NASA CONTRACTOR REPORT

NASA CR-159

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NASA CR-1599

AWAKENING EFFECTS OF SIMULATED SONIC BOOMS AND SUBSONIC AIRCRAFT NOISE ON SIX SUBJECTS, 7 TO 72 YEARS OF AGE

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Prepared by
STANFORD RESEARCH INSTITUTE
Menlo Park, Calif.
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1970

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ABSTRACT

Six persons aged 7, 8, 41, 54, 69, and 72 years were exposed during sixteen experimental nights to simulated sonic booms (0.63 to 2.5 psf) and recorded noise (101 to 113 PNdB) from a subsonic aircraft. The results, considered tentative because of the small number of subjects, showed that the oldest subjects were awakened about 70% of the time by sonic booms, and about 45% of the time by the subsonic aircraft noise; the middle-aged group were awakened about 3% of the time by booms, and 7% of the time by the noise; the children were not awakened by the boom, and about 2% of the time by the aircraft noise.

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AND SUBSONIC AIRCRAFT NOISE
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Stanford Research Institute

I INTRODUCTION

Although studies (Refs. 1,2,3)* have provided considerable information about building damage caused by sonic booms and about probable public response to sonic booms and subsonic jet flyover noise, little data are available regarding the effects of these stimuli on the sleeping individual. In view of this lack of information, Stanford Research Institute, under contract to the National Aeronautics and Space Administration, developed a simulator of the indoor effects of sonic booms, and is conducting studies of the effects of these booms and other aircraft noise on the sleeping individual. This report describes the second of two studies on this subject. A report entitled "Preliminary Study of the Awakening and Startle Effects of Simulated Sonic Booms" (Ref. 4) provides a detailed discussion of the sonic boom simulator, and the initial study.

Six college students were the subjects of the first study. The subjects of the study of sleep reported here consisted of six people ranging in age from 7 to 72 years.

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* References are listed at the end of the report.

II OBJECTIVES

The objectives of the study reported here were to determine: (1) the effects, over a period of about one month, of sonic booms and subsonic turbojet aircraft engine noise on the electroencephalographic (EEG) activity and the behavioral awakening of a sleeping person, and (2) the difference in sensitivity among individuals of different age groups to sonic booms and jet aircraft noise.

III PROCEDURES

Subjects. Six people of three different age groups were subjects. They were: (young) two females, ages 7 and 8 years; (middle-aged) two males, ages 41 and 54; and (old) two males, ages 69 and 72 years. Audiograms for the young and middle-aged subjects indicated that their hearing was within normal limits. Insofar as normative data are available, a loss of about 40 dB at 4000 Hz is to be expected in males ages 60 and older (Ref. 5,6,7). These norms also suggest that an additional drop of 7 to 10 dB is to be expected per decade of age. Our subjects showed greater loss: The 72-year old showed a loss of about 90 dB at 4000 Hz, and the 69-year old showed a loss of about 60 dB at the same frequency, but their thresholds at 1000 Hz were near estimated normal levels. It is concluded, therefore, that the two oldest subjects had hearing losses somewhat greater than comparable normative age groups at 4000 Hz and above but not at 1000 Hz or lower.

The subjects indicated that they had heard sonic booms and aircraft noises infrequently in the past few years, and that because of the infrequency were not heavily biased for or against air transportation of either sub- or supersonic variety.

Test Procedure. On the first night in the laboratory the subjects were told informally about the goals of the experiment and what was expected of them; they were shown the boom-generating equipment, and a 1-psf boom was demonstrated. The subjects then put on their pajamas and the electrodes were attached. Four to five nights were permitted the subjects to accommodate to sleeping in the laboratory environment, and during this time the experimenter learned the characteristics of the EEGs of the different age groups.*

On the accommodation and experimental nights after the subjects were in bed and the instrumentation calibrated, the subjects were asked to push the awake switches three times as if to check that the switches were operating properly. Two awake switches--one for each subject--were hanging from headboards of the beds. Every night before the lights were extinguished the subjects were told that if they should wake up for any reason during the night they were to push the "awake switch" three times. The subjects were given no further instructions. They were never told if booms and flyovers would occur.

After the experimenter was assured that both subjects had fallen asleep--usually one subject was in Stage 3 or 4 and the other was in any other stage with the exception of Stage 1, and at least 30 minutes after the last prepared subject was in bed--the stimulus sequence for the night began. A simulated sonic boom or flyover was presented at random on an average of every 15 minutes, with a range of 10 to 30 minutes. Because of the distribution of sleep stages throughout the night it was hoped that using such a procedure would result in an equivalent number of stimuli occurring during each of the stages of interest: Stage 2, Delta (Stage 3 and 4 combined), and Stage REM (Rapid Eye Movement) (Refs. 8,9,10,11). These stages comprise about 90 percent of total nighttime activity.

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* It is unfortunate that most of the sleep data reported in the literature have been obtained on college students. We have observed that the EEGs of our young and old groups vary widely with respect to amplitudes of the various waves as compared to the amplitudes in college student EEGs.

To stimulate the subject too frequently during the night would have been undesirable since his usual sleep pattern would have been disrupted. It was estimated that if stimulation at low intensity levels occurred irregularly but on the average at about 15 minute intervals, the subject could be stimulated six or seven times in each of the sleep stages without any significant disruption of sleep pattern. As it turned out, it was not feasible to stimulate an equal number of times in each of the three sleep stages. Since there could be no assurance that two subjects would have identical sleep patterns, stimulation for one subject would occasionally be delayed because the other subject was in a sleep stage during which stimulation was not required. It also developed that the old subjects were found to be awakened very frequently by even the least intense stimuli, so that the total number of stimulations for this group were reduced from a total of 20 planned per night to approximately six per night. After about two experimental nights the middle-aged subjects began complaining that they were very fatigued in the morning, although they may have been fully awakened but once by the stimuli. The schedule for these subjects was reduced to about 12 trials per night.

The method of constant stimuli was used--i.e., a single intensity of boom and subsonic aircraft noise was presented throughout an experimental night. In order to determine if the subjects adapted differently to the three intensities of stimuli and to maintain a constant number of stimuli of each intensity between the first six (baseline) nights and final six (adaptation-test) nights, the stimuli were presented in order of increasing intensity, with two nights of testing at each intensity. The middle nights included two nights of test at each of the two highest intensities. The intensities and number of booms and aircraft noise presented on each test night are shown in Table I. As a rule, the subjects were tested twice per week, but on nonconsecutive nights.

Table I

NUMBER AND INTENSITY OF STIMULI TESTED ON DIFFERENT EXPERIMENTAL NIGHTS

Age Group	Stimulus	Number and Intensity	Experimental Nights															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
7 & 8 Years	Sonic Boom	N	10	10	10	10	10	10	10	6	8	4	8	10	10	10	10	10
		Psf	0.63	0.63	1.25	1.25	2.5	2.5	2.5	2.5	1.25	1.25	0.63	0.63	1.25	1.25	2.5	2.5
	Subsonic Flyover	N	10	10	10	10	10	10	10	5	7	5	8	10	10	10	10	10
		PNdB	101	101	107	107	113	113	113	113	107	107	101	101	107	107	113	113
41 & 54 Years	Sonic Boom	N	6	10	8	6	6	4	4	5	5	6	7	4	8	6	8	8
		Psf	0.63	0.63	1.25	1.25	2.5	2.5	2.5	2.5	1.25	1.25	0.63	0.63	1.25	1.25	2.5	2.5
	Subsonic Flyover	N	6	10	8	6	6	4	4	4	5	6	7	6	8	7	8	8
		PNdB	101	101	107	107	113	113	113	113	107	107	101	101	107	107	113	113
69 & 72 Years	Sonic Boom	N	6	6	3	3	3	3	3	3	3	3	3	3	4	3	4	5
		Psf	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	1.25	1.25	1.25	1.25	0.63	0.63
	Subsonic Flyover	N	6	6	3	3	3	3	3	3	3	3	3	3	3	3	4	5
		PNdB	101	101	101	101	101	101	101	101	101	101	107	107	107	107	101	101

Three nights of testing of each group included control trials in which the stimulus-triggering switches would be pushed, but no stimuli occurred. The specific trails for these tests were selected at random before the subjects arrived at the laboratory, and were superimposed upon the usual procedure. Of the 37 control trials, in only one instance was any EEG change found to occur within 10 seconds of the test, when about 2 seconds of "spindling" was observed. No behavioral awakening occurred in any of these trials.

Electroencephalograms from a central electrode, monopolar with respect to the contralateral ear, and bipolar eye movements from two electrodes proximal to the outer canthi were recorded throughout the experimental nights. These locations are in accord with recommendations of Rechtschaffen and Kales (Ref. 12).

Stimuli. The parameters of the booms and flyovers are indicated in Table I and will be presented in conjunction with the results. It is sufficient to note here that the boom intensities were selected to be representative of those expected from the supersonic transports. The flyover noise of the subsonic jet aircraft was selected from recordings made in the bedroom of a typical dwelling when the aircraft was passing overhead at an altitude of about 500 feet; it had a duration of about 5 seconds and was played back at various intensities depending upon the particular experimental conditions.

The sonic boom simulator used for these tests generates and modulates "booms" so that the noise and vibration are similar to that found in a typical home when struck by actual sonic booms. The boom and flyover intensities and other characteristics reported herein are those that would be present outside a typical house in order to create the levels present in the subjects' test chamber. Out-of-door levels are usually used when talking about sonic booms and flyover noise as a practical means of expressing the intensities of these stimuli.

Scoring of the Electroencephalogram. In the preliminary study (Ref. 4) a technique for scoring the changes elicited in the EEG by stimulation was developed. These scoring criteria are presented in Table II. In the study reported here, the scoring scheme was simplified to a three-point scale: No Response, EEG Change, and Awake. The No Response score included all the "K-complex" responses or scores of 0 to 2 shown in Table II, EEG Change included scores 3 to 5, and Awake included only behavioral awakening, a score of 7. Inclusion of the K-complex scores into the No-Response category appears warranted since Davis et al. (Ref. 13) reported that the "K-complex" in the awake subject is not specific for auditory stimulation but has been found for both visual and electrical stimulation, with differences in latency and shape due to the particular mode of stimulation. In addition, Williams (Ref. 14) showed that "K-complexes" tend not to be observable in Stages REM or 4, thus possibly introducing a scoring artifact. Indeed, in his study, if the "K-complex" scores were not considered, the result was a greater spread of the scored responses especially at lower stimulus intensity levels.

Table II

EEG SCORING CRITERIA

Score*	Change Required on EEG Record
0	No change.
1	Low-amplitude K complex, less than 150 microvolts, occurring within one second of termination of stimulus, but usually is coincidental with stimulation.
2	High-amplitude K complex, above 150 microvolts, or several K responses, occurring within two seconds of termination of the stimulus.
3	Presence of alpha pattern or synchronization within two seconds of termination of stimulation.
4	Movement of facial or eye muscles, or body movement, within six seconds of stimulus termination.
5	Shift in sleep stage one step (e.g., from a Stage 3 to a Stage 2) within one minute of stimulus termination.
6	Shift in sleep stage two steps (e.g., from a Stage 4 to a Stage 2) within one minute of stimulus termination. This category was never used, since a shift of two stages was always accompanied by awakening.
7	Prolonged alpha movement, and an awake response, within one and one-half minutes of stimulus termination. The delay was required to allow the subject time to find the switch that was hanging from the bed headboard.

