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PRELIMINARY STUDIES OF THE IMPULSE-NOISE EFFECTS ON HUMAN HEARING (PROJECT HUMIN)

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December 1964
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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND,
MARYLAND

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Aberdeen Proving Ground, Maryland

ABSTRACT

This report summarizes the accomplishments of the U. S. Army Human Engineering Laboratories impulse-noise program (Project HUMIN). After reviewing past research and stating the rationale for studying how impulse noise affects human subjects, it gives detailed descriptions of the apparatus and procedures which have been developed for the program. The results of four preliminary impulse-noise experiments with human subjects are presented and discussed, together with certain special problems which have arisen during the conduct of the program. Finally, the projected future course of the project is outlined.

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PRELIMINARY STUDIES OF THE IMPULSE-NOISE EFFECTS ON HUMAN HEARING (PROJECT HUMIN)

INTRODUCTION

The Impulse-Noise Problem

The U. S. Army Human Engineering Laboratories (HEL) are studying how exposure to impulse noise (e.g., gunfire) affects human hearing and behavior, because temporary or permanent decrements in auditory acuity, or noise-induced decrements in human performance, may be expected to affect the ability of Army personnel to carry out their assigned tasks.

The term "impulse noise" is used to refer to several transient acoustic events which accompany weapon discharges when projectiles are discharged from a tube or barrel, particularly closed-breech weapons. The first of these is "blast," in which the gaseous combustion products escape from a small volume state to a volume compatible with ambient atmospheric pressure. Blast is a one-way flow of molecules outward from the center, rather than an oscillatory motion, and is confined to a relatively small volume around the center of the reaction (i.e., the muzzle of a gun). The second event is the "shock wave," which is an instantaneous increase in pressure caused by a disturbance moving faster than the speed of sound. In this phenomenon the molecules move in an oscillatory fashion. The third event, an "impulse sound wave," also involves the oscillatory movement of molecules, but travels at the speed of sound (13).

This research program (Project HUMIN) is concerned with both the shock wave and impulse sound wave -- or with the effect of the increased pressure resulting from these phenomena -- and, for the purposes of this report, both shock waves and impulse sound waves are subsumed under the term <u>impulse noise</u>. These two events will not be distinguished, because the transducers used to measure pressure do not differentiate between air molecules moving <u>at</u> the speed of sound (impulse sound waves), and those moving <u>faster than</u> the speed of sound (shock waves). (There are several photographic techniques for establishing whether or not a shock wave passes a given point, but these techniques cannot readily be used for day-to-day impulse-noise measurements.)

Both of these phenomena are transient in nature. They differ from steady-state noise in two important ways: their peak-pressure levels are very high, compared to the root-mean-square (RMS) level; and their peak pressures are short, compared to the time between impulses. Two quantitative factors which do distinguish shock waves from impulse sound waves are amplitude and rise time. At any given point around an Army weapon, a shock wave has greater amplitude and shorter rise time than an impulse sound wave.

This report calls any transient pressure an impulse noise (regardless of its cause), and calls its maximum pressure the peak sound-pressure level (SPL).

It has been observed that the long-term exposure of personnel to impulse noise in both military (18, 34) and industrial (37) environments can cause permanent damage to hearing. This observation is important not only for humanitarian reasons, but also because hearing damage may keep personnel from performing efficiently and because severe permanent hearing damage is compensable under Veterans Administration disability regulations. Obviously, permanent noise-induced damage to hearing can cost the Government dearly, both in human efficiency and in dollars.

In addition to permanent hearing losses, it has been found (2, 6, 8, 17, 30, 31, 32, 34, 42, 49) that relatively short-term exposure to impulse noise can cause temporary hearing losses (hereinafter referred to as "temporary threshold shifts" -- TTS). If the TTS is large enough, it may interfere with speech communications or with detecting the enemy in auditory surveillance situations. Many authorities in the field of psychoacoustics (e.g., 25, 27, 39) assume that TTS's occurring during years of near-daily noise exposure will somehow cumulate into the permanent hearing damage discussed in the preceding paragraph.

Recognition of the hazards associated with exposure to noise (both of the impulse and steady-state types) has stimulated the development of a number of hearing-protective devices, e.g., ear plugs and earmuffs, and it has been found that such devices, used either singly or in combination, afford some protection from noise effects (10, 23, 35, 41, 46, 50). Therefore it could be argued that, to solve the noise problem, personnel should be instructed to wear hearing-protective devices in hazardous noise environments -- thus obviating the necessity for studying how noise affects hearing and behavior.

In many instances, however, personnel cannot, or will not, wear hearing-protective devices (e.g., troops in combat). It is important to be able to anticipate the type and amount of TTS which unprotected ears may show after short-term exposure to such situations, as well as the amount of permanent noise-induced hearing damage which may result from long-term exposure under these conditions. In addition, while hearing-protective devices attenuate impulse noise to a certain extent, no known protective device affords complete protection from the risk of TTS; thus it becomes desirable to know how much TTS may result when personnel do wear protective devices in high noise-level environments.

Impulse noise has a number of measurable characteristics, including peak SPL, rise time, duration, and rate of repetition. Their relative effects on hearing -- both singly and in interaction -- should be examined to determine how much TTS will result from exposures to various conditions. This information can be used to derive both damage-risk criteria and weapon-system design criteria. The damage-risk criteria can be used to specify how much noise personnel can be exposed to without risk of excessive TTS, while the weapon-system design criteria will be especially valuable if future developments in weapon-system technology allow us to modify some of the characteristics of current Army weapons, e.g., excessive peak SPL.

A Review of Past Research

The first systematic studies of how impulse noise affects humans were published by Murray and Reid in 1946 (31, 32). These Australian scientists exposed enlisted men to a variety of small arms and artillery and, despite relatively crude instrumentation, provided the first quantitative data about the effects of impulse noise on hearing. Figure 1 shows some of their results. Note that, after exposure to ten rounds (impulses) at a peak SPL comparable to that in the crew area of a current U. S. Army 105mm howitzer, the TTS was about 85 dB.

Judging from the literature, impulse-noise research was dormant from 1946 until the 1950's. (A few animal studies were reported during this period, but no references to studies of humans have been found.) The next studies of note were published by Harbold and Greene in 1961 (19, 20). These investigators established that personnel going through Marine Corps basic training incurred small but permanent hearing losses. Needless to say, this finding sparked considerable interest in impulse noise.

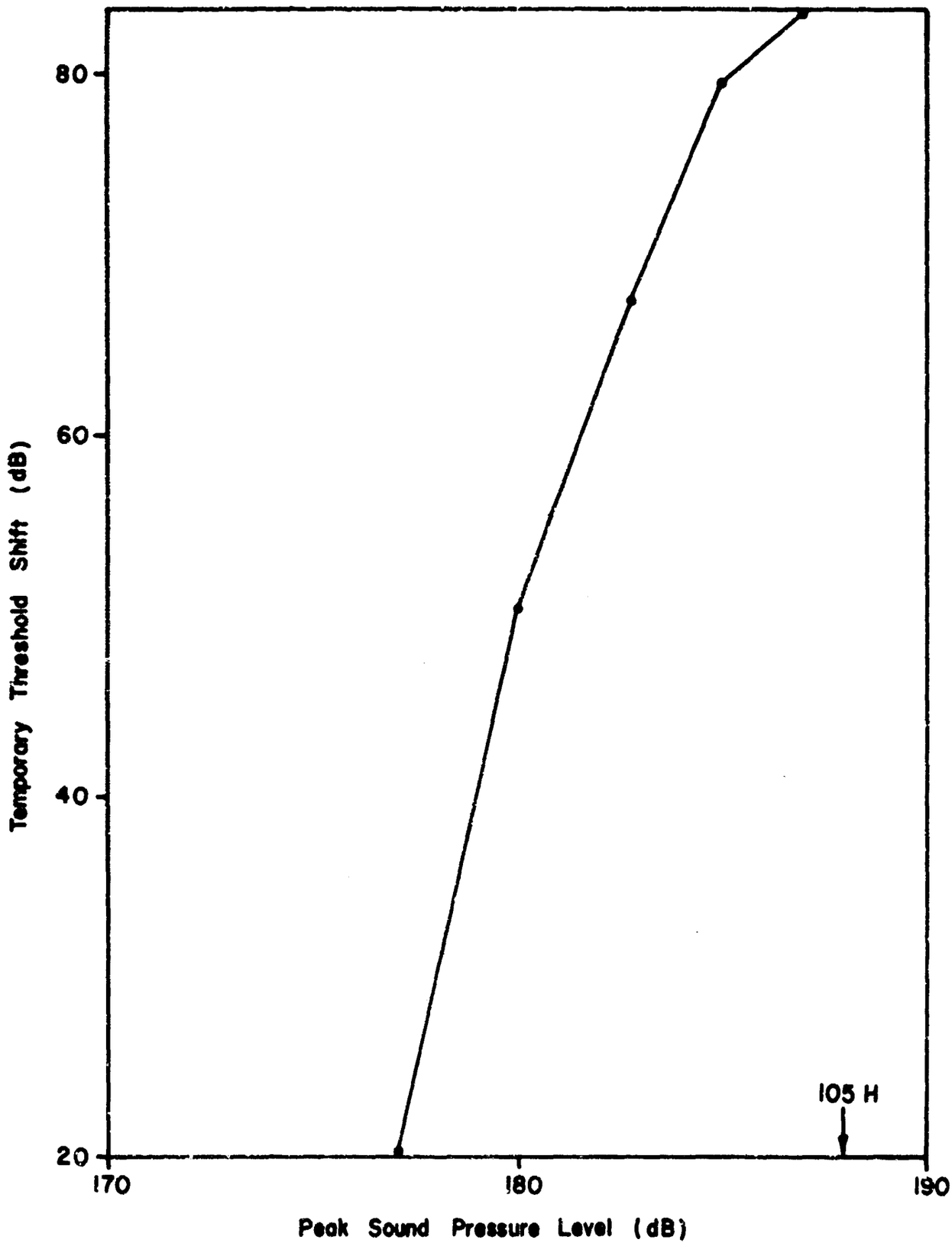


Fig. 1. TEMPORARY THRESHOLD SHIFT AS A FUNCTION OF EXPOSURE TO TEN IMPULSES AT VARIOUS PEAK SOUND-PRESSURE LEVELS
(Data from Murray and Reid, Refs. 31, 32)

In the past four years, there has been considerable research on the impulse-noise problem, much of it carried out or sponsored by Army research laboratories. However, methodological shortcomings cast some doubt on the usefulness of much of this work for predicting TTS in Army personnel.

Since it is impractical for many researchers to use firearms as impulse-noise sources, and likewise impractical to fire weapons indoors under rigidly controlled laboratory conditions, some other form of impulse-noise source was needed. A number of mechanical and electronic impulse-noise sources have been constructed for use in laboratory research (22), but all those known have the same limitations, i.e., the acoustic impulses they produce are sufficiently unlike those the Army weapon systems produce, to cast some doubt on the usefulness of the quantitative data published. In other words, the amounts of TTS which have been attributed to certain noise conditions are, in many cases, of questionable value because it is doubtful whether the noise conditions are comparable to those Army weapons produce. However, the qualitative relationships among various exposure conditions used in a given study are probably valid. The major shortcoming of most of these mechanical and electronic noise sources is that the impulses' rise times are too long and their durations too short for them to approximate the impulses Army weapons produce.

Assuming that at least the qualitative relationships are valid, the following summarizes our present knowledge in this area:

a. There are very large individual differences in susceptibility to impulse noise in the Army population, and within the population of Americans in general. This fact is illustrated, in Figure 2, by data from a study by Carter and Kryter (6). It can be seen that the subject represented by the upper curve sustained a TTS of 41 dB after exposure to 20 impulses having a peak SPL of 156 dB, while another subject, represented by the lower curve, sustained a TTS of only about 8 dB from exposure to just as many impulses with a much higher peak SPL, viz., 168 dB. The impulses used in this study were generated by an electronic impulse-noise source employing a conventional loudspeaker as the final electrical-to-acoustic transducer, but similar variation in susceptibility has been reported by Smith and Goldstone (42) and Donley (12) using the M14 rifle as a noise source in studies carried out in these Laboratories. It has been estimated that at least five percent of the Army population are extremely susceptible to impulse-noise effects, while at least five percent are extremely resistant to these effects.

b. Other conditions equal, it appears that the higher the peak SPL, the greater will be the amount of TTS produced. This relationship is illustrated in Figure 1, showing some of the Murray and Reid (31, 32) data. The unknown quantity, however, is the lowest peak SPL which will cause a measurable TTS in the average subject. Figure 3 shows some data from Ward, Selters, and Glorig (49) in which exposure to 75 impulses with a peak SPL of only 132 dB produced a measurable TTS. It can also be seen that there was about 12 dB of TTS when the peak SPL was 141 dB. These data were gathered using other types of electronic or mechanical noise sources.

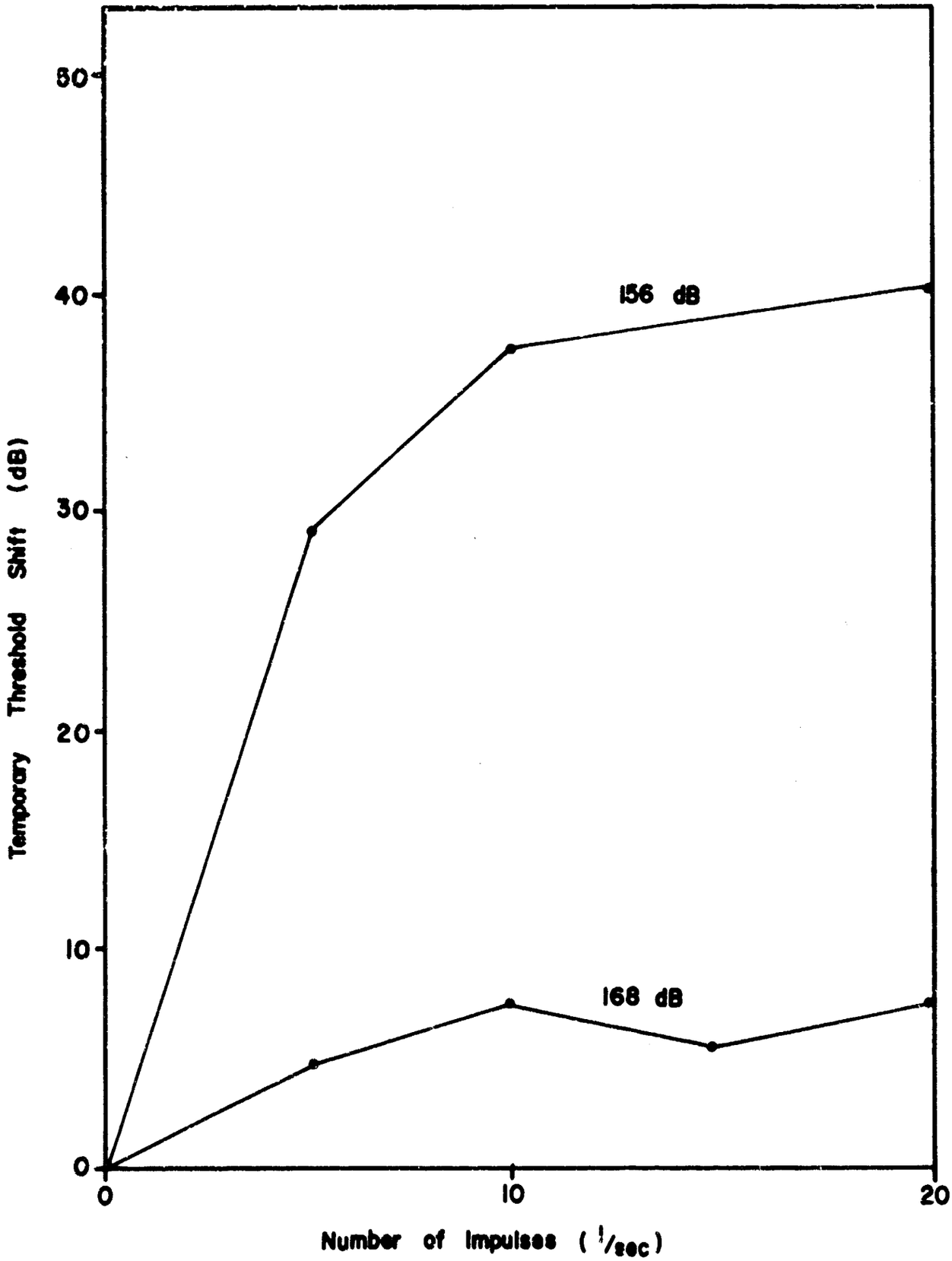


Fig. 2. TEMPORARY THRESHOLD SHIFT AS A FUNCTION OF NUMBER OF IMPULSES FOR TWO SUBJECTS DIFFERING IN SUSCEPTIBILITY TO NOISE EFFECTS (Data from Carter and Kryter, Ref. 6)

Experiments carried out in these Laboratories (4) have shown that there is negligible TTS (less than 5 dB) after exposure to 100 gunfire impulses with a peak SPL of 140 dB. Thus, while it may be logical to assume some relationship between peak SPL and amount of TTS produced, the data now in existence are insufficient or inadequate to answer the question, "What is the critical peak SPL where temporary hearing loss can be expected to begin to occur in the average subject?"

c. The rate of exposure has been shown to have an important bearing on the amount of TTS produced. Ward (48) demonstrated that, when the rate of exposure was between one impulse per second and one impulse per nine seconds, there was no significant difference in the amount of TTS produced. However, when the rate was decreased to one impulse every 30 seconds, the TTS was considerably less, indicating that some recovery occurred in the 30 seconds between successive impulses. A number of studies by the Army Medical Research Laboratory (Ft. Knox) have also shown that as the rate is increased to more than one impulse per second the TTS is decreased (cf. 14). This is taken, along with other evidence, as indicating that the acoustic (intratympanic muscle) reflex of the middle ear muscles, once activated and sustained in activation, provides a certain amount of protection from the subsequent impulse noise.

d. There is also some evidence to indicate that exposing a person to more impulses at a given peak SPL and rate of exposure, produces larger TTS, but this relationship requires clarification through further study.

