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A STUDY OF SENSITIVITY TO NOISE

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Prepared for:

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16. Abstract

In this study, 140 subjects were exposed to simulated sonic booms and recorded residential noises in one, two, or three two-hour sessions over a period of six months. Electrophysiological measures of heart rate and electromyographic responses to the stimuli were analyzed. Biographical, demographical, and personality inventories were also obtained for each of the subjects. The purpose of this research was to: (1) determine whether there are different degrees of psychological and physiological sensitivity to noise in a large group of people; (2) to determine whether and how such sensitivity varied in time; and (3) to relate such sensitivity to other psychological and personality variables.

Significant differences in psychological sensitivity to noise were found in the subject population. These differences remained stable for the duration of the experiment and were also found to be related to the attitudinal and belief structures of the individuals. Definite physiological responses to the simulated sonic booms were observed. However, the physiological indices used in this research did not show individual differences in physiological sensitivity to noie noise. These results do not preclude the possibility that more elaborate and extensive psychophysiological measurement might demonstrate varying physiological sensitivity to noise.

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FOREWORD

The need for this research arises from the fact that while some persons complain about adverse psychological and physiological effects from intense aircraft noise and impulsive sounds, such as sonic booms, other persons do not report such reactions to the noise. Information relative to individual differences in psychological and physiological reactions to such noise is important to the analysis of general human response to sonic booms and aircraft noise.

This study was performed under the auspices of the Office of Environmental Quality of the Federal Aviation Administration, Dr. John O. Powers, Director, and Mr. Raymond A. Shepanek, Technical Monitor. The study was conducted at Stanford Research Institute by Mr. Richard W. Becker, Mr. Fausto Poza, and Dr. Karl D. Kryter, principal investigator, under terms of Contract DOT-FA69WA-2211.

ABSTRACT

In this study 140 subjects were exposed to simulated sonic booms and recorded residential noises in one, two, or three two-hour sessions over a period of six months. They were asked to rate how annoying they found each of the noises. Electrophysiological measures of heart rate and electromyographic responses to the stimuli were analyzed. Biographical, demographical, and personality inventories were also obtained for each of the subjects. The purpose of this research was to: (1) determine whether there are different degrees of psychological and physiological sensitivity to noise in a large group of people, (2) to determine whether and how such sensitivity varied in time, and (3) to relate such sensitivity to other psychological and personality variables.

Significant differences in psychological sensitivity to noise were found in the subject population. These differences remained stable for the duration of the experiment and were also found to be related to the attitudinal and belief structures of the individuals. Definite physiological responses to the simulated sonic booms were observed. However, the physiological indices used in this research did not show individual differences in physiological sensitivity to noise. These results do not preclude the possibility that more elaborate and extensive psychophysiological measurement might demonstrate varying physiological sensitivity to noise.

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I INTRODUCTION

The purpose of this research was to investigate the effects of certain kinds of impulsive noises and typical nonimpulsive noises upon the psychological and physiological behavior of adults. Specific goals were: (1) to compare the effects of the two kinds of noises, (2) to compare psychological with physiological responses, and (3) to attempt to find other characteristics of those individuals who were found to have the greatest reaction to noise.

Perhaps the most dramatic effect of noise upon man is the extreme physical discomfort and actual damage to the sound-processing ability of the human ear that can result from very loud sounds. Fortunately, the effects of such loud sounds are sufficiently well understood that individuals in the society can be protected from such sounds. Unfortunately, we have much less understanding concerning possible psychological or physiological effects that are more subtle--such as feelings of annoyance or physiological arousal.

Ideally, we would like to study the annoyance and physiological arousal effects of noise by actually observing many individuals carrying on normal activities in environments of different noisiness and objectively recording the changes in behavior caused by noises and other intrusions. Since such a large-scale social-anthropological study is not currently practical, this research was conducted using rating scales in an informal laboratory environment.

The validity of this research is dependent upon several assumptions. First, we assume that adults living in an urban society can bring to the laboratory a knowledge of the effects of noise upon them. We assume that because of the overall experience of people with many different noises in many environments, they can reasonably be expected to listen to a noise in the laboratory and extrapolate to the effects such a noise would have upon them in their normal daily activities. We assume further that while noise may have many different effects, people can lump these effects into a single dimension concerning how annoying or unpleasant a given noise would be if it occurred often in their daily environment. Finally, we assume that physiological effects of the noise, such as an increase in heart rate, will be substantially the same whether the noise occurs in a laboratory setting or whether it occurred while the individuals were in their normal environment. This is particularly expected to be true after the individual has become accustomed to the laboratory environment.

II EXPERIMENTAL PROCEDURE

A. Recruitment of Subjects

The subjects for the experiments were chosen from a group of 341 volunteers. The volunteers were recruited by appeals made at small civic gatherings and in response to newspaper articles describing our project. All prospective subjects filled out the first questionnaire shown in the appendix. In response to the question concerning whether they thought noise bothered them less than, the same as, more than, or much more than most people, 188 thought that noise bothered them less than or the same as most people, and 126 thought that noise bothered them more or much more than most people. Of the 314 people, 259 indicated willingness to participate in the experiment. One hundred and thirty-six people from these groups participated in the experiments as subjects. Of these, 60 considered themselves more sensitive to noise than most people.

B. Experimental Paradigm

The experiment was conducted in three phases. Phase I consisted of 19 experimental sessions employing 136 subjects over the period 11 May 1970 to 6 June 1970. In Phase II, 92 of the subjects returned in 12 experimental sessions lasting from 23 July 1970 to 7 August 1970. Of these 92 subjects, 68 returned for Phase III, which consisted of nine experimental sessions running from 23 September 1970 to 2 October 1970.

Eight subjects were scheduled for each experimental session, which was run either at 1:00 p.m. in the afternoon or 7:00 p.m. in the evening. In Phase I, the subjects were first given a general description of the experimental procedure and then asked to fill out employment forms and the general attitude and biographical questionnaire (see the appendix). While filling out the questionnaire the subjects were interrupted two at a time to go to another room to have electrophysiological electrodes attached to them and to have their hearing acuity tested using a Rudmose Model ARJ-4 automatic audiometer.

They were also seated in the chair that they would use in the experiment, and the EEG amplifier gains were adjusted for that subject. If the electrophysiological signals were unacceptably noisy, the electrodes were removed and reattached until an acceptable signal was obtained.

This took approximately 20 minutes. The purpose and use of the electrodes were explained to the subjects, and they responded in general with curiosity, interest, and little sign of apprehension.

After all subjects had finished the biographical questionnaire and had electrodes on, the laboratory noise rating questionnaire (see the appendix) was distributed, and the use of rating scales was explained. Other general instructions were given, including a brief description of the kinds of noises they would hear.

The subjects were then seated in the experimental rooms, and the experiment proceeded. The subjects were allowed to read during the session but were asked not to talk to one another, not to smoke, and not to chew gum or eat candy. There was seating for four subjects in each room. The subject chairs were separated by lightweight opaque curtains. The heart rate and EMG sensors were wired to a plug that could be removed from the terminal control box attached to the arm of each chair, thus allowing the subject to be mobile even after the sensors were attached to his body.

The first half of a session lasted approximately 55 minutes and the subjects heard from seven to nine noises. At this point, a fifteen-minute coffee break was taken. This time was also used to answer general questions concerning the purpose of the experiment and to show subjects their electrophysiological chart recordings. The last hour of the experiment was then conducted and electrodes were removed. The subjects were then asked to fill out the Cattell-Eber Sixteen Personality Factor Questionnaire Form A.

