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16. Abstract

Eight male subjects in each of three age groups (21-26, 40-45, 60-72 years) slept in pairs in the CAMI sonic boom simulation facility for 21 consecutive nights. The first five nights were used to acclimate the subjects (nights 1 and 2) and to obtain Baseline data (nights 3-5); the 12 subsequent nights (Boom) involved the hourly presentation of simulated sonic booms at an overpressure level of 1.0 psf (as though measured "outdoors"); during four additional nights (Recovery) there were no boom presentations. All-night records of EEG, EOG, EMG, ECG, and BSR were obtained and analyzed. None of these physiological measures showed any statistically significant effect of the boom presentations on nightly sleep patterns. However, the individual booms did arouse ECG, EMG, and BSR responses in all subjects; average heart rate increased during the minute following each boom (by less than one beat per minute), EMG responses occurred for 45-50 per cent of the booms, and BSR changed following 19 per cent of boom presentations. The frequency of these occurrences increased as a function of age. That these changes were probably mild is supported by the facts that only 5 per cent of the booms produced awakening and only 14 per cent produced shifts in stages of sleep (4 per cent of the stage shifts might be expected by chance); both of these measures showed higher frequencies of occurrence as a function of age. The changes in sleep appear roughly comparable to what might occur in response to the noise of a passing truck at 40-45 dBA.

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SIMULATED SONIC BOOMS AND SLEEP: EFFECTS OF REPEATED BOOMS OF 1.0 PSF

I. Introduction.

In the NAS-NRC Report on Human Responses to the Sonic Boom (1968), it was noted that "Understanding human response to the sonic boom is sufficiently important to warrant high priority for the maximum use of simulation facilities. . . . It is important to know more about the response of an individual to the sonic boom as a function of his ongoing activities such as skilled motor performance . . . sleep at night. . . . These relations should be studied independently for infants, children, and adults of all ages. . . ." Among the questions cited as particularly relevant as a background for management decisions were: "Do repeated booms cause changes in the depth of sleep as judged by the electroencephalogram (EEG)? Does the stimulated subject develop a chronic deficit of important stage of sleep? . . . . Do repeated brief awakenings of normal subjects cause behavioral changes, psychological distress or excessive fatigue?"

Relatively little research has been conducted concerning the effects of sonic booms on sleep behavior. However, there is a good deal known about the general influence of noise on sleep patterns (e.g., Dobbs, 1970; Kryter, 1970; Williams, 1970). A number of laboratory studies (Goodenough, Lewis, Shapiro, Jaret, and Sleser, 1965; Kramer, Roth, Trindar, and Cohen, 1971; Oswald, Taylor, and Triesman, 1960; Rechtschaffen, Hauri, and Zeitlin, 1966; Williams, Gieseking, and Lubin, 1966; Williams, Hammack, Daly, Dement, and Lubin, 1964; Williams, Morlock, and Morlock, 1966; Williams and Williams, 1966; Zung and Wilson, 1961) using different auditory stimuli have shown that waking responses are a function of the following variables: individual differences, intensity of the acoustic stimulus, age of the sleeper, sex of the sleeper, time of night, stage of sleep, amount of accumulated sleep, and personal significance of the auditory stimulus (e.g., the sleeper's own name). Moreover, most physiological responses (e.g., brain wave activity, heart rate) appear to show little or no adaptation to acoustic stimulation during sleep.

Of the very small number of studies involving sonic booms and sleep behavior, most have been conducted by Lukas and his co-workers (Lukas, 1970; Lukas and Dobbs, 1972; Lukas, Dobbs, and Kryter, 1971; Lukas and Kryter, 1968, 1970a, 1970b). Those several studies involved a total of 22 male and female subjects who were exposed to simulated sonic booms (ranging in "outdoor" intensities from 0.6 to 5.0 psf) and to recordings of subsonic jet flyover noise (ranging in "outdoor" intensity from 101–119 PNdB). With the exception of four middle-aged females, subjects were tested frequently but on non-consecutive nights; the female exceptions were tested for 14 consecutive nights (Lukas and Dobbs, 1972). Results of these studies, using criteria of arousal and awakening, may be summarized as follows: (1) children (5–8 years of age) appear to be undisturbed by noise during sleep; (2) in general, younger subjects are less sensitive to noise than are older subjects; (3) irrespective of age, individuals may show considerable variability in relative sensitivity to noise during sleep; (4) men appear to be less sensitive to noise than do women; and (5) the occurrence of behavioral awakening is a function of the intensity of the noise (Lukas, 1970). Morgan and Rice (1970) indicate that awakening appears to be related more closely to accumulated sleep time than to stage of sleep.

The present study was designed to investigate the effects on sleep of simulated sonic booms occurring regularly during the night over a consecutive 12-night period. Possible effects of the booms on subjective states and on objective measures of performance were also examined. An overpressure level of 1.0 psf (as measured "outdoors") was selected as the boom stimulus. The selection of this stimulus as an "acceptable" one was a compromise based partly on determinations from other studies which indicated that sonic boom overpressure levels of 0–1.0 would produce no significant public reaction day or night, while levels of 1.0–1.5 would produce probable public reaction (von Gierke, 1966). The 1.0 psf level has been likened to the sound of moderate thunder (Richards and Rylander, 1972) or of moderate to distant thunder (Ferri and Schwartz, 1972).

II. Method.

Facility

This study was conducted in the sonic boom simulator facility at the Civil Aeromedical Institute (CAMI). The facility was designed and constructed by the Stanford Research Institute (SRI) and was modeled after their device according to CAMI requirements. A detailed description of the SRI facility can be found in a paper by Lukas and Kryter (1968) and a description of the CAMI facility appears in a report by Thackray, Touchstone, and Jones (1971). Briefly, the facility at CAMI consists of two components, the boom generator and the test room, both of which are slightly larger than those at SRI. The boom generator (Figure 1) is an electromechanical device which can be set to provide simulated booms of various intensities directly to the test chamber (Figure 2). A piston, which is connected to a tightly sealed pressure chamber (Figure 1) causes a pressure change in the chamber when a "one-shot" clutch is activated. A cam, which rotates through 360°, can be offset to vary the intensity of the boom; the spring load can be varied to change the rise time of the boom while the motor speed determines the duration of the boom. In this study, the boom intensity was set at 1.0 psf, the rise time was 6.8 msec, and the boom duration was 299.5 msec. Inside the test room, the comparable data were 0.13 psf, 12.1 msec, and 283.6 msec, respectively (cf., Thackray et al., 1971). Sound levels of the booms, as measured by a B&K Impulse Precision Sound Level Meter (Type 2204), were approximately 80 dBA on the Impulse setting and 68 dBA on the Slow setting, at the position of a given subject's head.

The test room was constructed to simulate a middle bedroom in a frame house. The walls of the test room are of standard dry wall construction. One wall of the pressure chamber (Figure 1) forms the "outside" wall of the test room. There are two windows in the room—one in the "outside" wall and one (of one-way glass) in the opposite wall which was used for observation of the subjects by the experimenters.

Physiological Measurements

All physiological measurements were recorded on Beckman Type RM 8-channel polygraphs. Recordings were made of the electroencephalogram (EEG), electro-oculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), and the basal skin resistance (BSR). EOG, EMG, and EEG are measures which are used primarily to score stages of sleep, while ECG and BSR are primarily indicators of the level of arousal of an individual. One polygraph channel served as an event marker for the presentation of sonic booms. In addition, all data were simultaneously stored on magnetic tape by means of a 16-channel Ampex tape recorder, Model SP 300. Tape speed was 1⅞ ips; polygraph paper speed was 1 cm/sec.

Electrode placement sites and recording techniques employed for EEG, EOG, and EMG were those suggested by Rechtschaffen and Kales (1968). Acetone was used to clean all electrode sites and Redux paste was used for EEG and EMG sites prior to electrode application. EEG electrode sites were rotated between C4/A1 and C3/A2 (Ten-Twenty system) on alternate nights in order to minimize skin irritation. A standard Grass silver disc EEG electrode filled with Grass EC–2 electrode cream was attached to the scalp site (either C3 or C4) with a collodion-soaked one-inch-square gauze pad, and the reference electrode (either A1 or A2), similarly filled with EC–2 cream, was taped to the earlobe by means of Blenderm surgical tape. Polygraph settings for EEG were 50 microvolts/centimeter gain, and 0.3-second time constant.

For EOG, one standard EEG electrode, filled with electrode cream, was taped near the outer canthus of each eye, and both electrodes were referred to the previously described electrode located either at A1 or A2. This arrangement was used in order to identify the horizontal conjugate eye movements associated with the rapid eye movement (REM) stage of sleep. Recorder settings for these two EOG channels

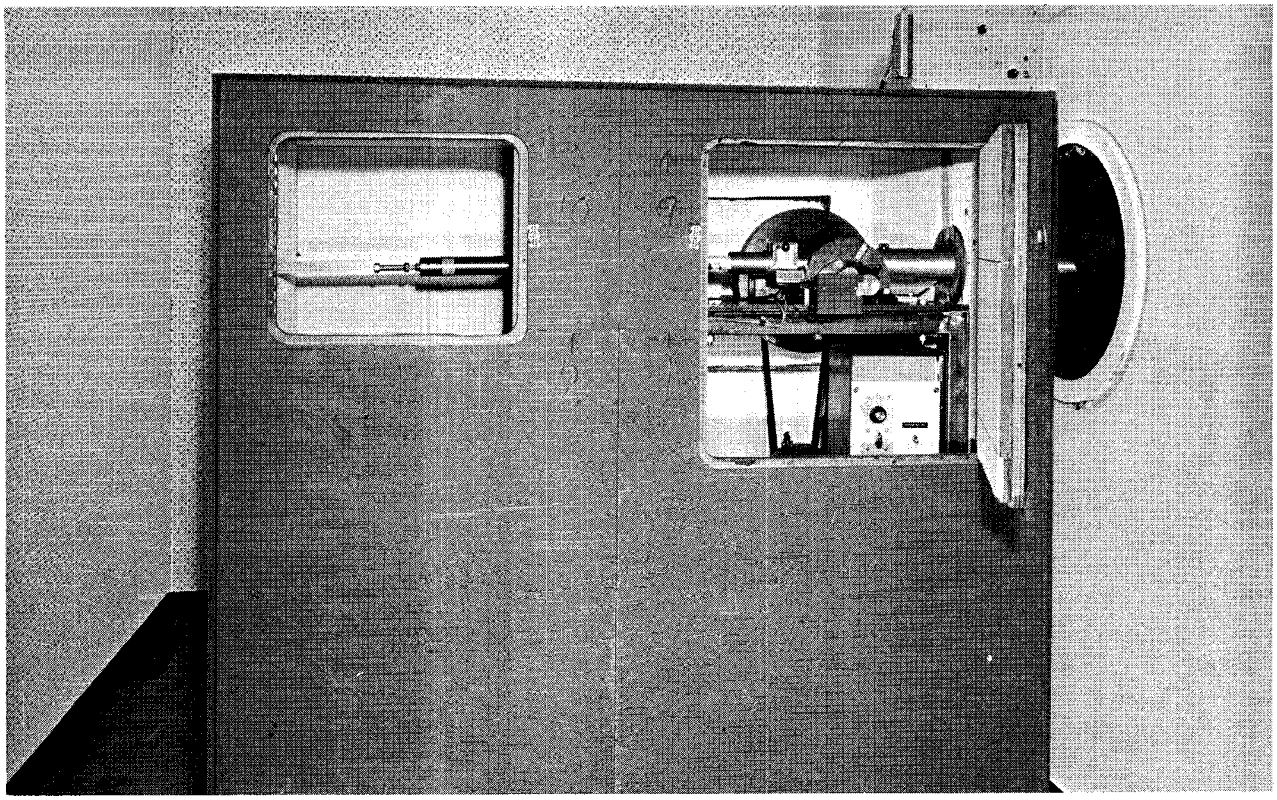

FIGURE 1. The boom generator section of the CAMI sonic boom simulation facility. The pressure chamber at the right is immediately adjacent to the test room (see Figure 2).

were 100 microvolts/centimeter gain, and 0.3-second time constant.