To summarize briefly, the knowledge available today is as follows:

a. There are large individual differences in susceptibility to noise effects.

b. Higher peak SPLs mean more hazard to hearing.

c. Rate of exposure can be important.

d. Number of impulses is important.

There are not many data that would indicate how these variables interact, or what type of trade-offs can be made between, or among, impulse-noise parameters.

Also, there is no information about the effects of rise time or duration of individual impulses, because it is not yet possible to generate the type of acoustic impulses needed for research. Research must therefore be conducted with other sources:

a. Electronic or mechanical noise sources which, while providing some control over rise time, duration, peak SPL, and repetition rate, generate impulses which are very much unlike the impulses Army weapons produce, or

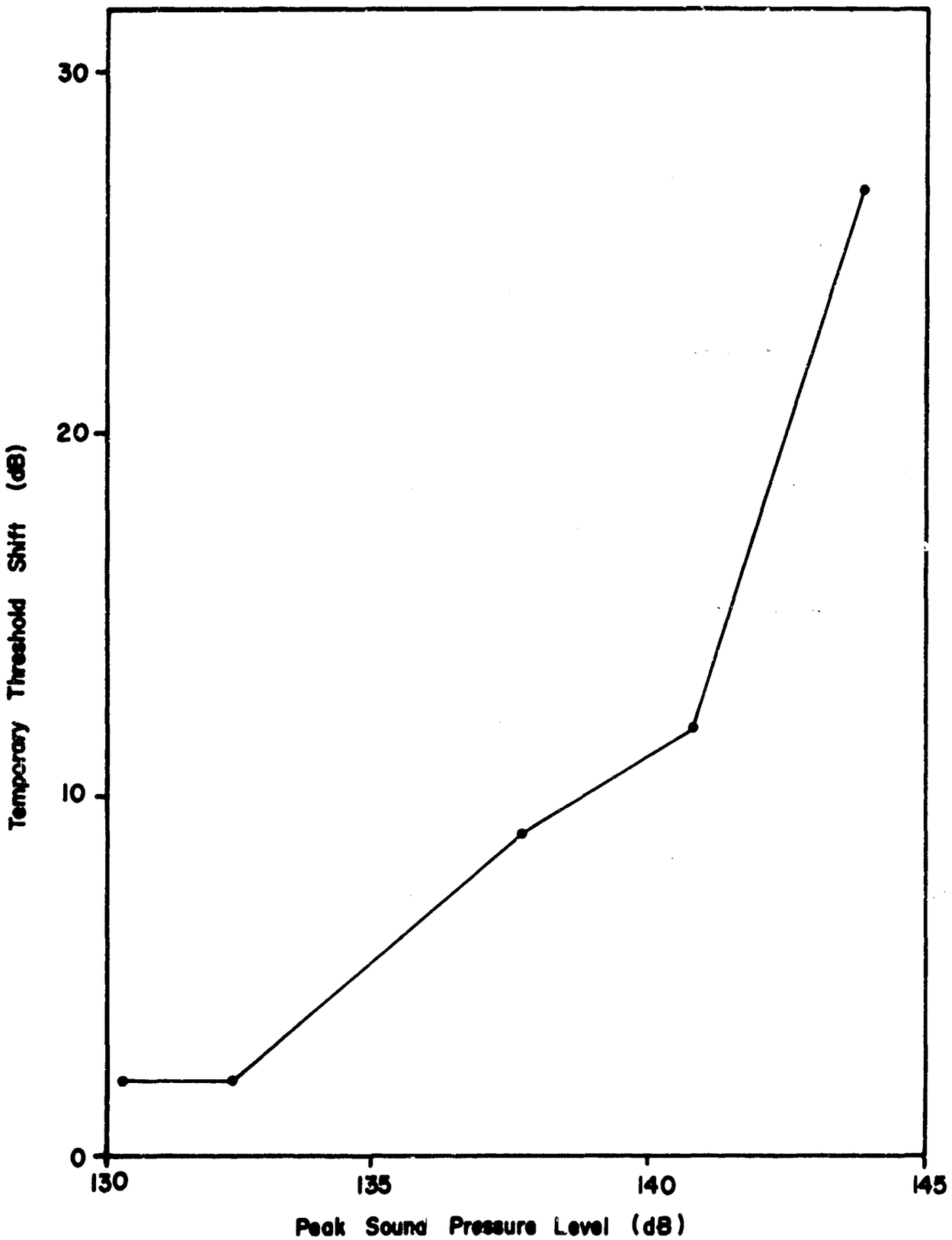


Fig. 3. TEMPORARY THRESHOLD SHIFT AS A FUNCTION OF EXPOSURE TO 75 IMPULSES AT VARIOUS PEAK SOUND-PRESSURE LEVELS
(Data from Ward, Selters, and Glorig, Ref. 49)

b. Actual small arms and artillery whose impulse-noise characteristics are, in general, invariant and can be modified only by placing the subject at various distances from the muzzle.

Goals of this Research Program

The goal of Project HUMIN, stated in a few words, is to discover as much as possible about the effects of impulse noise on human hearing. These data will be used to (a) establish tolerable exposure conditions and damage-risk criteria for the exposure of Army personnel to impulse-noise sources, (b) establish weapon-system design criteria which will obviate or minimize impulse-noise hazards, and (c) provide new basic information about human hearing and behavior.

Guidelines which have been adopted to direct the course of the research program include the following:

a. Firearms (current Army small arms and/or artillery) will be used as sources of impulse noise until such time as a suitable impulse-noise generator becomes available. While this may limit the types of studies which can be conducted, the use of sources producing acoustic transients having the desired characteristics will insure that the quantitative data are valid for the population of subjects from which samples have been drawn.

b. Human subjects will be used in order to avoid the necessity for finding transfer functions between animals and man. Subjects will be drawn from the Army population, subject to certain constraints, and sample size will be 15 or more whenever possible.

c. Initial studies will be concerned with solving the methodological problems arising from conducting impulse-noise studies with humans. When adequate solutions to these methodological problems have been found, studies will be conducted especially to assess the hazards of various impulse-noise conditions.

d. A fundamental ("basic research") approach to the impulse-noise problem will be pursued. The studies will be carried out as part of a long-range program, with minimal digression to study various "practical" problems, e.g., assessment of the hazards associated with new weapons systems.

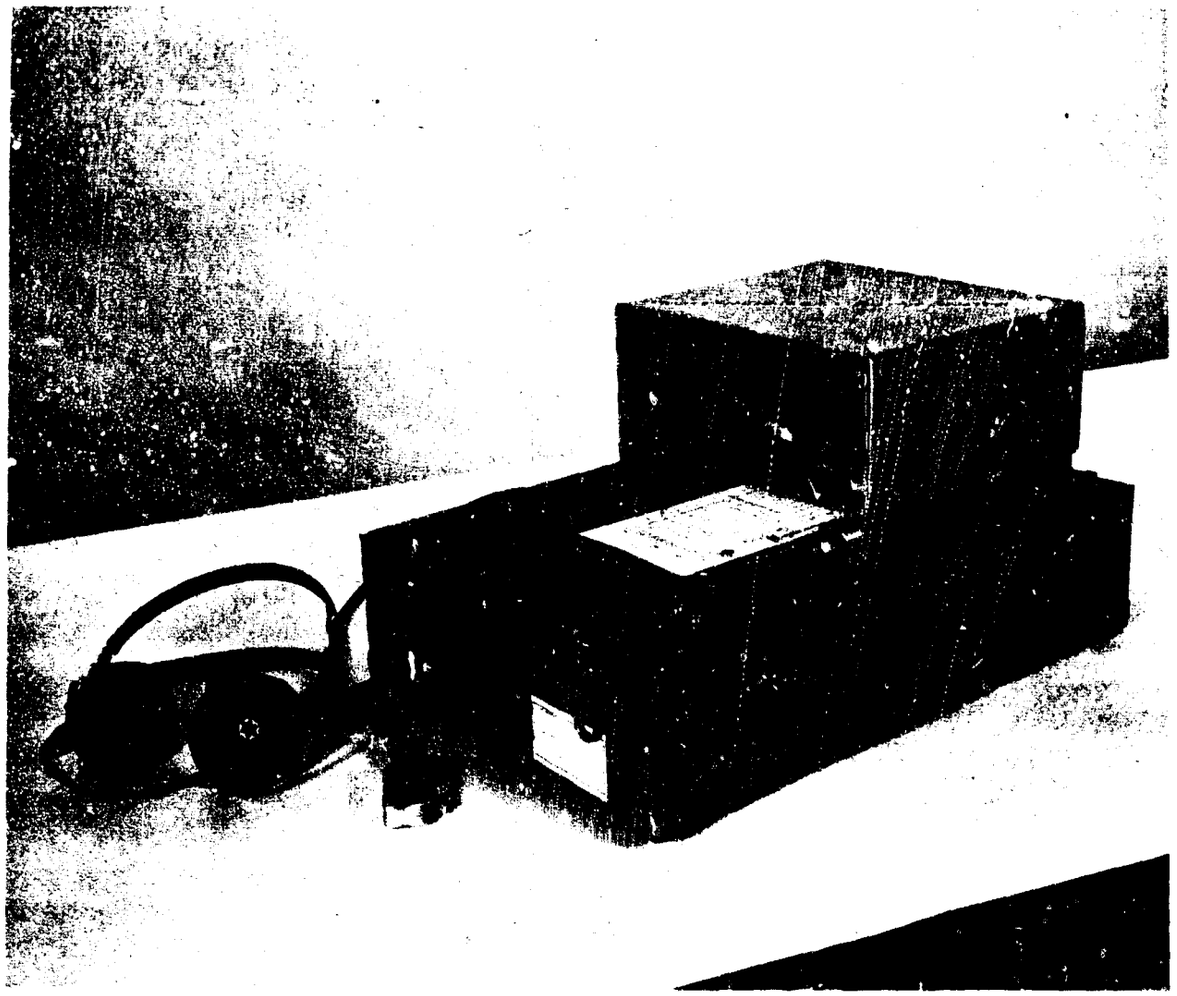


Fig. 4. RUDMOSE ARJ-4 AUTOMATIC AUDIOMETER

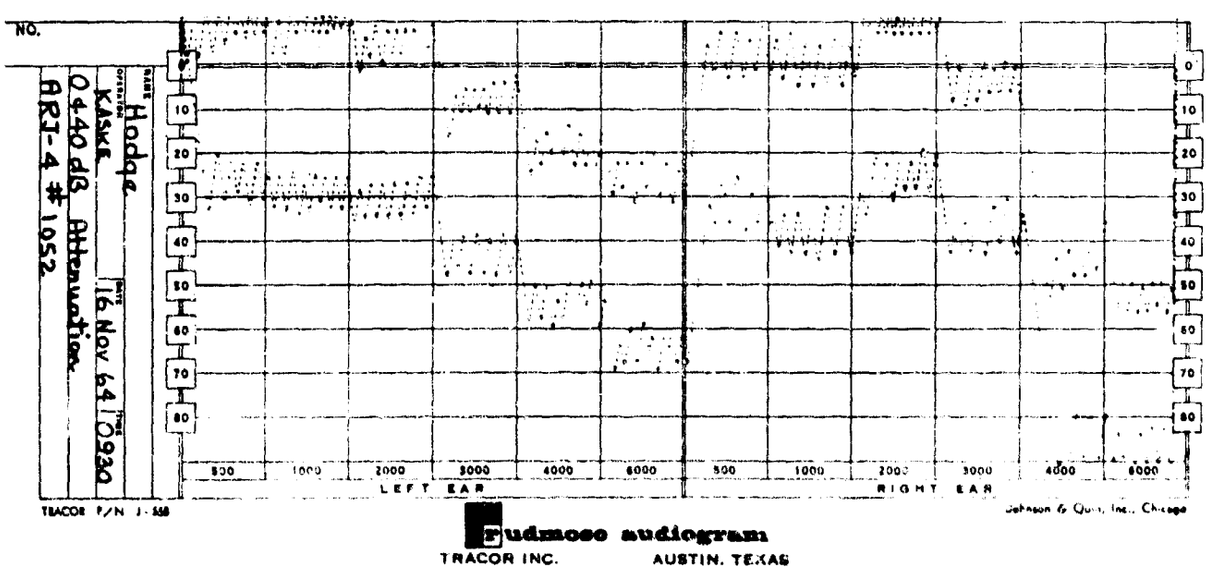


Fig. 5. SAMPLE AUDIOGRAM TAKEN WITH THE RUDMOSE ARJ-4 AUDIOMETER
(Lower trace has 40 dB of attenuation added; upper trace has 0 dB added. See text.)

APPARATUS

Audiometric Testing Facilities

Audiometers

The instrument used for measuring auditory thresholds in this program to date is the Rudmose ARJ-4 automatic audiometer (29). The basic instrument (Fig. 4) was designed for the air-conduction testing of hearing levels at pure-tone frequencies of 500, 1000, 2000, 3000, 4000, and 6000 cycles per second (cps) in each ear. Hearing level is defined as "the deviation in dB of an individual's threshold of hearing from the American Standards Association (ASA) value for the reference zero for audiometers" (11, p. 478). The automatic operation of the audiometer is based on the Békésy technique (45) wherein a reversible attenuator is controlled by the subject's pressing and releasing a response button when he "just hears" and then "just doesn't hear" the test tone; and the intensity of the tone presented via the earphones thus sweeps back and forth across the subject's threshold of hearing. A printing stylus is provided which moves synchronously with the attenuator and traces a permanent graphic record of the subject's responses on a calibrated record card. In using this instrument the operator inserts a record card and turns on the starting switch, whereupon the testing is begun in the left ear, runs through a 30-second test at each of the six frequencies, switches to the right ear and repeats the same six frequencies and, at the conclusion of the six-minute test, the instrument stops automatically. A sample audiogram record card is shown in Figure 5.

Originally the range of hearing levels that could be measured was from -10 to +90 dB (re ASA audiometric zero reference value), but the audiometers used in this project have been modified by adding two resistors and a selector switch so the original range could be attenuated by 20 or 40 dB, if desired. In this way, hearing levels as low as -50 dB can be measured. The need for measuring hearing levels that are considerably below ASA audiometric zero was dictated by the fact that many people have hearing which is far better than the ASA zero values. This fact is the subject of current discussions of the desirability of changing the ASA zero reference value for audiometers (cf. 3).

In addition, the audiometers were also modified so the operator could present tones of either 2000 or 4000 cps to either the right or left ear, continuously, for special purposes.

The upper limit of the frequency range which can be tested with the Rudmose ARJ-4 audiometer is 6000 cps. In a few cases it has been desirable to make tests at higher frequencies, and for that purpose a standard manual clinical audiometer (Maico H-1) was used. The Maico audiometer is shown in Figure 6. This audiometer's upper-frequency limit is 12,000 cps. A modified method-of-limits procedure is used to measure hearing levels at 8000 and 12,000 cps with this instrument.