Phases II and III were conducted in the same way except that subjects did not fill out the general attitude questionnaire or the 16 PF test. As a result these sessions lasted only about three hours instead of the four hours required for the Phase I sessions.

C. Physical Characteristics of the Noises

The two subject rooms were built specifically for the purpose of simulating sonic boom noises in ordinary houses.[1*] The construction is standard frame construction with a double wall for isolation. One wall of each room is contiguous with a wall of a narrow sealed pressure chamber. A forward movement of a motor-driven diaphragm rapidly compresses the air in this chamber. Withdrawal of the diaphragm beyond the neutral point reduces the pressure below atmospheric level, and another rapid movement of the diaphragm forward returns the chamber pressure to near ambient level. These diaphragm movements effectively produce a sonic boom in the chamber, which generates sound stimuli and affects the walls and floor of the test room in a manner similar to that which is obtained in a room in houses struck by aircraft-generated booms.

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*References are listed at the end of the report.

The booms were selected to simulate typical levels of booms that might be produced by some military and proposed civilian supersonic aircraft. All booms had a duration of 260 milliseconds and a rise time of 6 milliseconds. Three different levels of booms were used: 2.5 pounds per square foot (psf), 1.25 psf, and 0.625 psf. The level of the booms as specified is their level in the plenum chamber attached to the actual room occupied by the subjects, i.e., the "outdoor" level; the level in the subjects' room is, of course, somewhat less because of sound attenuation by the walls of the test room. Throughout the report, these levels are also referred to as high, medium, and low levels, respectively.

In addition to three levels of sonic booms, the audio stimuli that were presented to the subjects consisted of seven typical neighborhood and household noises: a jet aircraft flyover, a vacuum cleaner, a barking dog, a motorcycle at two different loudness levels, passing trucks, and low-level freeway traffic. The noises were all recorded in neighborhoods in and around the City of San Jose and, with the exception of the freeway segment, which lasted 13 minutes, the noises were all shortened to a presentation duration of 20 seconds. Care was taken to preserve a natural onset and termination for each noise, The levels at which the noises were played into the subject rooms are representative of the levels found for these noises in community surveys.[2] The levels of these noises were measured inside the test chamber and are shown in Table 1. White noise at a level 40 dBA was maintained in the background in each room in order to mask the onset of the audio tape recorder that presented the tape stimuli.

D. Experimental Control Procedure

The experiments were carried out in a laboratory that included two subject rooms, each with a sonic boom simulator attached, and a central

Table 1

PHYSICAL CHARACTERISTICS OF NONSONIC BOOM NOISES

Stimulus	Effective Duration* (seconds)	Max dBA†	EdBA†	Max PNdB†	EPNdB†
Airplane	9.2	90	90	96	95
Vacuum Cleaner	16.0	81	81	92	92
Barking Dog	2.9	85	76	89	81
Motorcycle (high level)	4.6	74	67	82	74
Truck Traffic	4.6	67	60	73	66
Freeway Traffic	11.6	57	60	63	64
Motorcycle (low level)	4.2	62	55	68	61

*All sounds except the freeway traffic lasted 20 seconds. The freeway traffic sound was 13 minutes long. The durations listed in the table represent the time between two levels, before and after the dBA maximum, which were 10 dBA down from the maximum.

†For a precise definition of these measurements, see Ref. 2.

control area, which included a minicomputer with multiplex A/D converter, AM and FM tape recorders, and one ten-channel electroencephalograph for each room. An XDS Model CE16 minicomputer with 4000 words of core memory and an XDS Model MD41 40-channel multiplexer and 15-bit A/D converter were used to gather and process the heart rate and EMG data from the eight subjects.

Because of the small amount of memory in this computer and its relatively slow permanent storage medium (paper tape), it was necessary to design a system in which the physiological responses of only the four people in one room were being monitored at any given time. While a particular room was being monitored and a stimulus being presented to the people in that room, the results of the monitoring of the responses to the previous stimulus were punched out on paper tape. The monitoring periods always consisted of at least one minute prior to the onset of a stimulus and at least one minute following the onset of a stimulus. Because only one room could be monitored at any given time, it was necessary to design a presentation schedule that did not allow stimuli to be presented simultaneously in both rooms.

E. Order of Presentation of Stimuli and Monitoring of Subjects

Several criteria were used in the selection of stimuli presentation orders:

(1) In a given monitoring interval, stimuli could occur in only one room.

(2) No stimulus could come closer than two minutes to another stimulus.

(3) Different presentation orders should result in each stimulus being presented at different points in the session for different groups of people since it was expected that behavior might change during the duration of an experimental session.

(4) Different presentation orders should result in stimuli having different neighboring stimuli inasmuch as possible.

(5) The three different levels of sonic booms should each be presented in the beginning, the middle, and the final thirds of each session, but not necessarily in the same order in each part of the session.

(6) To study changes in behavior during a session, it was desired that the same level boom that began the session would also be the level that would end the session.

These criteria dictated the use of six different stimuli order schedules. Each of three boom level schedules was used equally often with each of the six order schedules to produce a total of 18 different presentation schedules. The different schedules are illustrated in Tables 2 and 3. To make experimental logistics simpler, the six nonboom presentation orders were always paired in the same way for all sessions. Order 1 was always paired with Order 2, Order 3 with Order 4, and Order 5 with Order 6; that is, if in a given experimental session one room received Order 3 then the other room received Order 4. This pairing allowed the experiments to be conducted through the use of only one two-channel tape recorder and three master control tapes.

Implementation of the presentation order shown in Table 2 was accomplished through a fully automated timing system. The timing control was supplied by master control tapes run on a Honeywell 8100 FM six-channel tape recorder. Channel 1 of each FM control tape supplied a dc pulse whenever a boom was required in subject room A. Similarly channel 2 activated the boomer in subject room B, and channel 3 activated the AM tape recorder for presentation of a nonboom stimulus. The AM tape recorder was set up so as to stop automatically at the end of each stimulus. The FM control tape also had on it pulses one minute before any given stimulus was to occur. This pulse was used to inform the CE-16 computer that it was time to begin monitoring the room in which the stimulus would occur and to begin punching out the results of the last monitoring interval.

Table 2

STIMULUS PRESENTATION SCHEDULES

Order 1	Order 2	Order 3
High-level Motorcycle	Boom	Boom
Boom	Freeway Traffic	Vacuum Cleaner
Boom	Boom	Boom
Boom	Trucks	Jet Flyover
Vacuum Cleaner	Boom	Boom
Boom	Low-level Motorcycle	Freeway Traffic
Barking Dog	Boom	Boom
Boom	Jet Flyover	High-level Motorcycle
Jet Flyover	Boom	Boom
Boom	Barking Dog	Boom
Low-level Motorcycle	Vacuum Cleaner	Boom
Boom	Boom	Barking Dog
Trucks	Boom	Boom
Boom	Boom	Trucks
Freeway Traffic	High-level Motorcycle	Boom
Boom	Boom	Low-level Motorcycle
Order 4	**Order 5**	**Order 6**
Low-level Motorcycle	Boom	Boom
Boom	Barking Dog	Jet Flyover
Trucks	Boom	High-level Motorcycle
Barking Dog	Freeway Traffic	Boom
Boom	Boom	Boom
Boom	Low-level Motorcycle	Boom
Boom	Boom	Trucks
High-level Motorcycle	Boom	Boom
Boom	Vacuum Cleaner	Vacuum Cleaner
Boom	Trucks	Boom
Freeway Traffic	Boom	Low-level Motorcycle
Boom	Boom	Boom
Jet Flyover	Boom	Freeway Traffic
Boom	High-level Motorcycle	Boom
Vacuum Cleaner	Boom	Barking Dog
Boom	Jet Flyover	Boom