The two electrodes used for detecting EMG were standard EEG electrodes filled with electrode cream and taped to the underside of the jaw. One electrode was placed approximately one inch behind the point of the chin over the insertion of the submental muscle; the second electrode was attached about one and one-half inches behind the first electrode at a point just short of the terminus of the jaw bone. On alternate nights, homologous sites on the opposite side of the jaw were used in recording EMG. Recorder settings for EMG measurement were the following: gain was varied between 10–40 microvolts/centimeter (depending on signal strength) with the most common setting being 20 microvolts/centimeter, a 0.1-second time constant was maintained without high-frequency filtering. One polygraph channel recorded an integration of the EMG responses. The direct EMG signal was passed through a Beckman Type 9852A EMG averager (time constant: 0.2 seconds) and the amplified output of this coupler was written out on the polygraph. This averaged EMG signal was not placed on tape.

ECG was derived from two standard EEG electrodes taped to the subject's thorax. One electrode was taped just below the trapezius muscle on the right side of the back, and the

FIGURE 2. The test room of the CAMI sonic boom simulation facility. The window and wall at the head of the beds are adjacent to the pressure chamber.

second electrode was located approximately near the bottom of the left-side rib cage. EEG, EOG, ECG, and direct EMG signals were all carried to the amplifiers via standard Beckman A-C couplers Type 9806A.

BSR tracings were obtained from two Beckman biopotential (silver-silver chloride) electrodes, filled with K·Y surgical jelly, and taped to the palmar surface of the distal segment of the right forefinger and right ring finger. The Beckman Type 9892A skin resistance coupler was employed in this recording circuit. This coupler is a constant current device whose output signal, after appropriate amplification, can be scored directly in terms of resistance unit. Amplification of the BSR signal ranged from 2–200 millivolts/centimeter as a function of within- and between-subject variation in basal skin resistance. Lastly, a two x three inch silver electrode covered with K-Y surgical jelly and fastened to the subject's right forearm with an Ace bandage was used as the grounding source.

Mood Assessment

The Composite Mood Adjective Check List (CMACL) developed by Malmstrom (1968) was used to assess affective states prior to and subsequent to each sleep period. The list consists of 80 adjectives which the subject rates on a nine-point scale, with the lower end of the scale indicating a judgment of "not at all" descriptive, and the upper end of the scale indicating a judgment of "definitely" descriptive, of the subject's current feelings. Each CMACL was scored for the 15 mood factors listed by Malmstrom as well as for an index indicating the overall degree of positive or negative affect expressed by the subject. More detailed procedures concerning this aspect of the overall study appear elsewhere (Smith and Hutto, 1972).

Performance Measurement

The CAMI Multiple Task Performance Battery (MTPB) (Chiles, Alluisi, and Adams, 1968) was used to measure performance of complex tasks before and after each sleep period. Briefly, the apparatus was programmed to present two active and two passive tasks to the subjects. The former comprised mental arithmetic and pattern discrimination; the latter, monitoring lights and monitoring meters. Ten performance scores were derived for each subject.

(1) Red Lights I. Response time to onset of red warning lights while performing the arithmetic task.

(2) Red Lights II. Response time to onset of red warning lights while performing the pattern discrimination task.

(3) Green Lights I. Response time to the offset of green warning lights during arithmetic tasks.

(4) Green Lights II. Response time to the offset of green warning lights during pattern discrimination.

(5) Meter Monitoring I. Response time to detect correctly shifts in the mean positions of fluctuating pointers while performing the arithmetic task.

(6) Meter Monitoring II. Response time to detect correctly shifts in the mean positions of fluctuating pointers during the pattern discrimination task.

(7) Arithmetic I. Response time to add two two-digit numbers, subtract an additional two-digit number, and record the answer by means of a set of push-buttons. (Note: For the oldest group, one-digit rather than two-digit numbers were used due to the difficulties experienced in the training session by one of the first two 60–72 year olds.)

(8) Arithmetic II. Percentage of arithmetic problems solved correctly.

(9) Pattern Discrimination. Patterns of six vertical bars each were displayed on a screen for two to five seconds. Each problem involved a standard and two comparison patterns successively presented. Subjects pressed one of a set of three buttons to indicate whether the first, the second, or neither comparison pattern matched the standard. Scores comprised the percentage of correct responses. (Note: The task was made more difficult for the two youngest age groups by means of programmed random distortions of the comparison patterns.)

(10) Composite for Lights and Meters. The sum of the linear transformation of scores for Red Lights I and II, Green Lights I and II, and Meter Monitoring I and II.

More detailed procedures concerning this aspect of the overall study are reported elsewhere (Chiles and West, 1972).

Subjects

A total of 24 male subjects was used; eight subjects each were in groups aged 21–26, 40–45, and 60–72. Data concerning age, education, and employment status of these men appear in Table 1. A week or so prior to the start of a 21-night experimental sequence, subject-candidates were interviewed, given a hearing test (Békésy audiometer), and then administered the Cornell Medical Index Health Questionnaire (to screen out subjects who might have severe emotional disturbances). Results from the Cornell Questionnaire and mean audiograms are presented in Table 2 and Figure 3, respectively. In selecting the 24 subjects used in the study, 12 other candidates were rejected and two others (21–26 year olds) served as trial-run subjects for 21 nights to test out equipment and procedures. Ten of the rejections (two in the youngest, one in the middle, and seven in the oldest age groups) were based on judgments that their audiograms were below approximately normal levels for their age groups. The other two rejections were foreign students (21–26 year olds) who were judged, on the basis of the interview, to have insufficient command of the language to be able to follow all instructions adequately. Subjects were not selected on the basis of physical characteristics,

Table 1

Age, Education, and Employment Characteristics of the Three Groups of Subjects

Age Groups	N	Mean Age (Years)	Median Education	Employment Status: Number in Categories		
				Student	Full-Time Job	Retired
21-26 Year Olds	8	23.3	2.0 Yr. College	5	3	0
40-45 Year Olds	8	42.1	3.0 Yr. College	1	7	0
60-72 Year Olds	8	65.1	2.5 Yr. College	0	1	7
Totals	24			6	11	7

Table 2

Classification of Subjects According to Responses Made to the

Cornell Medical Index Health Questionnaire

Age Groups	N	CMI Categories: Severity of Emotional Disturbance			
		Not Significant	Mild	Moderate	Severe
21-26 Year Olds	8	8	0	0	0
40-45 Year Olds	8	6	1	1	0
60-72 Year Olds	8	7	1	0	0
Totals	24	21	2	1	0

Table 3

Mean Time to Bed, Time to Rise, Nightly Hours in Bed, and Nightly Awakenings Reported by Subjects in Each Age Group Prior to the Experiment. Records of These Sleep Data Were Kept by the Subjects for Periods Ranging From 4-10 Days Prior to the Beginning of the Experiment.

Age Groups	N	Mean Time to Bed (P.M.)	Mean Time to Rise (A.M.)	Mean Hours in Bed	Mean Nightly Awakenings
21-26 Year Olds	8	11:58	7:57	8.0	0.9
40-45 Year Olds	8	10:32	7:08	8.6	0.8
60-72 Year Olds	8	10:49	7:00	8.2	1.6

prior exposure to sonic booms, susceptibility to noise, or criteria other than those noted above.

Subjects who passed the screening tests were asked to begin to maintain a daily record of their sleep behavior and to present the information when they reported for the first of the 21-night sessions. The record was to indicate time to bed, time to rise, and number of awakenings for each night; these data appear in Table 3. In addition, they were given a brief orientation regarding the conduct of the study and what would be required of them. Subjects were not told that simulated sonic booms would be presented. They were told that CAMI was interested in sleep behavior, moods, and performance; that noises might occur during the night (including the presence of experimenters in the test room to adjust or replace electrodes as needed) but that their task was to ignore disturbances of any kind and get the best night's sleep possible. The subjects were then scheduled for a one-hour training session on the performance battery, usually the day before the 21-day session was to begin.

Procedure

Two subjects (from the same age group) reported to the sleep laboratory at 2000 hours each night for a total of 21 consecutive nights (Table 4). The first five nights of sleep in the laboratory served two purposes; the subjects became adapted to sleeping in the laboratory environment (nights 1 and 2), and Baseline data were collected on nights 3–5. During the next 12 nights, the subjects were presented with a simulated boom (1.0 psf "outside" intensity) at hourly intervals starting at 2300 hours and ending at 0600 hours. When the observers determined that a subject was not asleep at the time a boom was scheduled, the boom was delayed for periods not exceeding 10 minutes to allow the subject to fall asleep. The final four nights were termed "recovery nights" (no booms presented).

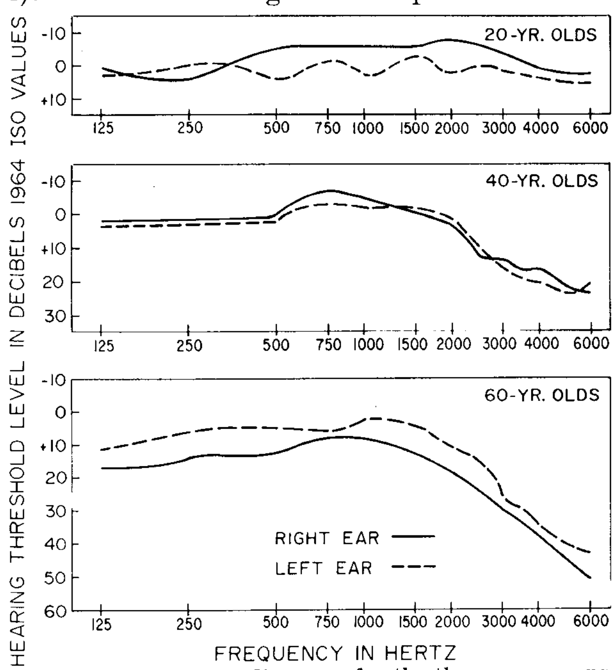

FIGURE 3. Average audiograms for the three age groups.