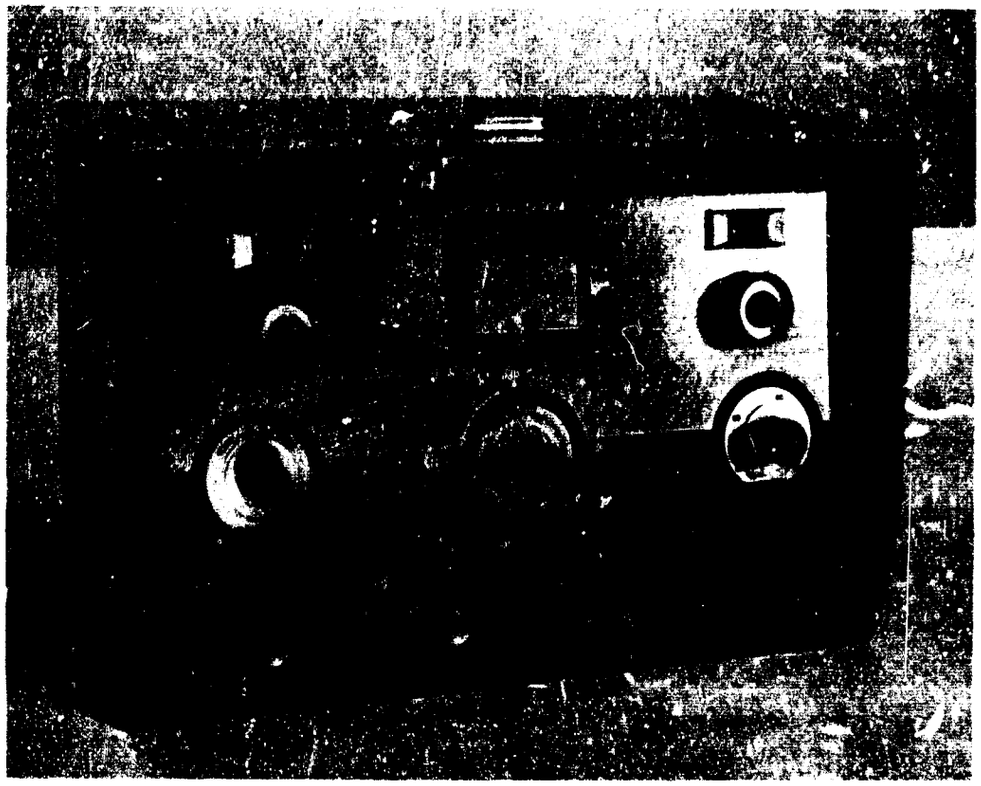


Fig. 6. MAICO H-1 MANUAL AUDIOMETER

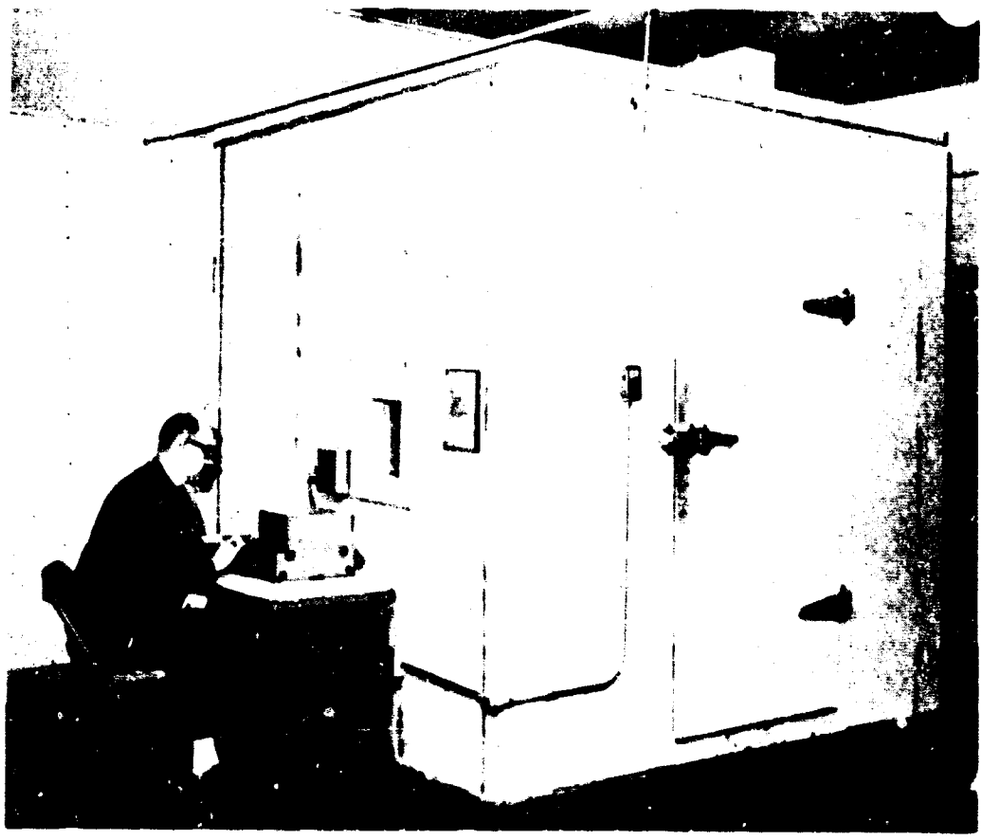


Fig. 7. AUDIOMETRIC ROOM USED FOR TRAINING AND RECOVERY TESTING

Audiometric Testing Rooms

The environment must be relatively quiet for testing auditory acuity to avoid problems due to masking, so two audiometric testing rooms were constructed for this program. The construction details of these facilities have been described by Spellman and Penniman (14). One facility (Fig. 7) is a double-walled room about 10' x 10' x 7', which was originally designed to keep noise in, and which was modified to provide improved attenuation of sound from outside the room. This room is located in a permanent building in a relatively quiet area of Aberdeen Proving Ground, i.e., away from firing ranges and motor pools, and is used for audiometric screening, for training subjects on the audiometric testing procedures used in the noise program, and for measuring recovery from the effects of noise exposures.

A second audiometric testing facility (Fig. 8) consists of a weatherproof, heated, and air-conditioned shelter about 6' x 10' x 10', with a smaller double-walled audiometric testing booth about 3' x 4' x 7' located in one corner. The larger shelter was designed to be portable and has, on occasion, been moved from the main laboratory area to one of the firing ranges without damage. It thus can be located near the place where subjects are given noise exposures, and it is used primarily for pre- and post-exposure audiometric testing.

It has not been possible to make any sound-attenuation measurements on these two audiometric testing facilities. However, maximum SPLs in various octave bands have been measured during normal operational conditions and these are shown, together with the ASA standards for audiometric rooms (1), in Table 1. It can be seen from an inspection of Table 1 that the SPLs in both rooms are well below the maximum allowable SPLs for audiometric rooms as specified by the ASA.

Source of Impulse Noise

In selecting an impulse-noise source for this project, the following characteristics were considered essential:

a. The acoustic pulses should resemble gunfire as closely as possible; they should actually be gunfire pulses produced by an Army weapon, if possible.

b. It should be possible to produce the pulses at any rate up to one per second.

c. It should be possible to produce any desired number of pulses even at the fastest rate of fire.

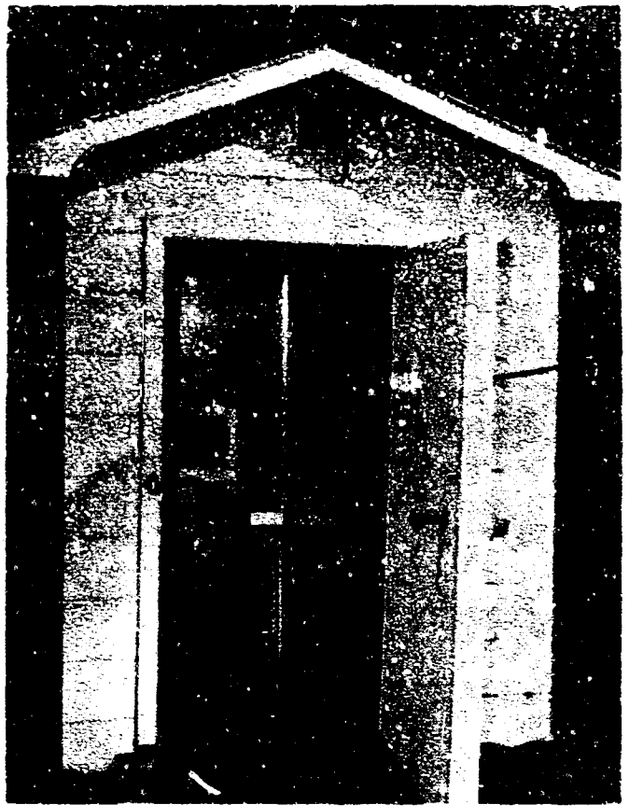


Fig. 8. PORTABLE SHELTER AND INTERIOR AUDIOMETRIC BOOTH USED FOR PRE- AND POST-EXPOSURE TESTING IN THE FIELD

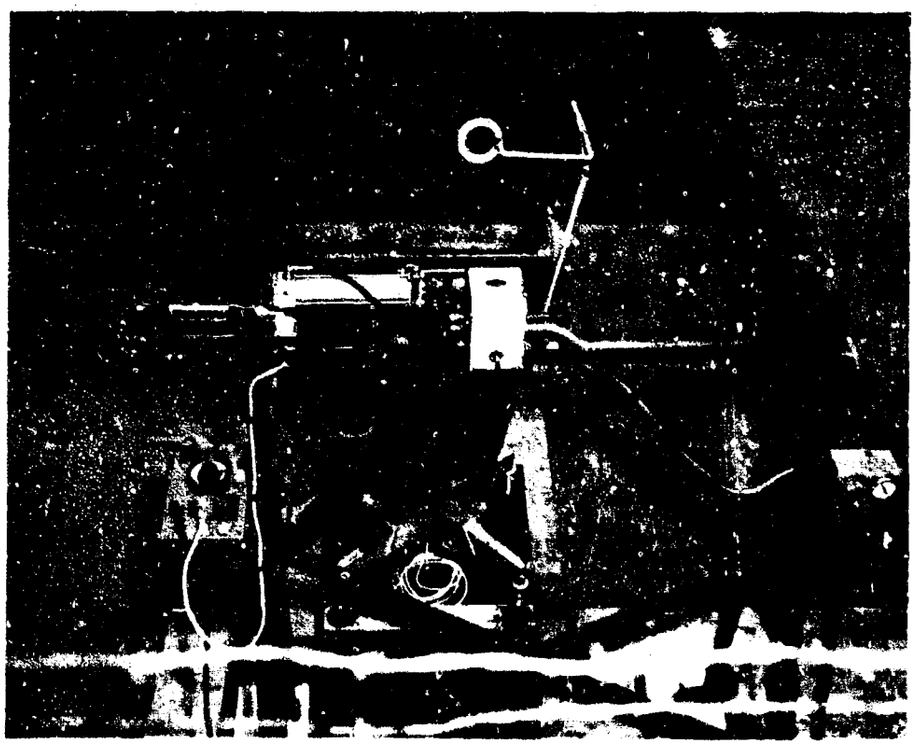


Fig. 9. M60 MACHINE GUN USED AS AN IMPULSE-NOISE SOURCE (Pneumatic operating mechanism -- near side; rigid firing stand, and subject's chair and ear-positioning device -- far side.)

TABLE 1

Sound-Pressure Levels (SPL) in Six Octave Bands
Measured in Two Audiometric Testing Rooms
(In dB re 0.0002 microbar)

Octave Band (cps)	SPL Room #1[a]	SPL Room #2[b]	ASA Maximum SPL
150-300	29	19	40
300-600	21	14	40
600-1200	19	11	40
1200-2400	18	12	47
2400-4800	18	14	57
4800-9600	19	15	62

[a] Used for pre- and post-exposure testing.

[b] Used for training and recovery testing.

Satisfying the second and third requirements would have required using a belt-fed, semiautomatic weapon, but there is no such weapon at present. HEL determined that the simplest solution was to modify an existing belt-fed automatic weapon (machine gun) so it would fire semiautomatically. The noise source used in the initial preliminary studies was an M60 machine gun firing blank ammunition. Since this gun is gas-operated (i.e., it uses part of the gas from the burning propellant to operate a piston which charges the weapon), it would not work as a machine gun with blank ammunition because the barrel pressure was much too low.* To provide the required semiautomatic operation HEL designed and constructed a pneumatically operated and electronically controlled attachment for the machine gun's operating handle, which ejects spent cartridge cases after firing and prepares the weapon to fire the next round. This system (Fig. 9) has been described in detail by Spellman, Patton, and Penniman (43).

* There is a "blank firing adapter" that constricts the muzzle opening and keeps the barrel pressure high long enough for normal gas operation of the mechanism, but this attachment changes the impulse-noise characteristics (lengthens the rise time and decreases the peak SPL) to such an extent that the noise produced is not suitable for use in this program.

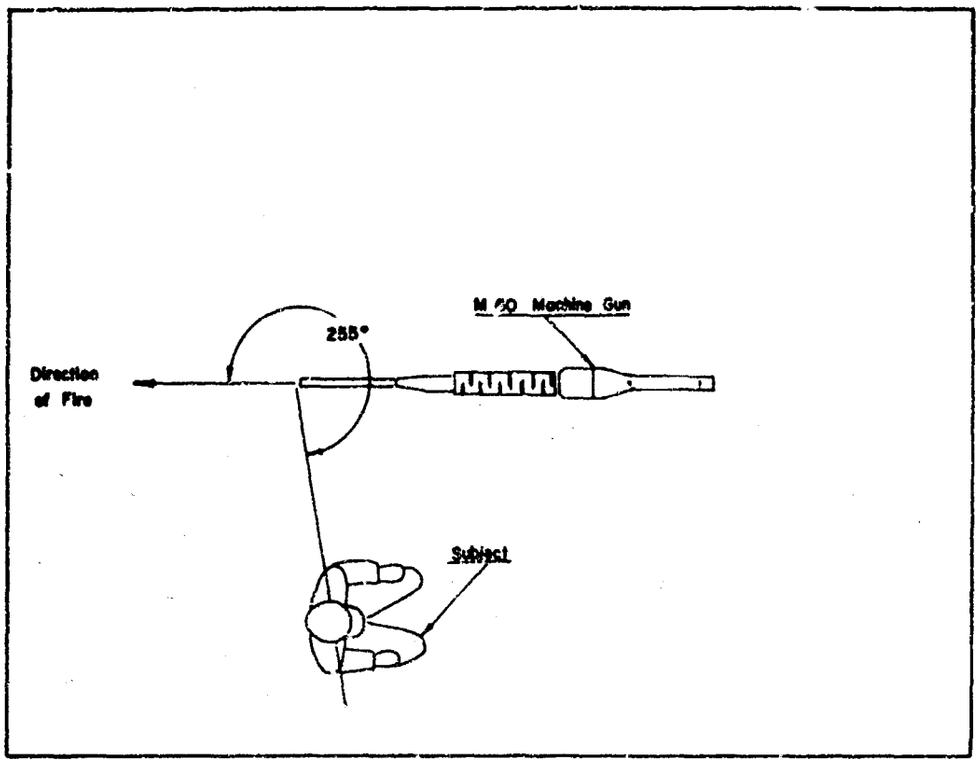


Fig. 10. SCHEMATIC DIAGRAM SHOWING THE SUBJECT'S POSITION RELATIVE TO THE MACHINE GUN MUZZLE

Fig. 11. SUBJECT'S CHAIR AND EAR-POSITIONING DEVICE, SHOWING THE CHAIR MOUNT, WHICH IS ADJUSTABLE IN HEIGHT

After three preliminary studies had been conducted with this firing system, there were difficulties in securing additional supplies of blank ammunition and it was necessary to continue the program by firing ball ("live") ammunition. (For a discussion of this problem, see the Special Problems section.) This change required immobilizing the gas piston of the M60 machine gun so the increased pressure of the gases in the barrel would not cause the weapon to operate automatically. Other aspects of the pneumatics and electronics remained the same.

Subsequently, an electronic firing circuit was devised to pulse the machine-gun trigger for less than 0.01 second. Inasmuch as the automatic rate of fire of the M60 machine gun is about 550 rounds per minute, pulsing the trigger for this short period of time (< 0.01 sec.) fired just one round. This new firing circuit eliminated the need for pneumatic operation, since the system is now essentially a gas-operated, semiautomatic weapon firing one round at a time, with an electronic timer controlling the rate of fire.

