of less than one second.

B. Analysis of Sleep Records

The amount of time spent in each sleep stage, the average number of awakenings per night, sleep latency, and REM latency were determined from the sleep records. The magnetic tape used to record sleep electrophysiology unfortunately ended before morning occasionally, causing a loss of approximately one percent of the data. No data were lost before cessation of flyovers; however, two nights' records ended prematurely in both the second and third experimental sessions.

Figures 7 and 8 show the average lengths of time spent in each sleep stage for the three measurement sessions. In Figure 7, sleep stages are condensed into three categories: 1) *Total Sleep Time* (including waking, movement, sleep Stages 1 through 4, and REM), 2) *Deep* Sleep (Stages 2, 3, 4, and REM), and 3) *Light* Sleep (waking, movement, and Stage 1).

Among the differences observed in these data were a 16 minute increase in *total* sleep time after cessation of flyovers ($t = .50$, $df = 21$), an additional six minutes spent in *deep* sleep after cessation of flyovers ($t = .18$, $df = 24$) and approximately 17 minutes additional time spent in *light* sleep three weeks after cessation of flyovers than at earlier times ($t = 1.78$, $df = 21$). Independent t-tests of these differences failed to indicate statistical significance at the five percent level of confidence.



7. AMOUNT OF TIME (AVERAGED

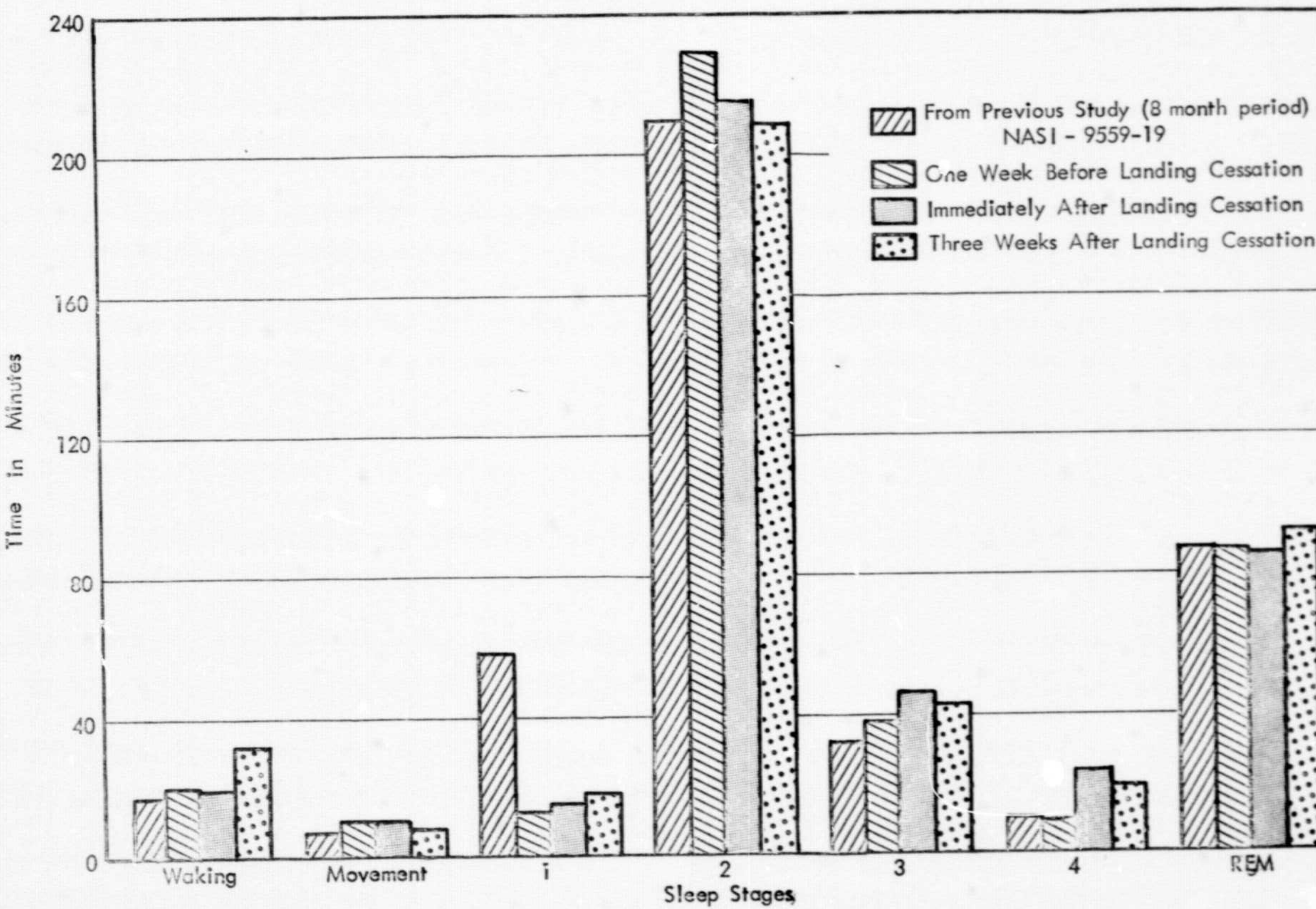


FIGURE 8. AMOUNT OF TIME (AVERAGED OVER SUBJECTS) SPENT IN EACH SLEEP STAGE

Amounts of time spent in each sleep stage are displayed in Figure 8 and Table II for the three data collection sessions. These data indicate little change in the amounts of time spent in the various stages before and after elimination of nighttime flyovers. As may be noted in Table II, approximately 50 percent of total sleep time was spent in Stage 2 during all three measurement sessions. Percentages of time spent in Stages 3 plus 4 increased from 11.6 percent before flyover cessation to 16.5 percent immediately after, and to 14.6 percent three weeks after cessation.