* These scores are not independent since a high score usually included all the lower scores. For example: A response of 3 indicated that K complexes also occurred.

IV RESULTS

Verification of Subject Pairing. To determine whether the grouping of the subjects into the young, middle-aged, and old categories was meaningful for purposes of further data analysis, the responses of the groups to both simulated and flyover noises regardless of intensity were compared statistically. It was found that the response frequencies of the subjects by age group were similar but that the age groups differed from each other, as shown in Table III. Accordingly, it was concluded that the data for the respective age groups could be combined for data analysis and interpretation.

Response to Simulated Sonic Booms. That the three age groups responded differently to booms at the intensities tested is shown in the data of Table IV. The old group was awakened much more frequently than was the middle-aged group which, in turn, was awakened more frequently than were the young children. Observed differences in responsiveness to sonic booms of the middle-aged and young groups was found to be statistically significant ($X^2 = 7.706$, 2 df, $0.025 > p > 0.002$) due, in the main, to the relatively large number of awake responses in the middle-age group. Note, also, in Table IV that the frequency of "No Responses" is inversely related to chronological age.

With respect to the effects of variations in boom intensity, the old and young subjects were found to respond similarly to booms at the intensities tested, and the middle-aged group showed statistically significant differences due to intensity. These data are presented in Table V.

Table III

RESPONSE FREQUENCIES OF THREE AGE GROUPS, TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE

Group	Age (yrs)	Frequency (N) and Percent of Responses	Response		
			Awake	EEG Change	No Response
Old[a]	72	N %	64 (57.1)	21 (18.8)	27 (24.1)
	69	N %	67 (59.8)	22 (19.6)	23 (20.5)
Middle Aged[b]	54	N %	10 (5.0)	43 (21.6)	146 (73.4)
	41	N %	9 (4.7)	68 (35.2)	116 (60.1)
Young[c]	8	N %	5 (1.7)	81 (28.0)	203 (70.3)
	7	N %	3 (1.0)	64 (22.1)	222 (76.8)

[a] $X^2 = 0.412$, 2 df (degrees of freedom), N.S. (Not Significant).

[b] $X^2 = 9.028$, 2 df, $0.05 > p > 0.025$,N.S. [Because of the small number of subjects in each group and the occurrence of few responses in some of the scoring categories, it appeared that a criterion of statistical significance of $p = 0.025$ would minimize the likelihood of attributing statistical significance due to errors of measurement while yet maintaining a reasonable likelihood of detecting real differences. In subsequent tables $p > 0.025$ will be reported as being nonsignificant (Ref. 15)]

[c] $X^2 = 3.342$, 2 df, N.S.

Table IV

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SIMULATED SONIC BOOMS

Group	Frequency (N) and Percent of Responses	Response		
		Awake	EEG Change	No Response
Old	N %	84 (72.4)	15 (12.9)	17 (14.7)
Middle-Aged	N %	5 (2.5)	73 (36.7)	121 (60.8)
Young	N %	1 (0.3)	86 (29.8)	202 (69.9)

$X^2 = 379.560$, 4 df, $p < 0.01$

Table V

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SIMULATED BOOMS OF DIFFERING INTENSITY

Boom Intensity[d]	Frequency (N) and Percent of Responses	Old[(a)] Response			Middle Aged[(b)] Response			Young[(c)] Response		
		Awake	EEG Change	No Response	Awake	EEG Change	No Response	Awake	EEG Change	No Response
0.63 psf	N %	69 (73.4)	12 (12.8)	13 (13.8)	0 (0)	13 (27.7)	34 (72.3)	0 (0)	15 (19.7)	61 (80.3)
1.25 psf	N %	15 (68.2)	3 (13.6)	4 (18.2)	2 (2.4)	40 (48.8)	40 (48.8)	1 (0.9)	34 (33.3)	67 (65.7)
2.5 psf	N %				3 (4.3)	20 (28.6)	47 (67.1)	0 (0)	37 (33.3)	74 (66.7)

[a] $X^2 = 0.304$, 2 df, N.S.

[b] $X^2 = 11.067$, 4 df, $0.02 > p > 0.01$

[c] $X^2 = 5.069$, 4 df,* N.S.

* Tabularized Chi-square significance levels are good approximations if, in cases with two or more degrees of freedom, fewer than 20 percent of the cells have expected frequencies of about 1 (Ref. 16, 17). In cases such as this where the rule was not met, the column containing the zeros was excluded from the Chi-square calculation. The Chi-square Distribution Table was then entered with the degrees of freedom that would have been used, had the column not been excluded. In effect, it is assumed that the expected probabilities for the cells of the column in question are zero. Note that since the degrees of freedom are increased through this procedure, the calculated X^2 must have a greater magnitude to be significant.

[d] Peak overpressure of boom as measured outdoors. Comparable peak level indoors about 8 dB less. Duration of booms was about 275 ms. Estimated effective rise time of booms was about 10 ms.

Inspection of the Chi-squares of each of the cells in the table for the middle-aged group revealed that the major contributor (about 30%) to the Chi-square for the entire table was the large number of EEG Changes to booms of 1.25 psf. The contribution of the other cells was relatively small (the largest contributing about 18%). Statistical comparison of the responses of the middle-aged group to booms of 0.63 psf versus those to booms of 2.5 psf revealed no significant differences (X^2 = 2.0665, 2 df, N.S). It is concluded, therefore, that for the middle-aged group the statistically significant difference due to boom intensity probably was a random error due to the particular experimental conditions present during exposure to booms of 1.25 psf.

Response to Simulated Sonic Booms During the Sleep Stages On the basis of reported studies (Refs. 4, 14, 18) it was hypothesized that the responses to booms would vary as some function of the stage of sleep. Data presented in Table VI and Fig. 1 show that the hypothesis was borne out. Two general results should be noted: (1) The groups uniformly were awakened most frequently by booms during sleep stage REM. Consistent with the findings presented above, the old group was awakened most frequently--i.e., by about 93 percent of the booms occurring during sleep stage REM, while the middle-aged and young groups were awakened by 4 and 2 percent, respectively, of the booms occurring during sleep stage REM. (2) While in sleep stage REM, the middle-aged and young groups were least likely to show any response in the EEG.

The relative responsiveness of the groups to booms during the sleep stages are shown in Fig. 2 where it will be seen that for the young group the response frequencies to booms during sleep stage Delta are similar to those during Stage 2 (X^2 = 0.36, 2 df, N.S.), while for the middle-aged group, responses during Delta are similar to those occurring in stage REM (X^2 = 4.57, 2 df, N.S.). In the older group the response

Table VI

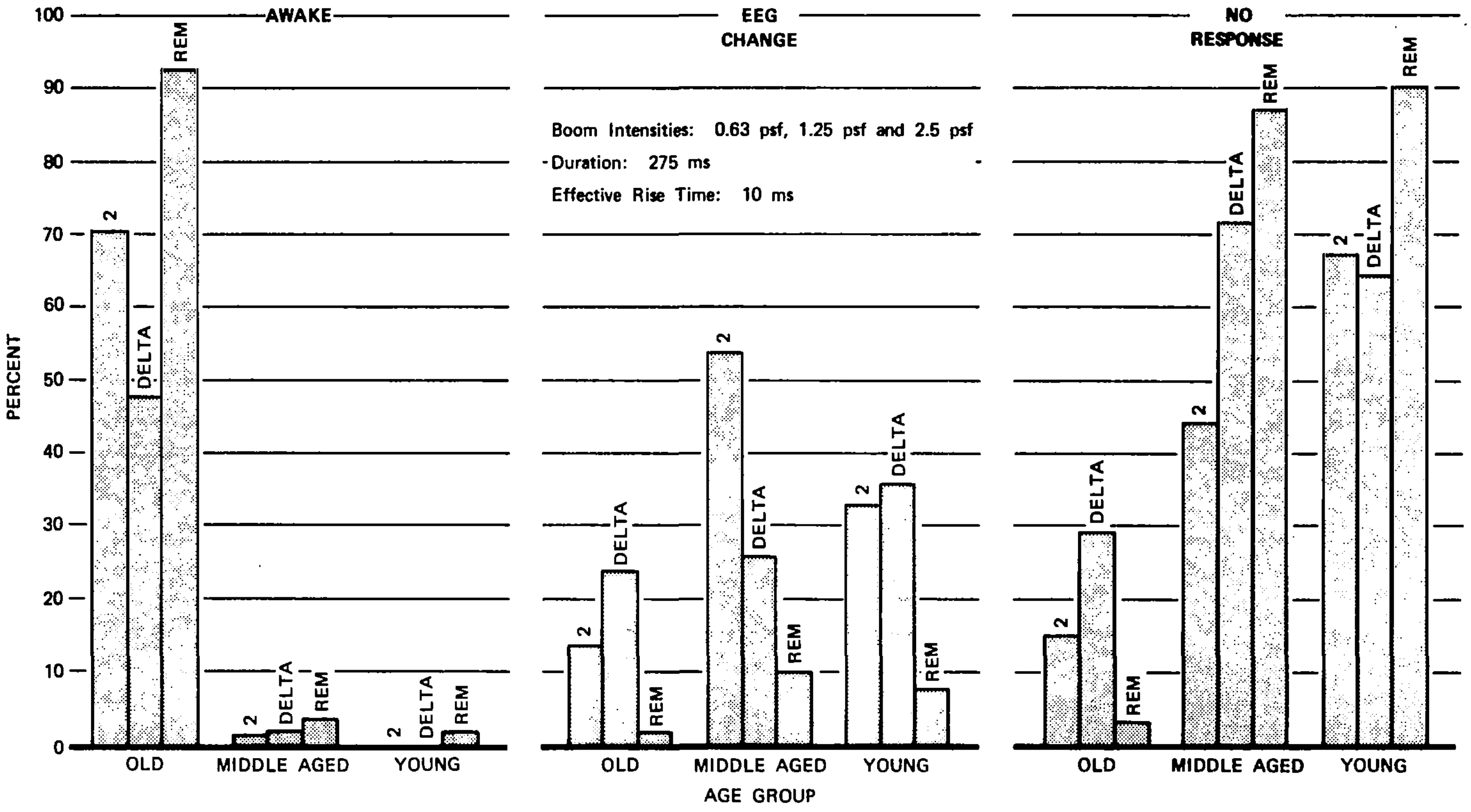
RESPONSE FREQUENCIES OF THREE AGE GROUPS, DURING SLEEP STAGES 2, REM, AND DELTA, TO SIMULATED SONIC BOOMS

