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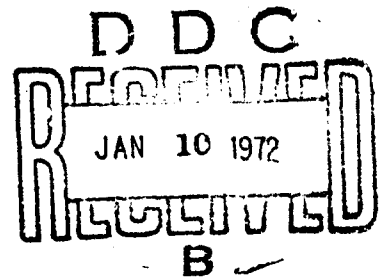
**A REVIEW OF ADVERSE BIOMEDICAL EFFECTS OF SOUND
IN THE MILITARY ENVIRONMENT**

DECEMBER, 1971

Prepared for

**LIFE SCIENCES DIVISION, ARMY RESEARCH OFFICE
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20310**

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13. ABSTRACT

This report provides a comprehensive review of the adverse effects of sound on man in the military environment. The diversity and complexity of Army systems that overexpose the soldier to noise have caused concern for his health and his capability to perform efficiently. Despite the recognition of the deleterious effects of noise exposure, problems with noise-induced hearing loss and human performance decrement continue to enlarge. It is generally recognized that overexposure to high-intensity noise during a lifetime will result in progressive hearing loss. There is no way to correct permanent threshold shift; permanent hearing loss is irreversible. It is not possible at the present time to identify audiometrically individuals with increased susceptibility or resistance to injury from noise exposure. Protection by sound attenuating devices, such as earplugs or earmuffs, has proved to be the most practical way to protect and to conserve the hearing of men required to work in a noisy environment. Effective hearing conservation and reduction of noise-induced hearing loss are compromised by lack of adherence to existing Army regulations and frequent waiving of equipment design standards. Work should be directed toward reduction of noise at its source; and, emphasis should be placed on increased support for Army hearing conservation programs. The report identifies research opportunities that are related to Army needs.

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Presbycusis						
Socioculus						
Noise						
Characteristics of						
Military Sources of						
Types of						
Continuous						
Impulse						
Intermittent						
Steady-State						
Sound						
Audible						
Infrasonic						
Ultrasonic						
Threshold Shift						
Permanent						
Temporary						
Tinnitus						
Voice Communications						

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FOREWORD

This technical report was prepared for the Life Sciences Division, Office of the Chief of Research and Development, Department of the Army, by the staff of the Life Sciences Research Office (LSRO), Federation of American Societies for Experimental Biology (FASEB), in accordance with the provisions of U.S. Army Contract No. DAHC19-71-C-0011. This study is one of a series in the biomedical sciences undertaken by the LSRO to provide scientific assessment of a subject based upon a comprehensive critical literature review and the views of knowledgeable scientists actively engaged in research in the field. The report develops a factual basis for subsequent discussions by research administrators.

We acknowledge the contributions of the numerous investigators who have assisted with this study. The report reflects the opinions of participants in an *ad hoc* study group who met at Beaumont, FASEB, on June 8-9, 1971, and other consultants. The report has been reviewed by these investigators and a judicious attempt has been made to incorporate the different points of view; however, the authors accept the responsibility for the contents of the report.

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SUMMARY

This report provides a comprehensive review of the adverse effects of sound on man in the military environment. It has been recognized for many years that the soldier is exposed to hazardous levels of sound. However, the proximity of noise fields, the duration and intensity of noise exposure, and the associated noise-induced hearing loss are increasing. The diversity and complexity of Army systems that overexpose the soldier to noise have caused concern for his health and his capability to perform efficiently. Despite the recognition of the deleterious effects of noise exposure, problems with noise-induced hearing loss and human performance decrement continue to enlarge.

The scope of this review includes the nature of sound exposure in military situations, the magnitude of the military problem, and the accurate identification of the characteristics of noise exposures. Particular attention is focused upon the effects of noise exposure on temporary and permanent auditory damage, on interference with voice communications, on performance of military duties, on devices and techniques that decrease or protect against excessive noise exposures, and on individual factors that affect the extent and severity of damage from noise exposures.

It is generally recognized that overexposure to high-intensity noise during a lifetime will result in progressive hearing loss. Exposure of the unprotected human ear to continuous noise in the audible range above a level of approximately 80 dB(A) is capable of producing both a temporary and a permanent change in the auditory threshold. At noise exposures of 105 dB(A) or above, a permanent threshold shift can be expected if exposure continues over several years. There is no way to correct permanent threshold shift; permanent hearing loss is irreversible.

High-intensity infrasound noise fields are rarely encountered by Army personnel at the present time; and adverse effects of infrasound are not a military problem. Similarly, high-intensity ultrasonic noise fields are uncommon in the Army environment, and airborne ultrasonic sound pressure levels up to 140 dB are considered to be essentially harmless.

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Audiologists, otologists, and others trained in clinical evaluation of hearing recognize wide variability in the human auditory system. As might be expected, responses to test stimuli of uniform frequency, duration, and intensity may vary among ostensibly normal subjects. Attempts to quantify noise effects within a population over periods of time usually exhibit both intra- and inter-subject variability. Unfortunately, it is not possible at the present time to identify audiometrically individuals with increased susceptibility or resistance to injury from noise exposure.

The modern soldier should not be exposed to undue noise hazards by using obsolete equipment with inadequate acoustical protection. In addition, the complexity and seriousness of the military problem suggests that additional emphasis be placed on the use of less noisy voice communication systems in Army vehicles, aircraft, and weapons systems.

The evidence marshalled in this study demonstrates that protection by sound attenuating devices, such as earplugs or earmuffs, has proved to be the most practical way to protect and to conserve the hearing of men required to work in a noisy environment. Distinctions can be made among such military demands as quiet nighttime sentry duty, exposure of troops to noise during vehicular or aircraft transport, and the obvious need for noise protection by aircraft and tank crews. Despite documented evidence to the contrary, most individuals think that ability to detect audible warning signals is reduced when they are required to wear hearing protectors. As a result, considerations of hearing conservation are overridden by fear or anxiety about failure to hear potentially life-threatening sounds. The importance of individual fitting, testing, and evaluating hearing protective devices is emphasized.

This report indicates that, although ototoxicity of several antibiotics and other therapeutic agents is well known, too little attention has been given to the use of nonprescribed drugs such as quinine and aspirin and their influence on hearing and the performance of the soldier.

Effective hearing conservation and reduction of noise-induced hearing loss are compromised by lack of adherence to existing Army regulations and frequent waiving of equipment design standards. More importantly, hearing conservation guidelines, education programs, and audiometric testing are often neither implemented nor

enforced by command emphasis. Additional manpower in the Army hearing conservation program is required. There is an immediate need for increased support for hearing conservation programs from the level of the Army General Staff down to the individual soldier.

The immediate application of existing scientific knowledge to the protection of the soldier against the adverse effects of high-intensity sound will be costly. However, these costs must be weighed against the loss of equipment destroyed, the investment in training qualified men, and the long-term disability expense of avoidable, service-connected hearing impairments.

This report points out that hearing is one of the most important sensory modalities possessed by the soldier, and every effort should be made to conserve the functional integrity of his auditory system. For this reason, work should be directed toward reduction of noise at its source; and, emphasis should be placed on increased support for Army hearing conservation programs.

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I. THE PROBLEM

The increasing diversity and complexity of Army systems that expose the soldier to high-intensity sound has caused concern for his health and his capability to perform efficiently. This study was conducted to provide the Life Sciences Division, Office of the Chief of Research and Development, Department of the Army, with a comprehensive review of the adverse biomedical effects of sound on man. This report is related to the Study of Factors that Affect the Performance of Army Flight Crew Personnel (Fisher *et al.*, 1969).

Hazardous levels of sound in military and civilian environments have been recognized for many years. However, the proximity of noise fields, the duration and intensity of noise exposure, and the ability to detect noise-induced hearing loss is increasing. Evolution of tactical concepts involving use of equipment such as the helicopter, rockets, and other weapons result in alarming levels and durations of noise exposure. Engineers have recognized the problems of noise generation and have furnished some guidelines on maximum permissible noise levels for Army equipment. However, the noise levels generated by many items of equipment under development exceed these guidelines.

In spite of repeated warnings, the problems of decrements in human performance caused by noise and the associated noise-induced hearing loss in military and civilian situations continue to increase. Most people do not appreciate the fact that prolonged exposure to noise of high intensity can produce both temporary and permanent hearing loss; and, that once noise-induced permanent hearing loss has been acquired, normal hearing cannot be restored. A program in hearing conservation developed by the Surgeon General of the Army has been in existence for many years. This program emphasizes the use of protective measures, helmets, and earplugs. However, the hearing protective measures recommended by the Surgeon General of the Army have not been adequately implemented.

Traditionally, engineering design and development have focused upon the reduction of sound at its source, i. e., sound attenuation; biomedical research has been directed toward

protection of the man from potentially damaging sound levels at the ear, i. e., hearing conservation. This dichotomy of engineering and biomedical emphasis and orientation to noise reduction and hearing conservation are reviewed in this study with reference to development of guidelines for future research related to Army programs in this field. As in most interdisciplinary fields, the dual problems exist of applying unrecognized but available knowledge, and identifying new research opportunities.

The Army requires efficient voice communications. Exposure to noise that does not interfere with speech or damage hearing may still produce annoying effects or other negative reactions. It is unclear if these should be classed as annoying, stressful, distracting, or in some obscure way physiologically disturbing. These noises may be of moderate intensity; they may be brief, intermittent, or continuous. The effects of such exposures have been considered in some studies of noise in industry and community living but have not been studied as a factor in military environments.

II. SCOPE OF THE STUDY

Preliminary discussions with research workers in universities and Army laboratories and with administrators directing engineering research and development programs revealed many facets of the broad problem involving generation of high-intensity sounds, effects of steady-state and impulse noises, signal perception and interpretation, and voice communication problems associated with performance in military situations. The relationships among temporary, repeated temporary, and permanent hearing losses, and the application of hearing conservation measures emerged as serious concerns of some Army medical officers. These fact-finding conversations and published reports were used in defining the scope of this study.

This study reviews the nature of sound exposure in military situations and the magnitude of the military problem. In addition, this review includes the characteristics of noise exposure, problems of measuring intensity, frequency and duration, and the noise level criteria employed to evaluate military and civilian life situations.

Exposure to excessive or prolonged high-intensity sound levels produces measurable effects on the auditory system, other body systems, and behavior of the individual. Of critical importance are temporary threshold shifts (TTS)* and permanent damage to the auditory system. The ability of the soldier to understand speech and detect the presence of the enemy are compromised by both TTS and permanent hearing loss (PHL). The relationship between TTS and the permanent threshold shift (PTS) that is indicative of certain types of noise-induced PHL is not fully understood. There appears to be considerable individual variability; some investigators feel that it is possible to predict the degree of PTS from TTS while others do not. Consideration of this subject is relevant because the ability to predict PTS or PHL on the basis of TTS would be useful. In addition, the report includes a discussion of individual variability in response to noise exposure and the hearing threshold changes that occur normally with aging.

* See p 105 for abbreviations used in the report.

In this report particular emphasis is placed on the adverse effects of noise on voice communication performance. Sound and speech detection, recognition, and intelligibility are vital aspects of effective military communications. The message "set," vocal effort, and signal level are factors that influence the efficiency of voice communication reception and of subsequent human performance in many military situations.

The nuisance effect of noise can be demonstrated by studies on sleep and the electrophysiological measures of "restful sleep." Sleep deprivation and its effects on human performance have been of interest to the military for many years.

The subjective effects of noise and its subsequent unfavorable impact on man is explored in this study because they influence performance capability. In addition, the altered performance ability of men with some degree of hearing loss is reviewed. The military implications of this particular problem have not been studied adequately.

Protection of the man by sound attenuation measures or devices has usually been the most practical way to conserve hearing in a noisy environment. New developments in the application of these types of hearing conservation measures and the development of superior sound attenuating devices are discussed. Likewise, the novel biological effects of infrasonic and ultrasonic sound exposures as they relate to the subject have been included because they represent areas that will require greater emphasis in future research.

The physiology of hearing, the assessment of auditory threshold and sensitivity, and the critical evaluation of the adequacy of damage risk criteria (DRC) and damage risk contours (DC) are excluded from this review.

III. THE NATURE AND MAGNITUDE OF THE MILITARY PROBLEM

A. GENERAL ASPECTS

Competent observers have recognized for many years that noise-induced hearing loss is a serious health hazard for military personnel. However, there are few extensive studies that document the magnitude and severity of this military problem. Hearing loss from weapons firing, operation of military vehicles such as tanks and helicopters, and noise generated and accentuated within communications systems are specific examples of the military problem. High-intensity noise levels are also produced by such Army equipment as the personnel carrier, field electric generators, tactical missile and rocket launchers, howitzers, and automatic rifles.

Continuous high-intensity noises created by electrical and mechanical systems in the armed forces have been studied as causes of hearing loss in military personnel (Fletcher and Loeb, 1963). Impulse noise from gunfire has been investigated to discover means to protect the soldier and especially instructors who experience long periods of noise exposure from this source (Acton and Forrest, 1968; Coles and Rice, 1966; Coles *et al.*, 1968; Elwood *et al.*, 1970; Keim, 1970). Most investigators suggest that weapons firing is the most common cause of hearing loss in the Army and that this type of exposure accounts for the largest number of service-connected noise-induced disabilities.

Aircraft noise is an additional source of exposure that may be injurious to flight crew, passengers, and ground personnel. The increasing use of the helicopter by the Army is resulting in more exposure of more men to noise generated by the aircraft and its weapons systems. The extensive use of helicopters to transport troops has increased the risk of hearing loss for a greater number of soldiers, and temporary hearing loss from this source could impair their performance (Bragg, 1968; Gasaway, 1970a; Kronoveter and Somerville, 1970). Noise problems associated with the operation of the major types of Army aircraft have been studied by Hatfield and Gasaway (1963), and a survey of the internal

and external noise fields in these aircraft has been made (Gasaway and Hatfield, 1963).

The public health aspects associated with aircraft noise continue to be a matter for intensive study by many research workers. Audiometric data from these investigations indicate the need for protection against hearing loss and annoyance resulting from prolonged exposures to aircraft noise (Cohen and Ayer, 1964). The military need to diminish aircraft noise is focused primarily upon prevention of detection.

Reviews of the causes of noise generation and its suppression in helicopters have been made to develop new approaches to noise suppression and to implement technological advances in equipment design (Miller, 1968). Present engineering goals have emphasized the performance requirements of these aircraft and little consideration has been given to the high levels of noise generated in meeting equipment performance requirements. The versatile nature of the helicopter in meeting Army needs has resulted in the acceptance of excessive noise as a trade-off. Noise encountered within these and other aircraft has been shown to be potentially hazardous to aircrews and other personnel in or near the aircraft (Gasaway, 1969; Gasaway, 1970a; Gasaway and Sutherland, 1970). However, subsequent appraisal of the effects of noise on men associated with these aircraft raises new questions. Can the noise be reduced? Is it possible to protect men against the noise by the use of sound attenuation techniques and devices? Proposed criteria for ambient noise exposures in fixed- and rotary-winged aircraft, including special-purpose military aircraft, are being evaluated by the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Academy of Sciences-National Research Council (NAS-NRC) at the present time.

In addition to weapons and aircraft noise, the military problem includes hazardous noise levels produced by combat vehicles and trucks. External noise created by high-speed trucks on a highway can be excessive and much of this noise appears to be related to truck tires, the load, and the road surface (Tetlow, 1971). In addition to these sources there is noise generated by the engine and power train. Investigations of noise levels inside military vehicles are being conducted by several Army laboratories.