Table 3

BOOM LEVEL SCHEDULES

Schedule 1 (psf)	Schedule 2 (psf)	Schedule 3 (psf)
1. 1.25	0.63	2.5
2. 0.63	2.5	1.25
3. 2.5	1.25	0.63
4. 2.5	1.25	0.63
5. 1.25	0.63	2.5
6. 0.63	2.5	1.25
7. 0.63	2.5	1.25
8. 2.5	1.25	0.63
9. 1.25	0.63	2.5

III PHYSIOLOGICAL REACTIONS

The effects of noise upon the physiological processes of the human body have been investigated through the use of many different indices. These include heart rate, blood pressure, peripheral blood volume flow, electromyographic measures from various muscles, gastrointestinal motility, and others.[2] As would be expected, most research that has found a physiological reaction to noise has also found that most of these measurements are correlated with one another. Because of these correlations it was decided in this research to concentrate on detailed examination of two of these indices in order to: (1) determine what the general population reaction, in terms of these two indices, would be to various kinds of moderate-level noises, (2) determine what the relationship would be between these physiological indices and psychological reactions of the subject population, and (3) attempt to characterize those individuals in the population who appear to be more than usually reactive to the acoustic stimuli.

A. Heart Rate Measurements

The basic data for the heart rate measurements were obtained through the use of electrodes placed upon the sternum, the nonwriting wrist of an individual, and his left earlobe. The heart signal was obtained by measuring the potential between the sternum and the earlobe. The wrist electrode was used as a grounding electrode. This potential difference was amplified through the use of a Beckman CE electroencephalograph using a time constant of 0.3 second and a gain that differed from subject to subject. This electrode configuration was used rather than one of the more standard lead combinations because extensive pilot testing indicated that this particular electrode placement was most impervious to "noise" (actually skeletal muscle potentials) that could be introduced through movement of the subjects. After being amplified, each subject's heartbeat signal was filtered by a 12-15-Hz active bandpass filter. This filtering produced an exponentially decaying sinusoid each time the heart signal had energy predominantly in the 12-15-Hz range, which occurred on each R-wave of each heartbeat. Thus, ideally the processed signal to be analyzed by the computer would consist of a 13-Hz sinusoidal wave modulated by an envelope that has a maximum corresponding to the R-wave in each heartbeat. Under these ideal circumstances, determining the duration of each heartbeat would simply be a matter of counting the time between each local maximum in the modulating envelope. However, it was possible for artifacts such as body movements and coughs to introduce false maximums in the modulating envelope. The elimination of these artifacts required a more complicated processing algorithm.

This processing was accomplished in several steps. First, the filtered signal was sampled and digitized every 4 milliseconds. The largest positive local maximum that occurs in the first 250 milliseconds is accepted as the first R-wave. The amplitude of the next local positive maximum is called the peak threshold. A search is then made for the next local positive maximum that (1) is larger than either of its neighboring maxima, (2) is at least 250 milliseconds later than the first R-wave, and (3) is greater than the peak threshold. This maximum is accepted as the next R-wave and the process is continued. This combination of electrode placement, pre-filtering, and software processing effectively rejected most artifacts and provided reliable heartbeat durations.

The result of this processing was, for each subject, the heartbeat-by-heartbeat durations for at least 60 seconds prior to and 60 seconds following each stimulus. To investigate the effects of the various noises obviously requires reducing these data to meaningful indices. Several such indices have been suggested in the past.[3,4,5] On the basis of these previous investigations, six indices were calculated for further examination. These are:

(1) The average heart rate in beats per minute for the 20-second interval prior to the onset of a noise.

(2) The average of the two fastest heartbeats that occurred during the five heartbeats immediately following the onset of a stimulus.

(3) The average heart rate for the 20 seconds following the onset of the stimulus.

(4) The average of the two slowest heartbeats that occurred in the interval from the sixth through the tenth heartbeats following the onset of a stimulus.

(5) The variance of the heart rate during the 20 seconds following the onset of a stimulus.

(6) The second moment of the heart rate during the 20 seconds following the onset of a stimulus as calculated about the mean of the heart rate during the 20 seconds prior to a stimulus.

The reason for the calculation of all these indices is that prior empirical investigations and theoretical hypotheses have suggested that the effect of noise upon heart rate might be either an acceleration, a deceleration, or an acceleration followed by a deceleration, i.e., an increase in variability of the heart rate. These indices were first analyzed in order to determine whether they had any validity in separating the effects of various kinds of noises. For an index to be useful it was believed that the index should show an overall different response to moderately high noises such as the higher-level booms and the aircraft flyover than to relatively low-level noises such as the freeway and the low-level motorcycle, and certainly that the reaction should be different from the control intervals in which no stimulus was presented. Preliminary analysis indicated that the indices that were particularly sensitive to decelerative action of the neart, namely, Indices 4 and 5, did not show any ability to discriminate amongst the various noises.

Table 4 shows the mean effects, as measured by Indices 2, 3, and 6, of each of the different stimuli in each of the three experimental phases. It can be seen that there is a definite accelerative effect found in the sonic boom stimuli, particularly the 2.5- and 1.25-psf booms as measured by Indices 2 and 3. On the other hand, these indices do not particularly seem to discriminate amongst the various nonimpulsive noises. Index 6, which was selected because it could be expected to be sensitive to either acceleration of the heart or deceleration of the heart, or both acceleration and deceleration of the heart, appears to have some validity, but it has such high variability that it cannot be considered a useful heart rate index.

Having determined that there is an accelerative effect in the heart rate as a result of some of the noises, particularly the sonic booms, we next turned to analysis of individual differences in heart rate reaction. However, the two accelerative indices, i.e., Indices 2 and 3, both have the property that for a given individual they will be a function not only of his reaction to a noise, but also of his natural heartbeat before the noise. Several techniques have been proposed for analyzing data that are contaminated by the pre-stimulus state of the organism. A relatively

Table 4

PHYSIOLOGICAL REACTIONS TO DIFFERENT STIMULI
AS MEASURED BY THREE HEART RATE INDICES

Stimulus	Index 2			Index 3			Index 6		
	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
1st High Boom	87.1	89.0	85.2	77.8	76.3	76.8	208.0	177.0	138.0
2nd High Boom	86.4	82.3	78.5	76.1	75.1	75.3	1150.0	237.0	143.0
3rd High Boom	83.8	86.8	77.4	73.9	76.1	73.0	198.0	316.0	72.2
Average High Boom	85.6	85.9	80.4	75.7	75.8	75.0	401.5	246.6	117.0
1st Medium Boom	79.2	78.7	80.0	75.8	76.2	76.0	94.9	148.0	73.1
2nd Medium Boom	79.7	80.6	79.1	74.0	74.4	75.3	112.0	134.0	122.0
3rd Medium Boom	75.8	83.3	77.6	74.1	75.1	73.3	154.0	195.0	109.0
Average Medium Boom	78.2	81.0	78.9	74.6	75.2	74.8	122.0	160.0	101.0
1st Low Boom	86.6	77.4	78.2	77.5	74.1	76.7	225.0	25.7	1510.0
2nd Low Boom	81.3	79.7	79.1	77.3	75.1	74.5	408.0	132.0	91.8
3rd Low Boom	80.7	83.9	76.3	75.0	76.1	74.2	139.0	199.0	75.1
Average Low Boom	82.8	80.5	77.8	76.5	75.2	75.0	251.2	124.6	496.9
Low Motorcycle	72.3	81.1	74.6	69.4	75.2	73.0	58.9	208.0	51.2
High Motorcycle	74.7	73.7	77.4	72.6	72.6	74.4	96.3	83.6	44.5
Trucks	74.4	72.4	75.2	71.5	71.7	73.6	73.4	91.1	67.5
Barking Dog	77.7	77.6	74.7	74.0	74.6	73.1	158.0	161.0	63.4
Vacuum Cleaner	84.5	79.1	74.1	77.9	73.6	73.8	1130.0	209.0	35.9
Jet Flyover	76.1	79.1	76.1	74.1	73.5	73.5	150.0	152.0	28.9
Freeway	76.0	75.6	74.0	73.0	73.5	72.1	97.8	120.0	41.3
Control	77.5	82.9	73.2	72.8	74.7	71.6	3380.0	251.0	28.9