Seating and Positioning the Subject

A noise exposure, as defined for the purposes of this research program, typically involves exposing a subject to a series of gunfire impulses that all have the same peak SPL and are delivered at some fixed rate. In order to keep the peak SPL at the entrance to the subject's ear canal the same throughout the exposure, it was necessary to provide a comfortable chair and a suitable head-positioning device.

In the preliminary studies conducted under this program, subjects have been exposed at various points on an azimuth of 255° from the direction of fire (Fig. 10). This arbitrary azimuth was selected because the equal-peak-SPL contours around the gun were more uniform in this vicinity, and also because safety regulations prohibit anyone in the immediate firing area from being forward of the muzzle during firing. Positioning the subject on this azimuth of 255° automatically placed the subject behind the muzzle.

The subject's chair is shown in Figure 11 (see also Fig. 9). The chair had a rigid base. Its seat height could be adjusted to keep all subjects' ears at muzzle height above ground. A head-positioning device (Figs. 9 and 11) was attached to the chair to keep the subject's left ear in a constant position during a noise exposure. The subject placed his external ear (pinna) through the foam-rubber-covered ring and held his head against the ring during an exposure. For some later studies the head holder was modified (Fig. 12) so that the subject placed the back of his head against the holder and looked directly to his front during the exposure. In this way, depending upon whether the subject is facing the muzzle or 90° away from the muzzle, either one or both ears could be given the noise exposure.

The subject's ear was kept at the proper distance from the muzzle by positioning the chair and its mount on a level plywood platform on the ground.

Fig. 12. MODIFIED SUBJECT'S CHAIR AND HEAD-POSITIONING DEVICE
(The subject is wearing an earmuff over his non-exposed ear. The experimenter is checking the height of the subject's ear canal above ground before a noise exposure.)

PROCEDURE

Subjects

Any research program should be carried out with subjects drawn from the population to which the results are to be applied. In this program on the effect of impulse noise on human hearing, the primary interest is to generalize the results to the Army population; therefore, Army personnel are used as subjects.

Most of the subjects used in these studies are stationed somewhere other than Aberdeen Proving Ground; they are assigned to temporary duty (TDY) with these Laboratories to serve as subjects in various human factors studies. The personnel, mainly enlisted men (EM), may be requested specifically for the noise program, in which case they also serve in other human factors studies as time permits. Or they may be requested for some other program and participate in the noise program on a time-available basis. In either event, a given group of subjects for the noise program is not used in any other study involving noise exposure sufficient to cause TTS.

Truly random sampling cannot be used to select subjects for these noise studies. However, experience has shown that personnel are assigned to this TDY from various Army Areas and from many stations, and it is believed that the incidental samples thus obtained are, for practical purposes, representative samples of the Army population.

Certain criteria are used in selecting subjects for these noise studies, to insure using only personnel who are free of chronic otolaryngological defects and possess "normal" hearing. The following is a quotation from a recent letter requesting subjects:

> "Medical personnel at home station should screen all personnel to insure compliance with the following criteria. Personnel not meeting these criteria cannot be used in the studies planned.
>
> "(1) Class "A" physical profiles.
>
> "(2) Personnel should be free of chronic otolaryngological conditions, such as colds, sinus infection or drainage, asthma, perforated ear drums, ear infection, excessive cerumen, tinnitus, etc.

"(3) Hearing levels of personnel should be tested with a calibrated audiometer and must be within 15 decibels of ASA audiometric zero at test frequencies of 500, 1000, 2000, 3000, 4000, and 6000 cycles per second in both ears. A copy of each man's audiogram must be furnished these Laboratories prior to his arrival at Aberdeen Proving Ground."

The practice of using only "normal" subjects in these studies insures that the data evolved can be compared with those of other investigators who screen their subjects in a similar manner. It also has the effect of rejecting from 30 to 50 percent of the Army population, and the problem of this very high rejection rate will be considered in the Special Problems section.

Briefing and Training

Personnel assigned to serve as subjects for this program are given a briefing and orientation before they participate in any studies. The overall mission of the Human Engineering Laboratories is discussed, and illustrative examples of the contribution of human factors engineering to improved Army materiel design are presented. (Most of the personnel assigned to this TDY have never heard of "human engineering" before arriving at Aberdeen.) Each project director who expects to employ the personnel as subjects then explains what is expected of them. These explanations vary in length, from a very detailed exposition on the noise program, to merely introducing an experimenter who prefers to brief his subjects individually as they are called on to participate in his study.

The briefing on the noise program is accompanied by sketches, pictures, and color slides which serve to familiarize the subjects with each step in the experiment. A seven-minute color movie showing the steps in a noise exposure is also shown. To motivate the subjects into doing their best, every effort is made to impress them with the research's importance and its potential benefits, both to the Army as a whole and to the individual soldier.

Following the briefing, subjects in the impulse-noise studies are given a period of training on the audiometric technique used in the program. Specifically, each subject is given at least six audiograms on the Rudmose ARJ-4 audiometer. It has been found in studies carried out in these Laboratories (21) that variability decreases, while ease of scoring Békésy audiograms increases, with increased use of the equipment. HEL studies show that, on the average, six complete audiograms constitute sufficient practice.

Pilot studies have also shown that practice on the audiometric technique is just as effective when all six audiograms are given on a single day (with rest between tests) as when they are spread over several days (21). As a result, five or six subjects are scheduled for audiometric training each day. These subjects are given the first audiogram in rotation, then their second test, and the rotated testing is continued until each man in the group has been tested six times. In this way, about 45 minutes elapses between successive tests for a single subject.

Before the first audiogram, the subject is seated in the audiometric testing room (Fig. 7) and given the following instructions:

> "Your hearing will be tested with the Rudmose Automatic Audiometer. This instrument tests your hearing at each of six frequencies, and in both ears. It switches from one frequency to the next, and from the left to the right ear -- automatically -- and prints out a record for each of the 12 tests.
>
> "Place the headphones over your ears so they fit snugly, being sure that the red phone is over your right ear. Keep the hand switch in your hand at all times. When the green light comes on, if you are ready, nod your head.
>
> "When the test begins, you will hear a series of tones or beeps. Hold the switch button down as long as you can hear the tones or beeps. Release the switch when the tones or beeps disappear. Note the instructions on the sign above the window: 'Press when you hear; release when you don't.'
>
> "You should breathe at your normal rate during the test, but you may find that you can hear better if you breathe through your mouth instead of through your nose.
>
> "The operation of the audiometer is under <u>your</u> control; it will print out a record according to your pressing and releasing the switch. This means that the printed record will only be as good as you make it!
>
> "If you have any questions at all, please ask the operator. Thank you."

During the period of audiometric training, each subject fills out a special personal history form (Fig. 13). The medical history section provides information which is of value in determining whether or not a subject is qualified to participate in the study (per screening criteria stated earlier). The sections on past and current noise exposure are helpful in estimating the average prior noise-exposure history of a given group of subjects.

HISTORY FORM #1

Name_____ Rank____ SN_____ MOS_____

Organization_____ Birth date_____ Age_____

Date entered service_____ Months in service_____

MEDICAL HISTORY:

Are (were) your parents, grandparents, brothers, or sisters deaf or hard of hearing? (Circle which)_____

Have you ever had: Ear aches___, Head injuries___, Mastoid infection___, Running ears___, Sinus trouble___, Asthma___, Hay fever___, Ringing ears___, Ear trouble of any kind___. (Check which) Do you have a cold, hay fever, or sinus condition today?_____

PREVIOUS CIVILIAN NOISE EXPOSURE:

Civilian occupation_____ How long?_____

Did you wear ear plugs on the job?_____. Have you been exposed to loud noises such as in hunting, target shooting, motor-boating, hot-rodding, aircraft, etc.? (Circle which)_____

PREVIOUS MILITARY NOISE EXPOSURE:

Military duties to the present_____

Months in combat_____ Months overseas_____ Where?_____

Advanced Infantry Basic?____ When?____ Weapons fired_____

Have you ever worked with tanks, artillery, etc.?____ When?_____

PRESENT OFF-DUTY NOISE EXPOSURE:

Are you exposed to loud noises during non-duty hours, or weekends, such as fire-arms, motor boats, lawn mowers, hot rods, aircraft, etc.? (Circle which)_____

COMMENTS:

_____

_____

_____

_____

Fig. 13. SPECIAL PERSONAL HISTORY FORM USED IN THE IMPULSE-NOISE PROGRAM

Impulse-Noise Exposure

Five or six subjects are usually scheduled for each exposure session, and sessions are conducted both morning and afternoon, five days a week, in all kinds of weather except for heavy precipitation (rain or snow).

The subjects for a given session are transported to the noise-exposure area in a group. The exposure area is some seven miles from the billets, on a firing range which is located in a relatively quiet area of Aberdeen Proving Ground (there is no interference from the noise of firing on adjacent ranges). Upon arrival at the range, the group of subjects is given a brief description of the test schedule and what will be expected of them. Following this briefing, the subjects are tested individually.

The following steps are used in exposing each subject to the impulse noise:

a. Subject and test director go into the audiometric testing facility at the range, and a complete audiogram is taken on the subject. Care is taken to insure that a valid test is recorded at all test frequencies in both ears, but especially in the ear that is to be exposed to noise. If the subject shows evidence of tinnitus or some other problem at one or more frequencies, those tests are repeated as necessary to secure an acceptable record.

b. Following the pre-exposure audiogram, the subject is taken to the exposure site (about 50 feet from the audiometric-testing building) and seated in the chair near the gun mount. The height of the subject's ear above ground is measured (Fig. 12) and the chair height adjusted, if necessary, to insure that the ear height is the same as muzzle height. Then the distance from the gun muzzle to the subject's ear is measured (Fig. 14) and the chair position moved, if necessary, to place the subject's ear at the proper distance for the particular noise condition being studied. If only one ear will be exposed to noise, a modified earmuff protector is placed over the other ear (Fig. 12). When the subject is seated facing the muzzle (ear canal side-on to the impulse-noise wave), he is instructed to look directly at the muzzle during the exposure. However, when he is seated facing 90° away from the muzzle (exposed ear canal normal to the impulse-noise wave), he is instructed to pick out an object directly in front of him, e.g., a tree, and look at that object during the exposure. This procedure insures that the subject's ear position will remain constant during an exposure.

c. The machine gun is loaded with a belt containing the appropriate number of rounds (Fig. 15a), and the test director fires it with the electronic firing-control mechanism (Fig. 15b). During the exposure the test director checks the machine gun to insure that it is operating properly, and watches a counter on the firing control box which records the number of rounds fired. If the gun malfunctions, he can pull out the "safety plug" to deactivate the firing circuit immediately.

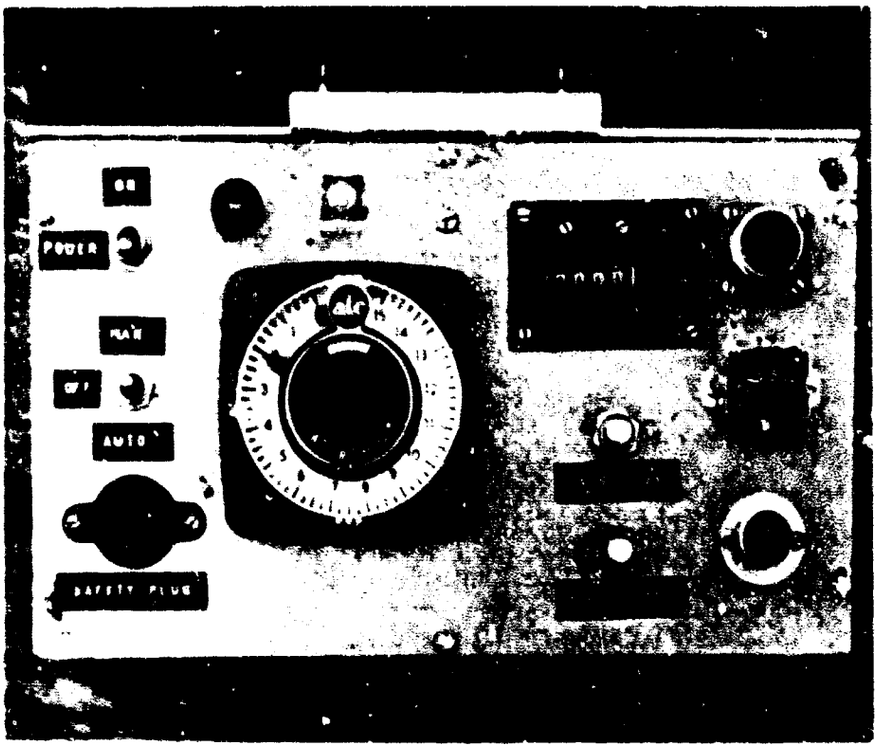
d. As the last round is fired, the test director starts a stopwatch, turns off the firing circuit, and he and the subject go immediately into the audiometric testing facility where a complete post-exposure audiogram is taken. The same audiogram record card is used for both the pre- and post-exposure tests, with different colors of ink, to simplify determining the amount of TTS which resulted from the exposure. The post-exposure test is started when the stopwatch indicates that 35 seconds have elapsed after the last round was fired, and this time is recorded on the audiogram record card. The time of day that the exposure ended is also recorded so it can be used as a base line for plotting recovery functions. (While this post-exposure audiogram is being given, the next subject comes to the test area from the rest area, about 200 yards away, so he will be ready to go at the conclusion of the post-exposure audiogram.)

e. Typically, only one post-exposure audiogram is given at the test area. However, should the results of this test appear atypical, e.g., if there is evidence of a positive TTS in excess of 40 dB, or evidence of a significant negative TTS (apparent improvement in auditory threshold after noise exposure), additional post-exposure audiograms may be given on separate record cards in order to chart the initial portions of the recovery functions.

f. After the post-exposure testing is completed, the subject is sent back to the rest area, and the above procedures are repeated with the next subject. At the conclusion of a testing session, all subjects are returned to quarters.

Fig. 14. EXPERIMENTERS MEASURING THE DISTANCE FROM THE SUBJECT'S EAR TO THE MACHINE GUN MUZZLE PRIOR TO A NOISE EXPOSURE

A. Loading the Machine Gun



B. Electronic Firing-Circuit Control Box

Fig. 15. MACHINE GUN

Testing for Recovery

Subjects take audiometric examinations during recovery from the effects of noise exposure either (a) to simply establish that recovery has occurred, or (b) to study the course of recovery over time. Since the recovery functions for TTS of 40 dB or less are well known (25), the latter is rarely of interest in this research program. Subjects are given one recovery test about four hours after exposure, and additional tests at approximately 24-hour intervals, if necessary, until recovery is complete to within 5 dB of the pre-exposure audiogram. (This criterion for recovery is dictated by day-to-day variations in auditory threshold as determined in pilot studies conducted at these Laboratories [21] and elsewhere.) If a TTS is more than 40 dB, recovery tests may be given every two or three hours to get data which can be used to derive recovery functions for large amounts of TTS.

Audiometric Scoring Procedures

A sample audiogram record card from the Rudmose ARJ-4 audiometer is shown in Figure 5. The dotted trace represents the forward and backward movement of an attenuator across the subject's threshold, at each of six frequencies, and in both ears.

Training and Recovery Audiograms

The technique used in scoring the hearing levels and variability of the training and recovery audiograms is as follows:

a. The instructions in the Rudmose Operating Manual (38) are followed, i.e., if the maximum excursion of the trace is 10 dB or less, the midpoints of the traces for a given ear and frequency are averaged by eye to the nearest 5 dB. When the excursion of the trace exceeds 10 dB, the tops of the traces are averaged and 5 dB is added to that value to arrive at the hearing level. In the latter case the hearing level for a given ear and frequency is empirical and "its justification lies in the fact that correlation between the data taken on the same people with automatic and manual audiometers is good when this scheme is used" (38, p. 4).

b. All hearing levels on training and recovery audiograms are scored to the nearest 5 dB.

c. The first one-eighth inch of each trace (for a given ear and frequency) is disregarded as unreliable.

d. If it appears inappropriate to score to the nearest 5 dB (i.e., when the hearing level appears to be some odd multiple of 2.5 dB), these arbitrary rules are used:

(1) If the hearing level is greater than ASA zero, the next lowest 5 dB level is assigned.

(2) If the hearing level is less than ASA zero, the next highest 5 dB level is assigned.

e. The measure of variability is the number of decibels of extreme range in the trace, scored to the nearest 2.5 dB. This is not the length of the longest single run of the pen but, rather, the total vertical space covered by all traces for a given ear and frequency. Variability scores are useful mostly to assess improvement due to learning the audiometric task.