As indicated in the procedural outline presented in Table 5, at 2000 hours and again at 0700 hours the subjects were tested on the Multiple Task Performance Battery; the test period was approximately 30 minutes long. At 2040 and at 0730 hours, the subjects were administered the Composite Mood Adjective Check List. Between 2100 and 2200 hours all electrodes were attached and other preparations completed so that the subjects would be in bed at 2200 hours. Recorders (all located outside the test room) were activated and calibrated and continuous recordings were made for 500 minutes (8 hours and 20 minutes) until the subjects were awakened at 0620 hours.

During the hours the subjects were not in the laboratory, they concerned themselves with their normal daytime activities. They were requested not to nap during the day and, although there

Table 4

General Protocol

Day	Procedure
Pre-Experimental Period	Hearing test, Cornell Medical Index, orientation, training on Multiple Task Performance device.
Experimental Period	
1 - 2	Adaption to laboratory environment. Collection of physiological, performance, and mood data; no simulated booms presented. (Data obtained during these two days are not presented in this report.)
3 - 5 (Baseline)	Collection of baseline physiological, performance, and mood data; no simulated booms presented.
6 - 17 (Boom)	Collection of physiological, performance, and mood data; booms presented at hourly intervals from 2300 to 0600 hours.
18 - 21 (Recovery)	Collection of physiological, performance, and mood data; no simulated booms presented.

Table 5

Daily Protocol

Time	Activity
2000 hours	Report to laboratory
2000-2030	Multiple Task Performance Battery (MTPB)
2030-2040	Rest Interval
2040-2050	Composite Mood Adjective Check List (CMACL)
2050-2100	Rest Interval
2100-2145	Attachment of electrodes
2145-2200	Preparation for bed
2200-0620	Sleep, recording of physiological data
0620-0700	Awaken, remove electrodes, dress
0700-0730	MTPB
0730-0740	CMACL
0745	Depart laboratory

was no attempt to regulate eating or drinking habits, the subjects were asked to refrain from excessive use of alcohol and to take no alcohol at all after 1800 hours.

Scoring of Physiological Data

Sleep Profiles

All-Night Measures. Two channels of EOG, one of EMG, and one of EEG were used to score stages of sleep. Using "A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects" (Rechtschaffen and Kales, 1968), each 30-second epoch was scored as: Awake, Movement Time, Stage 1 (non-REM), Stage 2, Stage 3–4 or Stage REM. The amount of time awake was further divided into the following categories: (1) the amount of time awake before sleep onset (Awake stage only), (2) the amount of time spontaneously awake, (3) the amount of time awake subsequent to boom presentations, and (4) the amount of time awake between sleep termination and arising. To assess the reliability of scoring, every fifth record was scored by a second person. The mean reliability between scorers (epoch by epoch) was 90.9 per cent. In addition, every tenth record was also scored by the director of the scoring project. The mean reliability between the two scorers and the project director was 94.1 per cent.

To further evaluate the nature of the sleep during the three experimental conditions, latencies to Stage 2 (sleep onset; includes Awake stage and Stage 1) and Stage REM were computed. Finally, the number of transitions between sleep stages was determined. Three different time bases were used to determine the number of sleep stage transitions (30 seconds, five minutes, and ten minutes); transitions were tallied on the basis of the predominant stage within the selected time period.

Measures of Responses to the Booms. Sleep profile changes in response to the booms were scored using the criteria developed by Williams (see Table 6) and described by Lukas and Kryter (1968). Since there is an inherent variability in the sleep record throughout the night, it was necessary to compare any changes in sleep resulting from a boom presentation to a pseudo stimulus control condition in which the boom was not presented in reality. Therefore, the sleep recording 30 minutes prior to an actual boom presentation was scored using the Williams Criteria. The reliability measure for the Williams Criteria was 90.0 per cent between two scorers based on five randomly selected nights for each of four subjects.

Heart Rate (ECG)

All-Night Measures. The unit of measurement for the ECG data was beats per minute. A one-minute segment out of every hour of recording (on the half-hour) was selected for scoring. In each one-minute sampling every inter-beat interval was measured. To avoid artifact, any inter-beat interval ± 3 standard deviations from the mean of that sample was rejected. Finally, any sample which contained less than 20 usable inter-beat intervals was rejected. Heart rate for the night was determined by averaging the night's samples. Variability in heart rate was obtained by computing the standard deviation of the heart rate for the 100 samples.

Measures of Responses to the Booms. ECG responses to a boom were measured by determining heart rate one minute before and one minute after a boom presentation.

Muscle Tone (EMG)

All-Night Measures. Muscle tone as recorded on an integrated EMG channel was measured by ruler in terms of both absolute level and variability during the night. EMG levels were scored every five minutes (unless there was an artifact or an arousal lasting less than 10 seconds, in which case the last "normal" recording was used); each score was the level of EMG measured at the end of a five-minute period. Because of the (normal) variability between nights, the first EMG recording of each night was given a reading of zero, and all subsequent recordings of the night were measured as deviations from that level. The overall level of EMG was averaged for each of nine periods of that night. The first period consisted of the initial 20 minutes of the night, and the subsequent eight periods were each an hour long. The variability of the EMG was obtained by computing the standard deviation of the 100 EMG readings made each night.

Measures of Responses to the Booms. The percentage of boom presentations resulting in any measurable EMG response within five seconds was determined as well as the percentage of boom presentations showing recovery within ten minutes. In addition, these measures were also obtained from the EMG recording 30 minutes prior to an actual boom presentation. These

Table 6

The Williams Criteria for Scoring EEG Tracings (Adapted from Lukas and Kryter, 1968). These Scores Are Not Independent Since a High Score Usually Includes All the Lower Scores, e.g., a Williams Score of Three Indicates That K Complexes Also Occurred.

Williams Score	Change Required on EEG Record
0	No change.
1	A K complex of low amplitude (less than 150 microvolts) which occurs within one second after boom presentation, but is usually coincidental with the boom.
2	A K complex of high amplitude (above 150 microvolts) or several K responses which occur within two seconds of termination of the boom stimulus.
3	The presence of an Alpha pattern or synchronization within two seconds of termination of the boom stimulus
4	Body movement or movement of facial or eye muscles within six seconds of termination of the boom stimulus.
5	A one-step shift in sleep stage (e.g., from a Stage 3 to a Stage 2) within one minute of termination of the boom stimulus.
6	A two-step shift in sleep stage (e.g., from a Stage 4 to a Stage 2) within one minute of termination of the boom stimulus. (This score was not assigned since we used a combined Stage 3-4 and a shift of two stages resulted in awakening.)
7	Prolonged Alpha movement and an Awake response within one and one-half minutes of termination of the boom stimulus. (The delay was recommended for studies which require the subject to signal his awareness of being awake; it allows time for the subject to find the signalling device.)

data served as the pseudo stimulus control condition to compare with changes resulting from an actual boom presentation.

Basal Skin Resistance (BSR)

All-Night Measures. The BSR was measured in terms of both absolute level and variability during the night. BSR was scored every two minutes except when a movement artifact occurred at that point; in this case, the last "normal" BSR recording was taken. Because of the large (normal) variability between and within subjects on the initial BSR level for a night (differences greater than might be expected due to the boom), the first BSR recording was given the value of zero ohms. All subsequent measures were computed as deviations from the original level. Also, any two-minute epoch which contained a balance change (i.e., a shifted baseline) was omitted because of difficulty determining the appropriate BSR level. The mean BSR level was obtained for each of nine periods during the night. The first period was the initial 20 minutes of the night, and the next eight periods were each an hour long. The variability of the BSR was computed by calculating standard deviations for each night.

Measures of Responses to the Booms. To evaluate the effect of the sonic boom on BSR, five dependent measures were used: (1) percentage of boom presentations showing any measurable change in BSR within five seconds of boom onset, (2) magnitude of response in kilohms, (3) latency of responses, (4) percentage of responses showing recovery within ten minutes, and (5) latency of recovery for those responses which returned to pre-boom levels within ten minutes.

III. Results and Discussion.

Sleep Profiles

Patterns of Sleep. The EEG scores obtained during the Baseline phase for time awake, movement time, and four stages of sleep are presented in Figure 4 and compared with data from Lukas (1970) and from Kramer, Roth, Trindar, and Cohen (1970). In general, the sleep patterns obtained in this study are similar to those reported by Lukas (1970) and by Kramer et al. (1970).

Table 7 presents percentages reflecting the average amounts of time the subjects in each age group spent in the four stages of sleep, in being awake, and in movement during sleep for Baseline, Boom, and Recovery phases, respectively. Analyses of variance conducted on these scores for each of these six aspects of sleep indicated no significant differences at the .05 level among the three phases. Thus, presentation of the booms had no significant effect on the proportion of time spent in any of the sleep stages. However, significant differences were obtained ($p<.01$–$p<.001$) among the age groups for five of the six sleep stages (Stage 3–4 was the exception) indicating that the proportion of time spent in one sleep stage or another was related to age but not to presentation of the boom (specifically, the sleep pattern of the oldest group accounted for most of these differences).