Sleep Stage	Frequency (N) and Percent of Responses	Old[a] Response			Middle Aged[b] Response			Young[c] Response		
		Awake	EEG Change	No Response	Awake	EEG Change	No Response	Awake	EEG Change	No Response
2	N %	46 (70.8)	9 (13.8)	10 (15.4)	2 (1.9)	57 (54.3)	46 (43.8)	0 (0)	47 (32.6)	97 (67.4)
Delta	N %	10 (47.6)	5 (23.8)	6 (28.6)	1 (2.4)	11 (26.2)	30 (71.4)	0 (0)	35 (36.1)	62 (63.9)
REM	N %	28 (93.3)	1 (3.3)	1 (3.3)	2 (3.8)	5 (9.6)	45 (86.5)	1 (2.1)	4 (8.3)	43 (89.6)

[a] $X^2 = 13.142$, 4 df, $0.02 > p > 0.01$

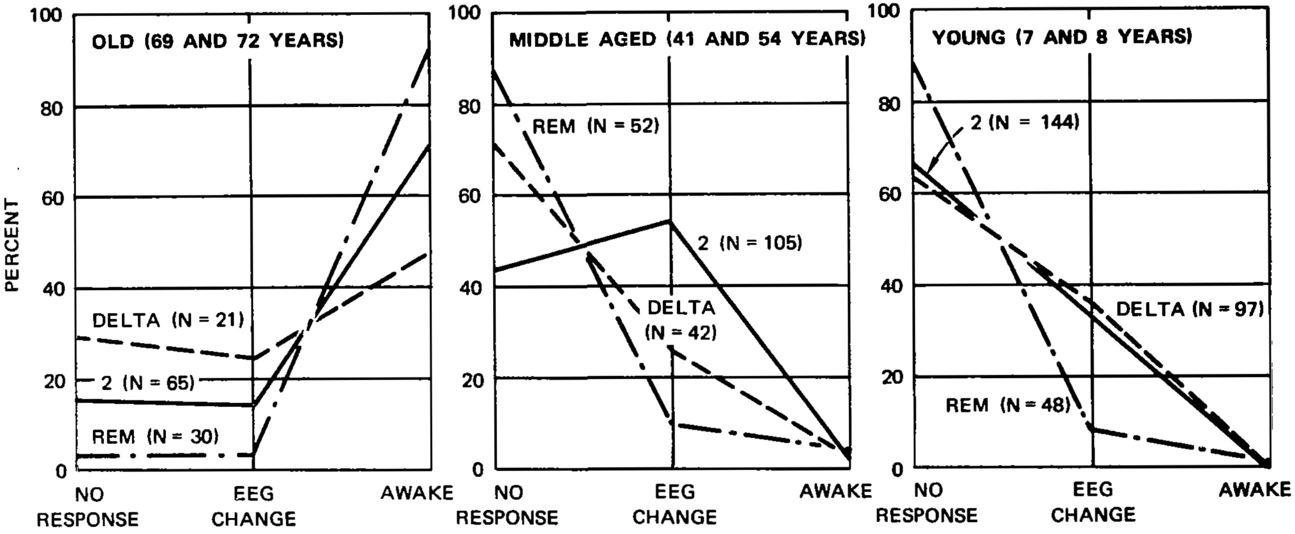
[b] $X^2 = 35.177$, 4 df, $p < 0.01$

[c] $X^2 = 12.395$, 4 df, $0.02 > p > 0.01$



Boom Intensities: 0.63 psf, 1.25 psf and 2.5 psf
Duration: 275 ms
Effective Rise Time: 10 ms

FIGURE 1 RESPONSE FREQUENCIES, DURING SLEEP STAGES 2, REM, AND DELTA, OF THREE AGE GROUPS, TO SIMULATED SONIC BOOMS



* Boom intensities: 0.63 psf, 1.25 psf, and 2.5 psf; duration: 275 ms; Effective rise time: 10 ms.

FIGURE 2 RESPONSE OF THREE AGE GROUPS TO SONIC BOOMS* AS A FUNCTION OF SLEEP STAGE frequencies during Stage 2 are midway between those found during sleep stage Delta and during stage REM. (Statistical comparisons of the response frequencies of the old group during Stage 2 with those found during Stage REM and Stage Delta were not significant: $X^2 = 6.071$, 2 df, N.S., and $X^2 = 3.758$, 2 df, N.S., respectively.) The results reported here for the young group are in general agreement with those of Williams (Ref. 14, see his Figs. 2 and 3, or Ref. 8, pp. 277 to 287, Fig. VIII.3), wherein, with soldiers aged 21 to 35 years, the scores of EEG arousal to tones during Stage 2 were similar to the average scores obtained during Stage 3 and 4, or Stage Delta as used in this report.

Adaptation to Simulated Sonic Booms. It is clear that because of the demonstrated response differences to booms in the sleep stages, tests of adaptation should be specific to the sleep stage. In fact, the previous study (Ref. 4) reported that in college students adaptation to low-intensity booms was found during Stage 2. The responses during the first six nights of testing in which boom intensity was increased from 0.63 psf to 2.50 psf (except for the old group who were tested with boom intensities of 0.63 psf and 1.25 psf) are compared with the last six nights during which the intensity was increased in an identical manner (see Table I).

In the old group, statistically significant adaptation was found during Stage 2, as indicated by the decrease in the frequency (from 89.7 to 61.5 percent) of awake responses and the increase in frequency of no responses (from 6.9 to 19.2 percent). These data are plotted in Fig. 3. A similar result suggests that adaptation to booms may have begun in Stage Delta, but the small number of trials precluded finding a statistically significant difference. Adaptation data for the old group are presented in Table VII.

In contrast to the adaptation found during Stage-2 sleep of the old group, no adaptation, as shown in Table VIII, was found in the middle-aged

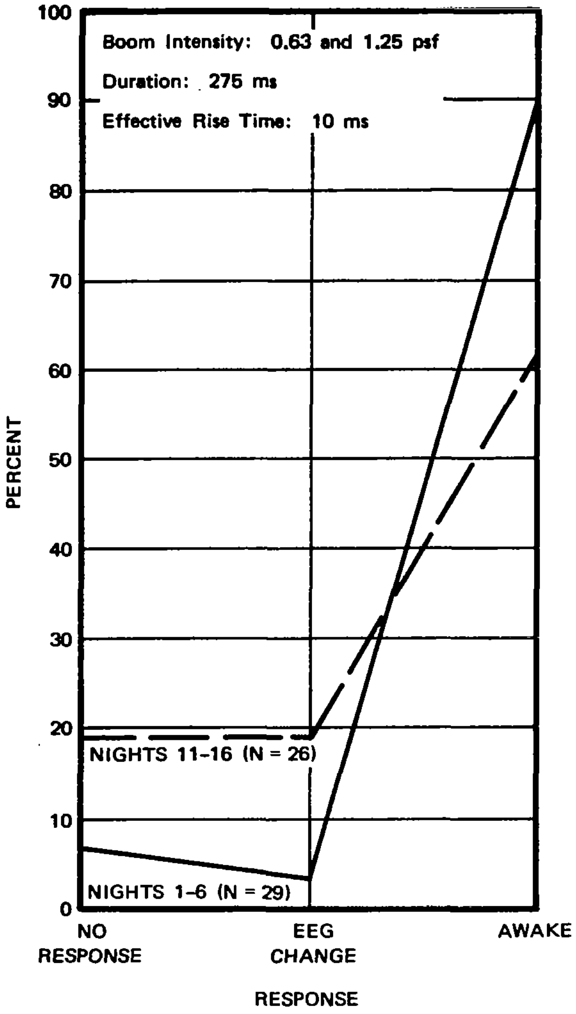


FIGURE 3 ADAPTATION OF SUBJECTS, AGED 69 AND 72 YEARS, DURING SLEEP STAGE 2, TO SIMULATED SONIC BOOMS

Table VII

RESPONSE FREQUENCIES OF SUBJECTS AGED 69 AND 72 YEARS, DURING SLEEP STAGES 2, DELTA, AND REM ON DIFFERENT EXPERIMENTAL NIGHTS, TO SIMULATED SONIC BOOMS

Sleep Stage	Frequency (N) and Percent of Responses	Response			Night	Boom Intensity
		Awake	EEG Change	No Response		
2[a]	N %	26 (89.7)	1 (3.4)	2 (6.9)	1-6	0.63 & 1.25 psf
	N %	16 (61.5)	5 (19.2)	5 (19.2)	11-16	0,63 & 1.25 psf
Delta[b]	N %	4 (66.7)	1 (16.7)	1 (16.7)	1-6	0.63 & 1.25 psf
	N %	3 (42.9)	2 (28.6)	2 (28.6)	11-16	0.63 & 1.25 psf
REM[c]	N %	13 (86.7)	1 (6.7)	1 (6.7)	1-6	0.63 & 1.25 psf
	N %	8 (100.0)	0 (0)	0 (0)	11-16	0.63 & 1.25 psf

[a] $X^2 = 6.188$, 2 df, $0.05 > p > 0.025$, one-tailed test.
[b] $X^2 = 0.737$, 2 df, N.S.
[c] X^2 not computed because of small expected frequencies.

Table VIII

RESPONSE FREQUENCIES OF SUBJECTS AGED 41 AND 54 YEARS, DURING SLEEP STAGES 2, DELTA, AND REM ON DIFFERENT EXPERIMENTAL NIGHTS, TO SIMULATED SONIC BOOMS

Sleep Stage	Frequency (N) and Percent of Responses	Response			Night	Boom Intensity
		Awake	EEG Change	No Response		
2[a]	N %	2 (4.1)	24 (48.9)	23 (46.9)	1-6	0.63, 1.25 & 2.5 psf
	N %	0 (0)	23 (51.1)	22 (48.9)	11-16	0.63, 1.25 & 2.5 psf
Delta[b]	N %	1 (5.3)	5 (26.2)	13 (68.4)	1-6	0.63, 1.25 & 2.5 psf
	N %	0 (0)	3 (15.8)	16 (84.2)	11-16	0.63, 1.25 & 2.5 psf
REM[c]	N %	0 (0)	1 (4.3)	22 (95.7)	1-6	0.63, 1.25 & 2.5 psf
	N %	1 (4.5)	3 (13.6)	18 (81.8)	11-16	0.62, 1.25 & 2.5 psf

[a] $X^2 = 1.877$, 2 df, N.S.

[b] $X^2 = 0.810$, 2 df, N.S.

[c] $X^2 = 1.333$, 2 df, N.S.

group during any of the sleep stages studied. Because of the small number of awake responses involved, any trend in data would be difficult to identify statistically. However, the EEG changes and No-Response categories likewise show no systematic indication of adaptation between the first six nights and the last six nights.

As with the middle-aged subjects, adaptation was not found in the young group. In fact, it appears that in Stage-2 sleep during nights 11 to 16, youngsters were more likely to show EEG changes than during nights 1 to 6, but there was no change in the frequency of Awake responses. These data are presented in Table IX.

Response to Subsonic Jet Flyover Noise: As was found with respect to sonic booms, the age groups responded differently to aircraft noise regardless of intensity. In Table X it will be seen that the old group was behaviorally awakened by 43.5 percent of the flyover noises, whereas the middle-aged and young were awakened by 7.3 and 2.4 percent of the aircraft flyover noises.

