N-96-01
II-A-176

United States
Environmental Protection
Agency

Office of
Noise Abatement and Control
Washington, DC 20460

EPA REPORT NO. 550/9-82-103A
March 1982

Noise

EPA

ANALYSIS OF NOISE-RELATED AUDITORY AND ASSOCIATED HEALTH PROBLEMS IN THE U.S. ADULT POPULATION (1971-1975)

VOLUME 1

N-96-01
II-A-176

ANALYSIS OF NOISE-RELATED AUDITORY
AND ASSOCIATED HEALTH PROBLEMS
IN THE U.S. ADULT POPULATION
(1971-1975)

EPA REPORT NO. 550/9-82-103A
March 1982

VOLUME 1

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. 550/9-82-103A	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE ANALYSIS OF NOISE-RELATED AUDITORY AND ASSOCIATED HEALTH PROBLEMS IN THE U.S. POPULATION (1971-1975)		5. REPORT DATE MARCH 1982 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) JUDITH D. SINGER with T. J. Tomberlin, J. M. Smith, A. J. Schrier		8. PERFORMING ORGANIZATION REPORT NO. 550/9-82-103A
9. PERFORMING ORGANIZATION NAME AND ADDRESS ABT ASSOCIATES, INC. 55 Wheeler Street CAMBRIDGE, MA 02138		10. PROGRAM ELEMENT NO. 5 11. CONTRACT/GRANT NO. 68-01-6264
12. SPONSORING AGENCY NAME AND ADDRESS ENVIRONMENTAL PROTECTION AGENCY 401 M. STREET SW WASHINGTON, DC 20460		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA ONAC

15. SUPPLEMENTARY NOTES

SEND OUT BOTH VOLUMES WITH ANY REQUESTS. (SEND 550/9-82-103A & 550/9-82-103B)

16. ABSTRACT The First National Health and Nutrition Examination Survey (NHANES I) was designed to characterize the overall health and nutritional status of the U.S. civilian noninstitutionalized population aged 1-74 years and to permit examination of the prevalence of specific health conditions on a subsample of adults aged 25-74 years. Analyses presented in this report are based on the national probability subsample of 6913 adults aged 25-74 years who were administered an audiometric test as well as detailed questionnaires and physical examinations dealing with hypertension and a variety of other health conditions. Detailed occupational descriptions were used in the present study to estimate approximate eight-hour noise levels for the sample of 3842 adults aged 25-74 years in the workforce. Among the major findings: 1. Hearing impairment is a widespread health problem in the United States; 2. Occupational noise exposure was identified as a major risk factor associated with the prevalence of hearing impairment among men; 3. Occupational noise exposure was not significantly related to hearing sensitivity among working women; 4. Occupational noise exposure was found to have a weak, but nevertheless significant association with hypertension for both men and women; 5. Among men, occupational noise exposure was associated with overall physical health, whereas among women, it was associated with only overall psychological health; and 6. No conclusive relationships were found between occupational noise exposure and the remaining indicators of specific health conditions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
U.S. HEARING DEMOGRAPHICS, NOISE, CORRELATES OF HEARING AND NOISE, NON-AUDITORY CORRELATES, HEARING TESTS, SPEECH DISCRIMINATION HYPERTENSION, NONAUDITORY EFFECT OF NOISE, OCCUPATIONAL NOISE	NOISE HEARING	

18. DISTRIBUTION STATEMENT AVAILABLE THROUGH NTIS	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES VOL. 1, 199 pgs.
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

ABT ASSOCIATES INC.
55 WHEELER STREET, CAMBRIDGE, MASSACHUSETTS 02138
TELEPHONE • AREA 617-492-7100

Authors:

Judith D. Singer
with
Thomas J. Tomberlin
Janet M. Smith
Alicia J. Schrier

FINAL REPORT

Hearing Status in the United States and the Auditory and Non-Auditory Correlates of Occupational Noise Exposure

12 March 1982

Project Director:

Judith D. Singer

Government Project Officer:

Jack Shampan

Prepared for:

Environmental Protection Agency
Office of Noise Abatement and Control
Washington, D.C. 20460

Contract Number: 68-01-6264

Contract Manager	Quality Control Reviewer	Management Reviewer

Table of Contents

Table of Contents
(Continued)

List of Text Tables

List of Text Figures

ACKNOWLEDGEMENTS

This report could not have been completed without the cooperation and assistance of numerous persons and groups. Several of these deserve special recognition for their contributions to the research effect which led to this report.

We are especially grateful to Jack Shampan, the Environmental Protection Agency Project Officer for this project, for his continuing guidance, assistance and support. It was he who first conceptualized this study and who has devoted much time and energy to ensuring that the final product would be useful to both researchers and policymakers.