straightforward technique has been suggested by Lacey.[6] This involves the calculation of an autonomic lability score that is a function of the difference between the post-stimulus reaction of the individual and the reaction that would be predicted from the pre-stimulus state of the individual. Specifically, Lacey's procedure calls for the calculation of both pre- and post-stimulus standardized Z scores; that is, for each noise each subject's pre-stimulus score is modified by subtracting the population pre-stimulus mean from each score and dividing by the population standard deviation. The same is done for post-scores. The correlation $r_{pre,post}$ between pre- and post-scores over the population is then calculated, and the autonomic lability score for that subject on that noise equals

$$50 + \frac{10(Z_{post} - Z_{pre} \times r_{pre,post})}{\sqrt{1 - r^2_{pre,post}}} \quad .$$

Thus the score actually indicates the degree to which a person exhibited a reaction that is greater than would be expected from his pre-stimulus state.

Autonomic lability scores were calculated for both Index 2 and Index 3, in both cases using the average pre-stimulus heart rate as the predictive corrective measure. These scores were then used to determine to what degree individuals reliably differed from one another upon different presentations of the same stimuli, both in the same day, and on different days. Table 5 indicates that there is no significant correlation between the reaction of an individual upon the presentation of a stimulus at one time and his reaction at any other time. This is true even if we restrict our attention only to sonic booms, which have the most pronounced effects. There is ar indication of a small

Table 5

BETWEEN-PHASE AND WITHIN-PHASE CORRELATIONS FOR EACH OF TWO AUTONOMIC LABILITY SCORES

Correlations Based Upon the Autonomic Lability Scores Calculated from Heart Rate Indices 1 and 2

Stimulus Type	Between Phase I Phase II	Between Phase I Phase III	Between Phase II Phase III	Within Phase I	Within Phase II	Within Phase III
2.5-psf Boom	0.01	0.09	0.22	0.11	0.11	0.31
1.25-psf Boom	-0.08	-0.08	0.03	0.19	0.10	-0.07
0.63-psf Boom	-0.02	-0.04	0.11	0.18	0.15	0.14
Nonboom Noises	0.00	0.02	0.05			

Correlations Based Upon the Autonomic Lability Scores Calculated from Heart Rate Indices 1 and 3

Stimulus Type	Between Phase I Phase II	Between Phase I Phase III	Between Phase II Phase III	Within Phase I	Within Phase II	Within Phase III
2.5-psf Boom	0.00	0.06	0.20	0.14	0.24	0.39
1.25-psf Boom	-0.06	0.13	0.03	0.25	0.31	-0.02
0.63-psf Boom	0.12	-0.03	0.08	0.09	0.06	0.31
Nonboom Noises	0.11	0.03	0.03			

correlation between the presentations of identical booms within the same day. However, there is virtually zero correlation between different days.

B. Electromyographic Measurements

It has been suggested that electromyographic surface measurements from inactive or irrelevant muscles can be used to indicate the general muscular tension of an individual and/or the degree of mental concentration upon a given task.[2] This would suggest that measurement of such inactive muscle potentials would be a prime candidate as a physiological measure of the reaction to noise. Such measurements might demonstrate either an involuntary reaction to a noise or, particularly during a long session, an increased mental effort in defending against noise.

Electromyographic measurements were made on all subjects in this experiment through the use of two electrodes placed on the jaw immediately behind the chin. As in the heart signal data, this bipolar measurement is made with respect to an electrode on the nonwriting wrist, which was used as a ground electrode and as a common mode rejection point. This signal was amplified 20 dB by the Beckman electroencephalographic amplifier unit with a high-pass time constant of 0.3 and no low-pass frequency cutoff. It was further amplified by 12 dB and then sampled and digitized 250 times per second. The average absolute value of these samples was then calculated for each 2-second interval for at least one minute prior to and one minute following the presentation of each noise.

The acquisition of electromyographic data was plagued with operational difficulties throughout this experiment. Ideally, the best place to obtain data of the kind we wanted would be from a large active muscle that was not being used in the experiment. However, because of the long durations of these experimental sessions, the subjects had to be free to move about within the confinements of sitting in a chair; thus they were free to cross or uncross their legs, to stretch, to change the positions of their arms, and so on. We believed that under the circumstances of the experiment it would not be feasible to attempt either to immobilize any of the limbs or to instruct the subjects to leave a limb immobile. In an attempt to find an electrode placement that would not be subject to general body movement and squirming, two placements were tried: (1) on the forehead one inch above the eyes, and (2) on the jaw immediately below the chin. The forehead placement has been recommended as a position for measuring general body tension.[7] However, its use in this experiment was thwarted because the subjects were reading and the potentials from the eye movements were often picked up by these electrodes. The chin placement, which is a standard placement for electromyographic measurements in sleep studies, was relatively impervious to general body movement, but, as would be expected, was affected by coughing, chewing, and, to some extent, swallowing. In addition, it was very difficult to apply the electrodes in this position in such a way as to maintain good skin contact throughout the two-hour duration of the session. This factor, combined with the relatively low amplitude of this potential, made this signal extremely susceptible to noise interference such as 60-Hz radiation or other electromagnetic radiation that was anywhere near the subjects or the cables bringing the signal from the subjects to the electroencephalographic units.

While methods were developed throughout the experimentation for improving the signal-to-noise ratio, analysis of the Phase III data revealed that the variability in the electromyographic measurements precluded any discrimination in the reactions to different stimuli or any significant correlation between the measurements on individuals in the different phases of the study.

These results should not be considered to indicate that surface electromyographic measures cannot be used in large-scale experiments to indicate physiological reaction to noise. It is very possible that the difficulties experienced in these studies can be overcome through several methods. One possibility is the use of several channels of electromyographic data; for example, one could use four channels from the muscles in the legs and arms as well perhaps as a channel from the neck muscles and possibly others. An algorithm could then be developed that would examine these channels in parallel and reject signals that were obviously the result of a given muscle being used actively at a moment, and also to reject completely epochs that indicated general body movement. If such channels were also notch-filtered so as to reject 60-Hz interference and any other narrow-band electromagnetic interference that is expected, it is highly likely that very reliable measurements could be made of general muscular tension from the use of surface electrodes, even over long durations in a relatively mobile environment.

The results indicate that the effects of a noise upon any given sample of people are the results of different people reacting at different times and that the reaction of an individual is a function of variables that were not controlled in these experiments such as the general physiological and psychological state or mood of the individual on any given test day and the general psychological state of the individual at the point the noise was heard. It is possible that even though there was no overall correlation of subject's responses for the entire subject population, some specific individuals did in fact consistently react more than others. However, a diligent search of the subject response space did not reveal any individuals who consistently reacted to the stimuli more than would be expected by chance sampling distributions.