B. NOISE REDUCTION AND HEARING CONSERVATION
ACTIVITIES OF ARMY AGENCIES

The Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, have established Maximum Noise Level for Army Materiel Command Equipment (HEL Standard S-1-63B), (Chaillet and Garinther, 1965). These noise limits have been incorporated into Department of Defense Human Engineering Design Criteria for Military Systems, Equipment and Facilities (MIL-STD-1472A, 1970) and thus are a mandatory inclusion to procurement actions for Army Materiel Command equipment. A significant portion of the military problems with equipment noise appears to result from waiver of these standards during early phases of design or testing. Although there is some question as to the universal applicability of these standards, they do provide operational goals for the equipment designer in meeting the need for noise reduction. The Human Engineering Laboratories have also participated in the development of hearing DRC for impulse-noise exposure (Coles *et al.*, 1967, 1968; Ward, 1968). The current research program includes investigations that will provide quantitative information about the effects of temporary and permanent hearing loss in relation to speech reception and personnel detection in tactical situations.

The Bio-Acoustics Division of the U. S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, Maryland, provides field consultations and advice to commanders concerning medical, engineering, and planning aspects of the installation's hearing conservation programs; identifies and evaluates noise-hazardous equipment, environment, and activities by on-site surveys; and periodically reviews Army directives relating to hearing conservation and specifications of potentially noise-hazardous equipment. The Division is developing an inventory of noise sources present in the Army and is a source of information for the Army's hearing conservation program. The Division also conducts an annual training course, "Military Hearing Conservation," for personnel responsible for implementation of hearing conservation programs at Army installations.

The Army Aeromedical Research Laboratory, Fort Rucker, Alabama, is investigating the adverse biomedical effects of military noise exposure associated with operation of Army aircraft. This

laboratory has reported studies on effects of noise on personnel, including "fatigue," temporary and permanent hearing losses in air crews, voice communication problems in aircraft, and aircraft mission failures associated with high-intensity noise. A number of outstanding research contributions have been made by this laboratory including development and demonstration of superior sound attenuation characteristics in the new SPH-4 aviator's helmet, flight proficiency assessment of Army helicopter pilots as influenced by their noisy cockpit environment, weapons firing effects, and voice communication intelligibility. One of the major concerns of the Fort Rucker laboratory is assessment of the risk of man's exposure to, and protection against, the noise of the helicopter and the effective utilization of this aircraft within Army operational requirements.

The U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, has studied noise problems associated with military vehicles for a number of years. In addition to research on assessment of risk of hearing damage from noise exposure, this laboratory has studied the effects of TTS and the recovery of auditory thresholds following exposure to impulse and steady-state noise. Studies on the application of the aural reflex to protect a man's ear from gunfire noise were conducted by workers in this laboratory. Voice communication problems in tanks, the influence of weapons firing within confined spaces and long-term operations in a noisy environment on a man's performance and hearing, screening techniques for noise-susceptible individuals, and hearing protective devices continue to be investigated by this laboratory. The documentation of military noise problems by this laboratory has helped to develop effective guidelines for the Army's hearing conservation program.

The U. S. Army Surgeon General's Preventive Medicine program includes protection of the soldier against hazardous noise exposure. Department of the Army TB Med 251 (1965) provides guidelines for noise assessment and conservation of hearing in military and civilian personnel. It provides exposure level limits of 90 dB(A) for steady-state noise and 140 dB(A) for impulse noise. TB Med 251 is being revised at the present time. Application of these guidelines to hearing conservation in the Department of the Army is provided by AR 40-5 (1969). Similar regulations are provided for the Department of the Navy (BuMed Instr. 6260.6B, 1970), and the Department of the Air Force (AFR 160-3, 1956, AFR 160-3B, 1967).

The recognition of noise as a special problem for military personnel has led to attempts to reduce excessive noise exposure and conserve hearing as much as possible within the constraints of military demands. TB Med 251 indicates that the preventive medical officer should supervise the use of personal hearing protective devices. These devices include earplugs, earmuffs, headsets, and helmets fitted with communication equipment. Effective protection of large numbers of men against noise-induced hearing loss includes education about noise hazards, discipline to insure use of hearing protectors by men assigned to hazardous noise duty, and correct measurement of hearing levels by audiologists.

The Army Audiology Speech Center (AASC) at Walter Reed General Hospital, Washington, D. C., conducts a research and epidemiologic program on noise-induced hearing loss. The AASC studies emphasize the importance and magnitude of noise-induced hearing loss in the Army and the need for continuing emphasis on recognition of this hazard by all levels of military personnel. Unfortunately, the serious nature of excessive noise exposure and the importance of audiological examinations are not generally appreciated in our society, and military personnel are no exception.

IV. CHARACTERISTICS OF SOUND EXPOSURE

Because this report is of interest to individuals in fields other than audition and psychoacoustics, it is appropriate to review briefly the nature of sound, the types of exposures encountered in the military environment, the measurement of sound and noise, and the generally accepted guidelines for exposure risks. For more complete information the reader should consult recent reviews (Burns, 1968; Goldman, 1970; Ward and Fricke, 1969).

A. SOUND

Sound is a physical phenomenon that involves a mechanical disturbance, propagated in an elastic medium, that is capable of eliciting the sensation of hearing. In the usual context, the sound consists of an alternately compressed and rarefied wave field that causes slight rapid changes in barometric pressure as it moves in the atmosphere. When the pressure variations at frequencies between 20 and 20,000 Hertz (Hz) are sufficiently large, they are audible; that is, they are capable of stimulating the human auditory system.

The elastic medium through which sound waves move may be solid, liquid, or gaseous. Frequencies below 20 Hz or above 20,000 Hz may be propagated in media other than the atmosphere and are not considered as "sound" because they do not excite the sensation of hearing.

There are three major physical attributes of sound that can be measured quantitatively: frequency, intensity, and duration. Frequency refers to the number of repetitions, or cycles, of similar pressure variation per unit of time. By international convention, the number of cycles per second (c/s or cps), or Hertz (Hz) is the accepted unit of frequency. Tone refers to a frequency or frequencies that elicit a sensation of definite pitch. Thus, pitch is the perceived auditory sensation of a tone, usually expressed in terms of an ordered scale related to frequency. Tones of various frequencies may be grouped in bands; an octave bandwidth has an upper frequency limit that is double its lower frequency.

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The amplitude or intensity of vibrations can be measured several ways; however, the most widely used are pressure or power levels relative to an arbitrary standard. Sound pressure levels (SPL) are expressed in decibels (dB) relative to a standard pressure. The American National Standards Institute reference pressure of $20 \mu\text{N}/\text{m}^2$ * (0.0002 microbar) is generally accepted; however, some investigators prefer to use $1.0 \text{ dyne}/\text{cm}^2$. Power wattage level (PWL) is a useful term in relating the total sound power emitted by a source to other power sources measured in terms of watts. Both SPL and sound power levels derived from PWL are usually specified in terms of dB which may be of a discrete frequency, octave band, or one-third octave band.

The duration of sound is measured in time units, usually in terms of microseconds to minutes. The duration of a sound is the time from initial change from ambient pressure to final return to ambient pressure.

B. NOISE

A universally acceptable definition of noise has not been developed. Most authorities define noise in terms of sound that is unwanted or undesired by the recipient. It is this concept of being "unwanted" that introduces ambiguity; at one instant an acoustic stimulus may be considered desirable or wanted, and, an instant later, the same stimulus may be judged undesirable.

Although noise involves value judgements by the listener, noises may be described in quantifiable physical terms. Noisy sounds contain few or many audible frequencies of measurable intensity and duration (Rudmose, 1969).

* Micronewtons per square meter. See glossary.

C. STEADY-STATE AND IMPULSE NOISE

High intensities of noise are commonly encountered in the civilian and military environments. This background of unwanted sound is associated with vehicular engines, motion of vehicles and aircraft, office machinery, cacophonous conversations, and weapons firing. Although some investigators disagree, steady-state noise is usually defined as random or periodic SPL variation within the range of audible frequencies with a duration ≥ 1 second.

The explosive force of weapons firing is an example of impulse noise. Automatic weapons fire, small-arms fire, and rocket blast are the most frequently encountered forms of impulse noise in the military environment. Impulse noise is distinguished by its transient nature, that is, a relatively large increase in SPL in an extremely brief time period. The rise in SPL and the time duration have been defined differently by several investigators (Coles *et al.*, 1967; Hodge and Garinther, in press; Kryter, 1970; Ward, 1968).

The lack of agreement about the precise definition of impulse noise makes difficult the comparison of data or results from several studies. For example, the noise produced by several lightweight automatic weapons with increased ballistic efficiencies may or may not be impulse noise, depending upon the exact criteria used to define SPL rise and duration of rise time.

D. MEASUREMENT OF SOUND AND NOISE

The most frequently measured aspect of sound is sound pressure level. The sound level meter provides a convenient indication of sound levels in terms of dB. This instrument consists of a microphone, amplifiers, sets of attenuators, weighting filters, and a readout device, usually a scale registering dB. The microphone transforms atmospheric pressure variations into electrical fluctuations (normally voltage) which are amplified, filtered, and actuate the readout device. In practice, numerous modifications can be made depending upon the need of the user. Although sound level meters do not accurately record frequency, the responses can be

altered by frequency weighting in the electronic circuitry of the instrument. Three weighted response networks dB(A), dB(B), and dB(C) are commonly used. The A-weighted response is most frequently used because it approximates the response of human hearing (Young, 1970).

The wide frequency range of audible sound requires instrumentation sensitive to frequency differences or spectra as well as intensity level. While the sound level meter indicates dB in broad frequency bands, the frequency analyzer (octave band analyzer) selects narrower bands of frequency and has been the instrument of choice in determination of frequency-intensity patterns. For example, the octave band frequency analyzer displays or records the SPL for each of several octaves or segments of a frequency spectrum. Typically the octave bands are denoted by the geometric mean of the frequencies within the octave band. More detailed analyses may require use of one-third octave analyzers. Measurement of impulse noise requires more specialized instrumentation that can respond to the nearly instantaneous rise times of these sounds (Coles *et al.*, 1968; Garinther and Moreland, 1965). Characteristics and limitations of the various types of acoustic instruments for measuring steady-state noise were summarized by Rudmose in 1969.

Measurement of the reception of noise requires psychoacoustic techniques that include quantification of loudness level, loudness, pitch, noisiness or annoyance value. The most frequently studied psychoacoustic parameter is loudness level. The loudness level of a sound is measured by the SPL of standard tones of specified frequencies that are judged to be of equal loudness by normal listeners. Loudness level identifies tones of equal loudness but different frequencies in terms of phons. Loudness, the listeners' impression of strength of a sound, is expressed in terms of sones. The mel is often used as a psychoacoustic unit of pitch difference discrimination. For a more complete discussion Burns (1968), Glorig (1958), or Rudmose (1969) should be consulted.

Kryter (1970) has introduced the concept of noisiness, measured as noys; these are somewhat analogous to sones. He also developed the perceived noise level (PNdB) as a frequency-weighted noise level in terms of noy units. Kryter has suggested that loudness and noisiness are significantly different; however, other investigators are of the opinion that the two concepts either overlap or are not

significantly different except in certain instances such as jet engine noise spectra.

Although the techniques of noise measurement have continued to improve, experience with continuous noise exposures is more extensive than either intermittent exposures to relatively steady-state noise, or repeated exposures to impulse noise. Numerous other parameters of sound and its aural perception may be measured depending upon the nature of the investigations. Many of these indices refer to recognition, perception, or interference; however, these aspects are beyond the scope of this report. More definitive treatment of these topics may be found in the publications of the American National Standards Institute and in textbooks of acoustic science.

E CRITERIA FOR EVALUATION OF SOUND EXPOSURE

The most frequently measured audiometric response is the detection of discrete frequencies of increasing or decreasing intensities. This technique provides a measure of the threshold of audibility. Changes in threshold values, i. e., auditory threshold shifts, can be determined for several frequencies after exposures to noise or sound. Both temporary threshold shift (TTS) and permanent threshold shift (PTS) depend upon the level and duration of exposure, the frequency spectrum of the sound or noise, the duration of time without exposure, i. e., rest periods, and the duration of chronic exposure. It is logical, then, that standards for acceptable or hazardous noise exposures must take these variables into account.

Determination of TTS depends upon accurate assessment of audibility measured before and after known exposures. However, PTS frequently must depend on measurement of thresholds separated by considerable periods of time, i. e., several years of intervening noise exposure. The evolution of criteria for acceptable noise exposure has been based on the assumption that below a certain SPL or within a prescribed time period, exposure to sounds of different frequencies and duration will not adversely affect auditory threshold. However, it is recognized that above a certain increased SPL or prolonged exposure (or both), there is a definite risk or hazard because of the induction of TTS or PTS.

1. Damage Risk Criteria (DRC) and Damage Risk Contours (DC)

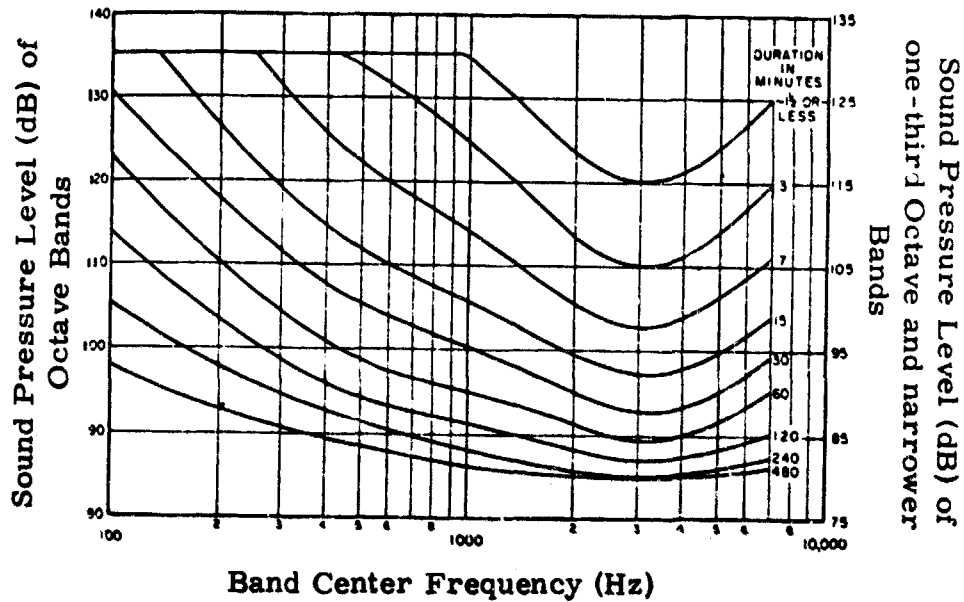
DRC and DC are based upon the assumption that a threshold shift can be an indicator of auditory damage. An "acceptable" noise exposure is safe, and a "hazardous" noise exposure involves risk of temporary or permanent damage to auditory capability. For example, using the DRC in Figure 1, exposure to noise with a band center frequency of 1000 Hz at 100 dB would be "acceptable" to 50% of the normal population if the exposure duration was 30 minutes per day, but "hazardous" to the other 50% of those exposed.

It is outside the scope of this report to review the evolution of DRC or to discuss the ramifications of applying various risk criteria to the military environment. Acton (1967), Coles *et al.* (1968), Eldredge and Miller (1969), Glorig *et al.* (1961), and von Gierke (1965) have prepared excellent reviews of the evolution of the concept of DRC and the development of DC. However, DRC are mentioned because these criteria are used by the Army in evaluation of hazardous noise levels and assessment of hearing conservation needs.