We wish to acknowledge the valuable assistance of the National Center for Health Statistics in providing data tapes, data documentation and background information. Special thanks go to Robert Murphy, Director of the Division of Health Examination Statistics and Jean Roberts, Chief of the Division's Medical Statistics Branch for consulting with the project staff and reviewing the report.

We also wish to thank our external consultants for their suggestions and guidance from the early stages of the project through the report preparation phase. Dr. Joseph McGuire, University of Michigan and Dr. Larry Royster, North Carolina State University developed the occupational noise exposure classification system which is used throughout this report. These two consultants were joined by Dr. Roy Gengel, University of Massachusetts and Dr. John Mills, Medical University of South Carolina in providng technical assistance in the areas of audiology and noise induced hearing loss. In addition, Dr. Cristina Leske, SUNY Stony

Brook Medical School and Dr. William Stason, Harvard Medical School contributed to our understanding of hypertension and other aspects of overall health as they relate to occupational noise exposure.

Finally, we would like to acknowlege the work of Abt Associates Inc. staff and consultants to the project. In particular, Alicia Schrier directed the data processing and performed analyses investigating the relationships between hypertension and occupational noise exposure; Janet Smith performed analyses investigating links between the remaining health conditions and noise; and Jerry Tomberlin provided statistical support and undertook the analyses of the auditory effects of noise. Dr. John Himes reviewed the final manuscript from a technical perspective and Nancy Irwin reviewed it for clarity of presentation and style. Special thanks also go to our administrative and secretarial staff, particularly Karen Hudson, Project Secretary and Carolyn DiBella, who joined her in typing and producing this final report. The support of all of these persons has been instrumental to the successful completion of the project and is very much appreciated.

Judith D. Singer
Project Director

EXECUTIVE SUMMARY

Noise exposure is a serious health problem in the United States today. Excessive noise exposure will cause temporary loss of hearing, and if the exposure persists, the loss will become permanent. Recent research has also linked noise to changes in the cardiovascular, endocrine and immune systems, disturbances in the gastrointestinal tract, physiological and psychological stress and fetal abnormalities. Given the often excessive levels of noise present in both the workplace and the living environment, these detrimental effects of noise are becoming important issues that individuals, employers and the government must address.

Yet much of the data required to make informed decisions concerning the health effects of noise exposure and noise regulation is not available. Although most researchers agree that the degree of effect is related to the exposure level, the length of "recovery" periods between exposures, and the number and duration of exposures, the majority of these relationships have not been precisely quantified. Moreover, few studies have been able to isolate the effects of noise exposure from variations in hearing acuity and health associated with demographic and physiological characteristics. Even on a more basic level, the most recent available data on the hearing status of the U.S. population date back to 1962.

Precisely these types of concerns led to the present study. Under authority of the Noise Control Act of 1972, the Environmental Protection Agency was charged with conducting research on the auditory and nonauditory effects of noise. As part of their overall research program, EPA sought to identify a current, generalizable data base that could be used for four purposes:

(1) to provide a generalizable profile of the hearing status of the U.S. adult population;

(2) to estimate the number of adults having a hearing impairment;

(3) to investigate the auditory correlates of noise exposure; and

(4) to investigate the nonauditory correlates of noise exposure.

Towards this end, the First National Health and Nutrition Examination Survey (NHANES I) was selected for study.

NHANES I was designed to characterize the overall health and nutritional status of the U.S. civilian noninstitutionalized population aged 1-74 years and to permit examination of the prevalence of specific health conditions on a subsample of adults aged 25-74 years. Analyses presented in this report are based on the national probability subsample of 6913 adults aged 25-74 years who were administered an audiometric test as well as detailed questionnaires and physical examinations dealing with hypertension, general well-being and a variety of other health conditions. Although no specific data were collected on noise exposure, detailed occupational descriptions were used in the present study to estimate approximate eight-hour noise levels for the sample of 3842 adults aged 25-74 years in the workforce.

Major findings may be summarized as follows:

(1) Hearing impairment is a widespread health problem in the United States today. The present study estimates that between 10 and 12 percent of the adult population have a hearing impairment in their better ear and between 20 and 25 percent have a hearing impairment in their worse ear. These prevalence rates translate into population estimates of between 11.0 and 13.2 million adults having a hearing impairment in their better ear and between 22.0 and 27.5 million adults having a hearing impairment in their worse ear.

(2) Occupational noise exposure was identified as a major risk factor associated with the prevalence of hearing impairment among men. Men whose current jobs entail exposure to high levels of noise have significantly poorer hearing than men employed in quieter environments. These effects are found across the entire frequency band examined, but are especially pronounced at the mid- and high-frequencies--2000 and 4000 Hz. Moreover, these mid- and high-frequency losses are found regardless of the age of the individual or his sociodemographic profile.