This laborious manual scoring process is simplified by using a transparent plastic overlay ruled with ten lines 0.075 inch apart. When the top line on the overlay is aligned with a horizontal line on the record card, the vertical divisions of 10 dB are effectively divided into 2.5 dB increments, making the scoring considerably easier.

Pre- and Post-Exposure Audiograms

In scoring the pre- and post-exposure audiograms to determine the amount of TTS which resulted from the noise exposure, the procedure is substantially as outlined above, except that the difference in the pre- and post-exposure hearing levels is scored to the nearest 2.5 dB (training and recovery tests are scored to the nearest 5 dB, because this is precise enough for these purposes). Rudmose (40) justified this procedure, which is contrary to instructions given elsewhere (38), by stating that it is legitimate for "highly trained" personnel to score the limit of the audiometer's attenuator (which is calibrated in 2.5 dB steps). After scoring and interpreting several thousand audiograms, the personnel working on this program would seem qualified as "highly trained," and thus the procedure used is justified. Determining the difference between pre- and post-exposure hearing levels is, of course, simplified considerably by the fact that both of these records are made on the same audiogram record card.

As stated earlier, the first post-exposure audiogram begins 35 seconds after exposure. The first frequency in the left ear is, therefore, tested between 35 and 65 seconds post-exposure, whereas the last frequency in the right ear is tested between 365 and 395 seconds post-exposure. This procedure's usefulness depends on a method for converting all of the TTS data to the same time after exposure.

By convention, most contemporary researchers use the TTS at two minutes after exposure (TTS_2) as the datum describing the effects of noise exposures on hearing (25, 26). In three of the preliminary studies conducted under this program (and described in the Preliminary Experiments section), the post-exposure testing was conducted in a different manner. The test was started at 2000 cps in the exposed ear and continued until two minutes had elapsed after exposure, when the frequency was changed to 4000 cps and continued for one minute. (Audiometer controls making this possible were described in the Apparatus section.) Thus the post-exposure hearing levels at 2000 and 4000 cps could easily be determined directly from the original audiogram. These frequencies were selected because 2000 cps is within the speech range and provided an estimate of the noise exposure's effect on subsequent speech communications, while 4000 cps is the frequency that many investigators report is most affected by noise (5, 15).

Kryter (25) recently presented data that can be used to convert either backward or forward in time to TTS_2 from other TTS, measured at from 10 to 1000 seconds (0.6 to 16.6 minutes) after exposure. These data are based on studies of the rate of recovery from various amounts of TTS. The data presented in his report hold for TTS not more than 40 dB. (It has been shown [47] that the recovery function for TTS above 40 dB is markedly different from that for TTS less than 40 dB.)

Kryter's data are presented in graphic form. However, Appendix A gives the conversion factors used in this program. This conversion table assumes using the Rudmose ARJ-4 audiometer and starting the post-exposure audiogram 35 seconds after exposure. The values were derived from Kryter's graph at points corresponding to the horizontal midpoints of the audiometric records at any given frequency, i.e., the 500 cps left-ear conversion is taken from the 50-second point (35 + 15 seconds), the 1000 cps left-ear conversion from the 80-second point (35 + 45 seconds), etc.

The availability of such conversion tables increases, by a factor of six, the number of frequencies for which TTS_2 data can be obtained. Using this conversion table, it now becomes feasible to expose both of a subject's ears to noise simultaneously and still derive TTS_2 data for all six test frequencies in both ears.

Repeated-Noise Exposures

In two preliminary investigations, subjects were exposed to the same noise condition repeatedly, to study the reliability of TTS_2. Two criteria used to select subjects for the repeated exposures were (a) they must have recovered from the effects of the previous exposure to within 5 dB of their pre-exposure hearing levels, and (b) the subject's previous TTS_2 must not have exceeded 40 dB. The former

criterion insured approximately the same baseline of auditory acuity for each exposure, while the latter criterion eliminated subjects who were highly susceptible to the effects of the noise and might be expected to develop a permanent noise-induced hearing loss after repeated exposures.

PRELIMINARY EXPERIMENTS

Goals of the Experiments

A ten-month review of the impulse-noise literature, discussion of the problem area with other workers in the field of psychoacoustics, and an assessment of the relative efficacy of various approaches to the problem helped to determine the goals of this program. Many of the methodological problems in noise research had already been investigated by other scientists, and at first it appeared that studies should be planned immediately to investigate the various parameters that could be manipulated with existing sources of impulse noise, e.g., number of impulses, rate of fire, peak SPL, etc. However, intensive study of the literature revealed that at least one important methodological problem had been overlooked or ignored: the reliability of TTS_2 after repeated exposures to gunfire.

In most published studies that compared two or more impulse-noise conditions, subjects were exposed to repeated noise. This procedure has several advantages, not the least of which is the smaller number of subjects required for the conduct of noise research. An additional statistical advantage lies in the fact that, in comparing the effects of several conditions, each subject in a "repeated measurements" experiment serves as his own control. Thus the comparisons of different conditions can be very precise -- if the assumptions underlying the use of repeated measurements are met.

The most important assumption underlying the use of repeated measurements, so far as the impulse-noise studies are concerned, is that the "treatments," i.e., the noise exposures, do not alter the subjects so that they are not the same people after recovery that they were before the noise exposure. Stated positively, one must assume that after a subject has been exposed to an impulse-noise source, has experienced a TTS, and has recovered to his pre-exposure hearing level (as determined by audiometric testing), he is, in fact, the same person that he was before the noise exposure. That is, if he were again exposed to the same noise source for the same exposure -- after recovering from the effects of the previous exposure -- it would have the same effect on his hearing, within certain statistical limits.

These statistical limits are not known, so the first major investigation under Project HUMIN aimed to find out what they are. As yet, literature reviews have not uncovered any study which determined limits for gunfire-noise exposure, although there has been some study of the problem of the reliability of TTS from continuous and intermittent noise (28). (Coles [9] has reported a study in which two subjects were repeatedly exposed to gunfire, but his sample was much too small to yield meaningful data.) The problem has, however, been alluded to in at least one paper. Ward (48), after exposing his subjects to four different impulse-noise conditions, tested them again on the first condition and reported that there was no significant difference between the TTS obtained in the first and last exposures.

The initial major study is addressed to this problem, posing the question, "How variable are the TTSs resulting from repeatedly exposing subjects to the same noise condition, when they are permitted to recover between exposures?" Before this major investigation could be carried out, however, it was necessary to determine what exposure conditions would be used. Exposures are defined in terms of (a) the number of rounds fired, (b) the rate of firing the rounds, and (c) the peak SPL of the impulse noise. It was decided that an exposure condition would be "acceptable" for the purposes of this proposed major study if it produced a median TTS_2 of 10 to 30 dB at test frequencies of 2000 and/or 4000 cps. It was also decided that two different exposure conditions would be used in this major reliability study, in order to test the generality of the findings. A series of preliminary experiments was conducted to specify the exposure conditions; these experiments are described below.

First Preliminary Study (November 1963)

The procedures used in this first experiment were, in general, those described in the Procedures section. The noise source was an M60 machine gun firing M82 blank ammunition from lot number FAL-12. The subject's left ear canal was exposed normal to the gun muzzle (on an azimuth of 255° from the direction of fire, as shown in Figure 10) to 25 rounds, fired three seconds apart with the side of the subject's head positioned 20 inches from the muzzle. At that point a peak SPL of 153 dB ± 1.25 dB had been measured. (A list of the instrumentation used in calibrating the noise-exposure positions is presented in Appendix B.) The two-frequency post-exposure audiometric testing procedure was used as described in the Procedures section, and thus it was possible to determine the amount of TTS_2 at 2000 and 4000 cps directly by comparing the pre- and post-exposure audiograms.

Subjects for this first experiment were 13 EM from Fort Hood, Texas, who were assigned to TDY at HEL primarily as subjects for a study about how long-term confinement in armored personnel carriers affects combat-relevant skills. The subject's ages ranged from 20 to 30 years, while their length of service ranged from 8 to 204 months. The subjects' pre-exposure hearing levels for the left ear are shown in Table 2.

TABLE 2

Range of Subjects' Hearing Levels (Exposed Ear):

First Preliminary Study

	Test Frequency (cps)					
	500	1000	2000	3000	4000	6000
Hearing Level (dB)	5/-25	5/-15	10/-20	15/-5	20/-5	15/-5

The distribution of TTS_2 resulting from the exposure of these subjects to the noise condition described above are shown in Figure 16. The median TTS_2 was only 5 dB at both the 2000- and 4000-cps test frequencies and it was concluded that this exposure was not acceptable for the purposes of the major reliability study.

Second Preliminary Study (March 1964)

The same procedures and exposure conditions were used in a second study, conducted to verify the results of the first study, with a different group of subjects. The subjects were 20 EM from Fort Monmouth, N. J., whose ages ranged from 18 to 34 years, and whose length of service ranged from 7 to 216 months. These subjects' pre-exposure hearing levels are shown in Table 3 for the left ear. Distributions of TTS_2 resulting in this study are shown in Figure 17. The median TTS_2 was zero decibels at both the 2000- and 4000-cps test frequencies. This finding, together with the findings of the first study, led to the conclusion that this exposure definitely did not cause enough TTS for use in the major reliability study.

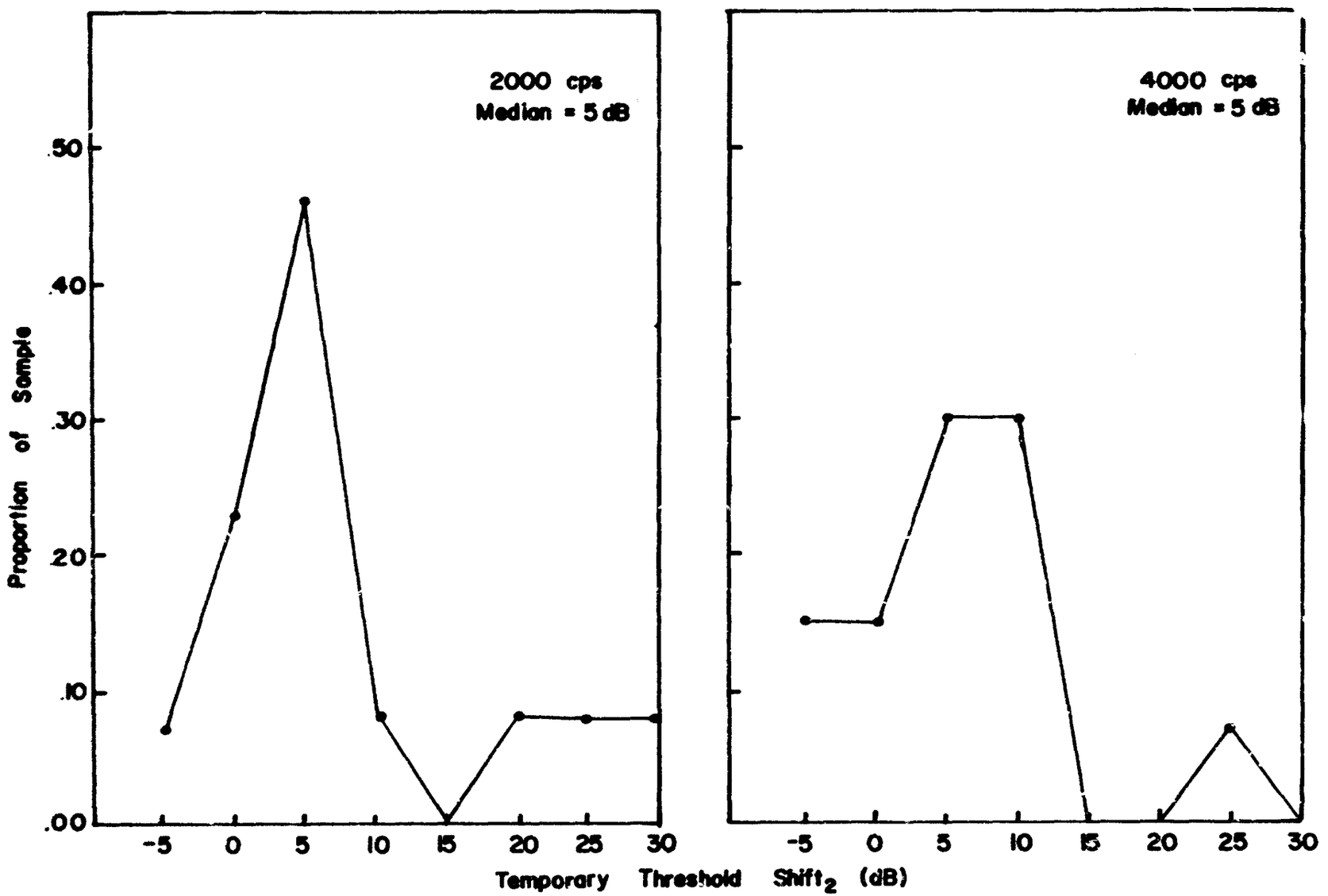


Fig. 16. DISTRIBUTIONS OF TEMPORARY THRESHOLD SHIFT AT 2000 AND 4000 cps FOR 13 SUBJECTS USED IN THE FIRST PRELIMINARY EXPERIMENT

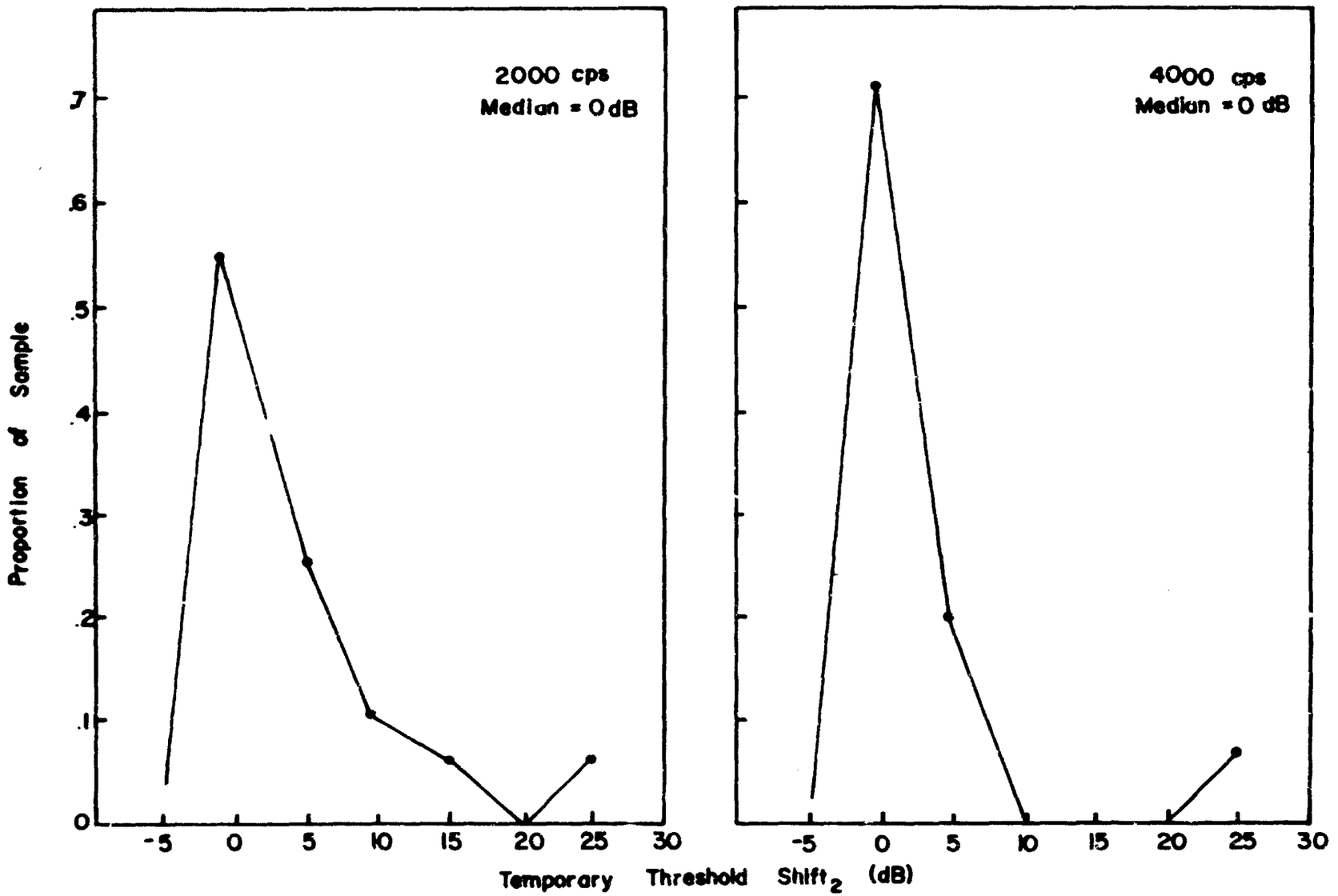


Fig. 17. DISTRIBUTIONS OF TEMPORARY THRESHOLD SHIFT AT 2000 AND 4000 cps FOR 20 SUBJECTS USED IN THE SECOND PRELIMINARY EXPERIMENT

TABLE 3

Range of Subjects' Hearing Levels (Exposed Ear):

Second Preliminary Study

	Test Frequency (cps)					
	500	1000	2000	3000	4000	6000
Hearing Level (dB)	20/-15	15/-10	15/-15	20/-45	15/-15	15/-10

Third Preliminary Study (April 1964)

Again, the same procedures were used. But with the same rate of fire (20 rounds per minute) and the same peak SPL of the impulse noise (153 dB), the exposure was increased to 50 rounds.