The average number of awakenings before and after nocturnal flyovers were discontinued is plotted in Figure 9 by individual subject. The average number of awakenings was observed to increase by 31 percent three weeks after cessation of flyovers. Again, however, this difference failed to achieve statistical significance (for t = 1.18, df = 9 at .05 level of confidence).

C. Noise Levels and Sleep Physiology

The relationship between noise levels and the relative frequency of shifts in sleep stages is plotted in Figure 10. The line depicting "After Landing Cessation" is a summation of the percentage of total events immediately after cessation and those measured three weeks later. This combination seems reasonable in view of the lack of significant difference in the amounts of time spent in *deep* and *light* sleep during these two measurement periods and the paucity of events after cessation.

Both the upper and the lower graphs demonstrate sleep stage shifts into either *light* or *deep* sleep due to changes in noise event levels. The average relative frequency of a sleep stage shift into *lighter* sleep during the period of late-night

TABLE II

AVERAGE AMOUNT OF TIME (IN MINUTES) SPENT IN VARIOUS SLEEP STAGES

	BEFORE LANDING CESSATION		IMMEDIATELY AFTER LANDING CESSATION		THREE WEEKS AFTER LANDING CESSATION	
SLEEP STAGES	MEAN	% TST*	MEAN	% TST	MEAN	% TST
WAKING	20.1	5.0	19.6	4.8	31.4	7.5
MOVEMENT	9.8	2.4	9.9	2.4	7.5	1.8
1	10.8	2.7	12.3	3.0	18.6	4.4
2	228.3	56.3	213.9	52.2	207.4	49.6
3	38.2	9.5	45.6	11.1	42.3	10.1
4	8.4	2.1	22.1	5.4	18.7	4.5
REM	86.6	21.5	86.0	21.0	93.9	22.5
TOTAL SLEEP TIME	402.2	100.0	409.4	100.0	418.2	100.0
DEEP SLEEP (2+3+4+REM)	361.5	89.9	367.6	89.8	362.3	86.6
LIGHT SLEEP (W+M+1)	40.7	10.1	41.8	10.2	57.5	13.7

*TST = Total Sleep Time
(W+M+1+2+3+4+REM)