In 1955, CHABA was asked to develop DRC and DC that would be useful in assessing noise exposures in the military environment. CHABA Working Group 46 (Kryter *et al.*, 1965) (see Figure 1) reviewed available data on TTS and PTS and published a series of guidelines on the specific risks of auditory damage from exposure to intermittent and steady-state noise (Kryter *et al.*, 1966). These guidelines cover continuous and intermittent noise exposures as well as short and long bursts of broad-band noise. DRC are based upon specific TTS data and probable protection of 50% of the normal population exposed. Botsford (1967) revised the tables by combining the contours for different octave bands and for interrupted and for intermittent exposures into a single set of contours. Botsford (1967) also replaced the specifications in terms of octave band levels with A-weighted sound level values [dB(A)]. The A-weighted method of assessing auditory risk has been studied by several organizations (Gasaway and Sutherland, 1971).

Coles *et al.* (1968) used TTS data as a basis of assessing risks of exposure to several types of impulse noise. CHABA Working Group 57 promulgated DRC for impulse noise of gunfire (Ward, 1968), based primarily on the formulation of Coles *et al.*

FIGURE 1



Example of Damage Risk Criteria: damage risk contours for one exposure per day of either one octave band (left ordinate) or one-third octave or narrower (right ordinate) band of noise. The graph can be applied to individual band levels in continuous broad-band noise. (From Kryter *et al.*, 1965).

(1968). Both groups recognized the problem of individual differences in response to impulse noise and the difficulty of accurate audiometric evaluation. They suggested that the previously accepted values of 135 dB or 140 dB were inadequate, and indicated that further clarification of the hazards of impulse noise was needed. Impulse noise DRC are based on a 95% protection level, rather than the 50% level employed with previous CHABA steady-state noise DRC.

Some of the suggested duration and level maxima inherent in the CHABA standards for nonimpulse noise have been incorporated into Hazardous Noise Exposure (Department of the Air Force, AFR 106-3, 1956; AFR 160-3B, 1967) and BuMed Instruction 6260. B (1970) concerning the Department of the Navy hearing conservation program.

The Occupational Safety and Health Act of 1970 sets standards for noise exposures which may be hazardous or dangerous to the safety and health of civilian employees engaged in work under government contracts. Age-adjusted DRC that reflect the interest of the Walsh-Healey Public Contracts Act of 1969 have been incorporated in a recent revision of the Guide for Conservation of Hearing in Noise, prepared by the Committee on Conservation of Hearing, American Academy of Ophthalmology and Otolaryngology (1969).

Although there is some lack of agreement that TTS is the most accurate basis for prediction of subsequent auditory damage, the DRC do provide acceptable standards for both safe and hazardous noise exposures (Eldredge and Miller, 1969). Differences in noise exposure intensity and duration among the various "standards" or "guidelines" may be reduced as additional data become available. Furthermore, as noted by Cohen (1963), the readiness of the general public to insist on noise exposure criteria for protection appears to be enhanced by continued recognition of the hazards of excessive exposure.

The most widely used DRC are those developed from the CHABA recommendations. These criteria are based upon the normal working day. The evolving military concept of continuous operations will require extension of current knowledge to prolonged exposure periods exceeding 8 hours. Long-term exposures producing TTS require longer recovery periods. There is a need for more information on performance of men exposed to noise during continuous operations. Similarly, DRC for intermittent exposures during prolonged periods need further substantiation.

In addition, the DRC for steady-state noise exposures are based on a protection of 50% of the individuals exposed; that is, exposures exceeding the recommended DRC will be hazardous to 50% of the population exposed. CHABA recommended a 95% protection level with impulse noise exposures which may be a more realistic protection level for all DRC. Even more important is the need to convert DRC into intelligible terminology. For example, the statement, "one out of two men will be unable to hear for up to 16 hours after a 3-minute exposure to weapon X" is more readily understood by the nonspecialist than "3 minutes' exposure to 110 dB(A) white noise of an octave band centered at a frequency of 3000 Hz will induce at least 20 dB hearing loss in 50% of those exposed." Obviously, such simplifications may be scientifically imprecise; however, they are more practical.

In summary, currently promulgated DRC suggest that: first, prolonged exposures to noise fields below 70 to 80 dB(A) are safe; that is, no permanent auditory damage is expected. Second, these DRC indicate that hearing will probably be impaired in at least 50% of the population exposed to steady-state noise fields of 80 to 95 dB(A) for prolonged time periods. Third, continuous exposure to noise fields in excess of 105 dB(A) will definitely induce hearing loss in a majority of those individuals so exposed. Within these limitations DRC such as those prepared by CHABA and the American Academy of Ophthalmology and Otolaryngology provide useful guidelines on the risks of auditory damage from continuous or intermittent noise exposure. There is a continuing need for additional data on damage risk from impulse noise exposures.

2. Army Guidelines on Sound Exposure Evaluation

The various standards and guidelines for acceptable and hazardous noise levels and exposures have been incorporated into several Department of the Army regulations and directives. For example, reference to these standards can be found in equipment design specifications, explanations of hearing conservation programs, and evaluations of hearing loss. Pertinent Department of the Army statements include:

- a. The essential aspects of the Army Hearing Conservation Program are covered in AR 40-5 (Department of the Army, 1969). Guidelines

for hazardous noise exposure levels refer to TB Med 251 (Department of the Army, 1965); further reference to increasing noise as a cause of hearing loss is made in DA Circular 40-79 (Department of the Army, 1971).

- b. A more complete statement of the U.S. Army Hearing Conservation Program is given in Department of the Army Technical Bulletin, Noise and Conservation of Hearing, TB Med 251 (1965). This bulletin "summarizes some important facts relating to noise and its effect on the ear, and outlines the essential features of a preventive program which has as its aim the conservation of hearing. Its purpose is to alert medical officers and other physicians in the Army to this problem, and provide guidance in those circumstances where a problem of potentially hazardous noise exposure exists, either among military or civilian personnel." TB Med 251 states that a hearing conservation program is indicated if noise spectrum analyses reveal sound levels in excess of:

Octave bands Hz	SPL in dB
150 - 300	92
300 - 600	85
600 - 1200	85
1200 - 2400	85
2400 - 4800	85
4800 - 9600	85

(From Table 1, p 3, TB Med 251, 1965).

It should be noted that these guidelines are based on noise levels for an 8-hour daily exposure to steady-state noise and are a slight modification of CHABA recommendations (see Figure 1). In the absence of complete noise spectrum analyses, the hearing conservation program is required when overall noise intensities exceed 90 dB.

The maximum allowable impulse noise exposure level for unprotected ears is set at 140 dB. As noted previously, a revision of TB Med 251 will be published in 1971 or early 1972.

- c. The Bio-Acoustics Division, Medical Directorate, Army Environmental Hygiene Agency (AEHA) conducts noise level surveys at Army installations upon request. An inventory of noise generated by all military hardware and equipment is being compiled. Because these surveys are adjuncts to the Army's hearing conservation program, the criteria promulgated in TB Med 251 are used as a guideline.
- d. The Human Engineering Laboratories (HEL) have developed standards that establish the maximum noise levels permitted at personnel-occupied spaces in equipment designed, developed, or procured by the Army Materiel Command (Table 1). HEL Standard S-1-63B (Chaillet and Garinther, 1965) refers to maximum noise allowable. These standards have been incorporated into MIL-STD-1472A and are consistent with those proposed for industry in general by the American National Standards Institute. It is important to recognize that these standards are for noise generation by equipment; they are not intended to be used as DRC for evaluation of auditory risk. In addition, these limitations on maximum noise levels apply only to situations where there is neither a need for direct communication nor a requirement for electrically aided communication. For equipment where unaided person-to-person communication is essential the noise level limits are much lower; that is, equivalent to a speech interference level of 60 dB. (See Table 4, p 11, in Chaillet and Garinther, 1965, for explanation).

TABLE 1
MAXIMUM STEADY STATE NOISE LEVEL
FOR ARMY MATERIEL COMMAND EQUIPMENT
(Preferred Frequencies [ASA S1.6-1960])

Octave Band Limits (Hz)	Center Frequency (Hz)	Noise Level (dB)
44 - 87	63	119
87 - 175	125	114
175 - 350	250	107
350 - 700	500	99
700 - 1400	1000	91
1400 - 2800	2000	89
2800 - 5600	4000	89
5600 - 11200	8000	91

See text for explanation.

(From Chaillet and Garinther, HEL Standard S-1-63B, p 5, 1965).

V. EFFECTS OF EXCESSIVE SOUND EXPOSURE

Prolonged exposures to high-intensity noise produce measurable effects on the auditory system, other body functions, and may modify behavior of the individual. Auditory thresholds increase following excessive exposure. This transient but measurable loss of the ability to recognize sounds interferes with normal communication and compromises individual safety. Irreversible damage to the auditory system may follow the temporary changes after excessive sound exposures and ultimately may lead to permanent loss of hearing.

Overstimulation of the auditory system will produce temporary secondary effects in the cardiovascular, gastrointestinal, and other body systems. Although there is little evidence that noise produces permanent nonauditory effects, the effects of excessive noise exposures on nonauditory systems are not fully known. Finally, the effects of noise exposure on the auditory and other body systems may influence behavior and human performance.

A. AUDITORY EFFECTS

In most working environments, there is normal background noise; that is, its presence is constant although frequency, intensity, and duration may vary. With certain exceptions, background noise is perceived as sound that conveys no meaningful message. This noise may interfere with perception of useful auditory information, e. g., may cover up, or mask, meaningful auditory stimuli.

1. Tinnitus and the Aural Reflex

Tinnitus is a ringing, hissing, or musical sound that may occur within the ear after exposure to noise levels above approximately 70 to 90 dB(A). Tinnitus is a frequent consequence of excessive noise exposure. Large differences among individuals are evident. Tinnitus may diminish or disappear following either continued exposure or cessation of exposure; and, it is often

constantly present in ears with permanent noise-induced hearing loss. Tinnitus is thought to be the result of continued discharge of auditory nerve fibers following intense stimulation of the organ of Corti (Burns, 1968). Because of the variability in occurrence, severity, and subjective nature of tinnitus, it is not used extensively as a qualitative or quantitative indicator of exposure to noise. However, Atherley *et al.* (1968) have shown that the pitch of a noise-induced short-duration tinnitus appears to have a constant relationship to the frequency of the stimulus noise. Because tinnitus is a sign of damage or impending damage that may have predictive value, it should receive further study.

The aural reflex involves two small muscles attached to the malleus and the stapes (Figure 2) that contract involuntarily when stimulated by intense sound. Muscle tension restricts tympanic membrane movement by altering the capacity of the ossicles to vibrate freely. Thus the aural reflex results in decreased transmission of lower frequency stimulation from the outer ear to the cochlea. For example, the aural reflex is activated by SPL of approximately 80 dB for 1000 to 2000 Hz and 85 dB at 250 and 4000 Hz. In this manner, the aural reflex protects the inner ear from excessive SPL at 2000 Hz or below; however, this protection from noise exposure in general is incomplete.

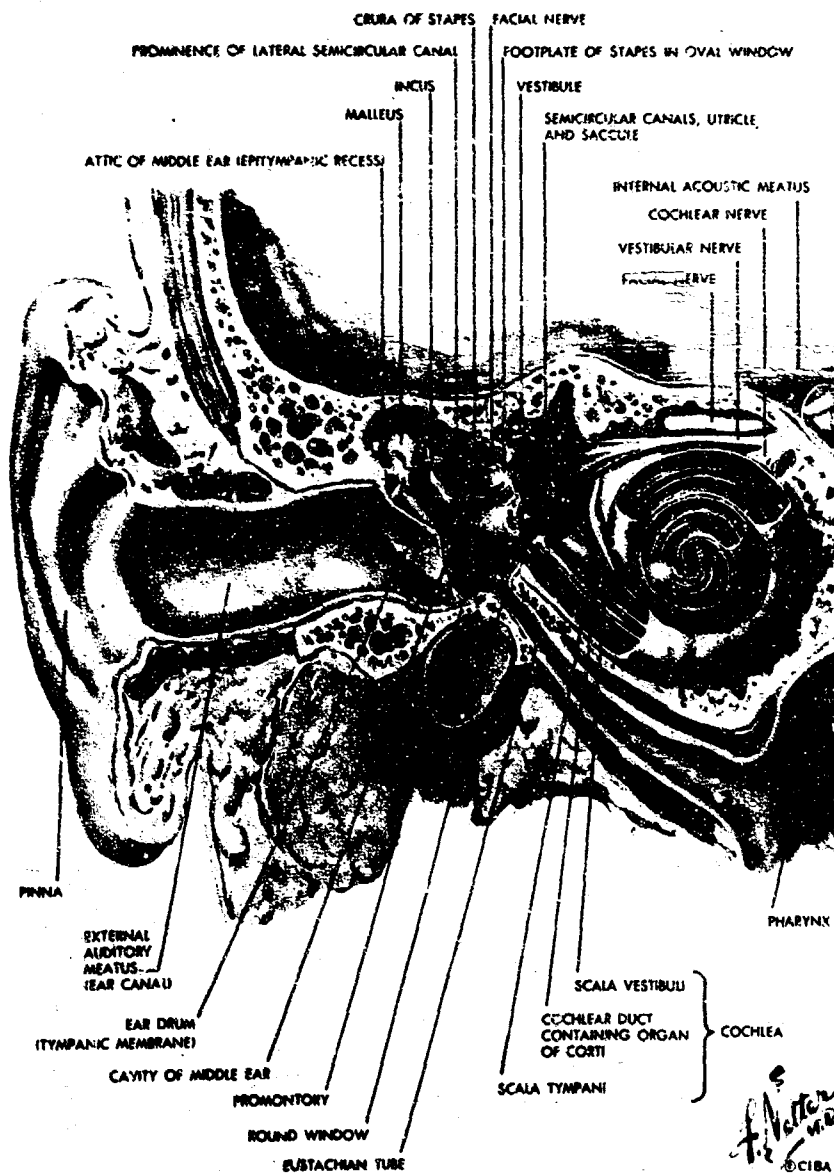
Brasher *et al.* (1970) concluded that middle ear muscle activity had little importance in reduction of auditory hazard in many types of noise exposure. In a carefully controlled study, they observed little correlation of induced aural reflex function with variations in TTS (Brasher *et al.*, 1970). They suggested that the aural reflex was protective only in situations where additional sound was superimposed on steady-state noise, where steady-state noise occurred between or prior to other noise, or when the characteristically rapid adaptation of the aural reflex does not occur.

Reviews by Wersall (1958) and Jepsen (1963) should be consulted for additional information on the physiology and function of the aural reflex.

2. Temporary Threshold Shift, Permanent Threshold Shift, and Acoustic Trauma

Noise-induced temporary threshold shift (NITTS) and

FIGURE 2



The Pathway of Sound Reception.

(From Myers et al., 1970. Copyright 1970, CIBA Corporation; reproduced with permission from Clinical Symposia, illustrated by Frank H. Netter, M.D.).

noise-induced permanent threshold shift (NIPTS) markedly affect recognition of environmental sounds and voice communications. Continued exposure to intense noise causes the threshold of hearing to rise. If exposure ceases, the threshold may return to the previous or "normal" threshold value for that individual. NITTS is markedly affected by frequency, intensity, and duration of the noise to which the ear has been exposed.