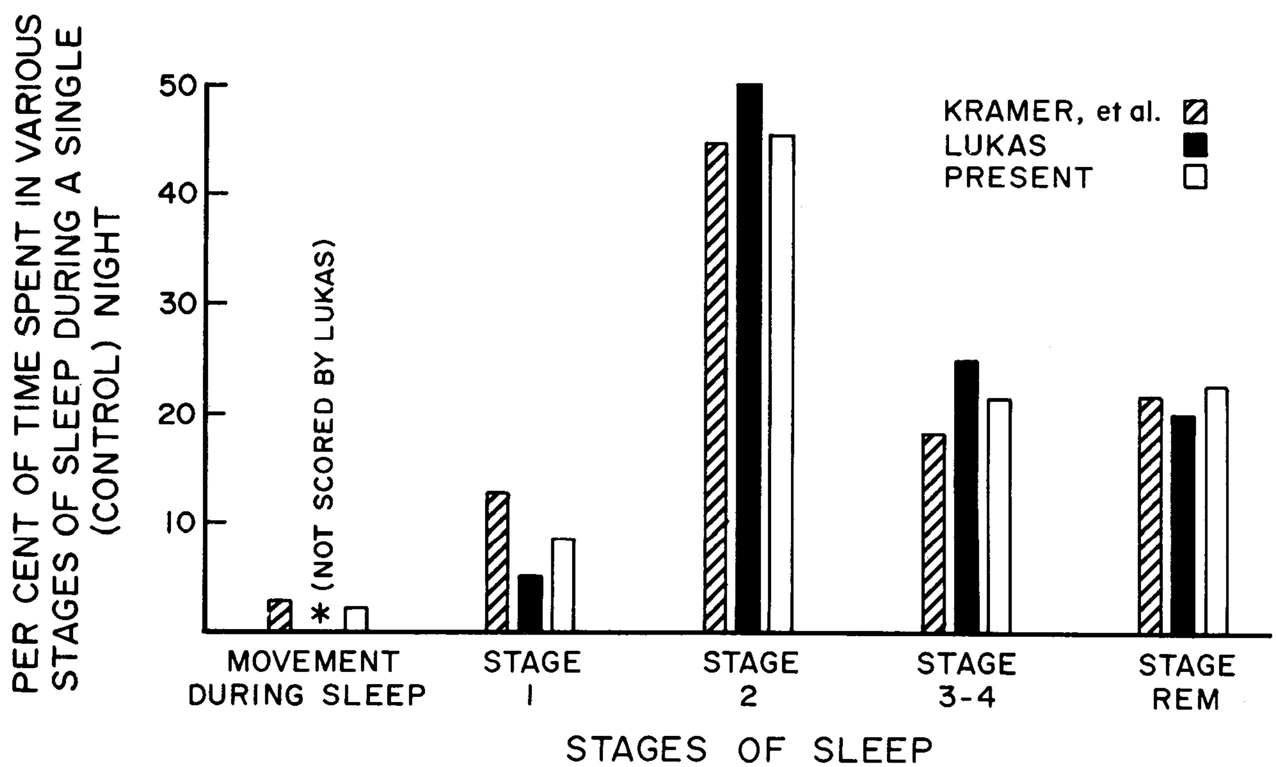

FIGURE 4. A comparison of the percentages of time scored as movement time during sleep and as sleep stages 1, 2, 3–4, and REM for the present study (based on three Baseline nights), for a 1971 study by Kramer, Roth, Trindar, and Cohen (based on two Control nights), and as approximated by Lukas (1970) for normal sleep (Lukas did not include an estimation of movement time during sleep).

Table 7

Mean Per Cent of Night (500 Minutes) in the Various Stages of Sleep and Wakefulness for Baseline, Boom, and Recovery Nights

Stages of Sleep	Age Groups								
	21-26 Year Olds			40-45 Year Olds			60-72 Year Olds		
	Baseline	Boom	Recovery	Baseline	Boom	Recovery	Baseline	Boom	Recovery
Total Time Awake	6.6	8.0	11.1	10.9	9.2	7.9	18.2	16.9	16.2
Movement Time During Sleep	2.2	2.2	2.4	1.6	1.3	1.3	1.5	1.4	1.4
Sleep Stage 1	5.3	5.2	5.2	9.4	8.7	9.3	7.5	8.1	8.4
Sleep Stage 2	44.9	45.4	44.9	40.3	40.4	42.0	34.6	35.3	36.8
Sleep Stage 3-4	19.0	18.0	16.5	16.3	18.1	17.3	21.8	20.2	20.1
Sleep Stage REM	22.0	21.2	19.9	21.5	22.3	22.2	16.4	18.1	17.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The distribution of time awake during the night, the latency for onsets of Stage 2 and of Stage REM, and the number of changes in sleep stages during the night are presented by age group in Table 8 for Baseline, Boom, and Recovery nights. Analyses of variance of these scores yielded no significant difference at the .05 level across the three phases. Thus, these sleep profiles showed no effects which could be attributed to the boom presentations. Significant differences which were obtained among the age groups for spontaneous time awake ($p<.001$),

Table 8

Distribution of Time Awake (in Minutes), Mean Number of Sleep Stage Alternations, and Mean Latencies (in Minutes) to Stages 2 and REM for Baseline, Boom, and Recovery Nights

Measures	Age Groups								
	21-26 Year Olds			40-45 Year Olds			60-72 Year Olds		
	Baseline	Boom	Recovery	Baseline	Boom	Recovery	Baseline	Boom	Recovery
Minutes Awake Before Sleep	21.9	27.0	27.9	24.0	21.2	19.3	25.2	24.1	25.3
Minutes Awake During the Night	8.0	12.1	15.4	24.1	19.9	15.2	52.3	51.6	47.8
Minutes Awake After Sleep	3.1	0.4	1.8	6.7	4.6	3.4	13.3	9.7	7.7
Minutes Latency to Stage 2	14.2	16.4	20.4	15.0	11.8	11.7	14.0	13.0	14.1
Minutes Latency to Stage REM	60.0	66.1	78.3	62.1	54.7	49.9	52.9	54.2	53.4
No. of 30-Second Stage Changes	63.6	64.8	63.9	62.3	65.2	64.5	72.1	69.3	69.7
No. of 5-Minute Stage Changes	10.5	10.6	10.3	13.5	13.1	12.7	15.5	15.5	15.3
No of 10-Minute Stage Changes	8.1	7.9	7.3	9.5	9.8	9.7	10.0	10.6	10.5

latency to Stage REM ($p<.01$), and shifts in sleep stages using 5-minute and 10-minute time bases ($p<.001$ in both cases) reflect differences in sleep patterns with age and are independent of the presence or absence of the booms. Similarly, statistically significant interactions (age groups by the three phases) obtained for the latency scores for both Stage 2 ($p<.001$) and Stage REM ($p<.01$) reflected no effects of the boom presentations but, rather, increased latencies for the youngest age group from the Baseline through the Boom through the Recovery phases.

Awakenings. The frequencies with which awakenings occurred during the night were calculated from the tracings for Baseline, Boom, and Recovery phases. These data appear in Table 9 and show a fractionally higher incidence of awakenings during boom nights for all groups. However, an analysis of variance yielded only one significant effect ($p<.01$), viz., with respect to age. As is evident in Table 9, the frequency of awakenings increased with age, but no effect on awakenings can be attributed to the booms.

It should be noted that these data do not represent behavioral awakenings, i.e., subjects were not required to signal their awareness of being awake. Instead, the data represent awakenings as indicated by the physiological tracings; as such, the periods scored as "awake" might be as short as 30 seconds and might never be recalled by the subjects on the following morning. Moreover, the occurrence of age differences in awakenings is well known (e.g., Kramer et al., 1971; Williams, 1970) and the oldest subjects used in this study recalled more awakenings during sleep at home than did the younger groups (see Table 3).

EEG Changes in Response to Booms. The eight-point scoring criteria established by Williams were used to make direct comparisons of EEG responses to the booms with responses to periods of pseudo stimulus controls (i.e., to periods of sleep 30 minutes prior to presentation of a boom). From these comparisons, presented in Table 10, it can be determined that, while 74.2 per cent of the booms produced an EEG response (i.e., a non-zero Williams Score), only 36.2 per cent of the control periods showed an EEG change.

More "zero" and "1" scores were obtained in control periods and more "2" through "7" scores were obtained in response to the booms; these differences were significant by chi square analysis at the .01 level. Although statistically significant, these changes must be considered moderate since boom presentations produced awakenings only 5.5 per cent of the time (compared with 0.7 per cent for non-boom controls) and resulted in shifts in stages of sleep only 14.3 per cent of the time (compared with 4.2 per cent for non-boom controls).

Age. Chi square analysis of the data in Table 10 yielded a significant difference ($p<.01$) in EEG responses as a function of the age groups. This difference is due primarily to more frequent responses at the higher scores ("5" and "7") in the oldest group. The two youngest groups showed more "0" and "2" scores, and fewer scores of "5" (shift in stage of sleep) and "7" (awakening) than did the oldest group.

Table 9

Mean Frequency of Awakenings Per Night for Each Subject by Age Group.

for Baseline, Boom, and Recovery Nights

	Nights			
Age Groups	Baseline	Boom	Recovery	Mean
21-26 Year Olds	1.7	1.8	1.7	1.7
40-45 Year Olds	3.3	3.7	3.1	3.4
60-72 Year Olds	5.5	5.9	5.1	5.5
Mean	3.5	3.8	3.3	

Table 10

Mean Frequency of Occurrence (in Percentages) of Each Williams Score in EEG Tracings Following Presentation of Booms and of Pseudo Stimulus Controls

Age Groups	Williams Scores 0	1	2	3	4	5	6	7
21-26 Year Olds								
Boom	28.0	4.6	27.6	0.9	26.6	10.6	0.0	1.7
Pseudo Stimulus Control	69.0	8.2	13.1	0.0	6.0	3.4	0.0	0.0
40-45 Year Olds								
Boom	27.8	5.1	14.9	6.6	25.8	13.7	0.0	6.1
Pseudo Stimulus Control	61.7	5.8	12.1	1.5	13.9	3.9	0.0	1.1
60-72 Year Olds								
Boom	21.5	5.0	14.0	6.4	25.8	18.6	0.0	8.7
Pseudo Stimulus Control	60.7	12.6	7.7	0.5	12.1	5.4	0.0	1.0
All Age Groups								
Boom	25.8	4.9	18.8	4.6	26.1	14.3	0.0	5.5
Pseudo Stimulus Control	63.8	8.9	11.0	0.7	10.7	4.2	0.0	0.7

Adaptation. To examine possible adaptation effects across the 12 boom nights, analyses of variance were performed on Williams Scores which occurred at least 10 per cent of the time following boom presentations; those scores were "0," "2," "4," and "5" (see Table 10). The percentage of EEG responses under each of the four scores is presented in Table 11 by age group for each boom night. No differences among the 12 nights were significant at the .05 level for any score or age group by analyses of variance. Thus, there was no evidence in the EEG tracings of adaptation to the occurrence of the booms.