IV PSYCHOLOGICAL RATINGS OF LABORATORY NOISES

The 16 noises were rated by each subject on the questionnaire shown in the appendix. Table 6 shows the mean ratings of unacceptability of each of the noises in each of the phases of the experiment. It can be seen that the 2.5-psf boom was clearly more annoying than any of the other noises and that the 1.25-psf boom was rated more annoying than any other noises except for the aircraft flyover and the vacuum cleaner, whereas the 0.63-psf boom was rated only more annoying than the low-level motorcycle and the low-level passing trucks. The ratings of the non-sonic boom stimuli were best predicted by the EPNdB measure (product moment $r = 0.87$). The only deviations in prediction were the barking dog, which was rated much less annoying than would be predicted, and the freeway, which would be predicted to be less annoying than the passing trucks. However, it should be noted that the freeway noise lasted 13 minutes as compared to 20 seconds for the passing trucks, which undoubtedly accounts for its greater rated annoyance.

If Table 6 is examined in terms of changes in ratings from session to session, it appears that the noises were rated most annoying in Phase II and about the same in Phase I as in Phase III. However, the data in Table 6 are based upon different subject groups in each phase, since people dropped out of the experiment from phase to phase. If only the people who completed all three phases are analyzed, we find that the noises were rated similarly in Phases I and II, but that 15 of the 16 noises were rated more annoying in Phase III than in Phase II. This

Table 6

MEAN ANNOYANCE RATINGS OF NOISES

	Phase I	Phase II	Phase III	Average All Phases	Max dBA	Max N PNdB	N EPNdB
1st High Boom	5.95	6.12	6.00	6.01			
2nd High Boom	6.13	6.13	6.00	6.08			
3rd High Boom	5.89	6.24	6.16	6.11			
Average High Boom	6.02	6.16	6.07	6.07			
1st Medium Boom	5.22	5.49	5.16	5.29			
2nd Medium Boom	5.20	5.30	5.24	5.24			
3rd Medium Boom	5.20	5.42	5.28	5.29			
Average Medium Boom	5.21	5.41	5.23	5.27			
1st Low Boom	5.06	5.08	4.94	5.04			
2nd Low Boom	5.12	5.11	4.89	5.06			
3rd Low Boom	4.92	5.11	5.04	5.01			
Average Low Boom	5.03	5.10	4.96	5.04			
Jet Flyover	5.56	6.05	5.91	5.79	90	96	95
Vacuum Cleaner	5.59	5.83	5.78	5.71	81	92	92
High Motorcycle	5.15	5.40	5.21	5.24	74	82	74
Freeway	5.15	5.33	4.97	5.16	57	63	64
Barking Dog	4.98	5.22	4.99	5.05	85	89	81
Trucks	4.63	4.91	4.74	4.74	67	73	66
Low Motorcycle	4.20	4.38	4.33	4.28	62	68	61

suggests that increased exposure to the noises did not cause the subjects to find them more acceptable, but rather that the continued experimentation had the effect of sensitizing the subjects to the annoyance of noises.

A. Individual Differences in Noise Sensitivity

Several indices of noise sensitivity as measured by annoyance ratings in the laboratory were calculated as potential candidates for determining the noise sensitivity of a given individual. These were:

(1) The average rating of all 16 noises presented in a session.

(2) The average rating of the nine sonic booms presented in a session.

(3) The average rating of the nonsonic boom stimuli that were presented in a session.

(4) The average rating given to the loud sounds, i.e., the three 2.5-psf booms, the flyover, the vacuum cleaner, and the high-level motorcycle.

(5) The percentage of stimuli that were rated 6 or 7 by a subject.

Subsequent analysis revealed that all of these indices were highly correlated with one another, and only the first, namely, average rating of annoyance over all stimuli, will be used in the following discussion.

In investigating individual differences in psychological ratings, we first analyzed the data to determine whether any experimental artifacts had influenced the ratings. Because the rooms were constructed to represent typical frame construction residential rooms rather than anechoic chambers, the sound level of a noise delivered from the speaker could differ by as much as 2 dB at any given chair from the levels reported in Table 1. However, an analysis of variance of the ratings as a function of which chair an individual sat in revealed no significant effect as the result of this factor. A similar analysis of the data from the weekday afternoon sessions, as opposed to the evening and Saturday sessions, also indicated that this factor did not account for any differences in ratings of the annoyance of the laboratory noises.

Data were next analyzed to determine the reliability of ratings of each stimulus from phase to phase. Table 7 shows the correlation of the annoyance rating between Phases I and II, between Phases II and III, and between Phases I and III. It is clear that the ratings of the noises are reliable and that there is evidence of familiarization with the noises and stabilization of the ratings as the experiment progressed.

Table 7

PRODUCT MOMENT CORRELATIONS OF ANNOYANCE RATINGS BETWEEN PHASES

Phase I with Phase II	Phase I with Phase III	Phase II with Phase III
0.61	0.54	0.90

Having determined that the annoyance rating index was (1) apparently not contaminated by experimental artifacts, (2) different for different noises, and (3) reliable from phase to phase, we used this index to analyze the problem of hypersensitivity to noise in individuals. This rating index was available on all three phases of the experimental study. However, Phase I data were used to investigate the question of hypersensitivity because data were available for more people in this phase than in the following two phases.

The most obvious evidence of true hypersensitivity to noise would be a bimodal distribution of sensitivity ratings over the sample of 140 people. As can be seen in Table 8, such a bimodal distribution does not exist. The distribution is a somewhat skewed unimodal curve with a median of 5.5. Given no external evidence of a criterion to establish hypersensitivity, it is necessary to select an arbitrary definition of extra sensitivity to noise.

Table 8

CUMULATIVE DISTRIBUTION OF NOISE SENSITIVITY--PERCENTAGE OF SAMPLE WITH NOISE SENSITIVITY ≤ X

Mean Sensitivity (x)	Cumulative Percentage
2.4	1.4
2.6	2.2
2.8	2.9
3.0	3.7
3.2	5.9
3.4	7.4
3.6	8.8
3.8	11.8
4.0	13.2
4.2	16.2
4.4	20.6
4.6	23.5
4.8	27.9
5.0	34.6
5.2	42.6
5.4	47.8
5.6	59.6
5.8	69.1
6.0	76.5
6.2	83.1
6.4	90.4
6.6	97.1
6.8	98.5
7.0	100.0

Since such a criterion must necessarily be arbitrary, it was decided to separate the subject sample into thirds: those most sensitive according to their laboratory ratings, those least sensitive, and the third in between. Since we were not attempting to test any a priori hypotheses concerning prediction of noise sensitivity, this grouping appeared to allow maximum potential for producing a taxonomy of the characteristics which would delineate noise-sensitive versus noise-insensitive individuals in the population.

Tables 9, 10, 11, and 12 show the responses of (1) the noise-sensitive third of the sample, (2) the noise-insensitive third of the sample, and (3) the entire sample to the questions in the general attitude and biographical questionnaire and the screening questionnaire of all the people who participated in the laboratory experiments. The noise-sensitive third of the sample consisted of the 43 people who rated the 16 noises with an average score of 5.85 or greater. The noise-insensitive third of the population consisted of the 43 people who rated the 16 noises with a mean rating of 4.9 or less on the seven-point scale.

Table 9 shows the responses to question 1 of the general attitude questionnaire, which were ratings of acceptability of various environmental factors. These responses show that the noise-sensitive individuals rated everything in their environment much more unacceptable than did the noise-insensitive individuals. This is true even of non-noise environmental factors such as general climate, air pollution, and road traffic. Analysis of the second question in the questionnaire dealing with what kinds of noises in the environment are unacceptable and why they are unacceptable is shown in Table 10. These responses also indicate a difference between the noise-sensitive and the noise-insensitive individuals, particularly in the startling effects of noises and in the awakening effect of various noises.