If, after prolonged or repeated noise exposures and following a reasonable rest period, the threshold does not recover to the initially measured value, the residual loss of sensitivity is termed NIPTS. PHL may occur either from repeated exposures over months or years to sounds that produce NITTS, from a single brief exposure to extremely loud sounds, or from physical trauma. This latter type of PHL is termed acoustic trauma (Table 2). It is essential to differentiate between noise-induced acoustic trauma and other causes of acoustic trauma totally unrelated to noise exposures (Glorig, 1958). Similarly, the legal and medical definitions must be differentiated.

The insidious development of progressive hearing loss during continued exposure to noise over several years has led to extensive research on the threshold shift phenomenon. The relations between NITTS and NIPTS have been examined in attempts to discern some predictive measure of the permanent effects of noise on hearing.

Ward (1969) has recently summarized the relationships between noise and TTS that are supported by adequate data as follows:

- a. The increase of NITTS (in dB) is nearly linear with the logarithm of time; however, a NITTS of 40 to 50 dB represents a critical shift that may result in a residual NIPTS.
- b. Low-frequency noises produce less NITTS than high-frequency noises of equivalent energy.
- c. Narrow-band-noise exposures produce NITTS effects in frequencies one-half to one octave above the stimulus-frequency band.

TABLE 2

CLASSIFICATION OF HEARING LOSS TERMS

Cause of Hearing Loss	Medical Name	Legal Name	Suggested Names	
			Agent Identifying	Damage Identifying
continuous noise exposure	noise-induced hearing loss, occupational hearing loss, or frequently acoustic trauma	occupational hearing loss	noise-induced hearing loss	auditory trauma (caused by long continued noise exposure)
sudden explosive blasts	acoustic trauma	acoustic trauma	acoustic trauma (to the ear)	auditory trauma (caused by sudden noise)
mechanical blows to the head and/or ear	acoustic trauma	acoustic trauma	mechanical trauma (to the ear)	auditory trauma (caused by blows to head)

(Modified from Glorig, 1958).

- d. NITTS increases linearly with exposure levels from about 80 dB to 130 dB SPL.
- e. Continuous noise will produce more NITTS than intermittent noise; and further, NITTS is roughly proportional to the fraction of time the intermittent noise is present.
- f. Increase of and recovery from NITTS are apparently unaffected by drugs, circadian rhythm, or behavior.
- g. The physiological site of TTS appears to be in the region of the hair cells of the cochlea.

3. The Relationship Between TTS and PTS

Glorig *et al.* (1961) noted that NITTS appeared to be an integral part of NIPTS. They pointed out that the NITTS at 4000 Hz two minutes (NITTS₂) after an eight-hour exposure, was similar to the asymptotic NIPTS resulting from 10 or more years of daily exposure. Glorig *et al.* (1961) concluded that the NITTS₂ might be predictive of the subsequent NIPTS.

Numerous investigators have shown that, in general, the amount of TTS₂ increases with the intensity of the test exposure and with the duration of exposure. Similarly, the length of the recovery period is influenced by frequency, intensity, and duration of exposure, as well as individual susceptibility. Recovery from sound exposure is at first rapid, but slows with time. Data on TTS₂ have been employed as determinants in development of DC. For a more complete discussion of TTS recovery, the reviews of Burns (1968), Eldredge and Miller (1969), and Luz and Hodge (1971) should be consulted.

The CHABA Working Group 46 (Kryter *et al.*, 1965) concluded that PTS was excessive if a threshold shift exceeded 10 dB with frequencies at or below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at or above 3000 Hz, respectively. DC were prepared substituting TTS₂ data for PTS values (see Figure 1). The concept of using TTS₂ criteria in place of NIPTS criteria is based upon three assumptions:

- a. TTS_2 is a consistent measure of the effects of a single day's exposure to noise;
- b. All exposures that produce the same TTS_2 are equally hazardous; and
- c. There is a correspondence between the magnitudes of TTS_2 for one day's exposure and NIPTS for 10 or more years of exposure that is close enough to justify using one to predict the other.

Although each of these statements appears to be true, conclusive evidence has not been produced (Eldredge and Miller, 1969). While auditory thresholds appear stable (Delany, 1970), the threshold shift consistency can be affected by numerous factors which are difficult to control. Similarly, the hazard of NIPTS is one consideration while possible effects of NITTS are another. For example, the TTS_2 resulting from continuous exposure to steady-state noise recovers rapidly, if not larger than about 35 dB (Kryter, 1965). But TTS from intermittent noise may recover more slowly (Ward, 1970), and the same is true for TTS induced by long exposures (24 to 48 hours) (Mills *et al.*, 1970), and TTS from impulse noise (Luz and Hodge, 1971).

Thus a soldier exposed to continuous noise may have recovered sufficiently for return to duty after several hours. However, if he were exposed to intermittent noise, to prolonged exposure, or to impulse noise, he might have limited recovery in the same time period that would preclude return to duty, even though the TTS_2 was equivalent to that resulting from continuous noise exposure. In this context, there is a need to study the possibility of developing exposure limit criteria based upon recovery time rather than TTS. Such criteria would apply to the soldier exposed to noise fields for extended durations that are consistent with the concept of continuous operation.

The major overriding concern is that experimental induction of NITTS in human subjects carries the risk of producing NIPTS, thus much of the investigative work has been done with animals. While most reports support the hypothesis that TTS is of value in predicting PTS, the relationship requires further investigation. Some investigators suggest that TTS alone may not detect all the auditory damage resulting from noise exposures.

4. Physiological Basis of TTS and PTS

The occurrence of threshold shifts is measured audiometrically, comparing the threshold after exposure with the threshold measured before exposure. As noted previously, recovery from TTS occurs with time following cessation of exposure; however, in the case of PTS recovery to preexposure levels does not occur. It is well established that exposures to excessively loud sounds for brief periods, or prolonged exposures (years), to sound fields with SPL exceeding 85 dB do precipitate NIPTS and noise-induced hearing loss.

When stimulated by relatively large changes in SPL, the bones of the middle ear transmit these pressure changes to the perilymph and endolymph of the inner ear. Excessively rapid, prolonged, or violent movement and pressure changes in the perilymph produce shear forces that disrupt the integrity of the hair cells attached to the tectorial membrane (see Figure 2). Thus, anatomic changes in the middle and inner ear may occur in noise-induced hearing loss or noise-induced acoustic trauma (Chadwick, 1963).

The middle ear transmits most efficiently the frequency range of 100 to 4000 Hz; thus, at lower intensities relatively more energy reaches the cochlea at these frequencies. Similarly, the basal area of the basilar membrane is affected not only by the resonant frequency which induces maximal membrane displacement, but also by frequencies below its resonant frequency. Thus initial changes in inner ear components may be demonstrated first, along with loss of sensitivity to 4000 Hz. Mechanical disruption of hair cells, changes in oxygen tension within the cochlea, and altered metabolism have been found in studies of cochleae exposed to excessive noise.

The extent to which morphologic changes occur in NITTS and NIPTS can be determined most readily in animal studies or by postmortem examination of human ears. Investigations on several animal models confirm the presence of discrete morphologic changes; however, further quantitative definitive work is required to correlate audiometric observations with anatomic or physiologic changes (Burns, 1968; Chadwick, 1963).

Although histologically identifiable changes are associated with NIPTS and PHL in animals, the physiological basis of NITTS is not fully understood. The aural reflex may afford some protection of the middle and inner ear from lower frequencies and may be involved in NITTS. The asymptotic slope of the curve describing the recovery time of NITTS suggests that some structural or neurophysiological process is being restored. These and similar observations imply that the physiological processes involved in NITTS may not be identical to those showing the changes correlated with NIPTS. Lawrence *et al.* (1967) concluded, from studies on the guinea pig, that NITTS may be caused by temporary reduction of the blood supply to the scala media as the result of SPL-induced capillary occlusion. In related studies, David *et al.* (1958) and Misrahy *et al.* (1958) have shown that endolymphatic hypoxia may be involved. Further research is required to clarify this aspect of the understanding of TTS and PTS.

As noted previously, the absence of a firm quantitative relation between NITTS and NIPTS in no way diminishes the efficacy of TTS as a measure of the effect of noise or the status of an individual's hearing after a noise exposure. TTS is being used to assess the ability of noise-exposed soldiers to understand speech or to perform sentry duty, i. e., to detect potentially life-threatening sounds. From a knowledge of the amount of TTS and the type of exposure which induced it, the time needed to restore normal hearing acuity may be predicted.

B. SOMATIC EFFECTS

In addition to producing auditory changes such as TTS and PTS, exposure to noise affects other physiological processes. Acoustic stimulation and excitation of auditory nerve fibers may constitute an arousal or stress response that provides a mechanism for focusing attention on desired or life-threatening environmental stimuli. Auditory perception in higher cortical centers generates efferent nerve impulses that stimulate the cardiovascular, musculoskeletal, endocrine, and other body systems. Measurable physiological responses may occur with noise exposures that are below TTS-inducing thresholds.

The effects of excessive noise exposures on nonauditory systems have been reviewed by Jansen (1969), Kryter (1970), and Welch and Welch (1970). The typical responses may be summarized as follows:

- Cardiovascular changes are readily evident. Vasoconstriction in the peripheral blood system, changes in blood pressure, heart rate, and cardiac muscle tension can be measured during exposure to 70 dB SPL or above. As SPL increases, the intensity of response is elevated. Abnormal heart rhythm may be associated with long-term occupational noise exposures;
- Respiratory rate may be decreased;
- Blood corticosteroid levels increase, resulting in further endocrine gland stimulation;
- Continued exposure of animals leads to imbalance of blood electrolytes, blood glucose levels, size of the adrenal cortex, and ultimately changes in kidney, liver, and gastrointestinal tract tissues; and,
- Other responses include increased or decreased motility of the gastrointestinal tract, altered galvanic skin resistance, and deviation in electroencephalograph tracings.

It is obvious that many of these physiological responses to auditory stimuli reflect the usual patterns of stress response.

Jansen (1969) has suggested that physiological responses could be categorized as "stress reactions" and "vegetative reactions." The former occur in response to unfamiliar stimuli. With repeated exposure, adaptation takes place. "Vegetative reactions" include response to meaningless noise stimulation — i. e., background noise. Grandjean (1969) has proposed that the habituation to stressful stimuli and the "vegetative reactions" to peripheral stimuli constitute a potential human hazard. However, with the exception of noise-induced hearing loss, there is no identifiable somatic disease produced by noise exposure. Noise-induced stress could contribute to stress-related disorders in circulatory and gastrointestinal functions;

in addition, noise as an annoyance does precipitate recognizable behavioral changes.

C. BEHAVIORAL EFFECTS

Noise, as unwanted sound, contributes to the stress and tension of contemporary life and man's psychological and behavioral states are affected as sound levels rise or exposure durations are prolonged. As auditory thresholds rise or masking occurs, speech interference results in inability to communicate. By adversely affecting voice communication, elevating auditory thresholds, inducing nonauditory physiological responses, and producing stressful situations, noise affects the general state of health. PHL may lead to definite psychological problems. Thus, noise is considered an irritant, annoyance, or hazard to the emotional health and performance capability of the individual. The situation encountered in the military environment is analogous to that found in the civilian community.

It is difficult to make valid generalizations on the adverse behavioral effects of noise. Noise is subjectively perceived, and thus subject to individual variability with respect to perception, recognition, adaptation, and behavioral responses. As noted by Catlin (1965), noise may or may not affect human behavior, depending upon the type of noise and the type of behavior involved.

In a recent review of behavioral effects, Cohen (1989) concluded that noise does adversely affect human behavior by reducing work capacity, disrupting sleep and rest patterns, producing annoyance and irritability, and precipitating general mental distress. Annoyance and mental distress are expressed as anxiety and negative attitudes, but also reflect previous experience, personality, and the characteristics of the noise stimulus. Most workers agree that there is a need for additional data on the potential behavioral and mental health aspects of long-term chronic noise exposures. Previous research has focused upon hearing loss and other effects of chronic exposure on the auditory system. Noise as a "public health hazard" is currently generating considerable governmental and scientific concern (Goldman, 1970; Ward and Fricke, 1989).

D. BIOLOGICAL EFFECTS OF INFRASONIC AND ULTRASONIC SOUND EXPOSURES

Disciplinary separation of fields within acoustic science is related to the frequency range of the human auditory system. The audio-frequency range is generally considered as 16 to 20,000 Hz. Frequencies below 20 Hz are considered to be in the infrasonic region, although airborne acoustic energy at 200 Hz or below is considered by some investigators to be infrasonic. Strict interpretations of ultrasonic acoustic energies restrict the definition to frequencies above 20,000 Hz, although some ultrasonic sources have frequency components of 10,000 to 20,000 Hz (Goldstein and Sinskey, 1969).

1. Infrasonic Effects

There is a vast literature on the biomedical effects of vibration or, more properly, mechanically-coupled infrasonic frequencies (Guignard, 1963a). However, in this situation, mechanical contact between vibrating solids or liquids and the body gives rise to resonant vibration in organs and body cavities. Because of impedance differences between the body and airborne infrasonic vibrations, that is, "infrasonic noise," the adverse effects are thought to be minimal except at high intensities.

The effects of infrasonic noise on man were investigated by Mohr *et al.* (1965) employing, as a stimulus, low-frequency sounds of high intensity generated in spacecraft launch operations. Their investigations constitute the most definitive analyses of infrasonic noise effects on man. Mohr *et al.* (1965) noted that infrasonic noise was an identifiable component in several aerospace operations, such as booster rocket and turbojet engine exhaust, large propeller motion and engine noise. They concluded that infrasonic noise generated by aerospace systems had not reached intensity levels greater than those which could be controlled. Furthermore, none of the infrasonic noise levels observed in surveys were as high as those generated in the experimental studies.

Using experimentally generated infrasonic noise fields of measured frequency, intensity, and duration, Mohr *et al.* (1965) found that the most noticeable responses were nonauditory. For

example, chest vibration, gagging, respiratory rhythm changes, and diminished visual acuity due to eyeball vibration were observed in knowledgeable subjects exposed to broad-band and narrow band noise patterns with center frequencies of 2 to 50 Hz. Somatic effects were not observed until noise intensities reached 125 dB. Subjectively intolerable environments in the 50 to 100 Hz range occurred at 145 dB or above. The five subjects varied individually at all exposure levels.

No shifts in auditory thresholds were detected after exposures of at least two minutes to 142 to 153 dB narrow-band noise with center frequencies of 2 to 10 Hz. However, at all exposures in excess of 130 dB, eyeball, throat, and chest vibration produced observable decrements in visual acuity and voice communication. Mohr *et al.* (1965) suggest that these two phenomena may have operational significance in high-intensity infrasonic noise exposures. The authors concluded that subjects with noise experience wearing ear protectors can safely tolerate short-duration infrasonic noise exposures in the 1 to 100 Hz range at SPL up to 150 dB. The opportunity for exposure to such airborne low-frequency noise is extremely limited.

Alford *et al.* (1966) have reported TTS of at least 10 dB in unprotected subjects exposed to three minutes of 2 to 12 Hz at SPL of 119 to 144 dB. They concluded that the auditory system, rather than the cardiovascular or ocular systems, was most sensitive to intense low-frequency exposures. Differences in generation of infrasonic noise fields and use of hearing protection largely account for this contradiction between results of Mohr *et al.* (1965) and Alford *et al.* (1966). The conclusion of Kryter (1970) that high-intensity infrasound noise fields are rarely encountered suggests adverse effects of infrasound are not a significant military problem. However, low-frequency vibration of military equipment, such as the helicopter, is a serious problem because crew members are mechanically coupled to the sources of vibration. Deleterious effects of mechanical vibration on the visual and auditory systems are well known (Fisher *et al.*, 1969; Guignard, 1965a).