Sleep Stage. That subjects might be more responsive to booms during certain stages of sleep (cf., Williams et al., 1964) was examined. Per cent responses for the four stages of sleep (REM and Stages 1, 2, 3–4) of "0," "2," "4," and "5" scores (those scores which occurred at least 10 per cent of the time following booms) by the Williams Criteria are plotted in Figure 5 for all subjects combined. Analyses of variance were performed (without collapsing the age groups) for each of the four Williams Scores. Results indicated significant ($p<.05$–$p<.001$) differential responsivity to the booms during certain stages of sleep. Specifically, Sleep Stage 1 and Sleep Stage 2 yielded significantly fewer "0" scores and significantly more "4" scores following boom presentations than were obtained in control periods. This result is consistent with other studies (Lukas, 1972; Lukas and Kryter, 1970b) and may be attributed to the fact that Stage 1 in particular is a transition phase between being awake and reaching the deeper sleep of Stage 2. Williams Scores of "2" and "5" showed different results; for these scores, Stages 2 and 3–4 were most sensitive to the boom presentations. The latter finding might be expected because the K complex, which defines a score of "2," and stage shifts, which define the score of "5," are much less likely to occur in REM or Stage 1 sleep as a function of the boom presentations (a noise-induced stage shift from REM or

Table 11

Mean Frequency of Occurrence (in Percentages) of Williams Scores of 0, 2, 4, and 5

Following Boom Presentations During Each of the 12 Boom Nights

Age Groups	Boom Nights											
	1	2	3	4	5	6	7	8	9	10	11	12
21-26 Year Olds												
Score												
0	25.0	26.6	25.0	37.5	34.4	21.8	31.6	32.4	23.4	33.0	21.9	28.1
2	32.8	26.6	28.1	23.4	18.8	23.4	28.1	31.0	26.6	27.5	31.3	30.0
4	28.1	21.9	26.6	20.3	28.1	34.4	26.6	20.5	31.3	35.2	23.4	31.3
5	12.5	6.3	9.4	9.4	12.5	12.5	9.4	11.4	10.9	12.4	14.1	7.8
40-45 Year Olds												
Score												
0	17.2	23.4	28.1	17.6	20.3	23.4	29.7	34.4	33.9	34.4	28.1	34.4
2	21.9	12.5	14.1	27.2	7.8	12.5	14.1	17.2	14.3	10.9	12.5	14.1
4	20.3	35.9	29.7	29.0	26.3	23.4	26.6	25.0	19.0	31.3	21.9	23.4
5	18.8	12.5	17.2	7.8	17.2	12.5	15.6	10.9	13.6	12.5	17.2	7.8
60-72 Year Olds												
Score												
0	21.9	12.5	28.1	20.3	23.4	20.3	17.2	35.9	21.0	16.3	19.4	20.96
2	10.9	8.0	12.5	4.7	23.4	10.9	17.2	14.1	20.8	17.8	12.9	14.28
4	14.1	25.2	20.5	35.9	18.8	28.1	29.7	21.9	21.0	33.7	27.0	33.46
5	18.8	24.1	14.7	15.6	17.2	17.2	18.8	17.2	27.5	17.4	20.7	13.81

Stage 1 would most probably result in awakening and would thereby be scored as a "7").

Time-of-Night. Analyses similar to those noted above for sleep stages were conducted for time-of-night. For these purposes, each boom night (500 minutes) was divided into four quarters (results for all subjects combined are depicted in Figure 6). No significant time-of-night differences between booms and control periods were obtained for Williams Scores of "2" and "5"; however, significant increases in sensitivity to the booms were obtained for "0" and "4" scores ($p<.05$ and $p<.001$, respectively). There were proportionately fewer "0" scores for boom periods during the first and third quarters of the night than were obtained for control periods, and proportionately more "4" scores following booms during the second and third quarters of the night. Although these data extend the periods of maximal sensitivity into the third quarter of the night, they are in general agreement with other studies (Kramer et al., 1971; Morgan and Rice, 1970; Rechtschaffen et al., 1966; Williams et al., 1964) which show that sensitivity to noise is greater during early rather than later periods of the night.

Heart Rate

Nightly Patterns. Table 12 contains the means and standard deviations for number of heart beats per minute for each age group during Baseline, Boom, and Recovery nights. Analyses of variance were performed on both of these sets of data. Only one significant difference was obtained ($p<.05$): the age groups differed on mean heart rate. Thus, although the oldest subjects had significantly higher heart rates than the younger men, introduction of the booms produced no overall change in heart rate measures for any group.

ECG Changes in Response to Booms. The mean number of heart beats was calculated by age group, during each boom night, for periods one minute before and one minute after the presentation of each boom; these pre-boom and post-boom data appear in Table 13. Analysis of variance indicated that there was a significant increase ($p<.05$) in heart beats after boom presentations for all subjects across all nights.

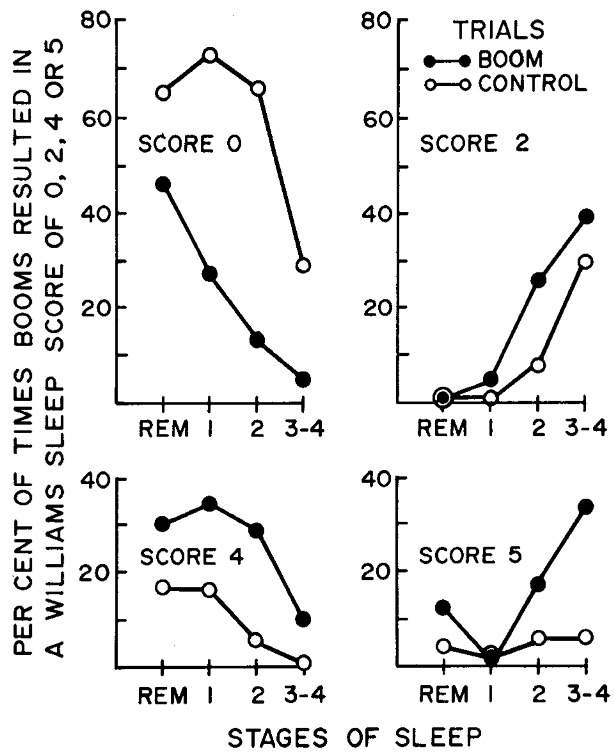

FIGURE 5. Frequencies of occurrence in percentages of Williams Scores of 0, 2, 4, and 5 following boom presentations in different stages of sleep.

However, there was no main effect attributable to age and there was no adaptation evident.

Muscle Tone

Nightly Patterns. Each test night was divided into nine periods (the first 20 minutes of the night and the next eight hour-long segments) and muscle tone (EMG) was scored in 5-minute blocks. The measure for the first 5-minute block was assigned a score of "zero" and all subsequent blocks were scored as deviations from that "zero"; these data on muscle activity are, therefore, in arbitrary units. Table 14 contains mean levels of muscle tone by age group for the nine periods of the night for Baseline, Boom, and Recovery phases. An analysis of variance of these data yielded only one significant effect ($p<.001$), viz., for period-of-night. This result is accounted for by a general decrease in level of muscle tone during most of the night. A sharp drop during the first period (first 20 minutes) may be attributed to the decrease of muscle tone which accompanies the onset of sleep; further declines during the next several hours probably reflect increasing concentrations of REM sleep in which low levels of EMG activity would be expected, then, during the last two hours, level of muscle tone increases as the end of the sleep period nears. There were no significant differences among age groups or across the Baseline, Boom, and Recovery nights.

A second measure of muscle activity appears in Table 15 where the mean variability (standard deviations of EMG scores) for Baseline, Boom, and Recovery nights is presented for each age group. An analysis of variance of these data showed only one significant effect ($p<.05$), viz., a steady overall increase in variability of muscle tone levels across the experimental conditions. This finding does not appear to be related to boom presentations since variability continued to increase during the Recovery nights when booms were no longer being presented. There were no significant differences among the age groups although the oldest group showed a slight decline in EMG across the three phases.

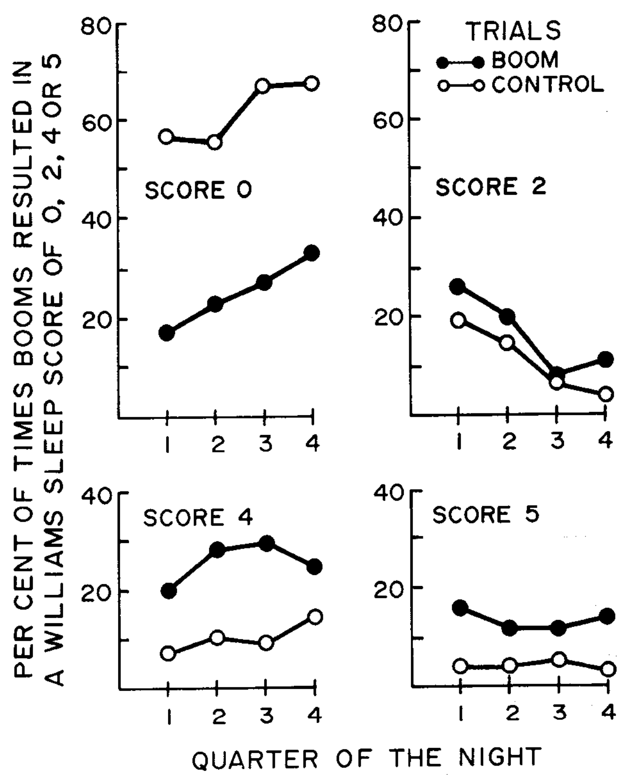

FIGURE 6. Frequencies of occurrences in percentages of Williams Scores of 0, 2, 4, and 5 following boom presentations in different quarters of the night.

Table 12

Mean Number of Heart Beats Per Minute and Mean Standard Deviations for Each Subject by Age Group for Baseline, Boom, and Recovery Nights. Note: These Values Are Slightly Higher Than Those in Table 13 (One-Minute Pre and Post Boom) Due to the Fact That These Scores Include Heart Rate During Awake Stages Whereas Subjects Were Virtually Always Asleep When Booms Were Presented.

	Nights		
Age Groups	Baseline	Boom	Recovery
21-26 Year Olds			
Beats Per Minute	63.6	62.4	64.9
Standard Deviation	3.8	2.7	2.9
40-45 Year Olds			
Beats Per Minute	62.4	62.0	63.1
Standard Deviation	3.5	2.9	3.0
60-72 Year Olds			
Beats Per Minute	69.7	68.9	68.4
Standard Deviation	2.8	3.2	3.0

Table 13

Mean Number of Heart Beats One Minute Before and One Minute After Boom Presentations for Each of the 12 Boom Nights

	Boom Nights												
Age Groups	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Mean**
21-26 Year Olds													
Before Boom	59.3	60.8	59.2	60.7	60.7	59.1	60.4	61.1	61.2	60.5	59.5	59.9	60.2
After Boom	60.2	59.3	60.3	62.2	61.8	59.8	60.6	61.5	61.3	61.6	60.2	60.4	60.8
40-45 Year Olds													
Before Boom	61.5	61.1	60.9	62.7	61.9	60.6	62.7	62.8	60.2	60.5	61.3	61.6	61.5
After Boom	61.3	63.7	61.3	62.8	61.3	61.8	63.3	62.6	62.0	60.4	62.1	61.8	62.1
60-72 Year Olds													
Before Boom	65.4	64.9	64.2	65.0	66.4	66.0	64.3	65.7	63.5	64.8	63.9	61.9	64.7
After Boom	65.4	66.3	65.0	66.0	67.2	66.4	65.4	66.1	65.8	65.2	65.1	61.8	65.5

Table 14

Mean EMG Levels During the Nine Periods of the Night for Baseline, Boom, and Recovery Nights