(3) Occupational noise exposure was not significantly related to hearing sensitivity among working women. Despite the highly significant relationship between noise exposure and hearing sensitivity among men, no parallel relationship was found for women. Although this differential may have a physiological basis, it is more probably attributable to differences in current noise exposure and noise histories between men and women.

(4) Occupational noise exposure was found to have a weak, but nevertheless significant, association with hypertension for both men and women. In particular, excessive noise exposure was associated with a decrease in the prevalence of normotension among men and an increase in the prevalence of labile hypertension among women. In addition, a direct relationship with elevated diastolic blood pressure was observed, especially for women.

(5) Among men, occupational noise exposure was associated with overall physical health, whereas among women, it was associated with only overall psychological health. Men in higher noise exposure occupations were more likely to be diagnosed by the NHANES I physician as having some physical ailment or abnormality. Although no comparable finding for overall physical health was noted for women, a significant decrease in psychological well-being was found among females in high noise occupations.

(6) No conclusive relationships were found between occupational noise exposure and the remaining indicators of specific health conditions. Of the 23 measures of specific health conditions examined, none were consistently associated with occupational noise exposure when controlling for background characteristics. Whether this is reflective of a true lack of relationships or whether it is due to the inability to isolate the effects of noise exposure from other characteristics can only be a point of speculation in the present study.

CHAPTER ONE: INTRODUCTION

> Noise is the most impertinent of all forms of interruption. It is not only an interruption, but also a disruption of thought . . . We shall only become quite civilized when the ears are no longer unprotected, and when it shall no longer be the right of everybody to sever the consciousness of each thinking being . . . with whip-cracking, barking, etc., etc.
>
> Arthur Schopenhauer
> The World As Will and Idea,
> "On the Senses"

Although Schopenhauer wrote these words over 100 years ago, they are perhaps more relevant today than they were in the nineteenth century. At that time, most people believed that excessive noise exposure was solely an occupational hazard, endemic to the jobs of blacksmiths, boilermakers and blasters. Moreover, the effects of noise were believed to be limited to a profound and permanent decrease in hearing sensitivity.

But today's complex industrialized society has completely changed this view. Noise exposure is acknowledged to be a serious health problem in the United States today. The workplace still continues to be the primary setting in which individuals are faced with excessive noise. However, the hazards are no longer restricted to a few select occupations, but rather touch a large number of individuals involved in the high speed and high energy industries. A Department of Labor study completed in 1974 estimated that 14.4 million production workers are exposed to noise levels in excess of 80 decibels, A-weighted sound pressure level (dBA); 8.3 million of these persons are exposed to noise levels in excess of 85 dBA, and 3.8 million of these persons are exposed to noise levels in excess of 90 dBA (BBN, 1974). An independent study by the National Institute of Occupational Safety and Health (NIOSH) confirmed these findings and estimated that almost 23 million workers are employed in industries with generally hazardous noise levels and 3.3 million of these persons are exposed to noise levels above 90 dBA (NIOSH, 1975).

Not only has the potential for occupational noise exposure increased dramatically in the last century, but the potential for non-work exposure has risen as well. Most obvious are the effects of modern transportation: passengers in automobiles, trains and airplanes are routinely exposed to excessive noise levels, as are individuals who live near major highways, railroad tracks and airports (EPA, 1973). Recreational sources of intense noise also abound, as increasing numbers of individuals use firearms or power tools or listen to loud music during leisure hours. Perhaps most staggering is the estimate that 12.2 million persons reside in areas with outdoor noise levels of 70 dBA or more and approximately 600,000 of these persons are exposed to outdoor noise levels in excess of 80 dBA (Galloway, Eldred and Simpson, 1974).

It is clear from these statistics that despite government regulations, such as the Occupational Safety and Health Administration's (OSHA) Noise Standard of 1971, the Noise Control Act of 1972, the Quiet Communities Act of 1978 and the Hearing Conservation Amendment of 1981, annoying and potentially dangerous noise remains an ever-present fact of modern American life. But exactly what are the consequences of this noise exposure? The most obvious effect has been recognized for centuries: excessive noise exposure will cause temporary loss of hearing, and if the exposure persists, the loss will become permanent. Such a noise-induced permanent threshold shift (NIPTS) will never reverse itself, nor is it easily corrected with the use of special hearing aids.

But because NIPTS can advance slowly and rarely produces symptoms that are life-threatening, its debilitating nature has been largely ignored. In fact, it was only in the mid 1950s that gradual NIPTS was incorporated into workmen's compensation laws (Newby, 1964). However, a noise-induced hearing impairment may severely affect an individual's physical and psychological/social well-being. A person with a noise-induced hearing impairment often experiences severe and persistent ringing in the ears (tinnitus) and a rapid increase in the sensation of loudness once his hearing threshold has been reached (recruitment). In addition, it may be extremely difficult to understand normal voice communication, especially against a noisy background (Suter, 1978). For example, in a study of jute weavers with NIPTS, Taylor (1972) found that 80 percent had difficulty in conversation with strangers, 77 percent had difficulty in conversation with friends and 72 percent had difficulty understanding speakers at public meetings, in church, at the theater, and so forth.