Whereas with booms the groups were not found to respond differently to intensity, with flyover-noise intensity did make a difference, as shown in Table XI. As the intensity of the flyover noise increased, the groups uniformly showed increased rates of awakening, increased rates of EEG changes, and a decrease in the percentage of No Responses.

The old group, as was shown with respect to booms, was more likely to be awakened by the flyover noise than were the two younger groups but, in addition, showed the most dramatic change in rate of awakening with a change of intensity. An increment of 6 PNdB (from 101 PNdB to 107 PNdB) of intensity resulted in about double (from 37.8 to 72.2 percent) the percentage of awake responses in the old group, whereas the middle-aged group shifted from 0 to about 10 percent and the young group from 0 to about

Table IX

RESPONSE FREQUENCIES OF SUBJECTS AGED 7 AND 8 YEARS, DURING SLEEP STAGES 2, DELTA, AND REM ON DIFFERENT EXPERIMENTAL NIGHTS, TO SIMULATED SONIC BOOMS

Sleep Stage	Frequency (N) and Percent of Responses	Response			Night	Boom Intensity
		Awake	EEG Change	No Response		
2^{a}	N %	0 (0)	10 (17.5)	47 (82.5)	1-6	0.63, 1.25 & 2.5 psf
	N %	0 (0)	26 (44.8)	32 (55.2)	11-16	0.63, 1.25 & 2.5 psf
Delta[b]	N %	0 (0)	10 (22.7)	34 (77.3)	1-6	0.63, 1.25 & 2.5 psf
	N %	0 (0)	3 (15.8)	16 (84.2)	11-16	0.63, 1.25 & 2.5 psf
Rem[c]	N %	0 (0)	2 (10.5)	17 (89.5)	1-6	0.63, 1.25 & 2.5 psf
	N %	0 (0)	1 (5.3)	18 (94.7)	11-16	0.63, 1.25 & 2.5 psf

[a] $X^2 = 0.051$, 2 df, $p < 0.01$

[b] $X^2 = 0.390$, 2 df, N.S.

[c] $X^2 = 0.362$, 2 df, N.S.

Table X

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SUBSONIC JET AIRCRAFT FLYOVER NOISE

Age Group	Frequency (N) and Percent of Responses	Response		
		Awake	EEG Change	No Response
Old	N %	47 (43.5)	28 (26.0)	33 (30.5)
Middle-Aged	N %	14 (7.3)	38 (19.7)	141 (73.0)
Young	N %	7 (2.4)	59 (20.4)	223 (77.2)

$X^2 = 147.978$, 4 df, $p < 0.01$

Table XI

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SUBSONIC JET FLYOVER NOISE OF THREE INTENSITIES

Flyover Intensity[d]	Frequency (N) and Percent of Responses	Old[a] Response			Middle-Aged[b] Response			Young[c] Response		
		Awake	EEG Change	No Response	Awake	EEG Change	No Response	Awake	EEG Change	No Response
101 PNdB	N %	34 (37.8)	23 (25.6)	33 (36.7)	0 (0)	5 (10.2)	44 (89.8)	0 (0)	4 (5.3)	72 (94.7)
107 PNdB	N %	13 (72.2)	5 (27.8)	0 (0)	8 (10.5)	13 (17.1)	55 (72.4)	1 (.9)	21 (20.6)	80 (78.4)
113 PNdB	N %				6 (8.8)	20 (29.4)	42 (61.8)	6 (5.4)	34 (30.6)	71 (64.0)

[a] $X^2 = 10.716$, 2 df, $p < 0.01$

[b] $X^2 = 12.991$, 4 df, $p < 0.02$

[c] $X^2 = 26.583$, 4 df, $p < 0.01$

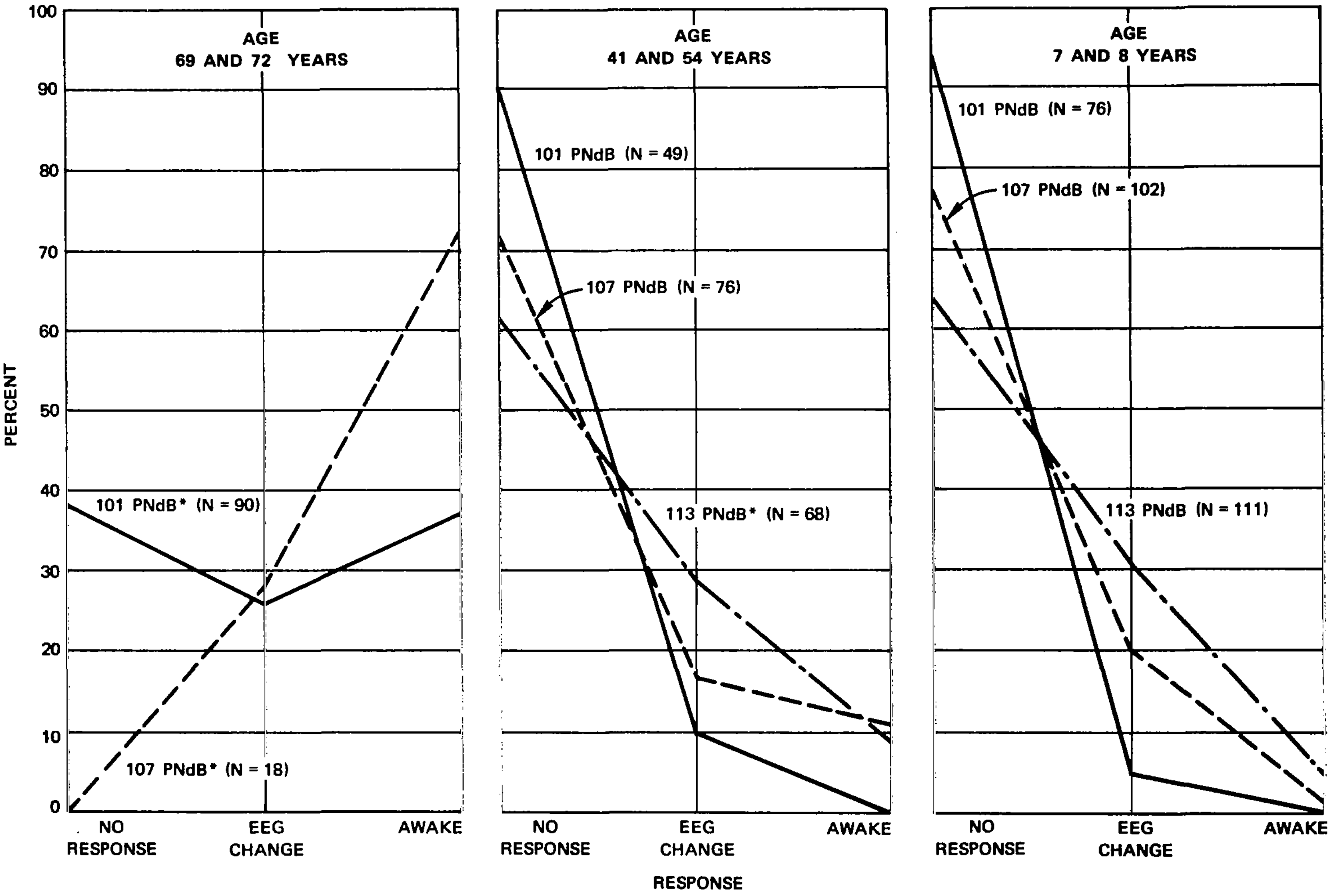
[d] Estimated intensity as if measured outdoors. Indoor intensity about 20 PNdB less.

1 percent. Note also that in the young group an additional increase of 6 PNdB resulted in an increase in the percentage of awake responses (from about 1 percent to about 5 percent) as well as an increase in the EEG Change Rate from 20.6 percent to 30.6 percent. These effects are illustrated in Fig. 4.

Responses to flyover noise were in part dependent upon the sleep stage, as shown in Table XII. However, that the relationships are by no means simple can be seen in Fig. 5, in which responses to flyovers of the three groups in the three sleep stages are plotted. Here it will be seen that in similar sleep stages the old group was awakened significantly more frequently by flyovers than were the younger groups. In Stage REM, for example, the old group was awakened by about 37 percent of the flyovers, the middle-aged group by about 10 percent of the stimuli, and the youngsters by about 8 percent. As was the case with sonic booms, all three groups were awakened most frequently while in Stage REM.

It is also of some interest to note that the difference between rates of awakening during Stage Delta and Stage 2 appears to be related to chronological age. For the oldest group the difference between rates of awakening during Delta and Stage 2 is about ten percentage points, for the middle-aged group about 6 percentage points, and for the 7- and 8-year olds the rates differ by about 1 percentage point. The old and middle-aged group were awakened more frequently during Stage 2 than during Stage Delta, while the young group appeared to be awakened as frequently in Delta as it was in Stage 2. The small difference, about 1 percentage point, may be within the limits of experimental error, so that for the 7- and 8-year olds the frequency of awakening in Stages 2 and Delta are equivalent.

The increased rate of awakening with increases in flyover intensity that was found for the three age groups regardless of sleep state (Fig. 4) was found to hold if the sleep stages of each of the age groups were held



* Estimated flyover intensities as if measured outdoors.

FIGURE 4 RESPONSE OF THREE AGE GROUPS TO CHANGES IN SUBSONIC JET FLYOVER INTENSITY

Table XII

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO
SUBSONIC JET FLYOVER NOISE IN SLEEP STAGES 2, REM, AND DELTA

Sleep Stage	Frequency (N) and Percent of Responses	Old[a] Response			Middle[b] Response			Young[c] Response		
		Awake	EEG Change	No Response	Awake	EEG Change	No Response	Awake	EEG Change	No Response
2	N	48	66	56	8	24	63	1	36	101
	%	(28.2)	(38.8)	(32.9)	(8.4)	(25.3)	(66.3)	(0.7)	(26.1)	(73.2)
Delta	N	11	16	36	1	10	39	2	14	84
	%	(17.5)	(25.4)	(57.1)	(2.0)	(20.0)	(78.0)	(2.0)	(14.0)	(84.0)
REM	N	30	6	46	5	4	39	4	9	38
	%	(36.6)	(7.3)	(56.1)	(10.4)	(8.3)	(81.3)	(7.8)	(17.6)	(74.5)

[a] $X^2 = 33.929$, 4 df, $p < 0.01$

[b] $X^2 = 8.761$, 4 df, N.S.