Table 9

MEAN UNACCEPTABILITY RATINGS OF VARIOUS ENVIRONMENTAL FACTORS

Environmental Factor	Noise Sensitive	Noise Insensitive	Total
Aircraft Noises	3.83	3.07	3.53
Impulsive Noises	4.76	4.00	4.57
General Climate	2.35	1.90	2.33
Amount of Air Pollution	5.28	4.45	4.84
Road Traffic	4.38	3.14	4.01
Road Noise	4.43	3.36	4.01
Dirt and Dust	3.88	3.71	4.00
Barking Dogs	4.17	3.21	3.82
Noise from Children	3.24	2.88	3.13

Table 11 shows the responses to the initial screening questionnaire and to questions 3 through 10 of the general attitude questionnaire. These questions concern the individual's beliefs about his own noise sensitivity and the effects of noise upon his health.

The major questions on the screening questionnaire were: whether subjects felt that noise was no problem, a minor problem, a serious problem, or a very serious problem, and whether subjects felt that they were bothered by noise much less than average, less than average, about the same as average, more than average, or much more than the average person. Analysis of these questions indicates that while subjects' replies are useful in predicting their noise sensitivity, such a broad categorization is not very useful in picking noise-sensitive subjects. That is, while 74 percent of the noise-sensitive third of the population considered noise a serious or a very serious problem, so also did almost

Table 10

PERCENTAGE OF PEOPLE REPORTING PARTICULAR EFFECTS OF 11 KINDS OF NOISES

(a) Aircraft Flying Overhead

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	21.4	19.0	18.6
Keeps from going to sleep	7.1	4.7	6.6
Wakes up	9.5	2.4	8.0
Interferes with TV, radio, telephone, or conversation	45.2	40.4	45.5
Vibrates house	19.0	7.1	14.7

(b) Street Noise from Passing Cars and/or Trucks

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	16.6	14.3	16.9
Keeps from going to sleep	9.5	7.1	8.0
Wakes up	19.1	21.4	17.6
Interferes with TV, radio, telephone, or conversation	23.8	19.1	24.2
Vibrates house	7.1	9.5	7.3

(c) Slamming Doors, Cars Backfiring, Bangs, or Other Impulsive Noises

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	52.4	50.4	51.4
Keeps from going to sleep	11.9	7.1	14.7
Wakes up	21.4	16.7	22.7
Interferes with TV, radio, telephone, or conversation	11.9	9.5	12.5
Vibrates house	4.8	4.8	4.4

(d) Dishwasher

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	4.8	2.1	2.9
Keeps from going to sleep	0	2.1	3.6
Wakes up	0	0	0.7
Interferes with TV, radio, telephone, or conversation	35.7	28.6	37.5
Vibrates house	7.1	2.1	3.6

(e) Washing Machine

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	2.4	0	2.2
Keeps from going to sleep	0	0	1.4
Wakes up	2.4	0	2.2
Interferes with TV, radio, telephone, or conversation	14.3	11.9	15.4
Vibrates house	14.3	11.9	13.2

(f) Other Appliances

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	21.4	9.5	11.7
Keeps from going to sleep	2.4	16.7	8.0
Wakes up	2.4	7.1	5.8
Interferes with TV, radio, telephone, or conversation	19.0	30.9	23.5
Vibrates house	0	7.1	2.9

(g) Sirens and/or Auto Horns

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	45.2	30.9	35.2
Keeps from going to sleep	11.9	4.8	9.5
Wakes up	28.6	23.8	31.5
Interferes with TV, radio, telephone, or conversation	9.5	16.7	14.7
Vibrates house	0	0	0.7

(h) Plumbing Noises

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	4.8	4.8	5.8
Keeps from going to sleep	7.1	11.9	13.9
Wakes up	9.5	4.8	10.2
Interferes with TV, radio, telephone, or conversation	9.5	7.1	8.8
Vibrates house	2.4	14.2	8.0

(i) Neighbors' Dogs Barking

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	11.9	11.9	10.2
Keeps from going to sleep	21.4	23.8	31.6
Wakes up	16.7	16.7	18.3
Interferes with TV, radio, telephone, or conversation	9.5	9.5	12.5
Vibrates house	0	0	0.7

(j) Noises Made by Children

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	11.5	14.2	10.2
Keeps from going to sleep	11.5	14.2	13.2
Wakes up	16.7	11.2	15.4
Interferes with TV, radio, telephone, or conversation	23.8	26.2	30.1
Vibrates house	4.8	2.4	2.2

(k) Noises Made by Adults

Effect	Noise Sensitive	Noise Insensitive	Total
Startles	9.5	4.8	6.6
Keeps from going to sleep	19.0	9.5	15.4
Wakes up	14.2	9.5	9.5
Interferes with TV, radio, telephone, or conversation	7.1	9.5	11.7
Vibrates house	0	2.4	1.4

50 percent of the noise-insensitive third of the population. Similarly, while 55 percent of the noise-sensitive population considered themselves bothered by noise more than the average person, or much more than the average person, so did 44 percent of the noise-insensitive third of the population.

Analysis of questions 3 and 4 of the attitude questionnaire shows that an individual who believes that he is less bothered than the average person by either impulsive or intermittent noises is unlikely to be in the sensitive third of our population. On the other hand, an individual who believes that he is bothered more than the average person is much more likely to be in the sensitive portion of the population than in the insensitive. However, it should be noted that most of the people in both categories responded that they are bothered about the same as the average person.

Questions 6 and 7 of the general attitude questionnaire may be the most effective discriminators between sensitive and insensitive

Table 11

BELIEFS OF SUBJECTS CONCERNING THEIR NOISE SENSITIVITY AND THE EFFECTS OF NOISE UPON THEIR HEALTH

Percentage of subjects who felt that noise was:

	Noise Sensitive	Noise Insensitive	Total Sample
No problem	7.14	9.52	9.56
A minor problem	19.95	42.86	30.15
A serious problem	47.62	42.86	47.06
A very serious problem	26.19	4.76	13.24

Percentage of subjects who felt they were bothered by noise:

	Noise Sensitive	Noise Insensitive	Total Sample
Much less than the average person	0	4.76	2.21
Less than the average person	11.90	21.43	18.38
About the same as the average person	33.33	40.48	35.29
More than the average person	42.86	33.33	37.50
Much more than the average person	11.90	0	6.62

Table 11 (Continued)

Subjects who are startled or bothered by impulsive noise:

	Noise Sensitive	Noise Insensitive	Total Sample
More than the average person	43.9	36.6	39.6
Less than the average person	4.9	19.5	14.1
The same as the average person	51.2	43.5	46.3

Subjects who are annoyed or bothered by intermittent noises such as aircraft:

	Noise Sensitive	Noise Insensitive	Total Sample
More than average	34.1	24.4	26.8
Less than average	4.9	24.4	17.2
Same as average	61.0	51.2	56.0

Subjects who consider their present neighborhood:

	Noise Sensitive	Noise Insensitive	Total Sample
Quieter	43.9	41.5	42.1
Noisier	26.8	26.8	28.6
Same as their previous home	29.3	31.7	29.3

Subjects who consider that their health has been affected by noise:

Noise Sensitive	Noise Insensitive	Total Sample
41.5	12.2	25.6

Table 11 (Concluded)

Subjects who indicated that intense noise can:

	Noise Sensitive	Noise Insensitive	Total Sample
Make them feel ill	29.3	2.4	14.4
Make them nervous	80.5	56.0	74.2
Bother their ears	48.8	41.5	48.6