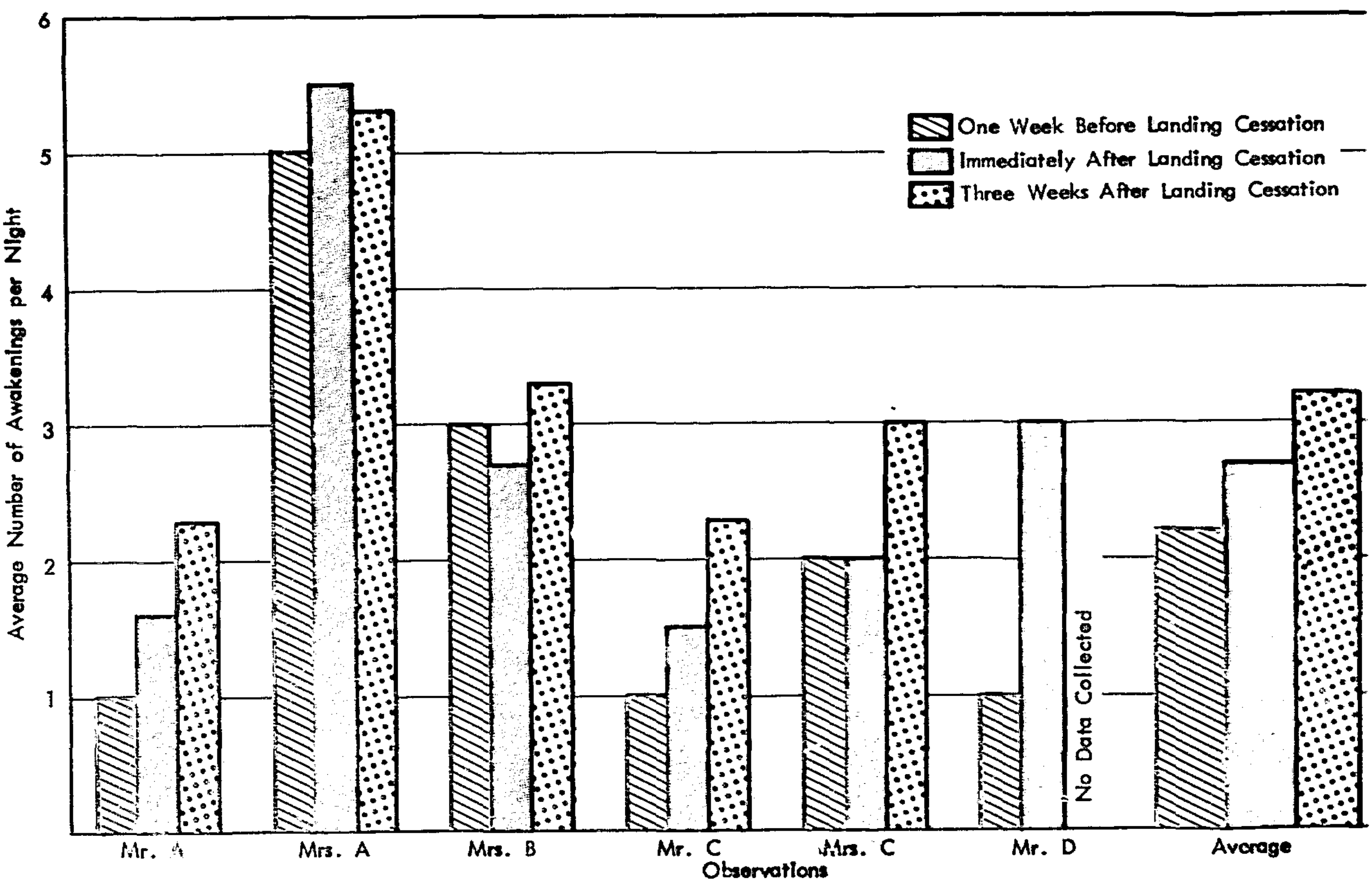


FIGURE 9. AWAKENINGS BEFORE AND AFTER AIRCRAFT LANDING CESSATION

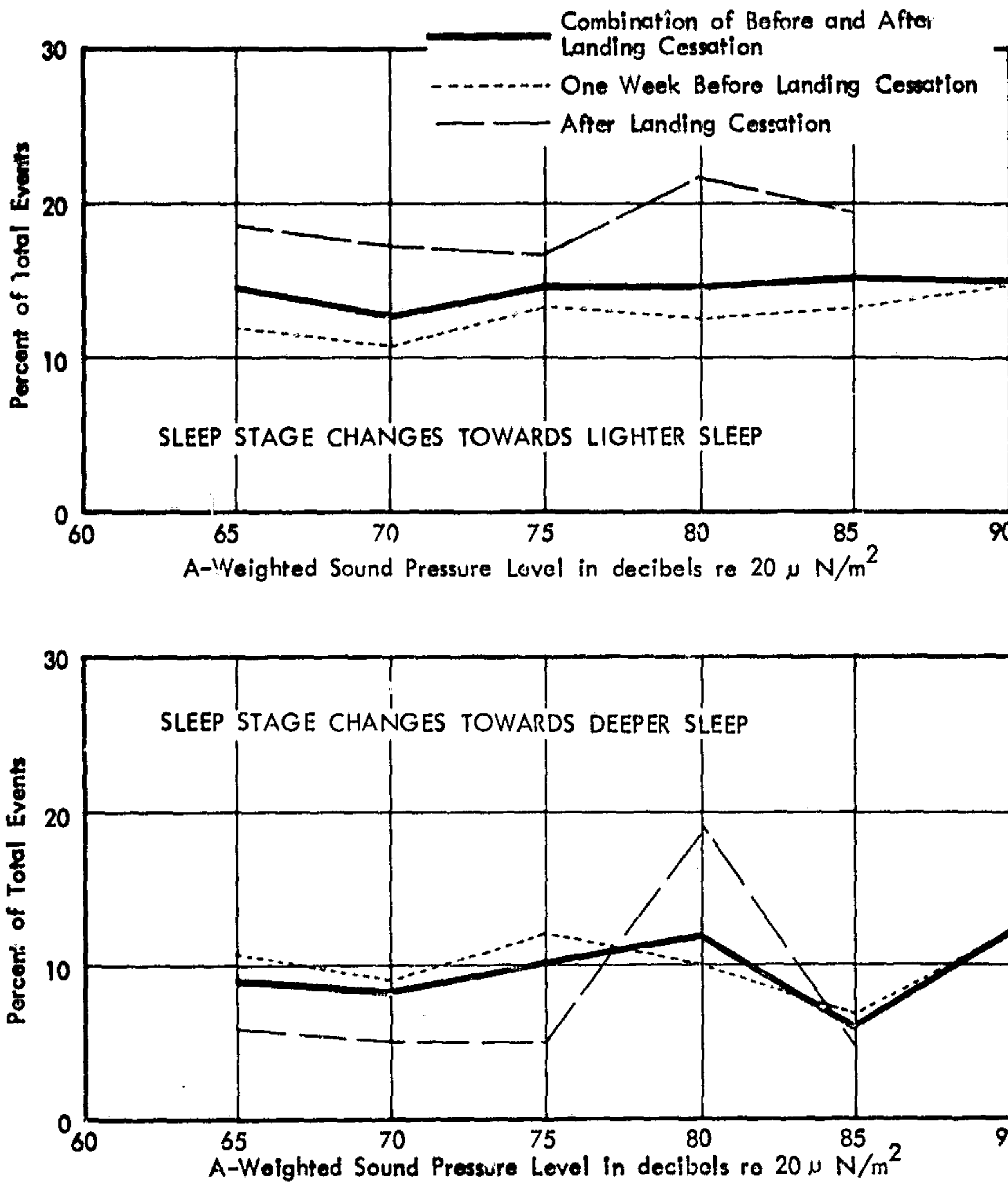


FIGURE 10. EVENTS ASSOCIATED WITH SLEEP STAGES CHANGES AS A FUNCTION OF NOISE LEVEL

flyovers was .12. After nocturnal overflights ceased, the relative frequency of sleep stage shifts was 0.18. A one-way analysis of variance failed to establish the statistical significance ($F = 1.20$, $df = 1/10$) of these findings at the .05 level of confidence. On this basis the resulting percentages before and after cessation of flyovers were combined to produce an average relative frequency of sleep stage change of 0.14.