Sixteen EM from various stations in the Third Army Area served as subjects. Their ages ranged from 19 to 39 years, and their lengths of service from 8 to 162 months. These subjects' hearing levels in the left ear are shown in Table 4.

TABLE 4

Range of Subjects' Hearing Levels (Exposed Ear):

Third Preliminary Study

	Test Frequency (cps)					
	500	1000	2000	3000	4000	6000
Hearing Level (dB)	0/-15	5/-15	15/-15	10/-10	15/-10	15/-10

The distributions of TTS_2 resulting from this exposure are shown in Figure 18. The median TTS_2 was 10 dB at 2000 cps and 5 dB at 4000 cps. According to the criteria previously stated, this exposure was considered an acceptable exposure for the reliability study.

Fourth Preliminary Study (July-August 1964)

Between the third and fourth preliminary investigations, the procedures were re-evaluated. As a result, the procedures were changed in two major ways: it was decided (a) to conduct future studies with ball ("live") ammunition, instead of blanks, and (b) to conduct a complete post-exposure audiometric examination, instead of the two-frequency check used in the first three studies. The events which led to the change in ammunition will be described in the Special Problems section, while the new audiometric technique has already been described in the Procedures section.

The fourth study investigated four combinations of two peak SPLs and two orientations of the ear canal relative to the gun muzzle. The conditions were as follows:

a. Peak SPL =155 dB, 50 rounds, 5 sec. apart, subject's ear canal side-on to the gun muzzle (155 dB Side-On).

b. Peak SPL =155 dB, 50 rounds, 5 sec. apart, subject's ear canal normal to muzzle (155 dB Normal).

c. Peak SPL =158 dB, 50 rounds, 5 sec. apart, subject's ear canal side-on to gun muzzle (158 dB Side-On).

d. Peak SPL =158 dB, 50 rounds, 5 sec. apart, subject's ear canal normal to muzzle (158 dB Normal).

The orientation of the ear relative to the gun muzzle could be varied and investigated because firing ball ammunition instead of blanks greatly increased the ear's "working distance" from the gun muzzle. Whereas a distance of 20 inches was used to secure a peak SPL of 153 dB in the first three studies with blanks, it was now possible to get that same level some 13 feet from the muzzle. At such a distance, it was feasible to turn the subject's chair 90° from its former position and thus place the subject's ear canal side-on to the muzzle (i.e., side-on to the impulse noise wave) rather than normal to it as in the three previous studies.

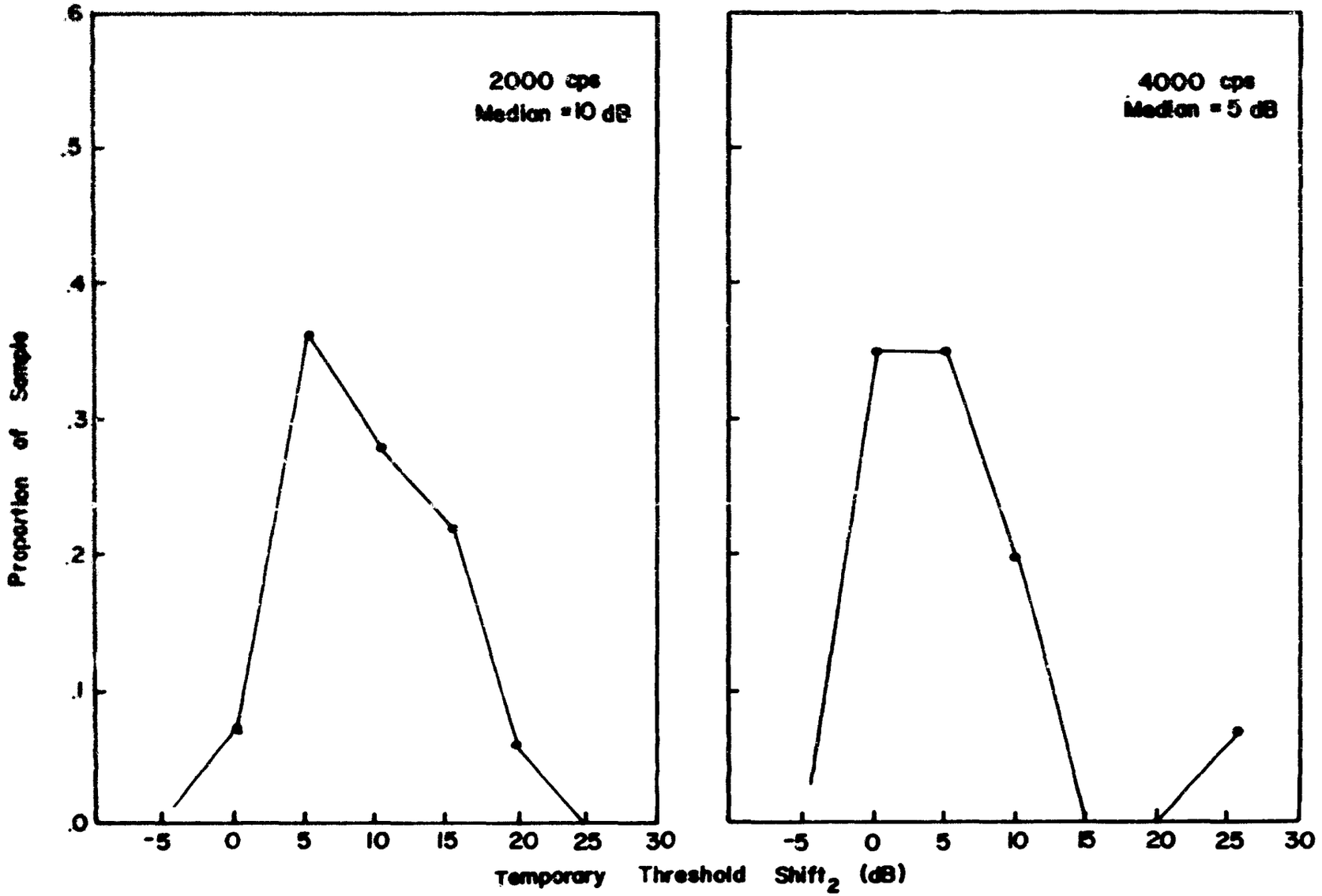


Fig. 18. DISTRIBUTIONS OF TEMPORARY THRESHOLD SHIFT AT 2000 AND 4000 cps FOR 16 SUBJECTS USED IN THE THIRD PRELIMINARY EXPERIMENT

In the first condition, the peak SPL was increased from 153 dB to 155 dB, and the rate was changed from 20 rounds per minute to 12 rounds per minute, to take advantage of some data from Bragg (4) that suggested the resulting exposure would be suitable for the reliability study's purposes. In the third and fourth conditions, the peak SPL was increased to 158 dB because exposure at 155 dB produced a relatively small TTS_2.

Table 5 shows demographic data for the subjects used in the fourth preliminary study's four sub-tests.

Table 5

Ranges of Subjects' Ages, Length of Service, and Hearing Level (Exposed Ear):

The Four Exposures of the Fourth Preliminary Study

Exposure			Age	Service	Hearing Level (dB)					
No.	Type	N	(yrs.)	(mos.)	500	1000	2000	3000	4000	6000
1	155 dB Side-On	16	18/27	6/72	0/-15	5/-20	10/-15	15/-5	10/-15	15/-10
2	155 dB Normal	12	18/31	5/148	0/-15	0/-15	5/-15	5/-10	10/-10	15/-10
3	158 dB Side-On	8	20/45	13/234	0/-15	-5/-15	0/-15	5/-5	15/-10	15/-5
4	158 dB Normal	7	19/31	8/144	-10/-20	-5/-20	0/-15	10/-10	5/-10	15/-5

Figure 19 shows the mean, quartiles, and range of TTS_2 at all six audiometric test frequencies for the same four conditions. This figure suggests the conclusion that, in general, a larger amount of TTS resulted from the 158-dB exposure than from 155 dB, and that the "normal" ear-canal orientation produced more TTS than the "side-on" orientation. The former result parallels the findings of Murray and Reid (31, 32), as well as Ward, Selters, and Glorig (49). The latter result follows from the discussion by Kinney (24), wherein he showed that the effective pressure on a surface (e.g., an eardrum) is greater when the impulse-noise wave strikes it directly than when it sweeps by it.

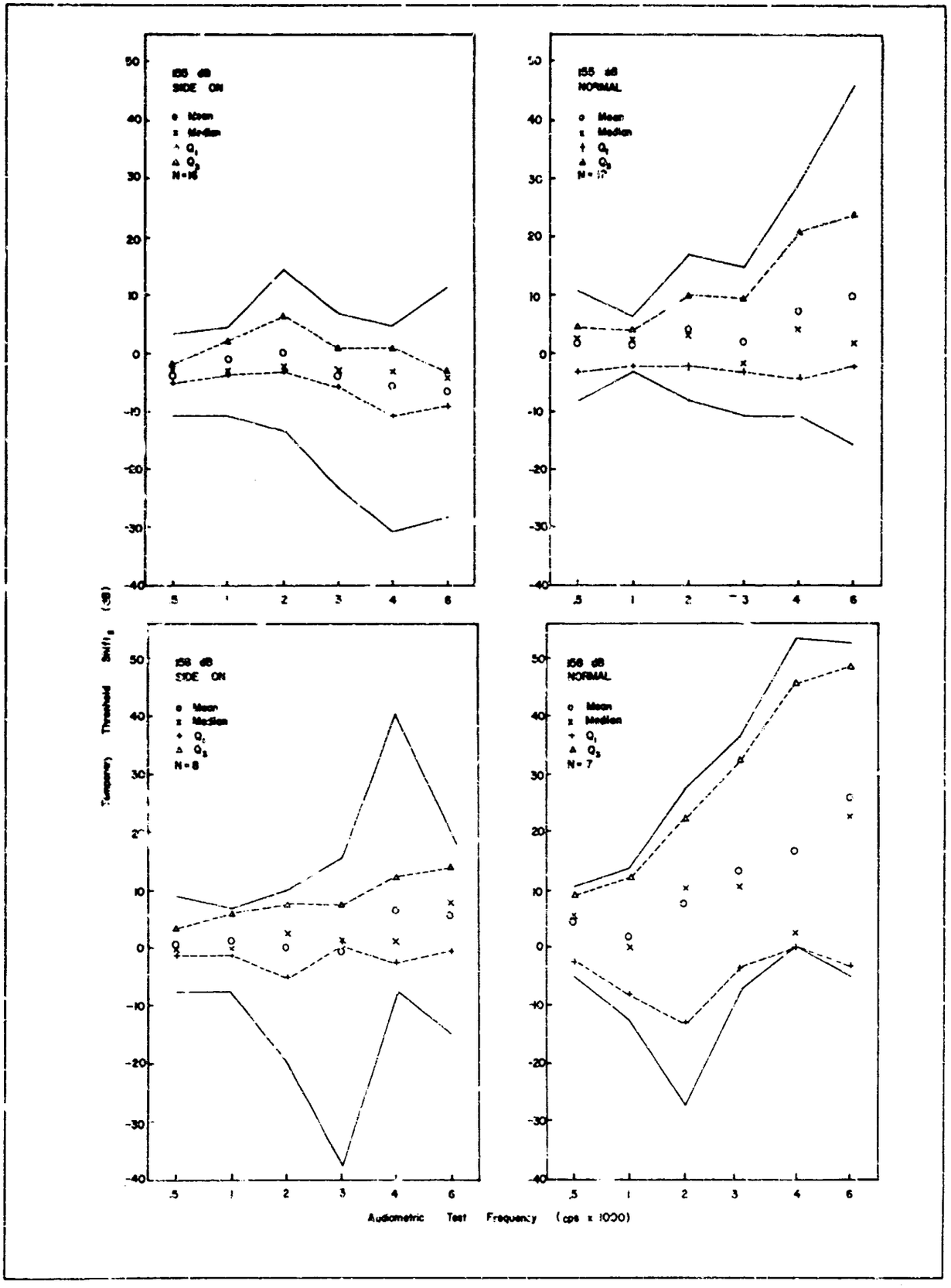


Fig. 19. MEANS, MEDIANS, AND QUARTILES FOR TEMPORARY THRESHOLD SHIFT AT EACH OF SIX AUDIOMETRIC TEST FREQUENCIES FOR THE FOUR CONDITIONS STUDIED IN THE FOURTH PRELIMINARY EXPERIMENT

Only one of the four conditions tested here meets the criterion of an acceptable exposure as set out in the introduction to this section, viz., the "158 dB Normal" condition. Two of the other conditions, "155 dB Normal" and "158 dB Side-On," approach the criterion of a median TTS_2 of 10 dB or more at 2000 and/or 4000 cps.

A most peculiar result in this study was the rather frequent occurrence of negative TTS. A negative TTS implies that hearing acuity is improved after a noise exposure. It may be legitimate to ignore small negative TTS, say less than 10 dB, invoking such explanations as equipment variability, moment-to-moment differences in threshold, increased motivation, shaking the cerumen in the ear canal loose, etc. However, when the negative TTS is on the order of 15 dB or larger, as it was in several instances in this study, such explanations seem inadequate.

Animal studies have established that noise exposures which produce permanent hearing loss deform certain structures in the inner ear (33, 36), consequently lessening the receptor cells' ability to respond to stimulation. Therefore it appears plausible that temporary changes in hearing involve some lesser degree of physiological change in these structures, although the mechanisms underlying TTS have not yet been fully determined. It is possible, then, though no mention has been found in the literature, that noise initially affects the hearing mechanism by sensitizing it in some way. If this were so, it would follow that, because of individual differences, some individuals should show more sensitization than others, which would account for the large individual differences found in the present study. Possibly the sensitization could be "central," as well as "peripheral."

One explanation frequently given to account for negative TTS is that the subject has tinnitus at one or more frequencies, and that he is tracking the tinnitus, rather than the test tone. It is true that the subjects who demonstrated negative TTS did so only at certain frequencies (i.e., not at all frequencies), so this possibility cannot be overlooked. However, special pains were taken to instruct the subjects in differentiating between tinnitus, which is usually continuous, and the audiometric test tone, which is pulsing. Also, when a subject troubled by tinnitus is tested on the Rudmose automatic audiometer, he typically holds the button down, causing the recording stylus to move to the top of the record card (lowest possible hearing level), and continues to hold the button down, so the trace is a solid line at the top of the card. When the test reaches a frequency where the subject's tinnitus no longer interferes with tracking the test tone, the subject resumes tracking normally. During the post-exposure testing, the subjects demonstrating negative TTS did not generally hold the button down until the trace reached the top of the card; instead, their traces appeared "perfectly normal," at least superficially, except for being on the wrong side of the pre-exposure trace. These facts suggest that tinnitus is not responsible for the negative TTS.

It is known that all subjects used in this study, including those demonstrating negative TTS, recovered to their pre-exposure hearing levels. It is indeed unfortunate that, during the study, neither equipment nor personnel were available to establish recovery functions for the subjects demonstrating negative TTS. It would be interesting to note whether or not the recovery from a negative TTS follows the same course as recovery from a positive TTS.

Repeated-Noise Exposures

The foregoing descriptions of the four preliminary studies include only data from subjects with a single exposure to noise. Two of the studies gave repeated exposures to get some tentative feeling for the reliability of TTS, and these data are described briefly below.