2. Ultrasonic Effects

Ultrasonic wave fields are generated by a variety of mechanical and other equipment such as washers, high-speed drills,

cleaners, degreasers, and jet engines. As noted previously, frequencies above the range of normal adult hearing border on ultrasound. In addition, subharmonics of frequencies around 20,000 Hz fall into the audible range. Airborne ultrasonic frequencies are often an unrecognized or unmeasured component of broad-band noise fields containing lower frequencies that extend well into the auditory range. There is some evidence that ultrasound is a normal, but usually undetected, component of human speech (Mason, 1968).

When jet aircraft were first introduced, there was wide-spread anxiety that jet engine noise would include sufficient ultrasonic noise to be harmful to man (Parrack, 1966). However, ultrasonic waves are rapidly absorbed by air and are propagated only a short distance. Thus, high-intensity ultrasonic wave fields are a problem only when the individual is very close to the source. At such proximities, audible noise levels in jet aircraft would be intolerable (Guignard, 1965b).

Goldstein and Sinskey (1969) have recently prepared a definitive review of the health hazards of ultrasonic energy. All but a few of the investigations reviewed by these authors involved liquid or solid coupling of the ultrasonic transducers to the experimental animal or human subject. The low acoustic impedance of air results in rapid power loss as the ultrasonic sound-wave field is propagated from the source of ultrasonic energy (Goldstein and Sinskey, 1969). Energy is dissipated primarily as heat but the threshold for human injury from heat dissipation is approximately 175 dB. Goldstein and Sinskey (1969) indicate that death would occur at about 180 dB because the body cannot dissipate heat energy as rapidly as the ultrasound would heat the body. Such excessively high intensities of ultrasonic energy are not yet encountered in industrial or military situations. Goldstein and Sinskey (1969), as well as Parrack (1966), concluded that airborne ultrasonic SPL up to 140 dB are essentially harmless.

Knight (1968), in a study of industrial equipment generating ultrasonic wave fields, concluded that exposures to several durations and intensities were not hazardous to the vestibular or auditory systems, although subjective effects were often reported. Acton (1968), commenting on these conclusions, reported no significant TTS in subjects exposed to 110 dB in one-third octave bands centered at 20,000 and 25,000 Hz.

In a related study, Acton and Carson (1967) suggested that subjective effects of ultrasonic frequency exposures above 70 dB were due to attendant high levels of audible noise rather than to the ultrasonic frequencies alone. Parrack (1966) had previously concluded that various subjective effects were psychosomatic and related to apprehension. However, Kryter (1970) has pointed out that TTS does occur in subjects exposed to 16,000 to 20,000 Hz in excess of 78 dB. Also, he noted that adverse subjective effects were more evident following ear-damaging exposures to ultrasonic frequencies, than following equally damaging exposures to broad-band noise at audible frequencies.

In summary, Parrack (1966) indicated that ultrasound was not a hazard until SPL exceeded 140 dB. Acton (1968) suggested that TTS could be prevented and subjective effects minimized if exposures were limited to SPL of 75 dB in one-third octave bands centered at 8000 to 16,000 Hz or 110 dB at 20,000 to 31,500 Hz. It is doubtful that military equipment such as high-speed machinery or helicopter turbines generate such levels of ultrasound. However, most studies of noise spectra of military equipment do not include measurement of frequencies over 10,000 Hz (Gasaway, 1969; Gasaway and Hatfield, 1963). There is a need for additional information on the frequencies and intensities of ultrasound generated by military equipment and their effects on performance of the soldier.

VI. FACTORS IN NOISE-EXPOSURE DAMAGE

A. INDIVIDUAL VARIABILITY

Audiologists, otologists, and others trained in clinical evaluation of hearing recognize wide variability in the human auditory system. This biologic variation is reflected in the range of normal hearing, the sensitivity of hearing, and the response to potentially hazardous noise fields (Burns, 1968; Stewart and Burgi, 1964). In addition to neurophysiological variability which is essentially an unknown, individual anatomical, psychological, and sociological factors affect each person's response to noise. Thus attempts to quantify noise effects within a population over a prolonged period of time usually exhibit both intra- and intersubject variability.

Ward (1965) suggested that individual physiological differences might be associated with the static or the dynamic characteristics of the middle ear, or attributable to several characteristics of the inner ear. Static characteristics of the middle ear might include differences in SPL within the ear canal and subsequent differences in hydrodynamic pressures in the cochlea as affected by such factors as elasticity of skin around the oval window, size and shape of the canal, the tympanic membrane and oval window, as well as the mass and geometry of the ossicles.

Individual differences in the strength and reaction of the middle ear muscles may be a possible dynamic basis for differences in threshold shifts. Ward (1965) noted that differences in the strength of contraction and the rate of adaptation could alter the effect of the aural reflex on threshold shift. The observation that muscle relaxants, such as curare, increase TTS suggests that the muscles of the middle ear are an important factor in dynamic differences (Smith *et al.*, 1965).

Variability of the inner ear characteristics has not been studied in great detail. Ward (1965) suggested that numerous static and dynamic factors may be important. These include: geometry and composition of the cochlear partition, density and spacing of epithelial hair cells, size and shape of the tectorial and basilar membranes, biochemical composition of the endolymph, adequacy of the cochlear

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blood supply, rates of oxygen utilization and carbon dioxide removal within cochlear cells, and density of afferent and efferent innervation.

Threshold testing and hearing loss evaluation involving subjective responses superimpose the psychological and behavioral variables upon the physiological factors. Although the latter are poorly understood, the former are frequently and readily measured. For example, Taylor *et al.* (1965), in a study of hearing loss in jute weavers, plotted PTS at 1000, 2000, 3000, and 4000 Hz. The PTS at each frequency for the large number of subjects tested differed in mean dB shift, but the range of PTS shift (approximately 70 dB) at each frequency exhibited essentially normal distribution. Similar observations have been reported by other investigators.

The normal variation of TTS among individuals is evident in large-scale tests, although repeated testing often discloses less individual variation in successive tests than that observed in single tests of different individuals (Hirsh and Ward, 1952). Kryter (1970) reported that at suprathreshold levels, intrasubject variability was approximately 1 to 2 dB and intersubject differences were approximately 2 to 4 dB, and that at threshold levels, perceived loudness or noisiness had a standard deviation of about 7 dB.

As might be expected, frequency, duration, and intensity of the test stimulus may be additional factors which elicit a range of response in a group of ostensibly normal subjects. Most experimental studies report mean data, but as pointed out by Burns (1968) and Stewart and Burgi (1964), the range of quartile values may be more valuable than median or mean figures.

Hearing loss surveys frequently uncover differences between males and females (Corso, 1963; Gallo and Glorig, 1964; Ward, 1966; Ward *et al.*, 1959). Most investigators have concluded that these sex differences can be attributed to greater noise exposures sustained by males in military service, occupations, and recreational activities. Thus differential exposure rather than differential susceptibility to noise is the generally accepted explanation. However, Ward (1966) observed less TTS in females than in males exposed to 1400 to 2800 Hz and attributed this difference to more efficient middle ear muscle function.

Using statistical probability techniques, Kryter (1970) proposed several scales that measure relative noise annoyance values. He suggested that the annoyance value, that is, the perceived noisiness, can be calculated from physical measurements of noise and psychological assessments of noise annoyance. Although Kryter's statistical procedures may require additional verification or modification, the use of such procedures in quantification of noise exposure effects does take into account the inherent variability of the human receiver. Such a value for effective perceived noise level in decibels (EPNdB) might be modified to measure the range of individual response to noise.

B. PRESBYCUSIS AND SOCIOCUSIS

Presbycusis refers to the loss of high-frequency hearing that is associated with physiological aging. In general, aging results in hearing losses in excess of 10 dB at 3000 through 8000 Hz after age 50 in normal healthy subjects (Hinchcliffe, 1958). An additional 10 to 15 dB loss at 3000 to 8000 Hz is measurable audiometrically in 60- to 70-year-old subjects. This loss of hearing due to aging is apparently due to deterioration in the middle ear, alterations in the cochlear fluid composition, neural changes, and "aging" of the higher cortical centers (Burns, 1968; Glorig and Nixon, 1962).

However, Glorig and Nixon (1962) pointed out that average hearing ability begins to decline long before age 50 to 60 even in individuals who have not been exposed to excessive noise levels or durations. They introduced the concept of sociocusis to account for the progressive effects of nonindustrial noise exposure throughout an individual's lifetime. Sociocusis is not age-dependent alone, but is related to cumulative noise exposures from diverse sources. Ward (1969) refers to sociocusis as "the toll exacted on a few individuals by the everyday noises of modern living." Cohen (1970) has recently reviewed sociocusis as a problem in the assessment of normal hearing and as a confounding factor in evaluation of occupational hearing loss.

Presbycusis and sociocusis are inextricably mixed; sociocusis cannot be measured by itself because human subjects totally unexposed to noise are not available. The pathology of noise-induced

hearing loss involves the integrity of the hair cells, but this can only be assessed postmortem. Comparisons of populations in relatively noise-free environments with populations living in noisy environments have suggested that an estimate of sociocusis could be made, but the average hearing loss differences may be a reflection of the genetic homogeneity characteristic of the two populations (Bergman, 1966; Rosen *et al.*, 1962).

Air-conduction and bone-conduction audiometry can be used to estimate differential changes in the middle and inner ear that are related to presbycusis alone. Thus mean values for age-induced hearing loss can be computed. Subtraction of presbycusis loss from measured hearing loss gives an estimate of sociocusis. As noted by Burns (1968) and Ward (1969), such "corrections" are useful in understanding the relationships between hearing loss and noise exposure, but should not be applied to individuals because of wide individual variability.

Accurate preemployment or preinduction audiograms and regular follow-up tests would preclude the necessity of estimating the probable contributions of presbycusis and sociocusis if and when hearing loss did occur. In fact, the primary goal of monitoring audiometry is to provide a baseline hearing assessment of each individual. Following exposures to potentially hazardous noise fields, subsequent audiometric monitoring can be compared with the preexposure baseline and the extent of threshold differences, i. e., hearing impairment, can be determined.

C. NON-NOISE-INDUCED HEARING IMPAIRMENT

It is assumed that a healthy person would not have a conductive hearing impairment caused by interference with the passage of sound waves through the external and middle ear, or a sensorineural impairment resulting from damage to the cochlear mechanism or the auditory nerve.

In the healthy individual, dermatological diseases of the external auditory canal are most common and, if untreated, may involve the tympanic membrane and middle ear. Otitis media, barotitis media, and other middle ear disorders are common

problems in some individuals in certain military operations; however, inner ear disease would require hospitalization.

One of the most distressing but usually not incapacitating conditions encountered in medical practice is tinnitus. Presumably this symptom may, if severe, be related to some injury to the auditory system; indeed, it may be of predictive value in early ear injury, but a clear understanding of the cause is not known and more research should be conducted on this subject.

Fatigue from sleep loss or other physiological stresses may cause a decrease in hearing efficiency. This is related to a general decrease in the overall performance capability of the man and not specifically to hearing. Cardiovascular disease may be a cause of hearing impairment; vascular changes or degeneration of the blood vessels supplying the inner ear adversely affect the sensitive structures of the cochlea.

Generalized trauma, lacerations, and thermal injury are hazards of combat duty that may result in hearing loss. Disease conditions can cause injury to hearing in a number of ways, and therapeutic drugs may be ototoxic, i. e., cause hearing loss by damaging the auditory system.

Some therapeutic drugs and chemical substances will selectively and independently cause cochlear injury and hearing loss. For example, the antibiotics used in chemotherapy of tuberculosis, streptomycin and kanamycin, cause deafness in some patients. Dihydrostreptomycin appears to have a pronounced toxic effect on the cochlear branch of the auditory nerve; it should not be employed in therapy except in life-threatening emergencies that require this antibiotic exclusively (Krantz and Carr, 1969).

Marked individual differences in response to these drugs have been reported, and some patients may have a measurable decrease in hearing with a high-pitched tinnitus after a week of drug therapy. Rarely, complete deafness may ensue. Perception of sound in the high-frequency range, outside conversational sound frequencies, is lost first and the individual is not aware of hearing loss unless a careful audiometric examination is made. Persons with hearing loss are not good candidates for therapy with these ototoxic agents because the drug toxicity is additive to the existing hearing deficiency (Manten, 1968).

The diuretic, ethacrynic acid, has been reported to cause transient and permanent hearing loss (Pillay *et al.*, 1969). Morphologic manifestations of toxicity (degeneration of outer hair cells) have been found in animals treated with this drug (Cohn *et al.*, 1971).

Some sensitive individuals experience a tinnitus following ordinary therapeutic doses of 0.3 g quinine sulfate. Antimalarial doses of quinine usually produce a marked tinnitus which, in a few patients, may be sufficiently severe to be partially incapacitating. Prolonged treatment has been known to produce PHL. According to Waters (1960), the use of quinine preparations for the treatment of upper respiratory tract infections may seriously interfere with hearing of aircraft pilots.

Low doses of salicylates produce tinnitus and hearing loss, especially for high frequencies of sound, in a few sensitive subjects. Large doses as in salicylate poisoning cause effects similar to those of Ménière's disease and, according to Waltner (1955), these effects are related to increased labyrinthine pressure. There is an association between the plasma level of salicylate and the hearing loss (Myers *et al.*, 1965). Pure tone sensitivity, especially in the higher frequencies, was reduced after administration of 3 aspirin tablets at 4-hour intervals for 4 days (McCabe and Dey, 1965). The mechanism of the ototoxicity of the salicylates is not understood and, considering the wide use of these substances, additional studies are required. Unfortunately, too little attention has been given to the use of nonprescribed therapeutic drugs such as quinine and aspirin and their influence on hearing and the performance of the soldier.

Drugs that depress the central nervous system such as alcohol, morphine, and the barbiturates may raise the normal threshold for perception of sounds. These effects are thought to occur in the auditory cortex and the associated pathways. Hallucinatory drugs that produce changes in the apparent perception of sounds and vision do not influence the threshold of sound perception. One of the most interesting substances to be studied in recent years is Δ^9 -THC [(-)- Δ^9 -*trans*-tetrahydrocannabinol, the active ingredient of marihuana]. Because marihuana smokers experience altered sensations of time lapse, space perception and sounds, these sensory modality changes were subjected to experimental verification. There was no evidence that the sound thresholds of the individual were changed following the smoking of marihuana cigarettes with amounts of Δ^9 -THC capable of producing the typical "high" of marihuana (Carr *et al.*, 1970).

Tobacco smoking has been reported to produce disorders of hearing, some degree of deafness, "middle ear lesions," and related symptoms of ototoxicity. These reports have been reviewed by Larson *et al.* (1961), and Larson and Silvette (1968). Shapiro (1964) concluded that nicotine produces vasospasm in capillaries of the internal ear and that this may cause lesions and hearing loss. In his clinical experience, hearing impairment in smokers was irreversible and complete abstention from smoking was indicated in such persons. The histopathology of the auditory organs of experimental animals exposed to tobacco smoke has been reviewed by Maffei and Miani (1960).

Depending on the degree of use of tobacco it is likely that hearing may be impaired to some extent; however, the matter does not appear crucial from a military standpoint. In this respect it is noteworthy that the Public Health Service Surgeon General's report on Smoking and Health (U. S. Department of Health, Education, and Welfare, 1964) and the Supplement (1968) do not include references to the effects of smoking on hearing.