[c] $X^2 = 13.220$, 4 df, $p < 0.02$

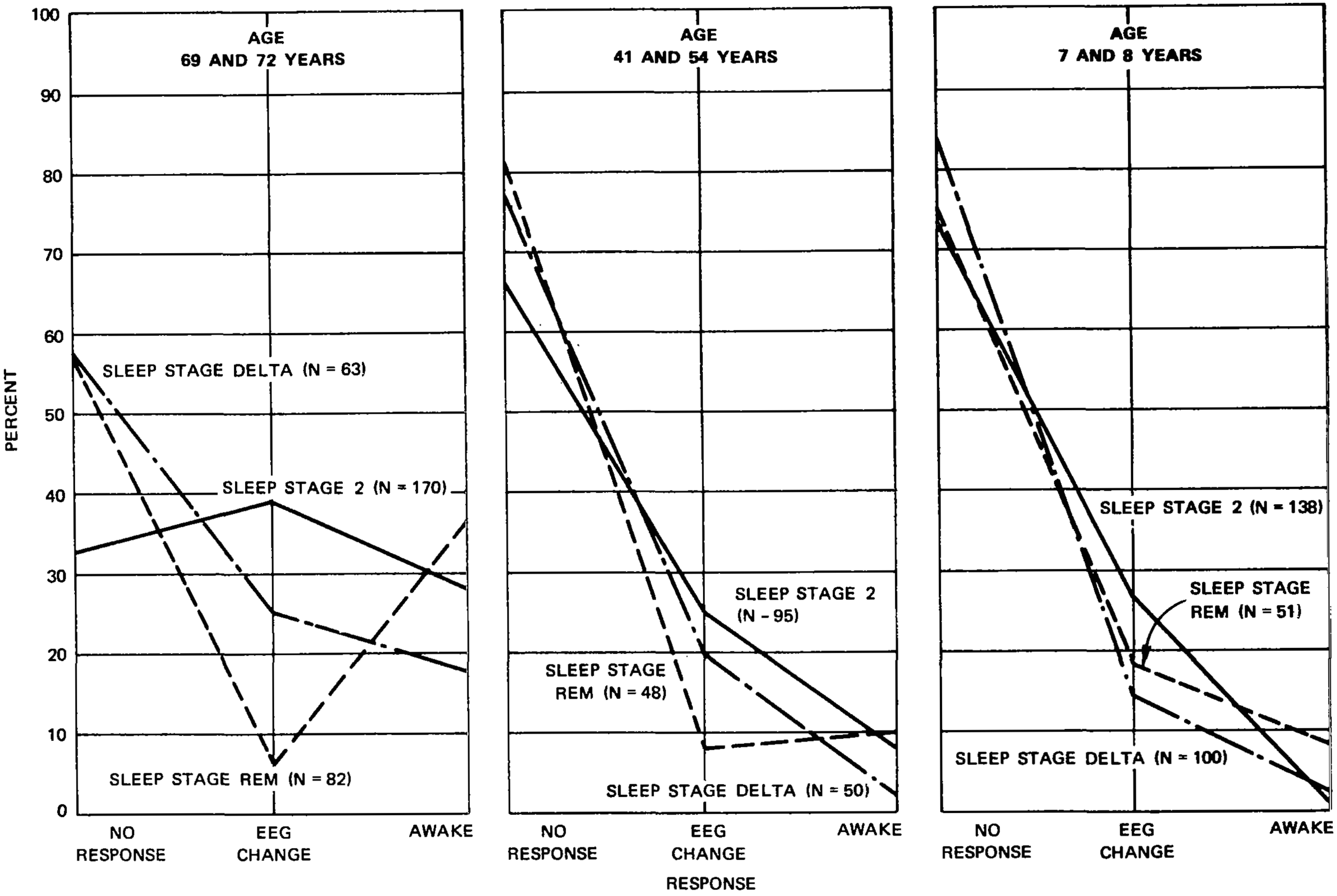


FIGURE 5 RESPONSE OF THREE AGE GROUPS DURING THREE SLEEP STAGES, TO SUBSONIC JET FLYOVER NOISE

constant. These results are illustrated in Figs. 6, 7, and 8. Note in Fig. 6 that for the old group a 6-PNdB increase in intensity resulted in the largest increase (from about 12 percent to about 66 percent) in the rate of awakening during Stage Delta, while the other groups showed the largest increase when the flyovers occurred during Stage REM. Typically, with the middle-aged and young groups the largest change in rate of awakening during Stage REM occurred if the flyover intensity was increased from 107 to 113 PNdB. In the middle-aged group an increase in intensity from 101 to 107 PNdB resulted in a rate change from 0 to about 6 percent, but an additional 6 PNdB (to 113 PNdB) resulted in about 77 percent awake responses during State REM (Fig. 7). The youngest group, in contrast, showed an increase from 0 to about 5 percent in rate of awakening when the stimulus intensity was increased from 101 to 107 PNdB, but increased to about 14 percent with an intensity increase from 107 to 113 PNdB. These results are illustrated in Fig. 8.

Note also in Figs. 6, 7, and 8, that within an age group, the rate of awakening during Stage Delta tends to be less, at comparable flyover intensities, than during Stage REM. This of course is consistent with the results found with sonic booms where the rate of awakening was greatest during REM (see Fig. 1).

Adaptation to Subsonic Jet Flyover Noise. The small number of stimuli occurring during each of the three sleep stages precluded tests for adaptation at each intensity of flyover noise in each sleep stage. It was necessary, therefore, to average the results over all sleep stages in an attempt to assess adaptation to the aircraft noise.

Adaptation, as manifested by a decrease in the rate of awakening with an increase in the number of No Responses, was found in the old group, to flyovers of 101 PNdB. Similar adaptation was not observed with respect to 107 PNdB flyovers; however, the statistically insignificant