Period of the Night	Age Groups: 21-26 Year Olds				40-45 Year Olds				60-72 Year Olds				All Ages
	Baseline	Boom	Recovery	Mean	Baseline	Boom	Recovery	Mean	Baseline	Boom	Recovery	Mean	Mean
1	-0.14	-0.26	-0.19	-0.20	-0.28	-0.35	-0.47	-0.37	-0.25	-0.23	-0.34	-0.27	-0.28
2	-1.13	-1.17	-0.91	-1.07	-1.14	-1.21	-1.24	-1.20	-1.25	-1.42	-1.38	-1.35	-1.21
3	-1.58	-1.52	-1.22	-1.44	-1.50	-1.78	-1.69	-1.66	-1.76	-1.94	-2.08	-1.93	-1.67
4	-1.75	-1.75	-1.42	-1.64	-1.62	-1.90	-1.74	-1.75	-1.38	-2.03	-2.31	-1.91	-1.77
5	-1.87	-1.77	-1.40	-1.68	-1.68	-2.00	-1.89	-1.86	-1.50	-2.04	-2.14	-1.89	-1.81
6	-1.63	-1.58	-1.47	-1.56	-1.75	-2.07	-1.99	-1.94	-1.30	-2.00	-2.05	-1.78	-1.76
7	-1.86	-1.90	-1.60	-1.79	-1.65	-2.03	-1.76	-1.80	-1.45	-1.95	-2.14	-1.85	-1.81
8	-1.80	-1.55	-1.61	-1.65	-1.72	-2.00	-1.81	-1.84	-1.34	-1.96	-1.92	-1.74	-1.75
9	-1.86	-1.47	-1.54	-1.62	-1.55	-1.94	-1.50	-1.66	-1.08	-1.66	-1.59	-1.44	-1.58
Mean	-1.51	-1.44	-1.26		-1.43	-1.70	-1.57		-1.26	-1.69	-1.77		

EMG Changes in Response to Booms. Comparisons were made of changes in EMG level in response to the booms and changes in muscle tone following the pseudo stimulus control periods (30 minutes prior to a boom). Scores reflecting the mean percentage of times changes occurred in EMG levels during the six seconds following the booms or the pseudo stimulus controls are presented in Table 16 by age group for each Boom night. An analysis of variance performed on these data yielded two significant effects; there was more frequently a change ($p<.001$) in EMG levels in response to the booms as compared with the control periods, and there were differences ($p<.05$) in the overall frequency of changes attributable to age. The significant effect of age is due primarily to the greater proportion of EMG changes which occurred in the oldest age group. In evaluating the significant changes in EMG levels attributable to the booms, it should be noted that all EMG levels returned to their Baseline values within ten minutes of any change due to the booms. The lack of any other significant effects from the statistical tests indicates no evidence of adaptation across the 12 Boom nights.

Basal Skin Resistance

Nightly Patterns. Mean BSR levels were computed for each of nine periods of the night (the first 20 minutes and the following eight hour-long segments) and are presented by age group for Baseline, Boom, and Recovery nights in Table 17. An analysis of variance of these data yielded three significant main effects and no significant interactions. The statistically significant effect ($p<.05$) for age groups is accounted for by the consistently lower level of skin resistance during all periods and across all conditions for the youngest subjects (in this instance, absolute differences among the groups may be attributed at least partially to differences in amplifier gain settings). The significant increase ($p<.001$) in BSR across the nine nightly periods reflects an expected decrease in skin resistance for all subjects during the course of the night. Finally, significant differences ($p<.01$) in BSR scores among the Baseline, Boom, and Recovery nights is accounted for by a steady decrease in skin resistance (signifying increased arousal) across the three experimental conditions. However, since skin resistance continued to decline during the Recovery (non-boom) nights, the effect cannot be related to boom presentations.

Variability in BSR levels was examined by using standard deviations. These mean variability measures by age group for the Baseline, Boom, and Recovery nights are presented in Table 18. An analysis of variance of these data

Table 15

Mean Standard Deviations of EMG Levels for

Baseline, Boom, and Recovery Nights

Age Groups	Nights: Baseline	Boom	Recovery
21-26 Year Olds	0.76	0.90	1.39
40-45 Year Olds	0.61	0.82	1.00
60-72 Year Olds	1.03	1.01	0.98
Mean	0.80	0.91	1.12

indicated two significant effects ($p<.05$), viz., for phases and for the interaction of age groups and phases. The latter finding was due to the different patterns of variability across the Baseline, Boom, and Recovery nights for the three age groups. Specifically, the two oldest groups showed steadily decreasing variability, while the youngest group had an irregular pattern (see Table 18). Despite these differences in pattern, the significant overall phase effect indicates that, across all subjects, variability declined from the Baseline through the Boom and Recovery phases (Table 18).

BSR Changes in Response to Booms. To assess the effects of the booms on skin resistance, five BSR measures were computed: (1) the percentage of occasions during which a change in BSR occurred within five seconds of boom pre-

Table 16

Mean Percentage of Times EMG Responses Occurred to

Boom Presentations and to Pseudo Stimulus Controls

Age Groups	Boom Nights: 1	2	3	4	5	6	7	8	9	10	11	12	Mean
21-26 Year Olds													
Boom Presentation	43.7	34.4	39.1	42.2	43.7	47.6	45.3	43.1	46.9	38.0	32.8	40.6	41.5
Pseudo Stimulus Control	9.4	12.5	10.9	7.8	3.1	12.5	15.6	10.9	10.9	7.8	7.8	12.5	10.1
40-45 Year Olds													
Boom Presentation	56.4	40.6	43.8	40.6	40.6	31.3	45.3	50.0	31.3	45.3	51.6	39.1	43.0
Pseudo Stimulus Control	14.0	15.6	6.3	10.9	17.2	9.4	21.9	17.7	20.3	7.8	17.2	12.5	14.2
60-72 Year Olds													
Boom Presentation	51.6	73.4	53.8	59.4	43.8	60.9	60.9	62.5	53.1	68.8	59.6	49.1	58.1
Pseudo Stimulus Control	26.6	17.2	23.4	18.8	17.2	12.5	17.2	18.8	18.8	18.8	17.4	17.2	18.7

Table 17

Mean BSR Levels (in Kilohms) of the Nine Periods of the Night for Baseline, Boom, and Recovery Nights

Period of the Night	Age Groups: 21-26 Year Olds Baseline	Boom	Recovery	40-45 Year Olds Baseline	Boom	Recovery	60-72 Year Olds Baseline	Boom	Recovery
1	2.71	2.16	0.23	8.30	9.37	5.81	8.29	8.96	7.45
2	3.34	3.18	1.30	16.90	12.29	6.89	10.41	10.03	8.70
3	3.59	3.88	1.92	19.65	13.13	7.25	10.43	10.15	8.58
4	3.98	4.44	2.23	19.41	13.81	7.50	11.07	10.59	9.04
5	4.50	4.64	2.55	21.36	14.19	7.65	11.60	11.01	9.55
6	4.91	5.07	3.04	25.33	14.81	7.98	11.84	11.24	9.93
7	5.12	5.37	3.11	23.05	15.24	8.07	11.97	11.79	10.10
8	5.55	5.54	3.36	23.65	15.93	8.30	12.20	12.30	10.35
9	5.68	5.67	3.42	25.25	15.46	8.72	12.75	13.08	10.54

sentations, (2) the magnitude of those changes in kilohms, (3) the latency of the changes in seconds, (4) the percentage of responses which showed recovery to the base level within ten minutes, and (5) the latency of recovery in seconds. The overall mean calculated for each of those five measures appear in Table 19. Disregarding age, a change in BSR level occurred within five seconds for 19.4 per cent of the booms, the mean latency for those occurrences was 3.2 seconds, and the mean change in BSR level was −5.0 kilohms. Recovery to pre-boom BSR levels occurred within ten minutes for 51.0 per cent of the boom-induced changes and, of these 51.0 per cent, the mean latency for recovery was 47.9 seconds.

Only two age-related tendencies appear in the data in Table 19. The percentage of BSR responses to the booms increased slightly (but not significantly) from the youngest to the oldest age group, and the mean amount of change in BSR level was successively higher for the ad-

Table 18

Mean Standard Deviations of BSR Levels for Baseline, Boom, and Recovery Nights

Age Groups	Nights: Baseline	Boom	Recovery
21-26 Year Olds	4.07	5.99	4.61
40-45 Year Olds	14.64	9.19	6.35
60-72 Year Olds	11.78	10.44	9.92
Mean	10.16	8.54	6.96

vanced age groups. However, analyses of variance conducted for each of the five BSR measures yielded only one significant effect ($p<.05$): the youngest subjects showed less change to the booms in BSR level than did either of the two older groups of subjects. The lack of any other statistically significant effects indicates that there was no adaptation of BSR responses to the booms across the 12 Boom nights.

Mood States

The 80-item Composite Mood Adjective Check List (CMACL) was administered every morning and every evening during the study. Scores ultimately derived for 15 mood factors and an overall mood index were treated by analysis of variance. More detailed analyses of these findings appear elsewhere in a report by Smith and Hutto (1972).

A mean Overall Index of mood (based on all CMACL items) was calculated for morning and evening sessions for each age group in the Baseline, Boom, and Recovery phases (see Table 20). In general, the oldest group had the highest mood levels (most positive affect) and the overall (all subjects) mood level declined across Baseline, Boom, and Recovery phases. Successive phases differed significantly ($p<.05$) from each other and, since the decline in mood continued through the Recovery phase, the effects cannot be attributed to the booms. In fact, this mood loss is accounted for primarily by a steady, marked decline within the youngest age group, a decline which may be related to the fact that the youngest group was the only one which showed increasing amounts of total time awake across the Baseline, Boom, and Recovery phases (see Table 7).

Scores obtained for the 15 individual mood factors appear in Table 21. There were several factors (Concentration, Dizzy, Friendly, Nonchalance, and Social Affection) which showed significant ($p<.05$) age effects; in all cases the oldest group had the highest scores. There were significant time-of-day effects ($p<.05$–$p<.01$), which favored evening scores, for only two factors: Surgency and Depression. Seven factors showed significant phase effects ($p<.05$–$p<.001$); six of these (AACL, Concentration, Friendly, Social Affection, Surgency, and Vigor) showed some overall tendency for a decline in moods (although only for Concentration and Vigor were the changes consistent for the three groups), while the other factor (Sleepy) showed a general improvement across Baseline, Boom, and Recovery nights. The finding with respect to Sleepy scores is of particular interest since, (a) it shows no overall deleterious effects of the booms, (b) it agrees with results reported by Morgan and Rice (1970), and (c) in spite of the overall trend toward successively less sleepiness across the Baseline, Boom, and Recovery nights for all subjects considered together, the youngest group had its highest Sleepy score during Recovery nights when their time awake had noticeably increased (see Table 7). Perhaps young subjects adapt less well than do older subjects to the relatively long-duration social restrictions required by the present study.