D. INDIVIDUAL SUSCEPTIBILITY TO AUDITORY DAMAGE

The readily measurable intra- and intersubject variability in auditory threshold, TTS, and hearing loss has fostered a concept of "susceptibility" to noise-induced hearing loss. This concept holds that certain individuals are more susceptible and that others are more resistant to both the temporary and permanent deleterious effects of noise because of anatomical, physiological, and psychological differences. If individuals extremely susceptible to TTS could be identified audiometrically, and if this susceptibility to TTS reflected an auditory system more sensitive to PTS, then individuals likely to be permanently affected by noise could be identified and protected against excessive exposures. As a corollary, some individuals may be markedly resistant to TTS and perhaps PTS. Thus, identification of such persons could be useful in selecting individuals who would tolerate excessive noise exposures with reduced risk of PHL.

The concepts of individual susceptibility and resistance to hearing loss were reviewed by Ward (1965). There is little evidence

to support the hypothesis of a bimodal distribution of susceptibility to TTS. Ward (1965) and others (Burns, 1968) have shown that hearing sensitivity and TTS susceptibility are distributed normally. Similarly, there is little evidence that susceptibility to PTS is distributed bimodally. Ward (1969), in reporting on studies using chinchillas, suggested that TTS and PTS are not closely related. The most satisfactory way to detect NIPTS appears to be repetitive audiometric monitoring. Similarly, there is little substantiation for the conclusion that individuals with some PTS are more susceptible to further PTS (Ward, 1969).

Thus, susceptibility of an individual to TTS or PTS from noise exposure depends primarily on the characteristics of the noise and the inherent sensitivity of his multipartite auditory system. Within a population, some individuals are more susceptible and others more resistant to TTS and perhaps PTS. Susceptibility to TTS is not known to be predictive of susceptibility to PTS. Pre-selection of the individuals most affected by noise exposure is not possible at the present time; thus, a hearing conservation program, including audiometric monitoring, remains the best method for protection against significant noise-induced hearing loss.

VII. EFFECTS OF NOISE ON HUMAN PERFORMANCE

A. ANNOYANCE AND DISTRACTION

Sound, if unwanted or if sufficiently loud, can interfere with physical and cognitive activities because it represents an environmental stimulus difficult to ignore. In this sense, noise may evoke displeasure or resentment, and is considered an annoyance or distraction. Broadbent (1957) suggested alternative theories to explain noise effects on performance: (a) annoying or distracting noise produces lapses in attention to relevant stimulus information; or (b) noise induces conditions of cortical overarousal with a resultant loss in behavioral control.

In the military environment, noise might be useful in warning of equipment failures; however, as in the civilian situation, noise would probably be annoying or distracting in that its presence would interfere with perception of auditory stimuli that might be life-threatening. In general, noise would be considered an additional "stress" on a man already stressed by the nature of his duties.

The effects of noise exposures on performance of work have been a major interest of experimental psychologists for years. Noise effects on performance appear to be a function of the nature of the noise conditions, the type of the task being performed, and the individual characteristics of the listener. Most of the studies have involved some performance criterion of subjects required to work in noise fields which border on annoying or distracting (Boggs and Simon, 1968; Cohen *et al.*, 1966; Harris, 1968, 1970). Thus work output, error rate, or other aspects of task proficiency are used as measures of noise effects. From these extensive studies, several theories of the effects of noise on work performance have been proposed. Kryter (1970) has reviewed these theories.

In general, work efficiency on tasks that involve vigilance over long time periods is degraded in broad-band noise fields in excess of 90 dB (Burns, 1968; Jerison, 1959; McCann, 1969). Broad-band noise fields with spectra that contain frequencies including 2000 Hz or above appear to be more deleterious to performance efficiency than noise fields with primarily low-pitched sound

components below 2000 Hz. Guignard (1965b) concluded that noise increases the incidence of errors in tasks that require both speed and skill, even when rate of performance may not be affected. In this sense, noise is distracting and affects performance adversely.

Intense unfamiliar noises of sudden onset can adversely affect work performance. The auditory stimulus is not recognized; until its identity is confirmed by other sensory modalities or it is perceived as nondangerous, the noise stimulus evokes a startle or stress response. As habituation occurs, the sense of distraction lessens, and capability to perform tasks is regained. Subjects placed in high-noise situations exhibit first a rapid deterioration of performance, then an increase in performance efficiency up to or exceeding the work level prior to the noise exposure (Burns, 1968). During these phases physiological changes include peripheral vasoconstriction, cardiac arrhythmia, and changes in respiratory rate and gastrointestinal motility. However, with continued exposure, these changes decrease or disappear (Glorig, 1971). Numerous studies suggest that the nonauditory effects of noise are related, in a general way, to avoidance responses such as startle, fear, or stress (Glorig, 1971).

Both Glorig (1971) and Kryter (1970) have pointed out that industrial work situations are not amenable to controlled experimentation. In addition, the temporary physiological and psychological reactions appear to disappear with time, i. e., adaptation occurs. Glorig (1971) has questioned the validity of available data cited by others in support of the concept of permanent nonauditory effects. Kryter (1970) concluded it was not possible to show that continued noise exposure by itself adversely affected nonauditory work efficiency. Most investigators agree that reduction or elimination of noise may lead to improved morale and increased work output, may reduce masking of useful sounds and thereby may allow perception of information needed for performance.

On the other hand, background noise such as music may provide beneficial effects to individuals in certain work situations. However, further studies comparing non-noise-exposed and noise-exposed subjects under controlled conditions are required before valid conclusions can be made with respect to permanent nonauditory performance effects of various noise exposures (Glorig, 1971).

B. INTERFERENCE WITH VOICE COMMUNICATION

In the civilian and military environments the most critical effects of noise are interference with voice communication. Where noise levels or duration are excessive, communication among individuals, either by direct speech, radio, or telephone, is less efficient because the spoken or transmitted auditory stimuli are masked by noise. Where noise exposure has affected hearing, an individual may have lost sufficient sensitivity to interfere with his capacity to perform his duties. In this instance, he becomes a hazard, both to himself and to others who depend upon him.

1. Masking

When the threshold of hearing for a sound is elevated by the presence of another acoustic stimulus, the former sound is said to be "masked" by the second. The elevation of the threshold above that measured in quiet, expressed in dB, is referred to as the masked threshold. At lower intensities, masking stimuli raise thresholds of hearing for sounds or bands of similar frequencies; but at higher SPL, masking effects become more pronounced at frequencies above that of the masking sound. Within the frequencies of voice communication (100 to 7000 Hz) masking noises are a serious impediment to speech reception, either in a face-to-face situation or over communications equipment.

Normal speech at a distance of three feet has an SPL of approximately 65 dB relative to $20 \mu\text{N/m}^2$ for adult males, but may range approximately ± 30 to 40 dB from speech minima at whisper to maximal peak SPL while shouting. During normal conversation, the range among individuals is about 20 dB. Thus if speech is too soft it will be masked by ambient noise; and in some communications systems, it will be masked by either system noise or both ambient and system noise.

The influence of masking noise on direct voice communication, that is, speech, represents a special situation. Direct voice communication between a speaker and one or more listeners involves the spoken message, background noise, and listener ability to hear and comprehend. There is a range of intelligibility which is affected by factors other than those directly related to masking

alone. For example, the level of background noise and the frequency of bandwidths of noise with respect to those of the spoken communication may affect the masked threshold. Similarly, continuous noise may interfere with speech more than intermittent sounds.

Communications equipment should incorporate techniques of separating signals from noise, that is, maintaining a signal-to-noise ratio allowing perception of useful information even when noise is present. However, the electronic noise generated within the system may further obscure the intelligibility of the message. In addition, the frequency bandwidths passed by the equipment are critical to maintaining high speech intelligibility. In some communications systems, excessive intensity can exceed the capacity of the system and distort the signal. Communications equipment should have a dynamic range of about 20 to 30 dB within which there is a capability of responding to input variations. Communications systems with this dynamic range are available, but most military radios and communications equipment have a much smaller dynamic range.

Thus, ambient noise provides an acoustic stimulation that may mask useful sounds such as speech. Amplification of ambient noise and the electronic noise inherent in available communications systems further interfere with reception and perception of voice transmission. Both forms of masking interfere with hearing and thus compromise safety and performance effectiveness.

2. Other Interfering Factors

The ability to communicate effectively by face-to-face voice communication in a noisy environment is determined by the spectrum and level of the noise, the spectrum and level of the spoken message, the distance between the speaker's mouth and the listener's ear, and the vocabulary used. Effective speech reception through communications equipment also involves the handling or modification of the signal-to-noise ratio by the equipment.

The vocabulary used for communications in certain military situations assumes disproportionate significance where inadequacies of communication equipment and situational factors make efficient communication more difficult. For example, military

pilots and air traffic controllers have a highly specialized "jargon" for various landing and takeoff procedures. In a study of aircraft-ground communications, Frick and Sumby (1952) observed that only 13 different types of phrases were used. More importantly, they found that given one phrase, pilots could predict with 77% accuracy the next phrase. Frick and Sumby concluded that in this situation, voice communication contained little information and served only as a monitoring function. It is generally recognized that the sequence of word patterns and meanings are in part a learned activity in radio communication.

Thus, even where speech intelligibility is poor, inadequate, or compromised by equipment, it is possible for listeners to comprehend instructions when only a portion of the message is perceived. For example, Beitscher and Webster (1956) collected data on isolated word intelligibility in voice transmissions between pilots and air traffic controllers. They found tower-to-aircraft word identification accuracy of 74%, but only 44% accuracy in aircraft-to-tower messages. They concluded that high noise, circuit distortion, and limited system bandwidths were the causal factors. Obviously, greater difficulty will arise in voice communications between individuals who are not familiar with the specialized vocabulary or messages.

Pickett (1969) concluded that the assessment of noise interference with voice communications in industrial situations may have limited usefulness until additional research on linguistics and situational constraints is accomplished. In the military environment, linguistic and situational constraints may be overcome, in part, by training and education, if current equipment efficiency is accepted as adequate. However, the complexity and seriousness of the military problem suggests that additional emphasis be placed on development and use of more efficient systems of voice communication.

3. Measurement of Speech Interference

The development of testing procedures that measure efficiency of voice communication has been reviewed recently by Gasaway (1970b), Kryter (1970), and Webster (1969). In general, two psychophysical techniques, the articulation index (AI) and the speech interference level (SIL) have been found to be the most useful.

The AI is a predictive measure of intelligibility based upon weighted physical measurements of peak speech levels and noise levels over several critical bandwidths or octaves within the speech frequencies. A calculated difference between speech and noise levels is derived by subtraction and interpolation. The resultant figure, or AI, on a scale of 0 to 1.0 is a relative measure of predicted speech intelligibility. Numerous modifications of the basic AI technique have been employed to assess various noise exposures (Kryter, 1970; Webster, 1969). Beranek (1947) suggested that a communications system with an AI of over 0.7 was excellent, 0.5 to 0.7 good, 0.3 to 0.5 acceptable, and below 0.3 marginal to unacceptable. Webster (1969) concluded that the AI was probably the most accurate method of predicting the effects of noise on speech intelligibility, but noted that the technique was difficult to use and interpret.

Beranek (1947) introduced a simplified speech interference level (SIL) which is computed from the average level of three octave bands from 600 to 4800 Hz. The SIL measures only noise level, and reference must be made to a table of standard values to obtain voice levels (in dB) required for effective communication at several distances. The SIL has been used in assessing the feasibility and acceptability of voice communications in a variety of noise environments. Using the SIL as a basic criterion, noise curves have been recommended for rooms, various types of offices, industrial working areas, and military situations.

Following the introduction of the SIL method, numerous applications and studies have developed modifications of the basic scheme. These techniques have been reviewed by Kryter (1970) and Webster (1969). Webster and Klumpp (1965) undertook a comprehensive study of speech interference methodology using 16 noise exposures commonly encountered in the U.S. Navy. They concluded that the best single method of measuring speech interference was the SIL, based upon averaging of 3 octaves (300 to 600, 600 to 1200, and 1200 to 2400 Hz). SIL computed from weighted scales or the AI derived from 5 or 6 frequency bands were acceptable methods, although the AI was more complicated. Results of these and other pertinent studies that are applicable to Army problems are discussed below and in the review of hearing conservation (p 67).

4. Improving Voice Communications

In a recent review of techniques of enhancing voice communication, Tolhurst (1971) concluded that the present status of voice communications in military situations is only slightly better today than it was during, and immediately after, World War II. Webster and Klumpp (1965) had previously determined that noise in typical U.S. Navy environments exceeds that found in civilian situations where equivalent communication tasks are required. Although noise spectra and exposures might be different, there is sufficient evidence to conclude that inadequacies in voice communication are commonly encountered in the U.S. Army (Gasaway, 1970b; Gasaway and Hatfield, 1963; Hatfield and Gasaway, 1963).

There are numerous techniques already available for improving the efficiency of direct and transmitted voice communications. The results of this current review suggest that serious attention be directed to the application of available knowledge. There is a critical need for evaluation of various existing types of improved communication equipment and an additional need for further study of techniques of communicating and listening as well as training in speech communication applicable to Army interests.

C. SLEEP DEPRIVATION CAUSED BY NOISE

Williams (1970) and Kryter (1970) have reviewed various studies that indicate awakening thresholds for sounds perceived during sleep are affected by several factors: stimulus intensity, the stage of sleep, length of the sleep period, time relative to day or night sleep pattern, prior sleep pattern, and individual differences.

In general, acute or chronic sleep disturbance or loss results in impaired motor and mental performance as well as other noticeable behavioral changes (Williams, 1970). In one study, Williams *et al.* (1964) observed that the noise threshold for awakening subjects is 15 dB higher when sleep deprivation occurs prior to auditory testing. Thus, the physiological state of the subject affects the influence of noise exposure on response. Similarly,

adaptation to background noise does take place during sleep periods and in several sleep periods over time.

In an environment where noise is normally present, low-intensity and monotonous background noise may be soporific. Such situations might arise in the military environment where individuals already stressed or deprived of sleep are exposed to background noise of mechanical or electronic equipment. Such stimuli would be perceived and adaptation to relatively high ambient noise levels could occur.

Kryter (1970) noted that both research data and anecdotal observations support the view that even during certain stages of sleep, some individuals may respond to certain sounds while ignoring other auditory stimuli. In addition, some persons may be capable of altering their sleep state to some extent, thereby affecting their awakening threshold levels.

In a recent report on effects of subsonic jet aircraft noise and simulated sonic booms, Lukas *et al.* (1970) concluded that awakening response appears to be age-dependent; when asleep, children were less responsive to noise than middle-aged or older men. While it is possible that the length of the four stages of sleep vary with age, or that conditioning or recruitment were present, it is of interest that the group of older men who would be expected to have measurable presbycusis were more sensitive to auditory stimuli when asleep. This observation suggests that there is a need for further study of the effects of noise on sleep of military personnel who may already have measurable hearing loss.

Despite the confounding interaction of factors affecting sleep disruption, adaptation to noise, or variability of human response, it is not possible to quantitate the effects of noise on sleep with any degree of predictive reliability. For most people, sleep in high ambient noise environments is less restful than sleep in the absence of subjectively perceived annoyances such as noise. Since sleep is essential to health, efforts directed toward reduction or elimination of annoying or potentially hazardous noise are obviously desirable.