	Noise Sensitive	Noise Insensitive	Total Sample
Subjects who have taken sleeping pills or other medicines partly because of neighborhood noise	12.2	0	5.2
Subjects who have lived in neighborhoods where noise level was unacceptable	51.2	43.9	49.2
Subjects who have contemplated moving because of noise	41.5	30.9	35.1

individuals. Over 40 percent of the sensitive third of our sample stated that they believed that their health has been in some way adversely affected by noise, and over 80 percent of this third of our sample indicated that noise made them nervous. However, it should be noted that 56 percent of the insensitive third of the population also believed that noise made them nervous. Question 8 also indicates the validity of the noise rating system in that the only people who ever

Table 12

MEAN NOISE SENSITIVITY AS A FUNCTION OF DEMOGRAPHICAL CHARACTERISTICS

	Age					
	Under 30	30-39	40-49	50-59	60-69	Over 69
Sensitivity	5.26	5.32	5.38	5.04	4.87	4.78
Number	33	52	27	13	9	2

	Sex	
	Male	Female
Sensitivity	5.14	5.30
Number	41	95

	Education			
	High School or Less	Some College	Bachelor Degree	Post-Graduate
Sensitivity	4.93	5.22	5.53	5.25
Number	41	34	49	11

	Occupation of Head of Household			
	Blue Collar	White Collar	Professional	Other
Sensitivity	5.07	5.33	5.32	5.51
Number	16	26	77	15

Table 13

PERCENTAGE OF NOISE-SENSITIVE AND OF NOISE-INSENSITIVE INDIVIDUALS
FALLING IN EACH STEN ON THE 16 PF ANXIETY FACTOR AND EXTRAVERSION FACTOR

	Anxiety Factor Sten									
	1	2	3	4	5	6	7	8	9	10
Percentage of Noise Sensitive	0	9.5	7.1	23.8	9.5	19.0	21.4	4.8	0	4.8
Percentage of Noise Insensitive	0	9.5	19.0	19.0	28.6	9.5	7.1	7.1	0	0

	Extraversion Factor Sten									
	1	2	3	4	5	6	7	8	9	10
Percentage of Noise Sensitive	7.5	2.5	12.5	10.0	22.5	15.0	22.5	5.0	2.5	0
Percentage of Noise Insensitive	4.9	2.4	9.8	12.2	26.8	14.6	9.8	9.8	2.4	7.3

Table 14

CORRELATIONS OF AUTONOMIC LABILITY INDICES AND PSYCHOLOGICAL ANNOYANCE RATINGS AS A FUNCTION OF STIMULUS AND EXPERIMENTAL PHASE

Autonomic Lability Index Based Upon Heart Rate Indices 2 and 1

Stimulus	Phase I	Phase II	Phase III
2.5-psf Booms	+0.01	+0.15	-0.10
1.25-psf Booms	+0.02	-0.03	-0.07
0.63-psf Booms	+0.08	+0.06	+0.01
Nonboom Noises	+0.07	+0.04	-0.14

Autonomic Lability Index Based Upon Heart Rate Indices 3 and 1

Stimulus	Phase I	Phase II	Phase III
2.5-psf Booms	+0.02	+0.15	-0.19
1.25-psf Booms	+0.06	+0.04	-0.18
0.63-psf Booms	+0.06	+0.06	-0.07
Nonboom Noises	+0.13	-0.08	-0.04

take sleeping pills or other medicines because of neighborhood noise were in the sensitive third of our population.

The responses to questions 9 and 10 again indicated that the individuals in the sensitive third of the population either lived in a noisier environment than the insensitive third, or that they are more sensitive to the intrusion of noise into their environment than the insensitive third.

Table 12 shows mean noise sensitivity as a function of various demographical characteristics. These scores indicate that while age and sex do not appear to be related to noise sensitivity, noise sensitivity does increase with educational level and with socio-economic status.

Overall analysis of the general attitude and biographical questionnaire indicates that the best predictors of noise sensitivity lie in questions concerning actual behavior of individuals and beliefs about effects of noise on physical health, i.e., questions concerning medication taken to reduce the noise problem, and, by implication, presumably questions concerning other techniques for defending against noise, and questions concerning whether or not the individuals believe noise to have affected their health, and, if so, in what way.

B. <u>Noise Sensitivity versus General Sensitivity</u>

It is reasonable to ask whether people who are extra sensitive to noise are sensitive only to noise or whether they could be classified as in general extra-sensitive individuals. Table 13 shows the percentage of noise-sensitive and insensitive individuals that fall in each sten of the 16 PF anxiety and extraversion factors. These data indicate no relation between extraversion and noise sensitivity but do suggest that noise-insensitive people are likely to have low anxiety scores. Note, however, that a low anxiety score does not preclude noise-sensitivity in that 50 percent of the noise-sensitive individuals fall into stens one through five.

Further evidence on this question is provided by the ratings of general climate, air pollution, and road traffic in the general attitude and biographical questionnaire. It is clear that the noise-sensitive third of the population rated these factors much more unacceptable than did the insensitive third of the population. This can be construed to indicate a generally greater dissatisfaction with our environment and a greater willingness to indicate displeasure with our environment in all of its phases.

C. An Experiment with Light Stimuli

In a further attempt to analyze the question of general sensitivity versus noise sensitivity, the Phase III experiments included two 30-second intervals in which the room was flooded with colored light. The first interval used red light and was separated by three minutes from the second interval, which used green light. Subjects were asked to rate on the same seven-point scale from pleasant to unpleasant how they would find sitting in a room in this lighting for a duration of one-half hour to one hour. Correlation of these ratings with the noise sensitivity ratings indicates a very slight positive association ($r = 0.2$) between the unpleasantness of the green lights and the unpleasantness of the 16 noises and no relation between the rating of red light and noise sensitivity. While this finding supports the hypothesis that individuals who are noise sensitive are also sensitive to other intrusions into their environment, it does not suggest that it is a good predictor of noise sensitivity.

D. Correlations between Psychological and Physiological Indices

It was pointed out previously that the physiological reaction of an individual to noise seems to depend on the general psychological and physiological set of the individual at the time that the noise occurred and that these variables were not controlled in these experimental sessions. However, it is possible that the same psychological or physiological set that influenced the physiological reaction would also influence the rating of the annoyance of a given noise. Table 14 shows the correlation between the psychological and physiological reactions for different kinds of stimuli. These correlations are based upon the autonomic lability indices discussed above and are shown separately for each experimental phase. While there is some evidence of a weak association between these measures of reaction to noise, it is clear that the reactions are relatively independent of one another.

V CONCLUSIONS

The relative ranking of the perceived annoyance of the various noises remained constant over the six-month duration of the experiment. The 2.5-psf boom was distinctly the most annoying sound. The 1.25-psf boom was rated more annoying than all other noises except for the 90-dBA jet flyover and the 81-dBA vacuum cleaner. The 0.63-psf boom was rated less annoying than all noises except for the 67-dBA truck traffic and the 62-dBA motorcycle recording. (The sonic boom overpressures are herein expressed at the levels that would be found outside a typical frame house with windows and doors closed; the subject actually heard the booms and noises at the levels that would be present inside the house. The other noises are as measured inside the test room.)