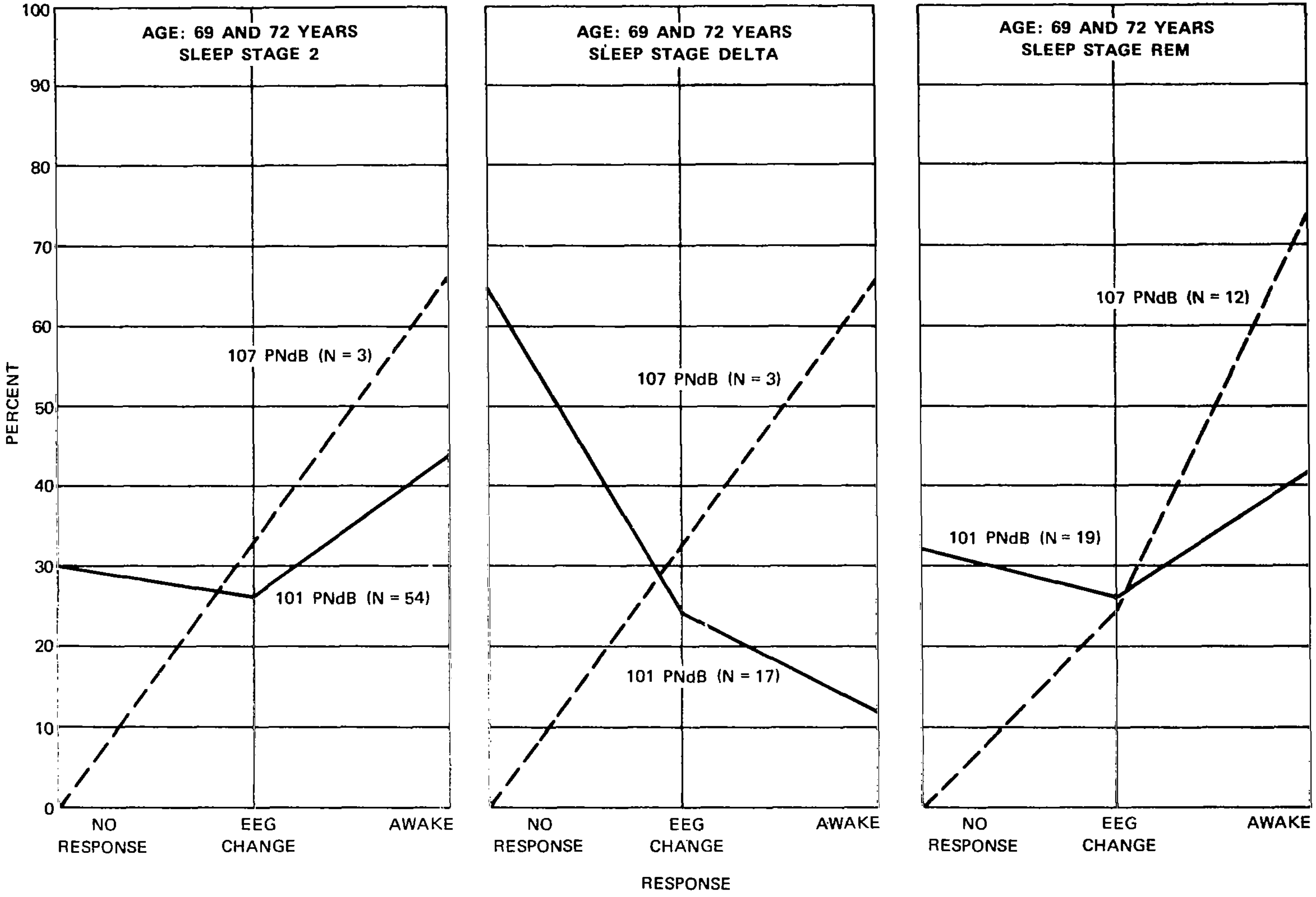


FIGURE 6 RESPONSE OF OLD GROUP IN THREE SLEEP STAGES, TO CHANGES IN SUBSONIC JET FLYOVER NOISE INTENSITY

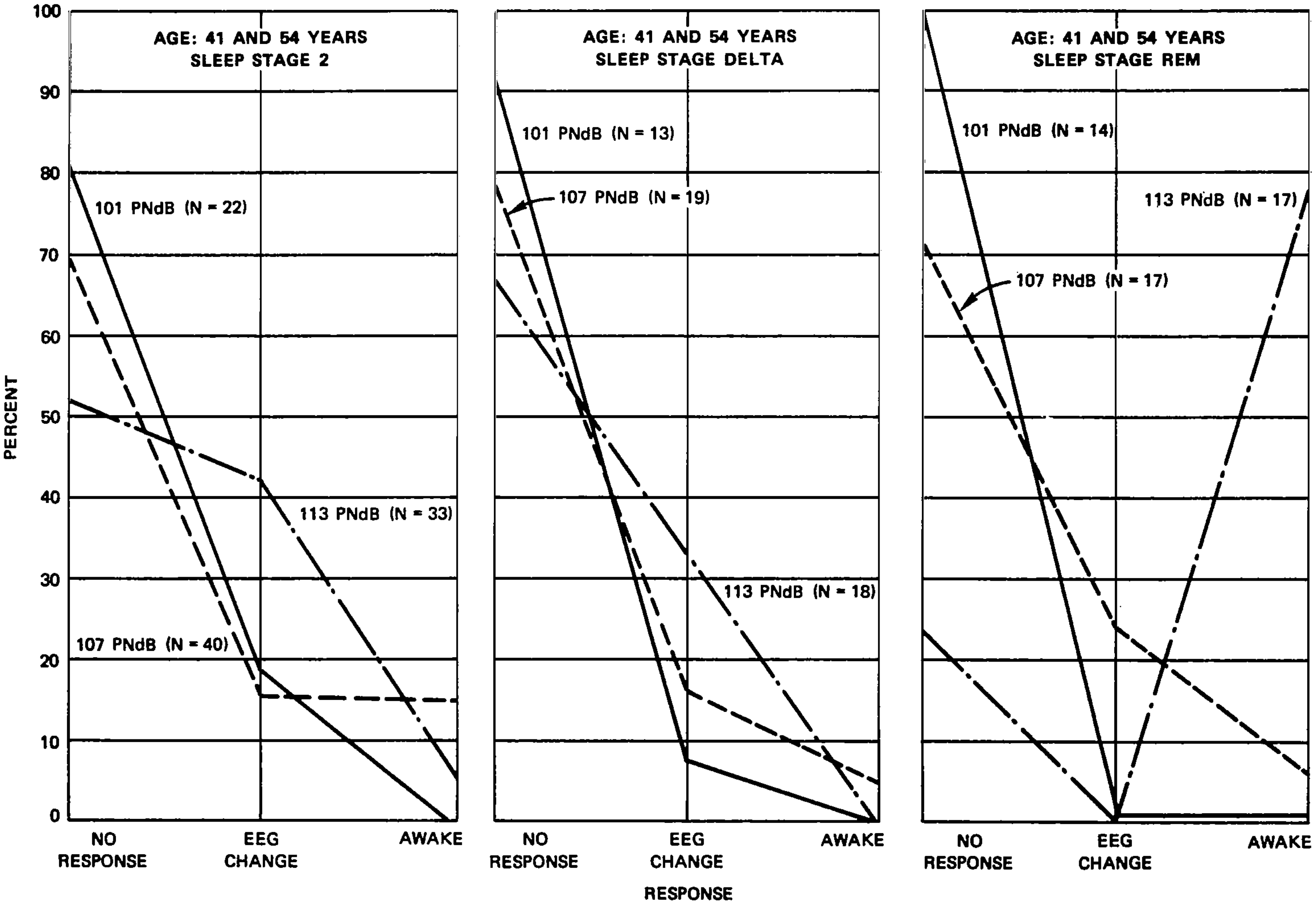


FIGURE 7 RESPONSE OF MIDDLE-AGED GROUP IN THREE SLEEP STAGES, TO CHANGES IN SUBSONIC JET FLYOVER NOISE INTENSITY

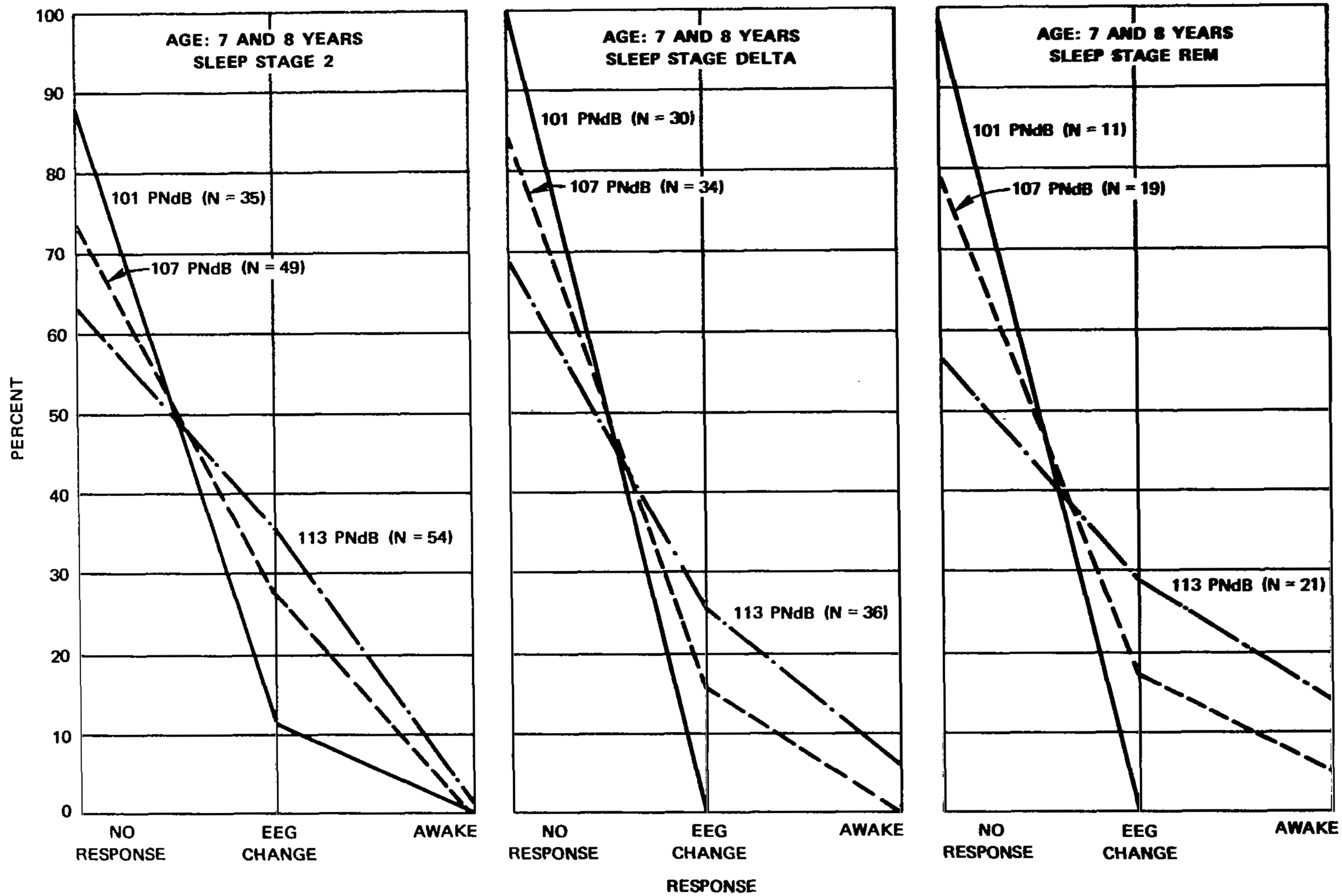


FIGURE 8 RESPONSE OF YOUNG GROUP IN THREE SLEEP STAGES, TO CHANGES IN SUBSONIC JET FLYOVER NOISE INTENSITY

result may have been due to the limited number of tests resulting from but 4 experimental nights. These results are presented in Table XIII.

Table XIII

RESPONSE FREQUENCIES OF SUBJECTS AGED 69 AND 71 YEARS, ON DIFFERENT EXPERIMENTAL NIGHTS, TO SUBSONIC JET FLYOVER NOISE

Flyover Intensity	Nights	Frequency (N) and Percent of Responses	Response		
			Awake	EEG Change	No Response
101 PNdB[a]	1 & 2	N %	13 (54.2)	6 (25.0)	5 (20.8)
	15 & 16	N %	3 (16.7)	5 (27.8)	10 (55.5)
107 PNdB[b]	11 & 12	N %	6 (75.0)	2 (25.0)	0 (0)
	13 & 14	N %	7 (70.0)	3 (30.0)	0 (0)

[a] $X^2 = 7.299$, 2 df, $p < 0.05$, one-tailed test

[b] $X^2 = 0.055$, 2 df, N.S.

The effects of adaptation on the responses of the old group to flyover of 101 PNdB are illustrated in Fig. 9. These effects, it will be seen, are a reduction in the relative number of awake responses (from about 54 percent on nights 1 and 2, to about 17 percent on nights 15 and 16), with an increase of the number of No Responses (from about 21 percent to about 56 percent).

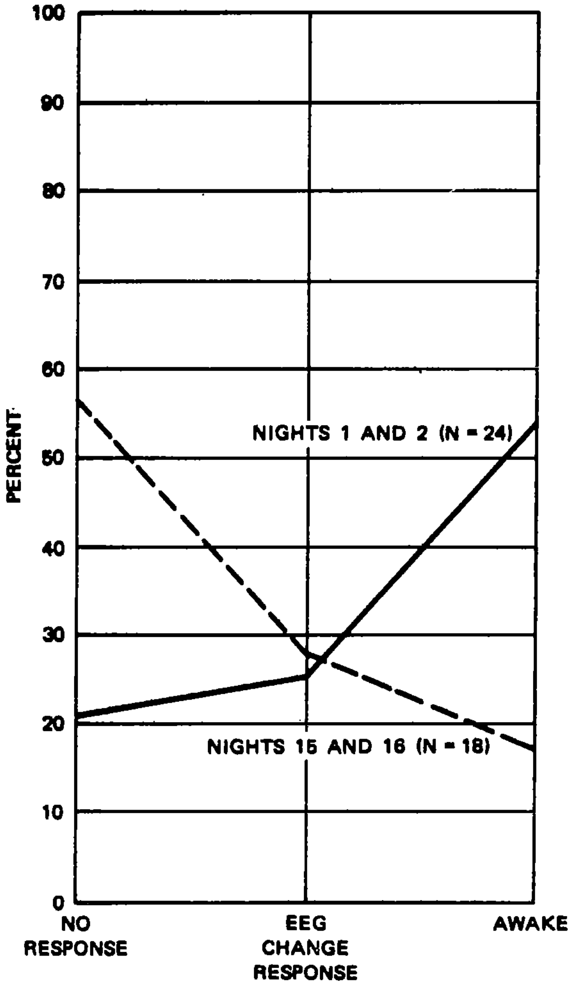


FIGURE 9 ADAPTATION IN 69- AND 72-YEAR-OLD SUBJECTS TO SUBSONIC JET FLYOVER NOISE OF 101 PNdB

Adaptation in the middle-aged group was found, to flyover noise of 113 PNdB. As can be seen in Table XIV, the shifts in relative numbers of Awake and No Responses to 107 PNdB flyovers was in the anticipated direction--i.e., a decrease in the percentage of Awake responses on the latter nights--but the shifts were not of sufficient magnitude to be statistically significant. With flyovers of 101 PNdB the relative number of No Responses on nights 11 and 12 was found to decrease, but no Awake responses had occurred during nights 1 and 2 or 11 and 12. Figure 10 illustrates the adaptation observed to flyover noise of 113 PNdB.

In contrast with the adaptation found in the old group to flyover noise of 101 PNdB and with that found in the middle-aged group to flyovers of 113 PNdB, the young subjects did not adapt to flyovers of any intensity. These results are presented in Table XV.

Summary of Responsiveness of the Three Age Groups to Booms and Subsonic Aircraft Noise. It is perhaps of interest to consider the general responsiveness (or lack of responsiveness) of the three groups of subjects to the sonic booms and the aircraft noise without precise regard to the intensities of stimuli. It is seen in Table XVI that the probability of being awakened is greater for the older age group regardless of the type of stimulus.

Figure 11 shows the generally greater sensitivity of older versus younger people with respect to behavioral awakening. In terms of a change in EEG as the result of a sonic boom or aircraft noise, the groups are less markedly different, even showing a possible reversal in apparent sensitivity between the two younger groups.