D. PERFORMANCE OF MEN WITH SOME DEGREE OF HEARING LOSS

It is obvious that prolonged exposures to high SPL result in measurable TTS in normal subjects. Ultimately, if exposure duration or intensities are sufficiently high, PTS will occur. The phenomenon of noise-induced hearing loss as a consequence of military activities is well recognized. Individuals who perform duties in high-noise environments, such as tank or artillery crews, or soldiers with several years of military service, often exhibit measurable hearing loss (Meyer, 1968; Tooley, 1964, 1965; Yarrington, 1968). Where severe hearing impairment occurs, individuals should, if present hearing conservation criteria are enforced, be relieved from duty. However, the insidiously progressive nature of hearing impairment suggests that, over time, increased auditory threshold or reduced auditory capability could unknowingly interfere with efficient performance of military tasks.

There is little question that high ambient noise levels adversely affect motor and mental performance if the noise masks auditory signals essential to efficient performance. Similarly, the effects of presbycusis (Glorig and Davis, 1961) or sociocusis (Glorig and Nixon, 1960), as well as individual susceptibility make difficult the derivation of any general conclusions on the effects of noise exposure on performance of individuals whose hearing is already compromised by these factors.

These observations are relevant to performance of soldiers with some hearing loss. If a significant number of men exhibit measurable TTS or PTS, and high ambient noise adversely affects performance, then there is a need to evaluate the performance capabilities of soldiers with hearing impairment relative to performance of soldiers without hearing impairment. Evidence suggests that the higher the resting threshold, the smaller the amount of TTS due to noise. Thus in the noisy environment, the individual with some hearing impairment may be less able to discriminate voice communication messages than the normal person, even though the background noise and the speech levels are above normal threshold levels. There appears to be a need for studies that assess performance of military tasks by subjects both (a) before and after induction of measurable temporary hearing impairment, and (b) by paired groups of subjects both with and without temporary or permanent hearing impairment.

VIII. HEARING CONSERVATION

Protection by sound attenuating devices has usually proved to be the most practical way to protect or to conserve the hearing of men required to work in a noisy environment. Ear protectors such as plugs, muffs or canal cups, will reduce the noise level that reaches the tympanic membrane (Blackstock and von Gierke, 1956; Camp, 1966; Michael, 1965; Piesse, 1962; Rice and Coles, 1966; Shaw and Veneklasen, 1945). The degree of protection actually achieved is modified by the enthusiasm of the user for this type of protection and his willingness to wear the device faithfully as well as the adequacy of the protective device. In addition, intensity and frequency of the noise can influence the effectiveness of any type of hearing protector. Sound transmitted through the tissue and bone of the skull directly to the inner ear avoids the ossicular chain and is not reduced by these protectors. Large earmuffs and helmets may alter bone conduction of sound because they occlude sounds reaching the tympanic membrane by air conduction. However, bone conduction by itself may provide some attenuation of high intensity sound. Characteristics of several common types of hearing protectors, as reported by Rice and Coles (1966), are listed in Table 3.

A. TYPES OF HEARING PROTECTORS

1. Earplugs

A number of styles of earplugs are standard items in the military services. One of the most efficient is the V-51R type. It is a soft plastic bung with a flexible flange that conforms to the shape of the external meatus. It is available in five different sizes and should be fitted individually to provide as complete a seal as possible. Earplugs must be clean to minimize the risk of otitis externa; they tend to be uncomfortable because they must fit tightly. For these and other reasons, there has been difficulty in developing wide acceptability of these hearing protectors.

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TABLE 3
PURE-TONE ATTENUATION AND STANDARD DEVIATION (SD $\pm$)
CHARACTERISTICS OF HEARING PROTECTORS

Type of Protector	Measurement (dB)	Frequency (Hz)					
		250	500	1,000	2,000	3,000	4,000
Fluid-seal Muffs	Attenuation SD $\pm$	28 3	38 4	39 4	41 7	44 4	47 4
V. 51R Plug	Attenuation SD $\pm$	11 7	13 9	19 10	27 9	30 6	25 5
Glass-down	Attenuation SD $\pm$	11 5	13 4	17 7	29 6	34 7	35 7
Waxed Cotton	Attenuation SD $\pm$	10 9	12 9	16 8	27 11	31 10	32 9
Dry Cotton	Attenuation SD $\pm$	3 5	4 3	8 3	12 6	14 4	12 4

(Modified from Rice and Coles, 1966).

2. Earmuffs

Currently available earmuffs are quite efficient protectors, but are hard, bulky shells that cover the entire ear (ear cups). They conform to the head irregularities by a soft plastic ring that may contain foam material or fluid such as glycerine. A tight fit is essential and this is obtained by an adjustable headband. Earplugs may be worn beneath the earmuffs to give some additional attenuation of sound above approximately 500 Hz. Earmuffs are uncomfortable because they must be tight-fitting, but they do provide satisfactory protection from adverse effects of excessive noise exposures. Unfortunately, they are bulky and tend to be uncomfortably hot under certain environmental conditions. According to Flugrath and Wolfe (1971), attenuation differences among the various types of earmuffs are not as great as indicated by Rice and Coles (1966). They concluded that differences are slight and "wearability" becomes the primary consideration. This conclusion is still controversial.

3. "Glass wool"

Dry cotton earplugs are recognized as inefficient forms of hearing protection. On the other hand, Coles (1969) and Rice and Coles (1966) feel that "probably the most practical and acceptable of the disposable forms of earplugs are those made of glass-down." These are composed of a very fine fiber glass wool with a down-like softness. According to Coles, the extensive use of glass wool earplugs in the United Kingdom and in other countries has not given rise to reports of injury to the delicate skin of the ear canal. To be effective, and to avoid pieces of glass-down being left in the meatus, the plug must be folded from a layer of down according to specific instructions. Coles (1969) concluded that the glass-down earplug, provided it is properly formed and inserted, appears to be the earplug of choice for most noise exposure situations.

4. Helmets

Hearing protection features have been included in the construction of combat vehicle and aviation helmets in recent years (Bearce, 1970; Camp, 1966). Combat vehicle crewmen can be

protected in part against internal vehicle and weapons firing noise by the use of properly designed and fitted helmets. However, the voice communication system and its electronic components must not generate excessive noise under the headphone cushions because to do so would defeat the noise attenuation aspects of the helmet. Reports indicate that the state-of-the-art allows considerably more hearing protection for combat vehicle crewmen than is provided at present (Bearce, 1970). The Combat Vehicle Crewmen (CVC) helmet Model DH-132 is considered to be far superior to other current military helmets. Without considering the relative merits of specific helmet designs, it appears that hearing conservation would be enhanced in training and in combat by the development and use of improved sound-attenuating helmets for all personnel exposed to hazardous noise fields.

In many respects, the design and fitting of air crewmen's helmets and the associated sound attenuation problems are similar to combat vehicle crewmen's needs. The original APH-5 helmet should be replaced by the superior SPH-4 helmet for Army aircrews. It is of paramount importance to insure proper fitting of any helmet worn for sound attenuation and to initiate procedures to monitor the integrity of the initial fitting (Greene, 1970).

5. Amplitude- and Frequency-Sensitive Earplugs

Modifications of the standard earplug have been made to allow little interference with normal speech under relatively quiet conditions but still provide protection against loud impulsive noise. These are frequency-selective earplugs such as Selectone-K (Coles and Rice, 1966; Rice and Coles, 1966; Zwislocki, 1951, 1952) and the amplitude-sensitive earplugs such as Lee-Sonic Ear Valve (Piesse, 1962). Fletcher (1961) observed that the V-51R earplug reduced the TTS from gunfire noise more at frequencies of 2000 Hz and above than at frequencies of 1000 Hz or below. Fletcher and Loeb (1962) evaluated the effectiveness of the V-51R and Selectone-K earplugs. The reduction in TTS under impulsive noise conditions of rifle fire in the open was approximately the same for both types of earplugs.

A variation of the standard earplug with a small hole has been developed for protection against impulsive-type gunfire noise (Forrest and Coles, 1970). This device is called a

"Gundefender." The Gundefender earplug is, in principle, the standard type V-51R plug with its core replaced by a small metal disk with a 0.0265 inch diameter hole. Forrest and Coles (1970) suggested that this fine aperture permits the passage of low-intensity acoustic energies, i.e., those with laminar flow characteristics, while high-intensity sound waves, exhibiting predominantly turbulent flow patterns, are attenuated. These features of the Gundefender earplug are thought to allow low-intensity acoustic energies of speech to pass free while impulse sounds such as rifle fire will be attenuated. This type of hearing protector has certain advantages; and it has been suggested that with future research it may be possible to develop a device that provides the wearer with protection from high-intensity impulse noise while providing improved speech intelligibility (Mosko and Fletcher, 1971).

Mosko and Fletcher (1971) have evaluated the Gundefender and compared this type of earplug with the standard V-51R type as protectors against the TTS induced by M-14 rifle fire. The test results indicated the two types of earplugs were equally satisfactory in providing reductions in TTS under the conditions of the test. However, intelligibility scores obtained under low-noise and no-noise conditions suggested the superiority of the Gundefender earplug for communication purposes. Under high noise conditions the two types were similar. These data suggest that further refinement of this type of earplug may provide additional protection against impulse and other noise situations that otherwise would interfere with speech reception.

B. EVALUATION OF HEARING PROTECTORS

In 1966, Camp reported an evaluation of 36 hearing protective devices based on psychophysical measurements in a model test situation. The devices included earplugs, earmuffs, and helmets developed since 1950.

In general, Camp's study illustrates the factors involved in evaluating and using hearing protectors. The amount of attenuation provided by any device is a function of the frequencies present in the exposure sounds and affords greater attenuation in the high than in

the low frequencies. All devices tested attenuated 4000 and 8000 Hz at least 14 dB. The greatest attenuation obtained by any device at the two lowest test frequencies of 75 and 125 Hz was 20 dB. There was a fairly uniform degree of protection among different devices at the lower frequencies of 75, 125, and 250 Hz and the high frequencies of 4000 and 8000 Hz. On the other hand, there were marked individual differences between devices at the mid-range frequencies of 500, 1000, and 2000 Hz. The maximum and mean attenuations at each frequency for 36 devices are given in Table 4.

These findings have not been modified to any extent by subsequent studies. The importance of individual fitting, testing, and evaluating new hearing protective models and devices has been emphasized by Camp (1966) and Piesse (1962). Average values may obscure wide individual variations in fitting, testing, and conditions of rating. Sutherland *et al.* (1971) observed marked individual differences in the degree of attenuation provided by five types of Air Force hearing protective devices when measured in a standardized testing apparatus. They emphasize the need for individual attention in providing hearing protection.

Obviously, standardized average values cannot be relied upon as predictive indices of attenuation for any single individual. Coles (1969) and Piesse (1962) had made somewhat similar observations when comparing the results from different laboratories on the pure-tone attenuation characteristics of various types of hearing protectors. As noted by Coles (1969), the most widely accepted technique for measurement of the real ear attenuation characteristics of hearing protectors at threshold is the standard method (Z24.22, 1957) agreed upon by the American National Standards Institute and the Acoustical Society of America.

Knight and Coles (1966) made a careful six-year study of the effect of jet-aircraft noise on hearing in naval airmen. Employing sophisticated techniques for their audiometric survey, and allowing adequate time for recovery of TTS, these workers found that permanent hearing losses apparently do not result from frequent exposure to jet aircraft noise at levels up to 150 dB when fluid-seal earmuffs in a good state of repair and properly fitted are used. These earmuffs reduced the noise level at the ear by about 25 dB at 250 Hz and approximately 10 dB greater (35 dB) at higher frequencies. This study supports the general conclusion that hearing protectors are effective if used properly.

TABLE 4

MAXIMUM AND MEAN ATTENUATION IN DECIBELS OF REAL-EAR TESTING OF
36 HEARING PROTECTIVE DEVICES

	75 Hz*	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Maximum	20	20	28	36	41	38	50	41
Mean	10.1	9.5	10.7	17.5	22.3	26.5	34.2	31.8

* Computed for 34 devices only.

(From Camp, USAARU Rep. No. 66-6, p 10, 1966).

C. INDOCTRINATION IN USE OF PERSONAL PROTECTION DEVICES

There is a natural resistance to the use of personal protection equipment such as safety glasses, earplugs, and helmets in the civilian community. This also applies to numerous personal protective measures developed for use in military environments, e.g., helmets, armor vests, gas masks, and hearing protective devices. There has been a singular lack of success in indoctrination in the use of hearing protective devices. As Coles (1969) and Rice and Coles (1966) have pointed out, this may be related to self-consciousness, carelessness, bravado, tradition, or lack of appreciation for the danger.

In large measure, this resistance to the use of hearing protectors appears to stem from a lack of understanding of the lifetime hazard of noise exposure and a belief that the use of hearing protectors will make it more difficult to understand speech or to hear warning signals. There is ample evidence that properly fitted earplugs do not make speech communication more difficult for people with normal hearing in noisy environments where noise would otherwise cause interference. However, the ability of a man to detect threshold levels of sound is modified by any type of ear covering, e.g., steel helmets or jacket hoods. In an environment with a high level of noise, speech intelligibility may be actually improved when earplugs are worn because the speech sounds as well as the noise are reduced to a level that does not overload the ear. Other factors will influence the degree of usefulness of hearing protectors in speech communication in a noisy environment. These include the degree of hearing loss, the spectrum of the noise, and the sound attenuation characteristics of the earplug or earmuff.

In a study of the factors related to hearing conservation, Yarrington (1968) noted that soldiers assigned to a mechanized infantry division were reluctant to report hearing deficiencies because of possible loss of proficiency rating, career advancement, or that they might "miss the opportunity of combat zone assignment." Hearing protectors were not used because they had been lost, not issued, or because the men thought they might perform better or survive in combat if their ears were not "plugged." The overriding factors seemed to be lack of recognition of the serious nature of sound-induced hearing loss and that protection could be obtained

by relatively simple measures. It appears that some military commanders "support hearing conservation measures in theory but condemn them in practice." (Yarrington, 1968).

Persons with some degree of hearing impairment, especially high-tone, perceptive hearing loss, are likely to have their hearing ability for speech somewhat further reduced when hearing protectors are worn (Coles and Rice, 1965). On the other hand, with a background of continuous noise above 85 dB SPL, reduction of both the voice sounds and the noise signals to lower levels by the hearing protectors establishes a condition which facilitates improved speech reception. There are numerous individual factors that influence the overall usefulness of hearing protectors in persons with impaired hearing. This matter requires further study as well as attention to techniques of proper use.

D. OBJECTIONS TO THE USE OF HEARING PROTECTORS

The skilled engineer has learned to listen for aberrant sounds in operating machinery. His auditory acuity and experience permit him to detect a malfunction at an early stage or to pinpoint precisely a defect. There is an element of pride in this learned auditory skill, and the use of any device such as an earplug that interferes with the precise perception of sounds will be resisted. Despite documented evidence to the contrary, most individuals think that ability to detect audible warning signals is reduced when they are required to wear hearing protectors. Thus, considerations of hearing conservation are overridden by fear or anxiety over potentially life-threatening sounds.

This civilian situation is comparable to that of the skilled soldier who has learned that survival may depend on the detection and recognition of aberrant sounds — sounds associated with functioning of military equipment or the movement of the enemy. It is his impression that the indicator sounds become less distinct when he is wearing hearing protectors because the low intensities reaching his ear are further reduced. In critical situations even the steel helmet may be discarded because, in some circumstances, it will interfere with the reception of sounds. Distinctions can be made among military demands such as quiet nighttime sentry duty,

exposure of troops to noise during vehicular or aircraft transport, and the obvious need for noise protection by aircraft and tank crews. However, as noted previously, exposure of individuals without hearing protection to the noise of vehicles and aircraft can produce marked TTS. This effect alone compromises the subsequent effectiveness of the individual to perform his duties satisfactorily.