The average rating of all 16 laboratory noises provided a stable index of psychological sensitivity to noise. This index showed sensitization to the noises occurring in the last phase of the research. This index also revealed several potential differences between the most sensitive third of the subject population and the least sensitive third of the population. The noise-sensitive individual rated all kinds of noises as being more intrusive in their daily activities than the noise-insensitive individuals. They were also more likely to perceive themselves as being more sensitive to noise than the average person, and they were more likely to believe that noise was affecting their personal health. The noise-sensitive individuals were also more negative in their ratings of non-noise factors in their environment and were more likely to have high anxiety scores than were the noise-insensitive individuals. The best prediction of noise sensitivity came from questions about individuals' beliefs concerning the effects of noise upon their health and behavior intended to ameliorate the effects of noise. Personality-type tests do not appear to provide sufficient additional information related to sensitivity to noise to justify the time required for their completion.

Analysis of the physiological reactions to the noise indicated a definite heart rate acceleration in response to the simulated sonic booms. This was true even of the 0.63-psf boom, which was not rated as very annoying. It was not possible to find a physiological index that exhibited different responses to different nonimpulse-type noises, nor was it possible to find an index of individual physiological noise sensitivity, nor was there evidence of a correlation between psychological and physiological reactions to noise. These results cannot be taken as proof that such responses and correlations did not exist; rather the discovery of good indices of physiological responses to nonimpulse noises may depend upon the monitoring of more physiological parameters and the use of more elaborate electrophysiological recording and signal detection techniques.

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Appendix

QUESTIONNAIRES AND RATING SCALES

USED IN THIS RESEARCH

Budget Bureau No. 04-S69034

QUESTIONNAIRE

1. Do you consider noise to be to you:
   no problem _____, a minor problem _____, a serious problem _____, a very serious problem _____? If a problem, which type or types of noise are mostly responsible?
   Auto and truck _____, Aircraft _____, Industry _____, Neighbors _____, Other _____.

2. Do you think noise bothers you:
   a. Much less than most people _____
   b. Less than most people _____
   c. About the same as most people _____
   d. More than most people _____
   e. Much more than most people _____.

3. To the best of your knowledge is your hearing, for your age:
   a. Normal _____
   b. Less than normal _____.

4. Would you be willing to come, at your convenience, to Stanford Research Institute for:
   One _____, Two _____, or Three _____ two- to three-hour periods to participate in noise judgment and attitude tests? The test periods would be separated by about one month. The noises will be noises of the type heard everyday in some communities in the USA. You will be compensated ($2.50/hr) for one hour of travel time and the hours at Stanford Research Institute. The noises will be in no way unusual or harmful, merely like those to be found in everyday living in some localities. The results of the judgment tests will be kept anonymous and not related in any way to individuals by name. The purpose of the test is to provide general information that may aid the Government in the control of environmental noise.

 Budget Bureau No. 04-S69034

5. If you are willing to help with the project, please record your name, address, and phone number so we may contact you to arrange for scheduling a visit to Stanford Research Institute.

Name ______________________________ Phone ____________

Address ____

Please answer questions 1 through 4 above even though you do not fill out item 5.

Budget Bureau No. 04-S69034

	Startles	Keeps from going to sleep	Wakes up	Inteferes with TV or Radio	Interferes with Telephone	Interferes with Conversation	House Vibration
f) Other appliances, name ____________							
g) Sirens and/or auto horms							
h) Plumbing noise							
i) Neighbors' dogs barking							
j) Noises made by children							
k) Noises made by adults							

3. Are you startled and bothered by impulsive noise:

   More than the average person ________

   Less than the average person ________

   The same as the average person ________

4. Are you bothered and annoyed by intermittent noises such as from aircraft or automobiles:

   More than the average person ________

   Less than the average person ________

   The same as the average person ________

5. Do you consider your present neighborhood is quieter ________, about the same ________, or noisier ________ than your previous home.

6. Do you think your health has been in any way adversely affected by noise of any kind? Yes ________ No ________

   If yes, what was the noise or noises? ____________________

   If yes, in what way did it affect your health? ____________________

   ____

Budget Bureau No. 04-S69034

7. At the present time does intense noise ever make you: feel ill? Yes ________ No ________; nervous? Yes ________ No ________; bother your ears? Yes ________ No ________. If so, what kinds of noise cause these discomforts? ____________________________________

8. Do you take any sleeping pills or other medicines partly because of neighborhood noises? Yes ________ No ________.

9. Have you ever lived in a neighborhood other than your present one where the noise was not acceptable to you? If so, what kinds of noise were present? ____________________________________

____

10. Did you ever move or seriously contemplate moving from a neighborhood because of the noise? Yes ________ No ________

11. Please complete the following:

Age ________ Sex ________ Highest School Degree ________________

Your occupation ____________________________________

If housewife, husband's occupation ____________________________

Budget Bureau No. 04-S69034

I GENERAL ATTITUDE AND BIOGRAPHICAL QUESTIONNAIRE

1. Rate the following factors as they affect you in your present home:

a) AIRCRAFT NOISE

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

b) IMPULSIVE NOISE (Bangs, Doors Slamming, Car Backfiring, etc.)

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

c) GENERAL CLIMATE

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

d) AMOUNT OF AIR POLLUTION

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

e) ROAD TRAFFIC

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

f) ROAD NOISE

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

g) DIRT AND DUST

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

Budget Bureau No. 04-S69034

h) NOISE FROM DOGS BARKING

1 2 3 4 5 6 7

Very Acceptable | Just Acceptable | Very Unacceptable

i) NOISE FROM CHILDREN

Very Acceptable | Just Acceptable | Very Unacceptable

j) OTHER NOISE, Please name ______________________

1 2 3 4 5 6 7

Very Acceptable | Just Acceptable | Very Unacceptable

k) OTHER NOISE, Please name ______________________

1 2 3 4 5 6 7

Very Acceptable | Just Acceptable | Very Unacceptable

2. If any of the following noises is unacceptable to you in your present home, indicate in what way each, if any, of the noises disturbs you so much as to make it unacceptable in your present home:

	Startles	Keeps from going to sleep	Wakes up	Interferes with TV or Radio	Interferes with Telephone	Inteferes with Conversation	House Vibration
a) Aircraft flying overhead							
b) Street noise from passing cars and/or trucks							
c) Slamming doors, cars backfiring, bangs or other impulsive noises							
d) Dishwasher							
e) Washing machine							

Budget Bureau No. 04-S69034

II RATING SCALE FOR LABORATORY NOISES

You will hear in the laboratory from time to time, noises that we would like you to rate in terms of their relative unacceptableness, objectionableness, noisiness, unwantedness, or general annoyance if the noise you have just heard was to be heard periodically in your home, say 20 to 30 times, at random, every or nearly every day.

Remember, try to rate each of the noises as though you were to hear it in your home engaged in normal activities and rest, and the noise was a regular part of your living environment.

Each of the noises you will hear will be at a level of intensity typical for these noises in or near homes in various communities in the U.S.A. None of the noises will be unusual to many citizens in the U.S.A., and will be like noises heard everyday by those people.

1. ______________________

1 2 3 4 5 6 7

Very Acceptable — Just Acceptable — Very Unacceptable

2. ______________________

1 2 3 4 5 6 7

Very Acceptable — Just Acceptable — Very Unacceptable

3. ______________________

1 2 3 4 5 6 7

Very Acceptable — Just Acceptable — Very Unacceptable

4. ______________________

1 2 3 4 5 6 7

Very Acceptable — Just Acceptable — Very Unacceptable

5. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

6. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

7. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

8. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

9. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

10. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

11. ____________________

1	2	3	4	5	6	7
Very Acceptable			Just Acceptable			Very Unacceptable

12. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

13. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

14. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

15. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

16. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

17. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

18. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

19. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

20. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

21. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

22. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

23. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

24. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

25. ____________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

26. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

27. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

28. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

29. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

30. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

31. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable

32. ______________________

1 2 3 4 5 6 7

Very Acceptable Just Acceptable Very Unacceptable