In the third preliminary study, 13 subjects got two exposures to 50 rounds, three seconds apart, with a peak SPL of 153 dB. The reliability coefficients were 0.54 at 2000 cps ($p < .05$), and -0.05 at 4000 cps (not significant).

In the fourth study, three of the conditions were repeated. Twelve subjects got two exposures to the 155-dB Side-On condition. The reliability coefficients for the six test frequencies are shown in Table 6. Only at 3000 cps was the reliability significantly greater than zero.

TABLE 6

Reliability Coefficients for Temporary Threshold Shift for Two Exposures of 12 Subjects to the 155-dB Side-On Condition

Audiometric Test Frequency (cps)	r
500	.20
1000	.25
2000	.22
3000	.59*
4000	.11
6000	.18

* $p < .05$

Each of nine subjects was exposed to the 155-dB Normal condition four times. The mean TTS_2 for all six test frequencies are shown in Figure 20, while the reliability coefficients for all combinations of exposures, and for all six frequencies, are shown in Table 7. It would appear that the most reliable TTS_2 were those at 2000 and 3000 cps.

Each of seven subjects was exposed to the 158-dB Side-On condition four times. The mean TTS_2 are shown in Figure 21, and the reliability coefficients are given in Table 8. None of the six test frequencies appears to have yielded very great reliability in this case.

The 158-dB Normal condition was not used for repeated exposures, inasmuch as attrition reduced the original N from seven to four because of excessive TTS_2 on the first exposure.

Conclusions

1. Suitable methods and procedures have been developed for studying temporary effects of impulse noise on human hearing. Anticipated refinements include improving instrumentation for measuring auditory thresholds at frequencies higher than 6000 cps, and broadening post-exposure testing to plot recovery functions for large TTS and for negative TTS.

2. Suitable exposure conditions have been established for a major study of the reliability of TTS_2 resulting from repeated exposures to the same noise condition. The two exposure conditions are (a) 50 impulses, 5 seconds apart, peak SPL = 155 dB, ear canal normal to muzzle; and (b) 50 impulses, 5 seconds apart, peak SPL = 158 dB, ear canal side-on to muzzle.

3. Other things equal, exposure to a peak SPL of 158 dB produces more TTS than 155 dB, and noise has a greater effect when the ear canal is normal to the muzzle than when it is side-on.

4. The initial studies of TTS reliability are inconclusive. Future studies will use larger numbers of subjects ($N \geq 20$).

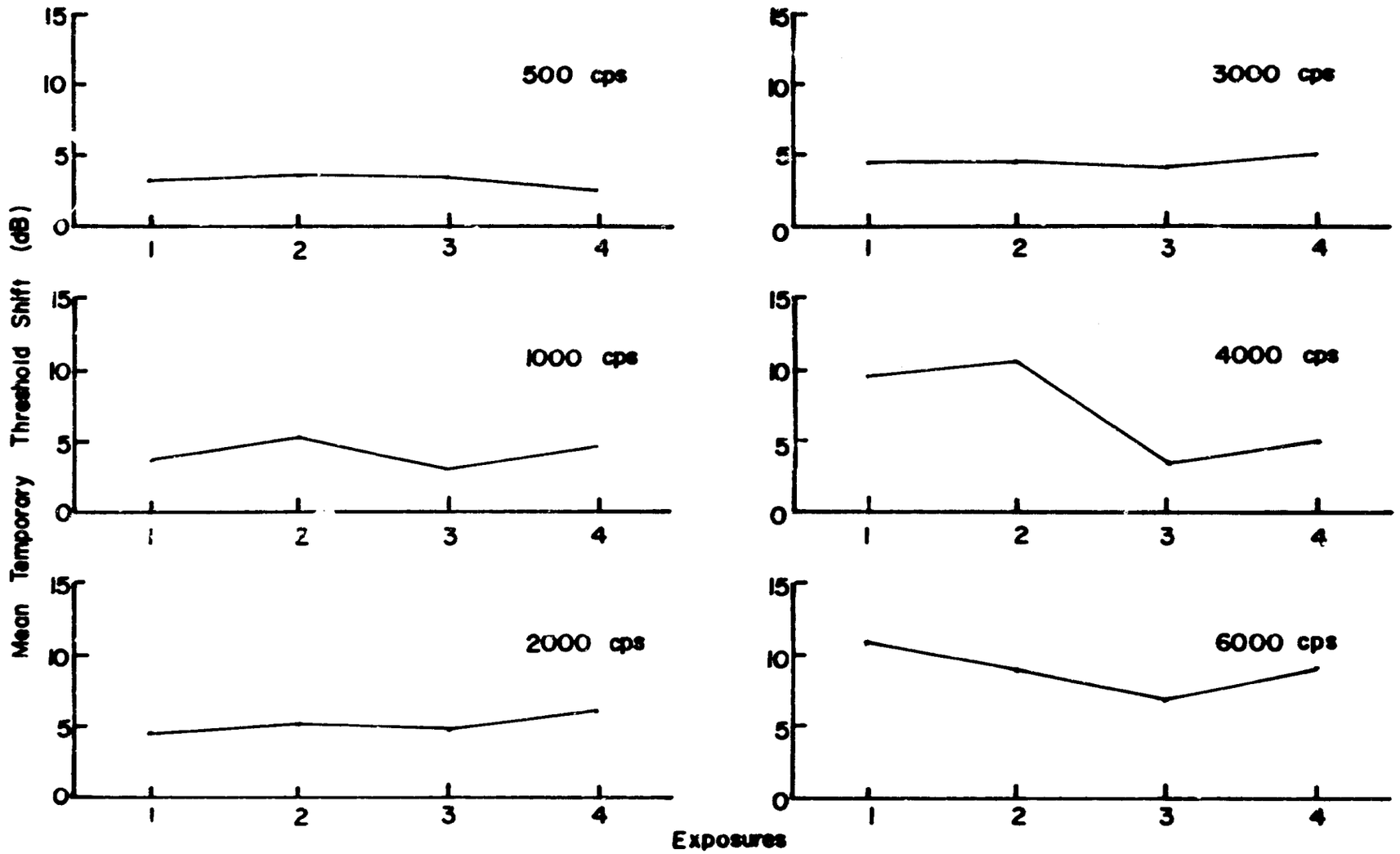


Fig. 20. MEAN TEMPORARY THRESHOLD SHIFT AT EACH OF SIX TEST FREQUENCIES FOR FOUR EXPOSURES OF THE SAME SUBJECTS TO THE 155-dB NORMAL-INCIDENCE CONDITION

TABLE 7

Reliability Coefficients for Temporary Threshold Shift for All Combinations of Four Exposures of Seven Subjects to the 158-dB, Side-On Condition

500 cps	Exposure No. 2	3	4
1	.46	.56	.36
2	--	.35	.21
3	--	--	.14

3000 cps	Exposure No. 2	3	4
1	.34	.83*	.97*
2	--	.54	.34
3	--	--	.90*

1000 cps	Exposure No. 2	3	4
1	.62	.72*	.66
2	--	.82*	.57
3	--	--	.51

4000 cps	Exposure No. 2	3	4
1	.73*	.34	.38
2	--	.65	.33
3	--	--	.85*

2000 cps	Exposure No. 2	3	4
1	.87*	.32*	.84*
2	--	.74*	.45
3	--	--	.93*

6000 cps	Exposure No. 2	3	4
1	.68	.09	.28
2	--	.35	.54
3	--	--	.89*

* $p < .05$

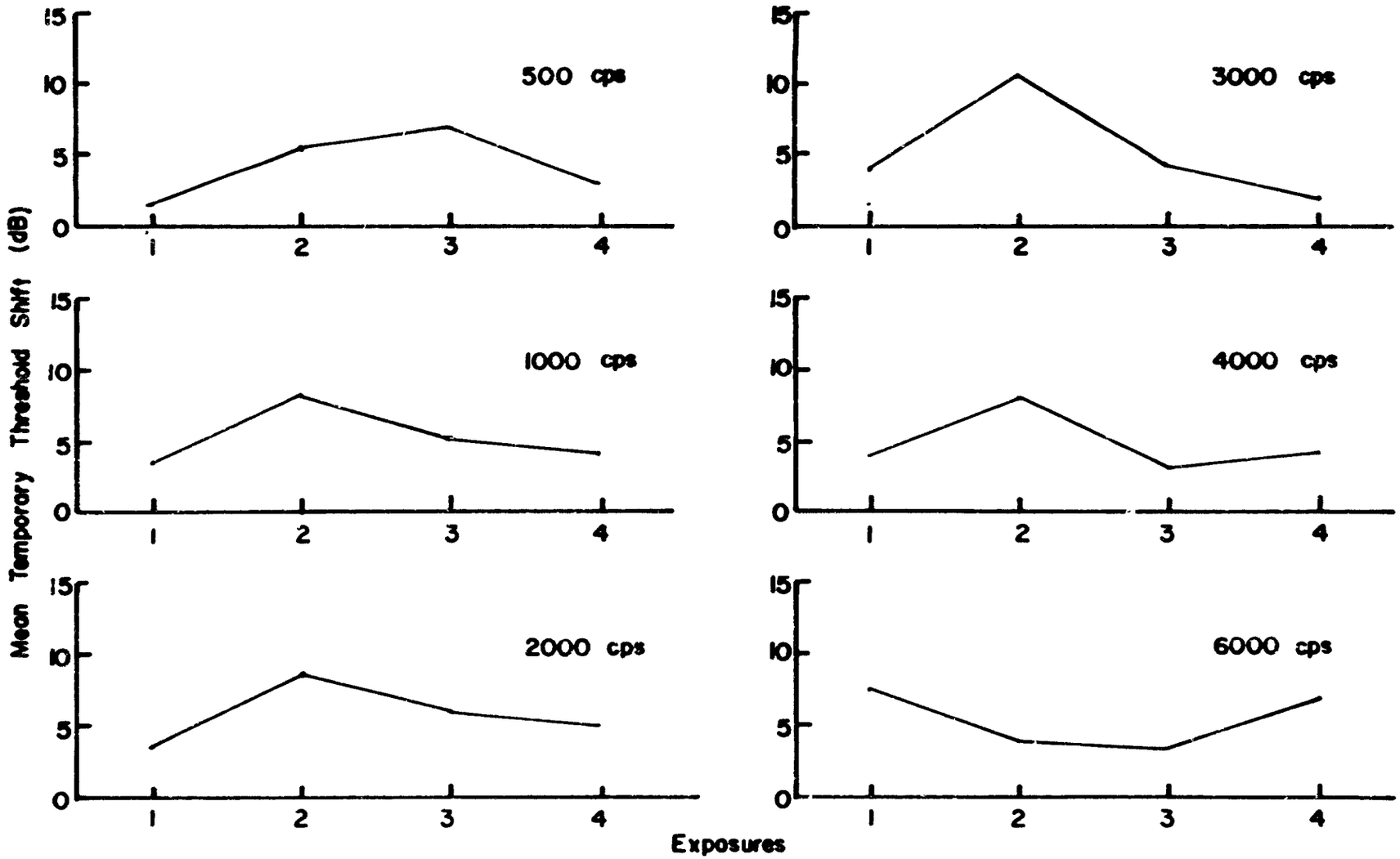


Fig. 21. MEAN TEMPORARY THRESHOLD SHIFT AT EACH OF SIX TEST FREQUENCIES FOR FOUR EXPOSURES OF THE SAME SUBJECTS TO THE 158-dB SIDE-ON-INCIDENCE CONDITION

TABLE 8

Reliability Coefficients for Temporary Threshold Shift for Combinations of Four Exposures of Nine Subjects to 155-dB, Normal Condition

500 cps	Exposure No. 2	3	4
1	.44	.46	.56
2	--	.42	.18
3	--	--	.60

3000 cps	Exposure No. 2	3	4
1	.63*	.24	.51
2	--	.20	.74*
3	--	--	.47

1000 cps	Exposure No. 2	3	4
1	.30	.93*	.66*
2	--	.19	.17
3	--	--	.32

4000 cps	Exposure No. 2	3	4
1	.53	.18	.09
2	--	.18	.03
3	--	--	.25

2000 cps	Exposure No. 2	3	4
1	.70*	.59	.04
2	--	.49	.07
3	--	--	.15

6000 cps	Exposure No. 2	3	4
1	.03	.44	.46
2	--	.00	.80*
3	--	--	.16

* $p < .05$

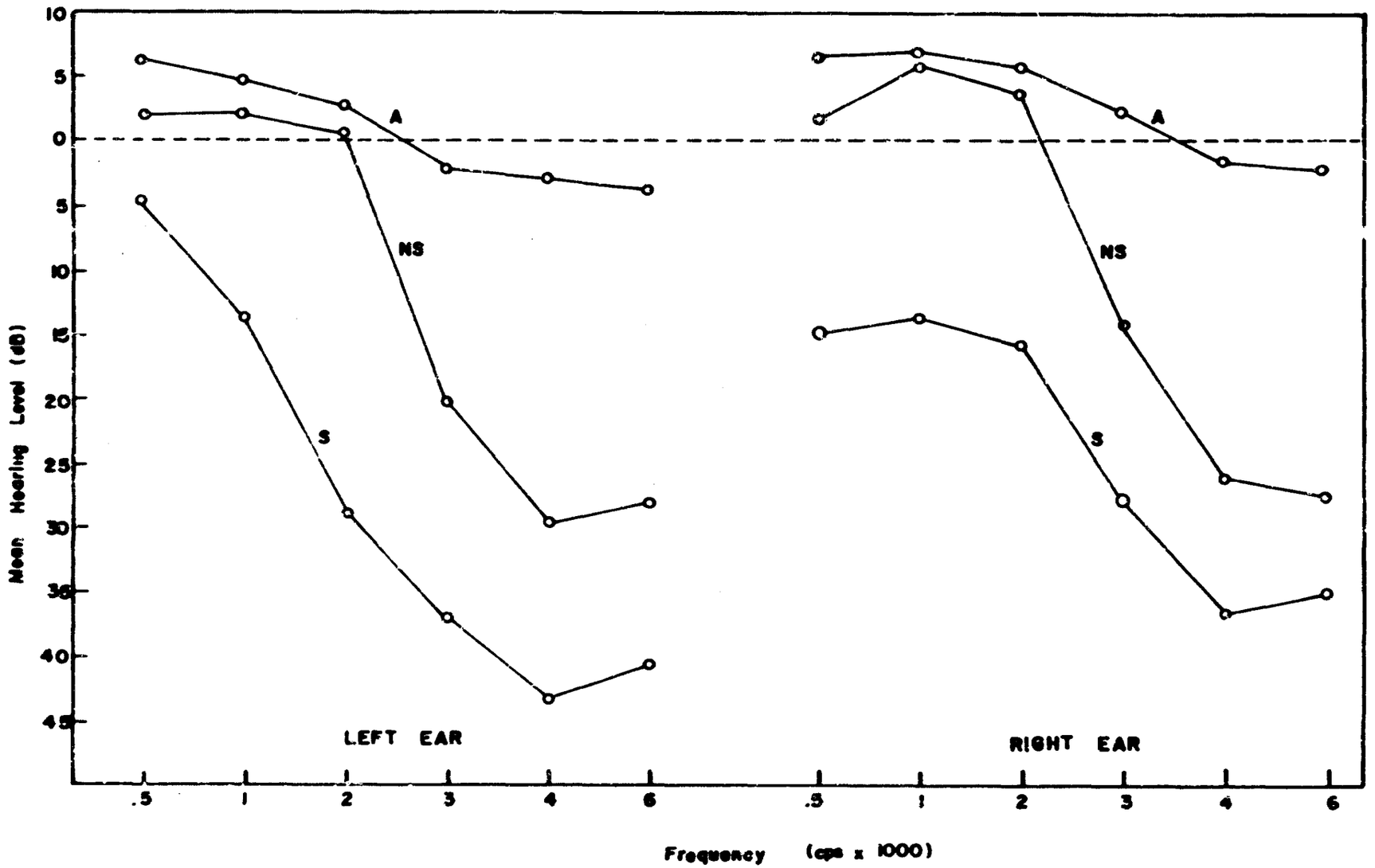


Fig. 22. MEAN HEARING LEVELS AT SIX FREQUENCIES IN EACH EAR FOR THREE GROUPS OF POTENTIAL SUBJECTS FOR THE FIRST PRELIMINARY EXPERIMENT
(Group A had normal hearing; group NS had excessive non-speech frequency hearing levels; group S had excessive speech-frequency hearing levels.)