The opposite trend was observed for the relative frequency of shifting into *deeper* sleep stages due to variations in event noise levels. The average relative frequency of sleep stage changes before cessation of flyovers was 0.10; after cessation it decreased to 0.07. Combining and averaging before and after results produced a mean relative frequency over noise level of 0.09.

IV. DISCUSSION

A. Discussion of Noise Analysis

The analysis of the noise data demonstrated that the independent variable (noise exposure) did indeed behave as anticipated. The cessation of flyover noise between the hours of 2300 and 0700 in fact greatly reduced noise levels to which the test subjects were exposed. The daytime noise levels were unaffected by the change in landing procedure. However, combining both nighttime and daytime levels, the resultant L_{dn} values were reduced by only 2 dB(A) for outdoor measurements. Estimates of L_{dn} for indoor noise suggested a reduction of only 1 dB(A).

A social survey undertaken at the same time as the current study gives additional information on human perception of the effect of reduced noise exposure in terms of L_{dn}. Fidell and Jones (Ref. 3) report that less than half of the residents surveyed in the high noise exposure neighborhood claimed to have noticed any change in number of flights near their homes after cessation of nocturnal overflights, and that the remainder of residents were about equally split between thinking there were fewer or greater numbers of flights. The majority of respondents in the same survey (about 70%) also reported greater annoyance from aircraft noise during daytime rather than nighttime hours, both before and after the cessation of overflights at night.

Thus, although the changes in the subjects' nocturnal noise environment occurred as expected, the effects of the changes on a daily basis were relatively small. The similarity in daily neighborhood noise exposure before and after the airport procedural changes may have delayed habituation to the reduced nighttime exposure.

B. Discussion of Sleep Analysis

No consistent pattern of dramatic improvement in sleep quality emerged from the change in nocturnal noise exposure. Mean differences in amounts of time spent in each sleep stage, and the average number of awakenings before and after the change in noise exposure were neither large nor statistically significant. Some of the observed differences were in a direction consistent with the hypothesis that relief from noise exposure improves sleep quality, however, these differences were not statistically significant at the .05 level.

The principal reason that observed differences in sleep behavior before and after the change in noise exposure did not achieve statistical significance at the .05 level of confidence was that the differences were fairly small. Independent t-tests of the sort employed were sufficiently powerful (sensitive to small effects) that the probability of improperly ignoring legitimate differences in the data was negligible. The small size of the observed differences, in turn, may be attributed to two factors.

First, the time course of habituation to a new noise environment may be long with respect to the measurement period of the current experiment. Thiessen (Ref. 4) has noted a continuing nightly decrease in number of awakenings associated with a constant noise regime over a 24 night testing period. Thiessen's subjects awoke less frequently after three and a half weeks of adaptation, suggesting that complete habituation may require yet further time. Thus, after an average of four years' exposure to jet landing noise, improvements in sleep quality may require more than a few weeks of relief. If sleep quality improves only after a longer period of relief from noise exposure, then measurements at that time might reveal differences not present in the current data.

Second, it seems possible that the sleep of the experimental subjects was abnormal both before and after the change in noise exposure. Those who scored the sleep records felt that both the periodicity of the REM cycle and the high frequency of movement from one sleep stage to another was highly irregular. Attempting to discern improvements in such abnormal sleep may be tantamount to attempting to deduce the normal from the pathological.

The other major reason that differences in sleep patterns did not achieve statistical significance was the variability within and between subjects in the study. Standard deviations of many of the measures of sleep (time in each stage, latency, etc.) were often on the same order as the mean differences, and occasionally larger. Very large samples (on the order of hundreds of subjects) are required to achieve statistical significance under such conditions. Of course, data collection on such a grand scale is of questionable value, if the goal is merely to demonstrate the improbability of random explanations for small effects.