E. EXTENT OF NOISE-INDUCED HEARING LOSS

It is difficult to obtain data on the extent and magnitude of noise-induced hearing impairment. Health statistics normally report hearing impairment as a disability and do not reflect the cause of the impairment (Peerboom, 1968). For example, vital statistics for the United States in 1960-62 indicate that 7.6% of the adult males, ages 18 to 79, had hearing thresholds 16 dB or more above an accepted normal threshold value for frequencies in the speech range (Roberts, 1968). Approximately one out of every ten adults in the United States is thought to have some degree of hearing loss (NANDS Council, 1969). The number of persons with noise-induced hearing loss has been estimated at 4 to 5 million (Goldman, 1970).

Noise-induced hearing impairment has been recognized as an occupational hazard only in the past two to three decades. Schedules of compensation and disability payments for occupationally induced hearing loss have been drafted by various medical and legal authorities (Frazier, 1965). However, in many states, detailed analyses of the etiology of hearing loss in workmen's compensation claims are unavailable. Similarly, the Veterans' Administration provides compensation for hearing loss associated with military service. Yarrington (1968) and Goldman (1970) indicate that hearing disability payments of the Veterans' Administration for service-connected hearing loss have exceeded \$30 million per year in recent years. Again, the etiology of the hearing impairment is obscure.

Studies on the extent of noise-induced hearing loss in ground combat forces and men exposed to noisy environments produced by military vehicles have been conducted (Meyer, 1968; Salmivalli, 1967; Schalthess and Huelsen, 1968; Tooley, 1964, 1965). A "significant amount" of hearing loss has been documented among

tank crewmen, infantry and artillery units, and men operating wheeled vehicles of various types. Helicopters pose special problems for their crews, and specific studies of the noise hazards for men operating these vehicles have been noted. These retrospective and prospective studies have been made on troops from several nations, including the United States. Not all of these investigations have employed ideal test conditions and the experimental designs might be criticized as lacking rigor.

However, most studies do present data which indicate that military service may include exposure to noise fields resulting in permanent hearing impairment. For example, Glorig *et al.* (1957) undertook a clinical audiometric (500 to 6000 Hz) and personal interview hearing survey at the 1954 Wisconsin State Fair. Individuals who reported having served in the armed forces were classified according to their description of duties into "low-noise" and "high-noise" exposed groups. While there were small differences in hearing thresholds at the low frequencies, at the higher frequencies tested, individuals with "high-noise" military service exhibited slightly more hearing impairment than those who had no military service or those who were exposed to "low-noise" environments during military service (Glorig *et al.*, 1957). The magnitude of hearing loss was most evident in 30- to 39-year-old rather than 20- to 29-year-old veterans. In addition, differences in hearing loss among subgroups were related to the branch of the armed forces in which they had served (Glorig *et al.*, 1957).

In this regard, the recent comprehensive study of Salmivalli (1967) on hearing losses among regular army personnel of the Finnish Defence Forces resulting from gun noise and blast waves is noteworthy. He employed sophisticated audiometric techniques, corrected for presbycusis and sociocusis, and used elaborate recording methods for the analysis of gun noise. He found that approximately 57% of the 422 men studied had serious hearing impairments related specifically to repeated exposure to noise fields generated by small arms firing.

The incidence of hearing loss among regular army personnel of the Finnish Defence Forces varied from 43.2 to 68.7% in the different branches of the service. Hearing loss appeared to be most prevalent in those men exposed to "high-noise" environments. On the basis of average curves, Salmivalli (1967) concluded that PHL develops rapidly, perhaps within five years. Continued exposure

to the noise of weapons firing does not induce further impairment, and the subsequent deterioration is primarily age-related.

The essential facts emerging from these several studies indicate that military occupations cause measurable hearing loss or impairment. Relatively little success has been achieved in hearing conservation measures in the armed forces of several countries. Within this country, it appears that the U. S. Air Force and U. S. Navy have been more successful in indoctrinating personnel in the proper use of hearing protective devices and in applying their hearing conservation programs.

The observations and opinions reported during this study suggest that temporary and permanent noise-induced hearing problems of the soldier could be reduced significantly by effective implementation of existing hearing conservation measures. While some hearing impairment is a risk of military operations in general, hearing conservation programs provide both prevention and protection; thus, the soldier could perform adequately and safely those military duties that must be done in noisy environments.

IX. RECOMMENDATIONS FOR FUTURE EMPHASIS

A. APPLICATION OF AVAILABLE KNOWLEDGE

Overexposure to high-level noise during a lifetime will result in progressive hearing loss. In general, the industrial, military, and social requirements for hearing conservation are recognized but it is very difficult to document an individual person's noise exposure history. Exposure of the unprotected human ear to continuous noise above a level of approximately 80 dB(A) is capable of producing both a temporary and a permanent change in the auditory threshold. At noise exposures of 105 dB(A) or above, permanent threshold shift can be expected if exposure continues over several years. There are no known techniques for correcting permanent threshold shift; preventive reduction of noise exposures is the only way to delay permanent threshold shift onset. Once permanent threshold shift occurs, there is no way to restore it; permanent hearing loss is irreversible.

Hearing conservation measures require adequate data for assessment of noise exposure hazards. These data are available and form the basis of the standards accepted by audiologists in military and civilian audiometric programs. However, experts in this field point out that many records are valueless because the audiometers were not adequately calibrated, the test rooms were too noisy, or the testing technician was improperly trained. In addition, in many cases, hearing thresholds were measured a short time after the man was exposed to high-level noise and thus temporary threshold shift effects prevented accurate assessment of his resting or true hearing threshold.

The criteria for hazard assessment are adequate, the techniques for audiometric testing are reliable, and competent audiologists, supervising technically proficient personnel, can conduct hearing conservation programs in the Army. Future plans to protect the soldier against noise exposure must take these facility and personnel requirements into consideration. The criticism has been made that, even with reliable data at hand, definitive action has not been taken; equipment design standards are frequently waived or ignored; elaborate military service regulations for hearing conservation and

testing methods often are not enforced.

It is not possible at the present time to identify individuals with increased noise susceptibility. It is agreed that all individuals at risk should be protected but few are willing to wear protective devices because they are inconvenient and because people are not convinced that they personally are endangered. In addition, a major effort may be required to protect a small percentage of personnel at the expense and inconvenience of the great majority who are less critically involved. Fundamentally, the matter appears to be one of education of commanders, as well as individual soldiers, about the hazards and the need for hearing conservation practices in most military activities. For example, there is no logical justification for not wearing earplugs or earmuffs on a firing range during training; however, there are equally excellent reasons for not wearing earplugs on sentry duty.

Recognizing that hearing is one of the most important sensory modalities possessed by the soldier, every effort should be made to conserve this sense. For this reason there should be increased support and additional manpower for the Army hearing conservation programs. Support for hearing conservation programs is necessary from the general staff level down to the individual soldier. These needs are of particular concern to the Vice Chief of Staff, the Deputy Chief of Staff for Personnel, the Deputy Chief of Staff for Logistics, the Chief of Research and Development, the Assistant Chief of Staff for Force Development, and The Surgeon General. The present noise exposures in many noncombat situations pose serious problems, but these can be overcome if the current Army regulations and the available knowledge in the field of acoustic science are implemented. The evidence marshalled in this study demonstrates that regulations are not followed; "waivers" are permitted for noisy vehicles; and hearing conservation guidelines are either not enforced or ignored.

Studies that have been reported point out the hazards of using military equipment that currently exceeds the recommended safe noise exposure levels. It does not appear possible to reduce significantly the noise levels of present equipment; however, numerous techniques for hearing conservation practices exist that are not employed. Unfortunately, noise-protective devices and techniques for monitoring hearing loss are not used as they should be because there is a lack of command emphasis. However, the actual effectiveness of hearing protectors will depend on the cooperation of the

individual, the fit of the device, its physical condition, and the man's ability to use the device properly. Discipline and example are two important aspects most conducive to the regular and effective use of any hearing protective device.

The modern soldier should not be exposed to undue noise hazard by using obsolete equipment. Accelerated obsolescence of current supplies of acoustically inadequate military equipment, when superior items have been developed and type-classified, would enhance the adoption of the existing improved noise-protective equipment and hearing conservation techniques. For example, improved noise communication systems with hearing protection devices available at the present time should be utilized. It is possible to conserve men and materiel if the basic principles for protection of the soldier's hearing in Army combat vehicles were adopted in the communications and weapons systems.

B. SUGGESTIONS FOR THE FUTURE

The immediate application of basic scientific knowledge to the protection of soldiers against the adverse effects of high-intensity sound will be costly. However, these costs must be weighed against the costs of equipment destroyed and the investment in training qualified men. The tactical losses caused by garbling of communication are recognized but difficult to document accurately. In addition, the cost of replacing men and the long-term compensation for hearing loss disability must be included in any cost-benefit analysis of improved performance of personnel protected against the adverse effects of sound in the military environment. Special consideration must be given to the implications of the Army's concept of continuous operations. Noise exposure criteria are generally based on the usual 8-hour work day of industry, and longer-term, continuous exposures may require modifications of existing Army plans, regulations, or criteria for maximum permissible noise exposures.

It has been suggested that a noise dosimeter device might be constructed to measure noise exposure "in toto" over a given time span, much like an ionizing radiation badge meter. There are commercially available sound meters that provide a measure of noise intensity exposure per duration, usually the 8-hour work day. It is

recognized that such meters do not record intermittency of exposure and only retrospectively indicate noise exposure per unit of time. Even though such devices do not accurately reflect at-the-ear levels of noise, future research should include an attempt to develop a device of this character.

Additional research is necessary to reduce noise at the source. It is estimated that the time for development of a military vehicle or a weapon system is approximately seven years. Thus techniques of sound reduction and implementation of design criteria focused upon noise reduction should be incorporated in the early stages of systems planning as an essential part of the vehicle or device.

The Army Surgeon General, prior to the development of any prototype system, should exercise a greater role in equipment design and be in a position to recommend measures to decrease or to prevent health hazards. Such reviews and analyses have not been utilized on a continuing basis by the Army in the early evolution of weapons systems, vehicles, and accessory equipment. Research and development may profitably include a careful consideration of the biological and medical effects upon personnel of new systems before they reach a stage of development that prohibits redesign to eliminate health hazards.

Proper engineering and mechanical design features conceivably could eliminate many sources of excessive noise generation if there were repeated emphasis on compliance with noise emission standards. When new devices and vehicles are type-classified, it should be more difficult to waive the noise level requirements. Obviously, many noise-generating components of mechanical equipment cannot be silenced, but the thrust of a vigorous program on hearing conservation includes minimizing noise in the design of new vehicles, communication systems, weapons, other military materiel, and enforcing rigorously the existing safety standards.

As an integral part of any program of hearing conservation there is an urgent need for increased emphasis on, and support for, audiometric monitoring and surveillance to establish the extent of noise-induced hearing loss in Army personnel. This information must be collected by competent audiologists using appropriate equipment which will give satisfactory results even

under field conditions. The fundamental aspects of such a general review and analysis have been developed in this report. Essential to future success will be the enthusiastic support of such a program by all branches of the Army.

These recommendations for hearing conservation have been made on the basis of peacetime military situations. The requirements of wartime combat operations could be overriding and therefore exceptions may be necessary.

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XI. APPENDIX

A. ABLREVIATIONS USED IN TEXT

AI	Articulation index
AT	Acoustic trauma
DC	Damage risk contour
DRC	Damage risk criteria
dB	Decibels
dB(A)	Decibels, A-weighted response network
NIPTS	Noise-induced permanent threshold shift
NIITS	Noise-induced temporary threshold shift
PHL	Permanent hearing loss
PTS	Permanent threshold shift(s)
SIL	Speech interference level
SPL	Sound pressure level(s)
TTS	Temporary threshold shift(s)
TTS ₂	TTS after two minutes

(See glossary for additional explanation).

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B. GLOSSARY

Acoustic Trauma (AT)	Sudden aural damage resulting from injury, trauma, or short-term intense exposure to large increases in SPL; e.g., impulsive noise such as gunfire.
Articulation Index (AI)	A relative measure of the interference of noise on speech communication. Expressed on a scale of 0 to 1.0, the AI is computed from noise spectra and can be used as a predictive measure of intelligibility.
Audiogram	A chart or table relating an individual's hearing level (usually threshold of hearing) for pure tones to selected frequency bands in the auditory range, measured by an audiometer.
Decibel (dB)	One-tenth of a bel. The bel is a scale unit used in comparing the magnitude of powers. The number of bels is the logarithm to the base 10 of the ratio of the powers. Sound pressures, in dB, are usually measured relative to a standard reference pressure of $20 \mu\text{N/m}^2$.
Frequency	In acoustics, the rate of repetition of cycles of air pressure change per unit time. Infrasonic frequencies are below 200 Hz, and ultrasonic frequencies above 20,000 Hz. The range of audible frequency is approximately 16 to 20,000 Hz, with speech frequencies between 100 and 7000 Hz.
Hertz (Hz)	The unit used to express frequency in terms of cycles per second.

Loudness	The auditory impression of the strength of a sound.
Masking	The process by which the threshold of hearing of one sound is raised due to the presence of another sound. Also, the increase, expressed in dB, in the threshold of hearing of the masked sound due to the presence of the masking sound.
Newton (N)	1.0 N is the force which will accelerate a 1 kilogram mass at the rate of 1 meter per second per second. Acoustic pressure measurements are given in force per unit area; e. g., N/m^2 or dyne/cm^2 . $10^5 \text{ N/m}^2 = 10^6 \text{ dyne/cm}^2 = 1 \text{ bar}$ or the force exerted by 14.5038 lbs per square inch.
Octave	A pitch interval between two tones, the second of which has a frequency twice that of the first.
Ossicles	The bones of the middle ear that provide the mechanical connection between the tympanic membrane and the oval window of the inner ear (see Figure 2).
Permanent Threshold Shift.... (PTS)	The component of auditory threshold shift that shows no progressive reduction with the passage of time after the apparent cause (sound exposure) has been removed or eliminated.
Pitch	The auditory impressio. of tones on a scale related primarily to frequency.
Presbycusis	Permanent threshold shifts and hearing loss, primarily in the higher

frequencies, that result from progressive physiological aging.

- Socioculus** Progressive hearing decline resulting from noise exposure throughout an individual's lifetime; not age-dependent alone, but related to cumulative noise exposures from diverse sources.
- Sound Pressure Level** The pressure, in dB, of a source
(SPL) sound equal to 20 times the logarithm to the base 10 of the ratio of the root mean square value sound pressure relative to a reference pressure (usually $20 \mu\text{N/m}^2$).
- Speech Interference Level** The average of the octave band sound
(SIL) pressure levels of a noise, centered on the frequencies 425, 850, and 1700 Hz together with the frequency 212 if the speech interference level in this band exceeds the other measured frequencies by 10 dB or more. There are several methods of computing SIL (see Webster, 1969).
- Temporary Threshold Shift** ... The reversible component of auditory
s) threshold shift that shows progressive reduction with the passage of time after the apparent cause (sound exposure) has been removed or eliminated. TTS_2 is the threshold shift measured two minutes after sound exposure ceases.
- Tinnitus** The sensation of noise in the auditory system, usually perceived as ringing, buzzing, clicking, roaring, or humming.

XII. LIST OF ATTENDEES

AD HOC STUDY GROUP MEETING, JUNE 8 AND 9, 1971

ON

A REVIEW OF ADVERSE BIOMEDICAL EFFECTS OF SOUND
IN THE MILITARY ENVIRONMENT

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