Responses of Four Age Groups to Sonic Booms and Subsonic Aircraft Noise. In the main, the data obtained in the study of the old, middle-aged, and young groups fits reasonably well with that obtained in an

Table XIV

RESPONSE FREQUENCIES OF SUBJECTS AGES 41 AND 54 YEARS ON DIFFERENT EXPERIMENTAL NIGHTS, TO SUBSONIC JET FLYOVER NOISE

Flyover Intensity	Nights	Frequency (N) and Percent of Responses	Response		
			Awake	EEG Change	No Response
101 PNdB[a]	1 & 2	N %	0 (0)	1 (4.3)	22 (95.7)
	11 & 12	N %	0 (0)	4 (15.4)	22 (84.6)
107 PNdB[b]	3 & 4	N %	4 (14.8)	5 (18.5)	18 (66.7)
	13 & 14	N %	3 (10.7)	3 (10.7)	22 (78.6)
113 PNdB[c]	5 & 6	N %	3 (15.0)	9 (45.0)	8 (40.0)
	15 & 16	N %	2 (6.5)	4 (12.9)	25 (80.6)

[a] $X^2 = 1.622$, 2 df, N.S.

[b] $X^2 = 0.743$, 2 df, N.S.

[c] $X^2 = 8.482$, 2 df, $p < 0.02$, one-tailed test.

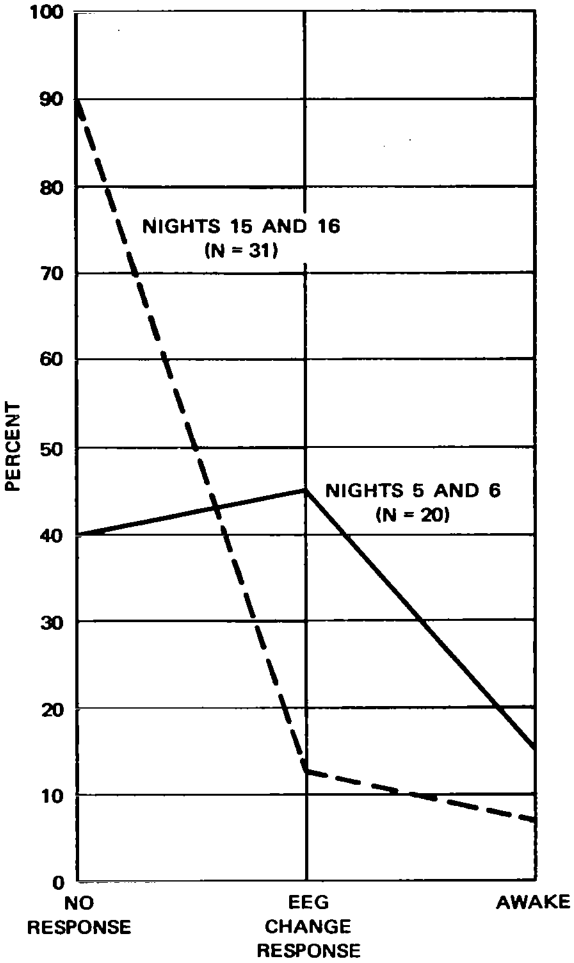


FIGURE 10 ADAPTATION IN 41- and 54-YEAR-OLD SUBJECTS TO SUBSONIC JET FLYOVER NOISE OF 113 PNdB

Table XV

RESPONSE FREQUENCIES OF SUBJECTS AGED 7 AND 8 YEARS ON DIFFERENT EXPERIMENTAL NIGHTS, TO SUBSONIC JET FLYOVER NOISE

Flyover Intensity	Nights	Frequency (N) and Percent of Responses	Response		
			Awake	EEG Change	No Response
101 PNdB[a]	1 & 2	N %	0 (0)	2 (5.0)	38 (95.0)
	11 & 12	N %	0 (0)	2 (5.6)	34 (94.4)
107 PNdB[b]	3 & 4	N %	0 (0)	7 (17.9)	32 (82.1)
	13 & 14	N %	0 (0)	6 (15.0)	34 (85.0)
113 PNdB[c]	5 & 6	N %	2 (5.0)	13 (32.5)	25 (62.5)
	15 & 16	N %	3 (7.3)	11 (26.8)	27 (65.9)

[a] $X^2 = 0.012$, 2 df, N.S.

[b] $X^2 = 0.125$, 2 df, N.S.

[c] $X^2 = 0.431$, 2 df, N.S.

Table XVI

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE REGARDLESS OF INTENSITY

Age Group	Stimuli	Frequency (N) and Percent of Responses	Response		
			Awake	EEG Change	No Response
Old[a]	Booms	N	84	15	17
		%	(72.4)	(12.9)	(14.7)
	Flyovers	N	47	28	33
		%	(43.5)	(26.0)	(30.5)
Middle-Aged[b]	Booms	N	5	73	121
		%	(2.5)	(36.7)	(60.8)
	Flyovers	N	14	38	141
		%	(7.3)	(19.7)	(73.0)
Young[c]	Booms	N	1	86	202
		%	(0.3)	(29.8)	69.9)
	Flyovers	N	7	59	223
		%	(2.4)	(20.4)	(77.2)

[a] $X^2 = 19.234$, 2 df, $p < 0.01$

[b] $X^2 = 16.736$, 2 df, $p < 0.01$

[c] $X^2 = 10.562$, 2 df, $p < 0.01$

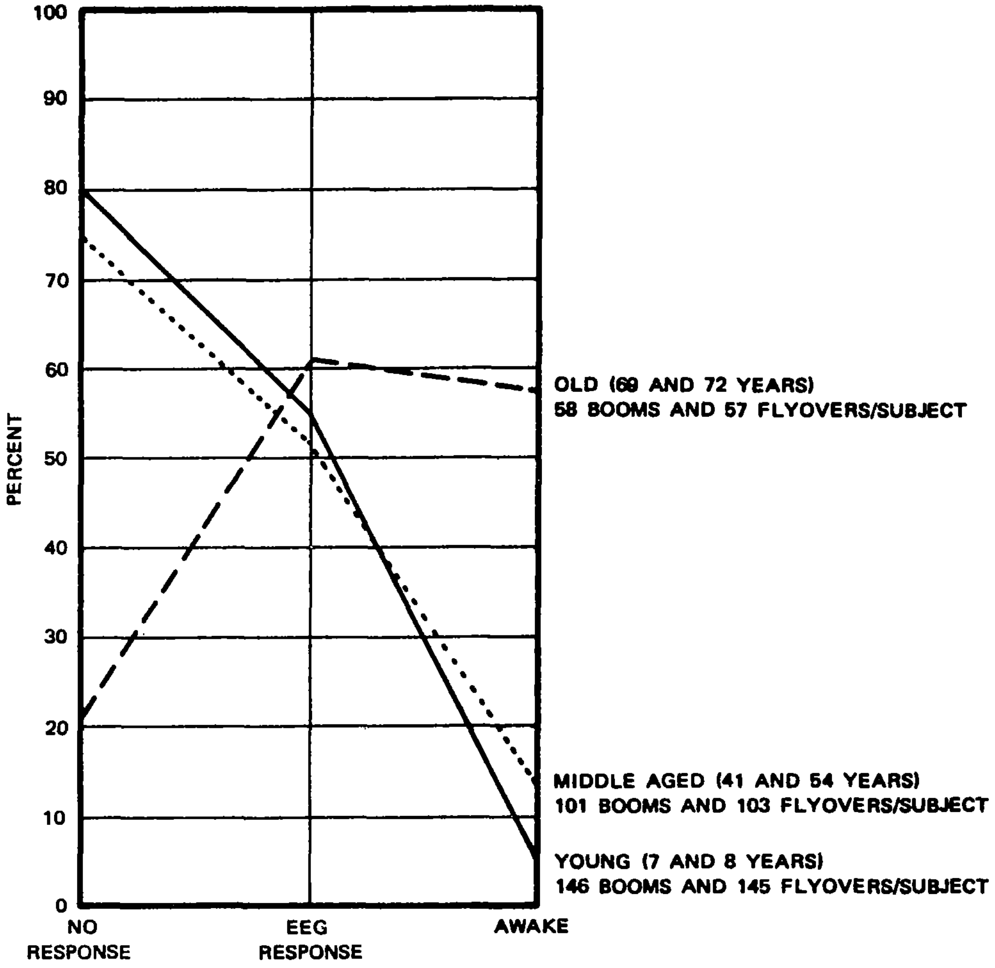


FIGURE 11 RELATIVE SENSITIVITY OF THREE AGE GROUPS DURING SLEEP, TO SIMULATED SONIC BOOM AND SUBSONIC JET FLYOVER NOISES

earlier study of college students (Ref. 4). The frequency of awakening of the college students and the subjects of the present study to simulated sonic booms and subsonic aircraft flyover noise are presented in Table XVII. The intensities of some of the stimuli were slightly different in the two studies, so that some intensity categories were combined to permit certain comparisons to be made among the four age groups.

There is an obvious lack of correlation between chronological age and awakening to the flyover noise: the 7- and 8-year-old group and the 41- and 54-year-old group were not awakened by flyovers of 101 and 103 PNdB, while college students were awakened by about 33 percent of these stimuli, or a rate similar to that observed for the 72-year-old group (37.8 percent). Further, with an increase of about 10 PNdB to 113 PNdB in flyover noise intensity, the young and middle-aged groups were awakened respectively by about 5 and 9 percent of the stimuli, while the college students were awakened by 91.7 percent of flyover noises of 113 PNdB.

With respect to simulated sonic booms, the data do not show wide discrepancies. The young and middle-aged groups were not awakened by the lowest-intensity booms (0.63 psf), while the college-age subjects were awakened by about 1.4 percent of these stimuli. At the high end of the boom intensity scale (1.9 and 2.5 psf) it is seen that the 7- and 8-year olds were not awakened, while the college students and middle-aged group were awakened by 5.0 and 4.3 percent, respectively, of those booms. The old subjects, in contrast, were awakened much more frequently by both the low-intensity (0.63-psf) and medium-intensity (1.25-psf) booms.

Equivalent Responses to Booms and Flyovers. It is reasonable to hypothesize that in the different age groups some intensity of flyover noise should result in response frequencies similar to those obtained by stimulation with simulated sonic booms. The distributions of responses to flyovers of different intensities for the three age groups (as shown in

Table XVII

PERCENT AWAKE RESPONSES OF FOUR AGE GROUPS TO SIMULATED SONIC BOOMS AND SUBSONIC AIRCRAFT FLYOVER NOISE OF SEVERAL INTENSITIES

Stimulus Intensity[a]	Age in Years			
	7 & 8 years	21 & 22 years	41 & 54 years	69 & 72 years
Boom Intensity[a]				
0.63 Psf	0/76 = 0%[b]	2/144 = 1.4%	0/47 = 0%	69/94 = 73.4%
1.25 Psf	1/102 = 0.9%		2/82 = 2.4%	15/22 = 68.2%
1.9 & 2.5 Psf	0/111 = 0%	6/120 = 5.0%	3/70 = 4.3%	
Flyover Intensity[a]				
93 PNdB		0/24 = 0%		
101 & 103 PNdB	0/76 = 0%	8/24 = 33%	0/49 = 0%	34/90 = 37.8%
107 PNdB	1/102 = 0.9%		8/76 = 10.5%	13/18 = 72.2%
113 PNdB	6/111 = 5.4%	22/24 = 91.7%	6/68 = 8.8%	

[a] As measured outdoors.

[b] (Number of awake responses/number of stimulations at intensity) X 100 = Percent.