SPECIAL PROBLEMS

High Rejection Rate of Potential Subjects

Initially, it was decided that subjects used in this project must be free of chronic otolaryngological signs and have "normal" hearing. This decision was based on two reasons: (a) most other investigators use the same or similar criteria for selecting their subjects, and (b) there is already a considerable body of knowledge about how noise affects "normal" people. Using these selection criteria makes this project's data comparable with those of other investigators, and eliminates subjects with "abnormal" hearing, whose responses to impulse noise are not well enough known to provide reliable comparisons.

It is recognized that, in order to establish damage-risk criteria for the Army as a whole, studies will eventually have to be carried out on subjects representative of the whole Army. Studies using subjects of the types now being rejected are not, however, planned for the immediate future.

This policy of screening the subjects has resulted in very high rejection rates in most cases. Smith and Goldstone (42), in their 1961 pilot study, reported a rejection rate of 32 percent due to otolaryngological signs and excessive hearing levels.

When the first preliminary study was conducted under Project HUMIN in November 1963, a total of 116 EM were assigned to TDY at the Human Engineering Laboratories as test personnel. Of these, 96 took audiometric examinations and, in addition, filled out the personal history form shown in Figure 13. More than 55 percent of these potential subjects were rejected because of excessive hearing levels. Three groups of EM were identified: (a) those having acceptable hearing level, (b) those having excessive hearing levels (> 15 dB) at one or more frequencies in the speech range (500, 1000, and 2000 cps), and (c) those having excessive hearing levels at one or more frequencies above the speech range (3000, 4000, and 6000 cps). The mean hearing levels for these three groups of personnel are shown in Figure 22.

The 96 EM screened in connection with this first preliminary study were from the armored infantry at Fort Hood, Texas. Their ages ranged from 18 to 44 years (median = 24 years), with length of service ranging from 5 to 239 months (median = 23 months). These men had spent most of their service time in the armored infantry, and several findings -- Fletcher and Solomon (16) about armor personnel's hearing acuity, and Harbold and Greene (19, 20) about Marines' hearing acuity -- suggest the rejection rate would be high for this particular group of potential subjects. However, we have found similarly high rejection rates when screening EM from other groups in the Army, e.g., Signal Corps personnel. Personal history data for these EM have not yet been completely analyzed, but data from Fletcher and Solomon (16) and our own data agree about tinnitus and positive medical history: both are correlated with excessive hearing levels.

TABLE 9

Measurements of Peak Sound-Pressure Level

for Six Lots of M82 (7.62mm NATO) Blank Ammunition

Lot Number	Mean Peak SPL[a]	Range of Peak SPL	Standard Deviation
FAL-1	155.10	153.5 - 159.5	1.48
FAL-2	155.29	153.0 - 159.0	1.50
FAL-4	155.25	153.0 - 159.5	1.83
LCL-12048	154.74	152.0 - 162.0	1.66
LCL-12050	155.77	151.5 - 162.0	2.72
FAL-12	152.95	151.0 - 153.5	0.75

[a] dB re .0002 microbar.

Variability of Sound-Pressure Levels
Produced by Blank Ammunition

In the first three studies conducted under this project, the impulse-noise source was a modified M60 machine gun firing M82 (7.62mm NATO) blank ammunition from lot number FAL-12. Peak SPL measurements made in January 1963 indicated that the maximum round-to-round variation in peak SPL was about 2.5 dB. This amount of variability was considered acceptable.

In May 1964, when supplies of M82 blank ammunition from lot FAL-12 were finally exhausted, additional ammunition was procured from lot FAL-1. One of the experimenters (H. G.) commented later that "the noise sounded louder" than that produced by the ammunition from lot FAL-12. HEL made peak SPL measurements of a 50-round sample from lot FAL-1. The average peak SPL was, in fact, about 3 dB higher than for lot FAL-12. More important, however, the round-to-round variation in peak SPL was 7 dB -- nearly three times as much as for lot FAL-12.

As a result, the study which was in progress was terminated. Samples of M82 blanks were procured from the five lots available at Aberdeen Proving Ground. Fifty-round samples from these lots, together with another sample from lot FAL-1, were fired to get peak SPL measurements. These measurements were made at a point 20 inches from the muzzle of the M60 machine gun, at muzzle height, on an azimuth of 255° from the direction of fire. Single rounds were fired from the machine gun without flash hider or blank-firing adapter. Table 9 gives the results of these tests, along with some measurements made earlier using ammunition from lot FAL-12. The five lots tested differed only about 1 dB in mean peak SPL. However, all lots were about 2 dB or more "louder" than lot FAL-12. The round-to-round variation in peak SPL ranged from 6 to 10.5 dB among the five lots -- considerably more than the 2.5-dB variation within lot FAL-12.

These results were discussed with various small-arms ammunition experts in an effort to determine whether suitable blank ammunition could be procured. The experts were skeptical since, as they pointed out, blank ammunition need not be loaded as precisely or consistently as live ammunition to serve its intended training purpose. They did, however, suggest that since the five lots tested were older lots (i.e., had been manufactured up to four years ago) newer ammunition might have more stable round-to-round peak SPL.

Accordingly, we procured samples of 15 recently manufactured lots of M82 blank ammunition. Fifty-round samples of each lot were fired, together with another sample from lot FAL-1, in the same manner as before. We also fired additional samples of several lots which initially looked better than the rest. The results of these tests are presented in Table 10.

TABLE 10

Measurements of Peak Sound-Pressure Level

for 17 Lots of M82 (7.62mm NATO) Blank Ammunition

Lot Number	Year of Manufacture	Mean Peak SPL[a]	Range of Peak SPL	Maximum Variation	Standard Deviation
FAL-1	1960	153.50	151.0 - 159.5	8.5	1.8
		154.22	151.0 - 158.0	7.0	1.8
		153.98	151.0 - 165.0	14.0	2.4
LCL-12054	1961	154.30	151.0 - 160.0	9.0	2.4
LCL-12105	1961	151.84	149.0 - 157.0	8.0	1.8
LCL-12180	1962	154.96	150.0 - 159.0	9.0	2.2
LCL-12182	1962	153.93	149.0 - 160.0	11.0	2.6
LCL-12258	1964	151.64	149.0 - 155.0	6.0	1.1
		152.18	149.0 - 158.0	9.0	1.5
LCL-12285	1964	151.56	142.0 - 153.0	11.0	1.6
		151.96	150.0 - 157.0	7.0	1.4
LCL-12289	1964	152.10	150.0 - 156.0	6.0	1.2
		152.16	150.0 - 156.0	6.0	1.3
LCL-12293	1964	151.46	146.0 - 158.0	12.0	1.6
LCL-12296	1964	151.68	148.0 - 156.0	8.0	1.5
LCL-12297	1964	151.40	149.0 - 155.0	6.0	1.2
		151.54	149.0 - 155.0	6.0	1.2
		151.64	149.0 - 154.0	5.0	1.1
LCL-12299	1964	151.20	149.0 - 153.0	4.0	1.0
		151.10	149.0 - 154.0	5.0	1.0
		150.98	149.0 - 154.0	5.0	1.2
LCL-12302	1964	151.16	132.0 - 154.0	22.0	2.9
LCL-12304	1964	152.14	149.0 - 160.0	11.0	2.2
LCL-12306	1964	151.88	149.0 - 158.0	9.0	2.2
LCL-12308	1964	151.70	148.0 - 154.5	6.5	1.3
FAL-12	1960	152.95	151.0 - 153.5	2.5	0.8

[a] dB re .0002 microbar.

As Table 10 demonstrates, lots of ammunition manufactured in 1964 generally had slightly lower mean peak SPL than ammunition manufactured earlier. The newer ammunition also generally had smaller standard deviations, or more stable SPL. These data confirm the experts' opinion that new ammunition is better than old, i.e., that ammunition deteriorates with age.

The maximum round-to-round variation in peak SPL was greater in all lots than in lot FAL-12. Even the lots with the smallest variation were nearly twice as variable as lot FAL-12.

It could perhaps be argued, since there was large variability in 20 out of 21 lots of ammunition, that the instrumentation was in error when the earlier measurements were made on lot FAL-12. This possibility has not been overlooked. However, a recheck of a number of peak SPL measurements made at the same time indicates that the other measurements are correct. Thus the peak SPL measurements made on lot FAL-12 seem perfectly valid, and finding the very small round-to-round variation in peak SPL with that lot of ammunition was fortuitous.

The foregoing peak SPL measurements on 21 lots of blank ammunition indicated that blank ammunition should not be used in further studies of how impulse noise affects hearing, because there would be serious questions about the equality of noise exposures given to different subjects. The possibility exists, however small, that one subject might receive an exposure composed mostly of low-peak SPL rounds, while another might be exposed to mostly high-peak SPL rounds, and there would be no way of detecting this difference in exposure. (Measurements of peak SPL are not made on every round or every exposure in these studies, but, rather, the measurements are checked only periodically to insure that they are the same.) Since the within-lot range of peak SPL was quite large in many cases -- up to 22 dB -- there could be substantial differences in exposure.

Blank ammunition was used originally because of certain administrative advantages over live ammunition. Permission had been secured to fire blank ammunition in a special fenced enclosure adjacent to the main laboratory buildings, so the firing area was accessible and it was simple to transport subjects to and from the firing area. As the round-to-round variability of the original lot of blank ammunition was considered acceptable (2.5 dB maximum), it was far simpler to fire blanks than live rounds.

TABLE 11

Measurements of Peak Sound-Pressure Level

for Ten Lots of M59 (7.62mm NATO) Ball Ammunition[a]

Lot Number	Mean Peak SPL[b]	Standard Deviation	Size of Sample
FAL-9	161.1	0.49	80
FAL-14	161.6	0.88	79
FAL-33	161.1	0.81	58
FAL-34	161.2	0.76	37
FAL-44	161.1	0.76	58
FAL-79011	161.2	0.69	57
RAL-5017	161.0	0.50	40
LCL-12005	161.1	0.83	58
LCL-12006	161.1	0.37	59
LCL-12014	160.8	0.57	77
Overall	161.1	0.68	624

[a] From an unpublished study by Donley (12).

[b] dB re .0002 microbar.

When acceptable lots of blank ammunition could not be procured, the ammunition problem and the problems involved in firing live ammunition were re-evaluated completely. It developed that there was already a substantial amount of data about the variability of live (ball) ammunition. HEL (12) conducted tests of ball ammunition several years ago, obtaining the unpublished results summarized in Table 11. These measurements of peak SPL were made at muzzle height above ground, at a point eight feet to the side of an M14 rifle's muzzle. (Note that the position and weapon differ from those used for measuring the peak SPL produced by blanks. The weapons and ammunition caliber -- 7.62mm NATO -- were the same.)

Firing ball ammunition produces considerably more consistent peak SPL than firing blank ammunition. The mean peak SPL of the two extreme lots of ball ammunition differed by 0.8 dB, as compared with about 4.0 dB difference between the extreme lots of blanks. The standard deviations of peak SPL for M59 ball ammunition ranged between 0.37 and 0.88 dB, compared with a range of from 1.0 to 2.9 dB for blanks.

FUTURE STUDIES ON PROJECT HUMIN

Reliability of TTS from Gunfire Impulses

In an investigation now in progress, subjects are being exposed at least nine times to the same noise condition, with time allowed for complete recovery between exposures. An exposure consists of 50 impulses produced by the modified M60 machine gun firing ball ammunition, each having a peak SPL of 155 dB. The impulses are given at the rate of 12 a minute. The subject's ear canal is oriented normal to the muzzle of the machine gun. At the present time it is planned to conduct another repeated-exposure study, using a different group of subjects and a different exposure condition.

At the conclusion of these studies, it will be possible to determine whether the mean TTS at each of six audiometric test frequencies changed over the course of the nine exposures and, if so, the direction of the change. It will also be possible to determine TTS reliability at each of the six test frequencies.

This information should be valuable in predicting the amount of TTS Army personnel will have during repeated exposures to the same noise condition, as well as helping determine whether repeated-measurements experimental designs are appropriate for future studies of how impulse noise affects human hearing.

Ear-Canal Orientation Relative to the Noise Source

In the fourth preliminary study conducted under Project HUMIN, subjects were exposed to impulse noise with the ear canal oriented two different ways relative to the noise source (gun muzzle). These orientations were (a) normal and (b) side-on. The results indicated that TTS was greater when the ear canal was oriented normal to the noise source than when it was oriented side-on to the noise source. Such a difference would have been predicted from Kinney's (24, p. 118) discussion of the differences in shock-wave pressure that are measured by gages oriented normal and side-on to the shock-wave front.

It is planned to conduct further studies of this effect, using larger numbers of subjects and three or more orientations of the ear canal relative to the noise source. These studies will provide information to aid in determining whether crew working positions around various Army weapons should be changed.

Number of Impulses and Rate of Exposure

Smith and Goldstone (42) conducted a pilot study of how different numbers of gunfire impulses and rates of fire affect TTS. However, the numbers of impulses studied -- 20, 25, and 30 -- were not different enough to cause differences in the amount of TTS, nor could any difference in TTS be attributed to the two rates of fire, one round per second and 12.7 rounds per second.

Ward (48) and Ward, Selters, and Glorig (49) have studied rate and number of impulses, using an electronic impulse-noise source. However, it is not known to what extent the TTS data from this electronic noise source can be replicated with a gunfire noise source.

Thus studies have been planned, using the modified M60 machine gun as a noise source, to vary both the number of rounds and the rate of firing. The results may show the extent to which TTS from exposure to gunfire is equivalent to TTS from exposure to an electronic noise source -- and, in this way, it may be possible to determine how much of the existing data about impulse-noise effects applies to Army noise environments.

Impulse-Noise Source

We are already investigating whether it is within the state of the art to build some type of impulse-noise source which will produce impulses that closely resemble gunfire. To be valuable for research, such a source should permit at least peak SPL and duration to be controlled independently within certain limits (22), and it should also permit the rise time of the impulses to be varied independently, if possible. So far, discussing this problem with a number of authorities in the acoustical field has not been fruitful. At least one investigator is attempting to build such a device, but just how much control over noise parameters can be achieved remains an open question.

High-Frequency Audiometer

The audiometric testing equipment now used in this project has an upper-frequency limit of 12,000 cps; the most frequently used audiometers have an upper limit of 6000 cps. Impulse-noise studies carried out in these Laboratories and elsewhere generally indicate that TTS is greater at higher test frequencies, i.e., that the same exposure results in a progressive increase in TTS from 500 cps through 6000 cps. However, the frequency at which maximum TTS is reached is not known.

We are now trying to acquire a Békésy-type audiometer that can measure auditory thresholds at frequencies up to 18,000 cps. If such a device can be obtained and if it proves to be a reliable instrument, we expect to be able to determine the frequency of maximum TTS.

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APPENDIX A

Number of Decibels to be Added to TTS
to Convert it to TTS_2
(Assuming the Use of a Rudmose ARJ-4 Automatic Audiometer,
and the Audiogram Starting 35 Seconds Post-Exposure[a])

	Left Ear						Right Ear					
TTS (dB)	500	1000	2000	3000	4000	6000	500	1000	2000	3000	4000	6000
5	0	0	0	0	0	0	0	0	0.5	1.0	1.5	2.0
6-10	-1.0	-0.5	0	0	0.5	1.0	1.5	1.5	2.0	2.5	3.0	3.5
11-15	-2.0	-1.0	0	0.5	1.0	2.0	3.0	3.5	4.0	5.0	5.5	6.0
16-20	-3.5	-1.5	0	0.5	1.5	2.5	3.0	4.0	5.0	5.5	6.5	7.0
21-25	-5.0	-2.0	0	1.0	2.0	3.0	4.0	5.0	6.0	6.5	7.5	8.0
26-30	-6.0	-3.0	0	1.0	2.5	3.5	4.5	5.5	6.5	7.5	8.0	9.0
31-35	-7.0	-6.0	0	1.5	3.0	4.5	5.5	6.5	7.5	8.5	9.0	10.0

[a]Computed from data of Kryter (25).

APPENDIX B

Instrumentation for Measuring Peak Sound-Pressure Level of Gunfire Impulses

1. Transducing equipment:

   a. Microphone, condenser -- General Radio (GR) type 1551-P1-25 (with type 21BR150 microphone cartridge).

   b. Power supply -- GR type 1551-P1.

2. Metering equipment:

   a. Sound-level meter -- GR type 1551-C.

   b. Impact-noise analyzer -- GR type 1556-A.

3. Calibrating equipment:

   a. Sound-level calibrator -- GR type 1551-B.

   b. Transistor oscillator -- GR type 1307-A.

4. This peak sound-pressure level measuring system has been found suitable for impulse-noise levels up to at least 160 dB.