Table 19

Measures of BSR Responses to Boom Presentations for Each of the 12 Boom Nights. Mean Values Per Subject by Age Group for the Percentage of Boom Presentations Which Showed BSR Responses, the Magnitude of Change in BSR Responses, the Latency of the Responses, the Percentage of Responses Which Showed Recovery Within 10 Minutes, and the Latency of Recovery for the Latter.

		Boom Nights												
Measure	Age Groups	1	2	3	4	5	6	7	8	9	10	11	12	Mean
% of Booms Showing BSR Responses	21-26 Year Olds	17.19	4.69	23.44	20.54	28.79	25.00	15.63	22.54	17.19	18.97	11.16	18.75	18.66
	40-45 Year Olds	18.75	25.?3	21.88	26.56	20.31	14.06	14.06	12.50	14.06	17.19	15.63	18.75	18.25
	60-72 Year Olds	27.61	29.69	22.10	24.11	16.75	15.63	16.96	25.00	18.30	20.09	24.79	14.06	21.26
Change in BSR Response (Kilohms)	21-26 Year Olds	- 2.78	0.47	- 1.88	- 2.95	- 1.19	- 2.38	- 1.48	- 7.28	- 4.31	- 3.63	- 2.94	- 4.38	- 2.89
	40-45 Year Olds	- 1.76	- 6.23	- 6.13	- 7.39	- 4.98	- 6.00	- 2.66	- 1.64	- 5.15	- 1.71	- 4.80	- 4.25	- 4.39
	60-72 Year Olds	- 7.96	-10.29	- 8.75	- 8.01	- 7.13	-12.04	- 5.00	-11.45	- 6.25	- 4.29	- 8.34	- 3.83	- 7.78
Latency of Response (Seconds)	21-26 Year Olds	2.31	1.25	3.15	3.26	3.19	4.59	2.89	3.66	3.59	3.79	2.75	3.54	3.16
	40-45 Year Olds	2.20	3.95	4.54	3.23	2.46	3.73	2.20	2.69	3.94	3.33	2.58	3.79	3.22
	60-72 Year Olds	3.70	3.53	3.13	2.55	3.81	2.23	2.45	3.88	3.73	2.38	3.89	2.24	3.12
% Responses Showing 10-Minute Recovery	21-26 Year Olds	24.16	12.50	68.75	60.41	66.68	53.13	50.00	72.91	50.00	72.91	62.50	53.13	53.92
	40-45 Year Olds	25.00	42.75	87.50	55.25	34.38	58.38	35.38	39.63	56.25	37.50	52.13	39.63	46.98
	60-72 Year Olds	43.75	47.18	55.21	38.34	58.34	47.50	46.88	68.75	59.38	62.50	58.34	39.59	52.14
Latency of 10-Minute Recoveries (Seconds)	21-26 Year Olds	46.00	4.50	145.75	38.88	120.13	37.75	83.50	88.75	34.13	81.63	41.38	36.00	63.20
	40-45 Year Olds	23.23	48.28	140.25	74.41	9.91	29.69	46.56	39.04	30.19	11.60	35.81	17.85	42.23
	60-72 Year Olds	26.13	61.86	41.79	27.69	19.50	51.11	5.63	60.08	30.48	24.79	88.48	22.63	38.34

Table 20

Mean Overall Index Scores Per Subject for the Composite Mood Adjective Check List by Age Group for Morning (A.M.) and Evening (P.M.) Sessions During Baseline, Boom, and Recovery Nights

		Nights		
Age Groups	Time	Baseline	Boom	Recovery
21-26 Year Olds	A.M.	6.99	6.82	6.54
	P.M.	6.97	6.83	6.26
	Mean	6.98	6.82	6.40
40-45 Year Olds	A.M.	7.00	6.82	6.93
	P.M.	7.09	6.79	6.84
	Mean	7.05	6.80	6.88
60-72 Year Olds	A.M.	7.50	7.46	7.44
	P.M.	7.56	7.63	7.47
	Mean	7.53	7.55	7.45
All Age Groups	A.M.	7.16	7.03	6.97
	P.M.	7.21	7.08	6.86
	Mean	7.19	7.06	6.92

Eleven of the 15 factors showed a significant interaction ($p<.05$–$p<.001$) for age groups and phases. Among the consistent results which produced these significant effects were (a) the decreasing scores (less positive affect) across all three phases in five factors (Friendly, Nonchalance, Social Affection, Surgency, and Vigor) for the youngest age group, in one factor (Vigor) for the 40–45 year olds, and in three factors (Sleepy, Surgency, and Vigor) for the oldest group, and (b) the increasing scores across all three phases in three factors (AACL, Anxiety, and Fatigue) for the youngest subjects, in one factor (Dizzy) for the 40–45 year olds, and in one factor (Social Affection) for the oldest group (see Table 21). None of these effects are boom-related.

Complex Performance

Mean scores for the ten measures of performance were calculated for morning and evening sessions for each age group in the Baseline, Boom, and Recovery phases (see Table 22). Each measure was separately treated by analysis of variance. More detailed analyses of these data are reported elsewhere by Chiles and West (1972).

Red Lights I and II. Response time for Red Lights I differed for age groups, phases, and time-of-day (all $p<.05$); a significant interaction ($p<.05$ and $p<.001$) was obtained for both I and II measures for age groups by phases. The significant effects which were obtained can be accounted for by the following: performance was better in the evening than in the morning, the two younger groups were significantly faster than the oldest group during Baseline trials, and the oldest group improved significantly during Boom and Recovery phases. None of these effects can be attributed to the booms.

Green Lights I and II. Significant effects were obtained for both measures for age groups ($p<.01$), phases ($p<.001$), and the age groups by phases interaction ($p<.01$ and $p<.001$). In addition, time-of-day was significant ($p<.05$) for the Green Lights I measure. In general, these findings reflect quicker response from the younger groups, significant improvement across phases for the oldest group, better performance in the evening, and no deleterious effect of the booms.

Meter Monitoring I and II. A significant phase effect ($p<.05$) was obtained for Monitoring I due to the improved performance of all groups during Recovery nights as compared with

Table 21

Mean Scores Per Subject for Each of 15 Factors in the Composite Mood Adjective Check List by Age Group for Morning (A.M.) and Evening (P.M.) Sessions During Baseline, Boom, and Recovery Nights

Mood Factor	Age Groups (Years)	Baseline			Boom			Recovery		
		A.M.	P.M.	Mean	A.M.	P.M.	Mean	A.M.	P.M.	Mean
*AACL (Zuckerman's Affect Score)	21-26	60.50	58.96	59.73	63.09	64.18	63.64	69.22	74.28	71.75
	40-45	59.17	57.96	58.56	64.22	64.12	64.17	62.31	62.44	62.38
	60-72	49.79	49.46	49.62	50.50	47.02	48.76	50.47	50.59	50.53
Aggression	21-26	7.88	7.50	7.68	7.54	8.29	7.92	7.56	8.78	8.17
	40-45	7.04	7.41	7.23	7.60	8.68	8.14	7.31	8.09	7.70
	60-72	7.17	6.75	6.96	7.48	6.88	7.18	7.75	7.66	7.70
Anxiety	21-26	11.13	10.54	10.84	11.45	11.37	11.41	12.22	12.97	12.59
	40-45	11.78	11.33	11.56	12.19	12.07	12.13	11.84	11.88	11.86
	60-72	12.79	11.56	12.19	11.12	10.74	10.93	11.38	10.66	11.01
Anxious	21-26	1.46	1.71	1.59	1.43	1.55	1.49	1.59	1.72	1.66
	40-45	1.42	2.25	1.83	3.36	2.85	3.11	3.47	3.12	3.30
	60-72	2.42	2.34	2.38	2.29	2.36	2.33	2.66	2.34	2.50
Concentration	21-26	39.17	38.67	38.92	34.60	34.93	34.77	31.03	30.03	30.53
	40-45	39.35	41.33	40.35	40.00	38.46	39.23	39.56	36.97	38.27
	60-72	61.08	62.17	61.63	58.62	60.25	59.44	58.26	58.16	58.22
Depression	21-26	23.63	28.59	26.11	25.94	26.03	25.98	28.25	33.09	30.67
	40-45	22.54	23.33	22.90	22.39	23.91	23.14	22.09	22.38	22.23
	60-72	23.33	23.50	23.42	21.58	20.81	21.20	21.28	21.91	21.59
Distrust	21-26	3.59	3.75	3.67	3.54	3.49	3.52	3.81	4.59	4.20
	40-45	4.62	5.07	4.85	4.25	4.45	4.35	4.53	4.41	4.47
	60-72	4.42	4.58	4.50	4.85	4.84	4.85	4.69	4.66	4.67
Dizzy	21-26	4.42	4.00	4.21	4.14	4.22	4.18	4.75	5.94	5.34
	40-45	4.66	4.37	4.52	4.42	4.81	4.61	4.31	4.66	4.84
	60-72	7.67	6.38	7.02	6.68	6.54	6.61	6.84	6.44	6.64
Fatigue	21-26	16.33	17.04	16.69	17.68	17.26	17.47	20.38	21.34	20.86
	40-45	21.00	17.75	19.38	20.99	20.92	20.95	17.94	19.56	18.75
	60-72	26.12	24.47	25.30	24.49	21.88	23.18	24.22	22.84	23.53
Friendly	21-26	12.83	13.12	12.92	12.50	12.09	12.30	11.09	9.19	10.14
	40-45	15.71	16.08	15.89	12.97	13.17	13.07	13.97	14.03	14.00
	60-72	19.75	20.50	20.13	19.94	20.55	20.24	20.28	19.81	20.05
Nonchalance	21-26	6.29	6.96	6.62	6.07	6.23	6.15	5.75	5.78	5.76
	40-45	8.25	8.25	8.25	6.38	6.69	6.54	6.84	7.25	7.05
	60-72	11.29	10.50	10.89	11.66	12.05	11.85	11.66	11.62	11.64
Sleepy	21-26	7.21	7.83	7.52	7.06	7.08	7.07	8.94	9.06	9.00
	40-45	9.62	8.04	8.83	9.65	9.61	9.63	7.09	7.53	7.31
	60-72	13.52	14.08	13.77	12.68	10.75	11.71	11.19	10.81	11.00
Social Affection	21-26	16.83	17.58	17.07	16.73	16.44	16.58	15.12	12.72	13.92
	40-45	17.75	18.08	17.92	15.67	16.07	15.87	16.97	16.75	16.86
	60-72	26.29	26.33	26.31	26.84	27.35	27.10	27.72	27.53	27.62
Surgency	21-26	21.58	23.17	22.37	20.02	19.89	19.95	16.38	15.47	15.92
	40-45	21.87	23.08	22.48	19.65	20.26	19.95	21.66	20.78	21.22
	60-72	26.46	27.88	27.17	24.40	26.31	25.35	23.44	24.09	23.77
Vigor	21-26	15.46	15.33	15.40	13.46	13.39	13.42	11.12	10.69	10.91
	40-45	14.95	15.59	15.27	14.09	13.93	14.01	14.28	13.66	13.97
	60-72	18.25	18.13	18.19	16.60	17.53	17.07	15.47	16.31	15.89

*For the AACL factor, higher scores reflect less positive affect.