Fig. 8), were visually compared to the distribution of responses to booms of the three intensities combined, and the flyover distribution approximating most closely that of the booms was tested statistically for goodness of fit.

Figure 12 shows the distribution of responses to sonic booms represented for each age group and the distribution of responses to flyovers that appeared to approximate the responses to the sonic booms. It will be seen that in the old and young subjects, flyovers of 107 PNdB resulted in response frequencies that are statistically equivalent to those obtained with sonic booms. (Old group: $X^2 = 5.706$, 2 df, $0.10 > p > 0.05$; young group: $X^2 = 5.172$, 2 df, $0.10 > p > 0.05$. The other comparisons--i.e., 101 PNdB versus booms and 113 PNdB versus booms, were different statistically.) In contrast, the middle-aged group's responses to booms most closely approximated those obtained to flyover of 113 PNdB. However, these distributions were significantly different ($X^2 = 11.789$, 2 df, $p < 0.01$), as were the other comparisons. The major contributor to the significant Chi-square was the difference of about 5 percentage points between the number of awake responses to booms and flyovers.

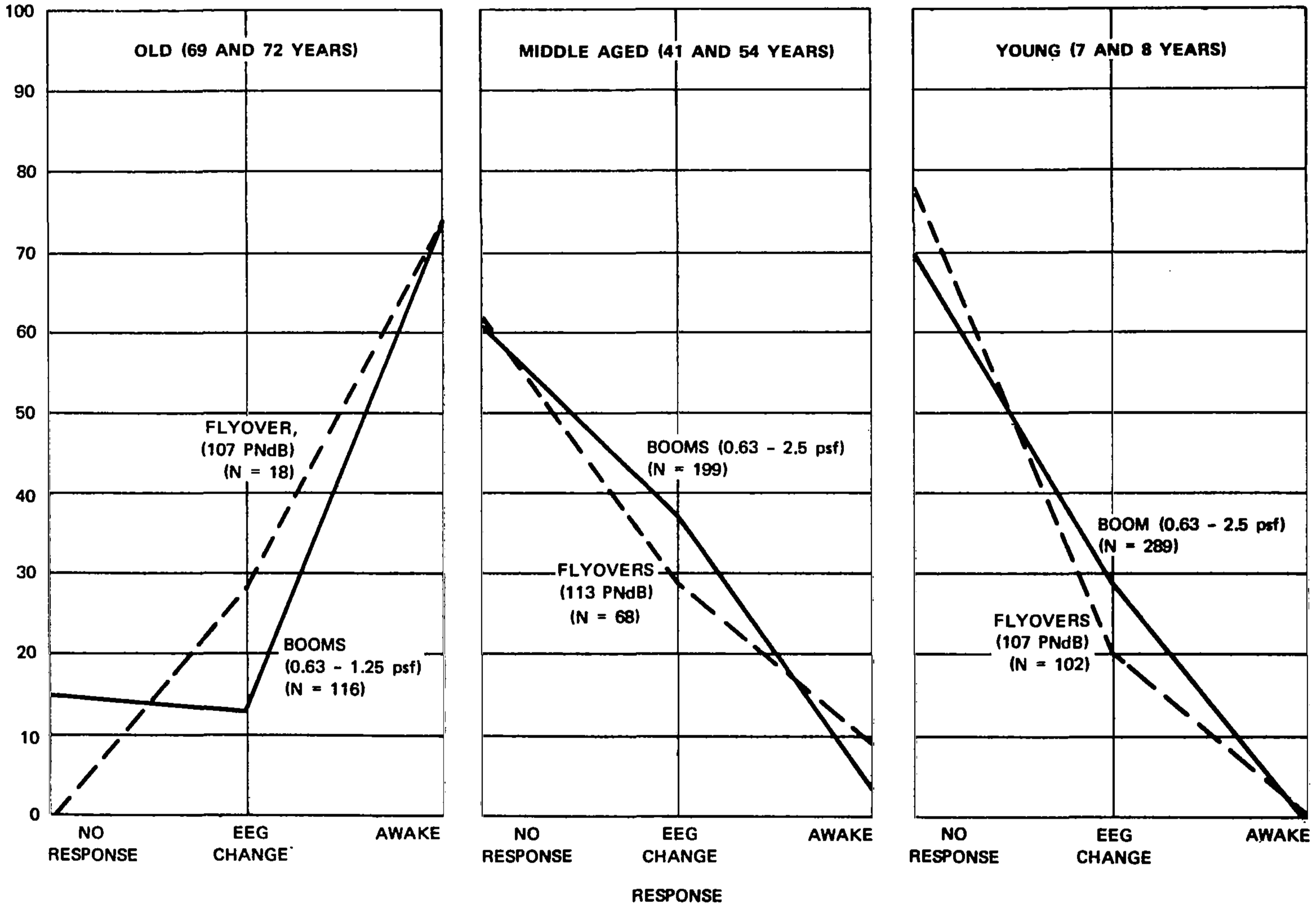


FIGURE 12 INTENSITY OF SUBSONIC JET AIRCRAFT FLYOVER NOISE RESULTING IN RESPONSES APPROXIMATELY EQUIVALENT TO THOSE OBTAINED FOR SIMULATED SONIC BOOMS OF 0.63 TO 2.5 psf INTENSITY

V DISCUSSION

Limited amounts of scientific information regarding the possible importance of brief interruptions of sleep, as evidenced by the EEG changes, to physiological well-being would suggest that behavioral awakening be used at this time as the major indicator of the disruptive effects of sonic booms and flyovers. Indeed, interpretation of the variability noted in the EEG responses during the different EEG stages remains a challenging area of research. Accordingly, our analysis of the results and the discussion to follow are concerned primarily with the response category of behavioral awakening.

There appeared to be no consistent differential awakening responses to sonic booms of the different intensities as used in these tests. A differential sensitivity is present perhaps in the 21- and 22-year olds and in the 41- and 54-year olds as shown in Table XVII, but is lacking in the 7- and 8-year olds, and even reversed for the oldest group. The lack of an apparent differential responsiveness for the children could, of course, be solely due to the fact that none of the booms used were of sufficient intensity to exceed the awakening threshold for the children. Perhaps for the oldest group the degree of responsiveness exhibited (about 70%) would occur with booms of almost any intensity. In short, the lack or general smallness of differential sensitivity obtained may be only apparent, and due to the particular subjects and/or experimental conditons present during these particular boom exposures.

Without reference to the types of stimuli, the rates at which the different age groups were awakened raise some questions about seemingly inconsistent physiological or psychological changes that supposedly occur as a function of age. As persons become older, auditory sensitivity decreases, and presumably the elderly are less likely to detect and respond to auditory stimuli. Simultaneously, however, older people apparently are less likely to sleep soundly than are younger persons. Younger individuals, in contrast, have much more sensitive ears, but also sleep much more soundly. If these opposing trends were equally influential, the expected net effect would be that the old and young groups should have similar rates of awakening to given intensities of auditory stimuli.

That these relationships are not linear with respect to age is indicated by the significant increase (roughly 65%) in the frequency of awakenings found in the 25-year span between the middle-aged and old groups, compared to an increase of about 6% found in the 37-year span between the young and middle-aged group. The data strongly suggest that a family of curves corresponding to age groups probably are required to relate responsiveness during sleep to changes in auditory stimulus intensity.

It is also to be noted that while these older people had significant hearing losses at frequencies above about 1000 Hz, somewhat in excess of those to be expected from normal aging, their auditory acuity at the lower frequencies was normal. Althought the subsonic jet aircraft noise has significant amounts of energy above 1000 Hz, the sounds from the booms are predominantly at frequencies less than about 200 Hz. Therefore it is to be expected that in the case of sonic booms a decrease in auditory acuity does not entirely compensate for the increased susceptibility to awakening as one grows older, but that it does to a greater degree in the case of jet aircraft noise. The trend of the data is consistent with this analysis--somewhat greater awakening in the oldest group than in the younger groups to sonic booms than to the noise of the subsonic jet aircraft.

Finally, it is interesting to note that 100 test subjects (residents of Edwards Air Force Base, ranging in age from 18 to 60 years) who had been habitually exposed in their homes for several years to sonic booms, rated sonic booms of about 1.7 psf as being subjectively equivalent (in acceptability) to the noise of a subsonic jet aircraft of 105 PNdB, when indoors, and 109 PNdB when outdoors (Ref. 2). As in this present study, the level of the boom and aircraft noise are as measured outdoors.

This general similarity between the relative sensitivity of people to booms and to subsonic jet aircraft noise when asleep and when awake may be fortuitous, or attributable to the particular degree of familiarity and adaptation to the booms and aircraft noise among the different groups of subjects involved in the tests. However, the subjects at Edwards AF Base were very much adapted to sonic booms and aircraft noise, and the subjects in the sleep tests presumably were not (at least consciously) attaching more significance to booms than to the aircraft noise. For this reason it may be reasonable to suggest that regardless of a person's age the basic relative equal arousal effect when asleep and equal subjective noisiness or unwantedness when awake is on the average represented by an aircraft noise at, say, 110 PNdB, and a sonic boom at 2 psf. It must be kept in mind, though, that while the two stimuli can possibly be adjusted to be approximately equivalent to each other in their awakening or non-awakening effects somewhat independently of the age of the subjects, the different age groups differ greatly from each other in general sensitivity to either the booms or the aircraft noise.

VI CONCLUSIONS

These conclusions are based on studies of small homogeneous groups of subjects, and therefore should be considered tentative at this time.

1. In a "typical" house, people aged about 70 years are more likely to be awakened by both simulated sonic booms and jet aircraft noise than are younger people (ages of about 8 years and 47 years).

2. People aged about 70 years are awakened by about 70 percent of the simulated sonic booms (0.63 to 1.25 psf, as measured outdoors), and on the average by about 55 percent of the subsonic jet aircraft flyovers (103-107 PNdB, as measured outdoors).

3. In a "typical house," people aged about 7 years, 21 years, and 41-54 years are likely to be awakened about 17% of the time by subsonic jet aircraft flyovers of intensities from about 90-113 PNdB, as measured outdoors, and about only 2% of the time by sonic booms of intensities 0.63 to 2.5 psf, as measured outdoors.

4. Changes in the EEG, indicating some arousal from sleep, are not as interpretable or perhaps as consistent an indicator of differences in sensitivity of the different age groups to booms or aircraft noise as is behavioral awakening.

5. Stage of sleep, as indicated by EEG pattern, is correlated with sensitivity to behavioral awakening. Subjects are most likely awakened in stage REM, less likely in Stage 2, and least likely in stage Delta. On the other hand, changes in EEG pattern occurred primarily and about equally, over all age groups in stages Delta and 2, and least frequently during Stage REM.

6. Adaptation effects as measured by a comparison between the responses on the first six and last six nights of testing were not consistent among the groups for either booms or aircraft noise. In general, there appears to be little adaptation to the booms but some adaptation to the aircraft noise.

7. Averaged over all age groups, it appears that booms of 0.63 to 2.5 psf are as awakening as aircraft noise of 93 to 113 PNdB (both sounds measured outdoors).

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NASA-Langley, 1970 —— 5 CR-1599