To determine whether scoring procedures or other methodological considerations could have contributed to the small size of mean differences and great variability, the current data were compared with those reported by Pearsons et al. (Ref. 1). Figure 8 is a plot of the comparison of time spent in each sleep stage in the two experiments. With the exception of a marked difference in the amount of time spent in Stage 1, general agreement was good. The difference in time spent in Stage 1 was significant at the .05 level of confidence ($t =$ [illegible].75, $df = 19$). Although little is known about the stability of sleep patterns over relatively long periods of time, the overall similarity of results suggest that procedural matters alone were probably not responsible for the findings of the current study.

Another limited form of independent confirmation of the reasonableness of the current data is available by comparison of awakening data (Figure 9) in the current study with data produced in a separate study conducted at the same time. Pearsons et al. (Ref. 5) recorded the number of behavioral awakenings (defined as depressions of a bedside response button when awakened) in the same neighborhood and during the same nights as those of the current study. One subject actually participated in both studies; her average EEG-scored number of awakenings per night over a one week period was 3.0, while her average number of behavioral awakenings was 3.1 per night.

Systematic analyses of the sleep latency (time from onset of the record to entry of Stage 2 for at least five minutes) and REM cycle data were precluded by the great variability of the data. Sleep latency analysis could have been misleading since not all subjects reached Stages 3 and 4 sleep for the same number of nights in the various data collection periods. The variability between and within subjects in the time from the start of one REM episode to the start of the next REM episode was also too great to support any statements about the mean time between cycles before and after the change in noise exposure.

C. Discussion of Noise and Sleep Analyses

The absence of substantial differences in sleep quality attributable to the marked change in noise exposure prompted a more microscopic examination of the sleep data. Figure 10 summarizes the results of such an analysis. The data plotted in the figure represent the number of times that the subjects' sleep shifted from one stage to another within 60 seconds of the occurrence of a noise event of a given magnitude. The upper plot shows no systematic trend of shifting into a lighter sleep stage following a noise event, while the lower plot shows no systematic trend of shifting into a deeper sleep stage following a noise event.

Interpreting these relative frequencies as probabilities, there would seem to be no uniform effect of the magnitude of noise exposure on the probability of sleep disturbance during any of the three data collection periods. Thus, the finding of no significant differences in amounts of time spent in *light* or *deep* sleep during the three data collection periods is corroborated by the absence of any effect of noise level on sleep stage shifts.

This finding is at variance with that of Thiessen (Ref. 4), who noted that the relative frequency of sleep stage shifts in a 24 night study increased with exposure to higher levels of noise intrusions. Once again, however, the differences between laboratory and residential settings must be borne in mind. The aftermath of four years' exposure to intense aircraft noise might easily persist for a month. Alternatively, it might also be the case that unfamiliar neighborhood noises unmasked by the absence of aircraft noise constituted a "novel" noise environment for the test subjects. Adaptation to newly-heard background noises in the neighborhood might have lengthened the time course of adaptation. The unfamiliarity of traffic or exterior residential noises might have been associated with the observed increase in number of awakenings after cessation of late night aircraft noise.

It would be premature to infer from the current study that there are no serious consequences of nocturnal noise intrusions on sleep quality. It would be quite inappropriate, in fact, to base criteria for nocturnal noise exposure upon data collected exclusively from samples similar to the present sample. A major factor to take under consideration is that the population from which the present sample was drawn was obviously deviant from the population of the United States as a whole, since it consists primarily of people who have managed to adapt to an extreme noise environment.

Apart from the issue of how representative such airport-neighborhood samples may be of the rest of the American population, it is equally important to consider whether people should have to adjust to a noisy environment.

V. CONCLUSIONS

On the basis of this study which employed six people who had been living underneath the approach path for the Los Angeles International Airport for at least two years it was concluded that:

1) Subjects' homes under study decreased 13 dB(A) during nighttime hours.

2) No dramatic changes in sleep patterns were observed either immediately after a marked change in nocturnal noise exposure or approximately a month thereafter.

3) No strong relationship was observed between noise level and sleep disturbance over the range from 60 to 90 dB(A).

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