Table 22

Mean Measures of Performance Per Subject on the CAMI Multiple Task Performance Battery by Age Group for Morning (A.M.) and Evening (P.M.) Sessions During Baseline, Boom, and Recovery Nights

		21-26 Year Olds			40-45 Year Olds			60-72 Year Olds		
Task	Time	Baseline	Boom	Recovery	Baseline	Boom	Recovery	Baseline	Boom	Recovery
Red Lights I: Response Time	A.M.	1.15	1.06	1.19	1.39	1.35	1.43	2.11	1.84	1.83
	P.M.	1.01	0.98	1.04	1.34	1.29	1.32	2.19	1.74	1.65
	Mean	1.08	1.02	1.12	1.36	1.32	1.37	2.15	1.79	1.74
Red Lights II: Response Time	A.M.	1.07	1.08	1.22	1.49	1.62	1.51	1.84	1.46	1.34
	P.M.	1.03	1.01	1.24	1.39	1.57	1.56	1.88	1.52	1.40
	Mean	1.05	1.04	1.23	1.44	1.60	1.53	1.86	1.49	1.37
Green Lights I: Response Time	A.M.	2.49	2.26	2.49	3.86	3.29	2.93	6.04	5.12	4.76
	P.M.	2.14	1.99	1.97	3.64	3.27	3.18	5.90	4.75	3.91
	Mean	2.31	2.12	2.23	3.75	3.28	3.05	5.97	4.94	4.34
Green Lights II: Response Time	A.M.	2.24	2.07	2.20	3.39	3.33	2.94	5.89	4.30	3.62
	P.M.	2.09	1.72	2.06	3.67	3.12	3.11	5.73	3.99	3.37
	Mean	2.16	1.89	2.13	3.53	3.23	3.02	5.81	4.14	3.49
Meters I: Response Time	A.M.	14.00	8.65	8.73	10.27	9.83	7.47	13.17	11.09	8.69
	P.M.	13.41	7.88	8.45	10.14	13.70	7.24	12.20	9.88	9.38
	Mean	13.71	8.26	8.59	10.20	11.77	7.36	12.68	10.49	9.04
Meters II: Response Time	A.M.	13.63	8.04	8.79	13.44	9.11	9.16	12.94	12.57	7.93
	P.M.	7.38	7.96	6.43	11.94	22.07	8.46	12.11	8.50	7.64
	Mean	10.50	8.00	7.61	12.69	15.59	8.81	12.52	10.54	7.78
Arithmetic I: Response Time	A.M.	8.12	7.87	7.21	9.02	8.23	7.65	8.38	7.78	7.66
	P.M.	7.81	7.42	7.07	9.01	7.99	7.59	7.87	7.51	7.04
	Mean	7.96	7.64	7.13	9.01	8.11	7.62	8.12	7.64	7.35
Arithmetic II: Per Cent Correct	A.M.	87.87	94.96	95.37	89.48	94.54	95.28	87.98	89.65	90.42
	P.M.	84.21	95.90	96.57	92.92	94.99	96.60	92.81	93.97	96.97
	Mean	86.04	95.43	95.97	91.20	94.77	95.94	90.40	91.81	93.70
Patterns: Per Cent Correct	A.M.	78.92	87.60	88.58	75.36	83.62	84.85	90.42	95.84	97.39
	P.M.	81.25	88.59	87.08	83.39	86.65	86.11	92.72	97.56	97.96
	Mean	80.08	88.09	87.83	79.37	85.13	85.47	91.56	96.69	97.67
*Lights and Meters Composite	A.M.	39.80	41.37	40.60	37.73	38.28	39.08	32.87	35.81	37.33
	P.M.	41.12	42.09	41.27	38.07	37.38	39.24	33.03	36.70	38.03
	Mean	40.46	41.72	40.94	37.90	37.83	39.16	32.95	36.26	37.68

*Higher scores indicate better performance.

Baseline nights. There were no effects attributable to the booms.

Arithmetic Per Cent Correct and Arithmetic Time. Both measures yielded significant phase ($p<.001$) effects; in addition, time-of-day was significant ($p<.05$) for Arithmetic Time and a significant age group by time-of-day interaction ($p<.05$) was obtained for Arithmetic Per Cent Correct. In general, arithmetic performance improved for all groups across the Baseline, Boom, and Recovery phases and evening scores were better than morning scores. The booms produced no deleterious effects.

Pattern Discrimination. Phases ($p<.001$) and age groups ($p<.01$) yielded significant effects in the percentage of patterns correctly discriminated. These significant F ratios are attributed to superior performance during Boom and Recovery nights as compared with the Baseline phase for all groups, and to more correct responses from the oldest group (the task had been made easier for the oldest group).

Composite Monitoring. Phases ($p<.001$), age groups ($p<.05$), time-of-day ($p<.05$), and the phase by age group interaction ($p<.001$) yielded significant F ratios. The oldest group performed significantly poorer than the other two groups during the Baseline nights, but its performance improved significantly during the Boom and Recovery nights. Overall performance was better in the evening than in the morning.

Summary of Performance Results. In no way was there any decrement in performance which could be attributed to the booms. The differences which were obtained relative to age and to time-of-day (the direction of which agree with other literature, e.g., Chiles et al., 1968; Ray, Martin, and Alluisi, 1961; Trumbull, 1966) indicate that the tasks were sensitive enough to detect decrements had they occurred. However, since overall sleep patterns had not been affected by the booms, no decrements in performance were likely. In fact, performance measures during Boom nights were better than the Baseline levels in 26 of 30 comparisons (ten measures by three age groups).

Overview

The results of this study demonstrated no significant effect of the simulated sonic booms, presented during sleep, on overall patterns of sleep when Boom nights were compared with Baseline and Recovery nights. Similarly, there were no deleterious effects on complex performance measures and no changes in assessed moods which could be attributed to the booms.

However, presentation of the booms did evoke some responses in all subjects. Heart rate increased slightly during the minute following booms (on the average, by less than one beat for any age group), changes in muscle tone occurred for 45–50 per cent of the booms (about three times more often than chance changes might be expected based on pseudo stimulus controls) and basal skin resistance changed in response to about 19 per cent of the boom presentations. It is of particular interest that, for each of the measures noted above, the frequency of occurrence of the changes increased with the age of the subject-groups.

That the boom-induced responses were functionally not significant is best attested to by the facts that overall sleep patterns and overall physiological activity (i.e., on a nightly basis) were not significantly affected, and that the booms rarely produced shifts in stage of sleep (about 14 per cent of the time as compared with 4 per cent for pseudo stimulus controls) and even more rarely produced awakenings (about 5 percent of the time). However infrequent, the occurrences both of awakening and of stage shifts increased from the youngest to the oldest age groups. On the average, booms produced awakenings once or twice and shift changes about ten times in each of the youngest subjects for all Boom nights (i.e., in response to a total of 96 booms per subject); the corresponding occurrences per subject in the 40–45 year olds were six and 13, respectively, and for each subject in the 60–72 year old group, eight and 18, respectively (cf., Table 10). These age-related differences in response to simulated sonic booms agree with other findings (Lukas, Dobbs, and Kryter, 1970; Lukas and Kryter, 1968, 1970a, 1970b).

To provide some frame of reference for evaluating the infrequent and/or short-duration responses to individual booms recorded in this study, a report by Thiessen (1970) may be useful. Thiessen used magnetic tape playbacks of the noise of a passing truck (levels ranged from 40–70 dBA) and presented seven noises a night for 12 successive nights. Based on his results, awakenings or shifts in sleep level would be expected between 10–20 per cent of the time in response to the lowest levels (40–45 dBA) of truck noise which he used. This frequency of response is similar to that produced by booms in the present study (Table 10; Williams Scores 5 and 7) even though the dBA level of the booms was higher than the levels of truck noise noted above. Perhaps, for a given behavioral effect, subjects can tolerate the higher sound level of very short-duration booms (at least at low overpressure levels) as well as they can tolerate lower sound levels of longer-duration noises.

In the present study, awakenings were scored on the basis of evidence in the physiological tracings and were not the "behavioral awakenings" (whereby subjects signal their waking state) reported by Lukas and his co-workers (e.g., Lukas, 1970; Lukas and Dobbs, 1972; Lukas and Kryter, 1970a). That we instructed our subjects to ignore disturbances and attempt to get the best night's sleep possible might well account for the smaller number of responses to the booms reported here, as compared with other data (e.g., Lukas and Kryter, 1970a) obtained under conditions in which the subject apparently was made more aware of the purpose of the study and was asked to signal whenever he awakened.

Another point of interest concerns what is usually referred to as "adaptation" in the literature on effects of noise. In agreement with earlier studies of noise effects on sleep (cf., Williams, 1970) there was no significant reduction across Boom nights in the low-level physiological changes which occurred following boom presentations. Similarly, no significant changes in the EEG measures occurred across nights as a result of repeated exposure to the booms; the latter finding agrees with data reported by Lukas and Kryter (1970a, 1970b) for simulated booms, by Thiessen (1970) for truck noise, by Kramer et al. (1971) for the striking of a hammer, and as summarized by Williams (1970) for other acoustic stimuli. However, it might be more appropriate to refer to such results as a failure to obtain "habituation" rather than "adaptation," considering the nature of the test situation and the relatively brief and infrequent presentations of the boom (or other acoustic) stimuli.

IV. Summary.

Eight male subjects in each of three age groups (21–26, 40–45, 60–72 years) slept in pairs in the CAMI sonic boom simulation facility for 21 consecutive nights. The first five nights were used to acclimate the subjects (nights 1 and 2) and to obtain Baseline data (nights 3–5); the 12 subsequent nights (Boom) involved the hourly presentation of simulated sonic booms at an overpressure level of 1.0 psf (as though measured "outdoors"); during four additional nights (Recovery) there were no boom presentations. All-night records of EEG, EOG, EMG, ECG, and BSR were obtained and analyzed. None of these physiological measures showed any statistically significant effect of the boom presentations on nightly sleep patterns. However, the individual booms did arouse ECG, EMG, and BSR responses in all subjects; average heart rate increased during the minute following each boom (by less than one beat per minute), EMG responses occurred for 45–50 per cent of the booms, and BSR changed following 19 per cent of boom presentations. The frequency of these occurrences increased as a function of age. That these changes were probably mild is supported by the facts that only 5 per cent of the booms produced awakening and only 14 per cent produced shifts in stages of sleep (4 per cent of the stage shifts might be expected by chance); both of these measures showed higher frequencies of occurrence as a function of age. The changes in sleep appear roughly comparable to what might occur in response to the noise of a passing truck at 40–45 dBA.

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