Although these difficulties for an individual with noise-induced hearing impairment have sparked some interest among policymakers and the public, the concern has not been as great as it has been for toxic substances such as asbestos and radiation. To some extent, this has been due to the fact that many people simply view excessive noise as an inevitable, albeit unwanted, by-product of increased modernization and industrialization. Moreover, the lack of accurate estimates of the numbers of pesons with NIPTS and the view that NIPTS does not have a dramatic impact on an individual's life further de-emphasize people's concerns. The identification of more obviously debilitating and life-threatening conditions as possible effects of excessive long-term noise exposure, however, may highlight the magnitude of the problem.

Recent research has suggested that noise is a generalized biological stressor. As a stressor, noise has been linked to changes in the cardiovascular, endocrine and immune systems, disturbances in the gastrointestinal tract, physiological and psychological stress and fetal abnormalities. (Welch and Welch [1970], MIT [1976] and Cohen [1979] all provide useful reviews of the literature.) Although much of the available research is sketchy, often conducted with animals instead of humans, or with too few subjects under less than ideal experimental conditions, a review of the literature led Welch (1979) to conclude that there is, at the least, convincing evidence that long-term exposure to industrial sound levels of 85-95 dBA and above impairs the regulation of blood pressure and may increase the risk of ischemic heart disease. The public health significance of these findings immediately becomes obvious when one realizes that even conservative estimates suggest that over 23 million adults in the United States have dangerously elevated blood pressure levels and that cardiovascular disease is the number one cause of death in this country, accounting for almost one million deaths per year (NCHS, 1980b; U.S. Bureau of the Census, 1980).

Given the often excessive levels of noise present in both the workplace and the living environment, these detrimental effects of noise are becoming important issues that individuals, employers and the government must address. Yet much of the data required to make informed decisions concerning the health effects of noise exposure and noise regulation is not available.

Part of the problem has been that there is no definitive answer to the basic question--just how much low- to moderate-level noise is hazardous to hearing and other aspects of human health? Although most researchers agree that the degree of effect is related to the exposure level, the length of "recovery" periods between exposures, and the number and duration of exposures, the majority of these relationships have not been precisely quantified. This has been due, in part, to difficulties in accurately estimating how much noise an individual is exposed to over a 24-hour period. A secondary problem in noise measurement is the quantification of the time-intensity tradeoff, or so-called doubling rule: how much of an increase in noise exposure should be allowed for each halving of exposure time? Faced with conflicting evidence and rather severe cost implications, OSHA recently adopted a 90 dBA noise limit for an eight-hour working period with a 5 dBA doubling rule (OSHA, 1981). But many feel that this limit is far too liberal, and that even if it were rigorously enforced, it would result in impaired hearing for millions of workers (Kryter, 1975). As a result, some researchers have advocated revision of the OSHA standard to an eight-hour noise exposure limit of 85 dBA, a position which has been consistently resisted because of anticipated high compliance costs, despite the support of organizations such as NIOSH (Eldred, 1976).*

A related problem is the inability of interested parties to agree on exactly what constitutes a hearing impairment (Suter, 1978). In 1959, the American Academy of Ophthalmology and Otolaryngology (AAOO) adopted the concept that hearing impairment "should be evaluated in terms of the ability to hear everyday speech under everyday conditions." In an attempt to quantify this position, the AAOO determined that hearing impairment begins when the average of the hearing levels at the so-called "speech frequencies"--500, 1000 and 2000 Hz--exceeds a "low fence" of 25 dB (ANSI-1969). To incorporate the findings from both ears, the AAOO-1959

---

*Even an 85 dBA eight-hour exposure limit would not completely eliminate the risk of noise-induced hearing impairment. Evidence presented by EPA suggests that only an eight-hour exposure limit of 75 dBA would eliminate NIPTS in most persons (EPA, 1974).

method employs a 5 to 1 better ear/worse ear weighting scheme. For years, this AAOO-1959 method was the most widely used formula for determining hearing impairment appearing in federal OSHA guidelines and is still the criterion used in many state workmen's compensation laws.

But the adequacy of the AAOO-1959 method for determining the beginning of hearing impairment was widely criticized in the 1970's for several reasons, including the following.

- It did not incorporate hearing levels at the higher auditory frequencies--3000 Hz and above--which are also associated with the ability to hear everyday speech, especially against a noisy background (NIOSH, 1972; Suter, 1978).

- Given the frequencies used, the low fence of 25 dB was far too high and resulted in the classification of many individuals with a hearing impairment in the normal category (Kryter, 1973).

- The 5 to 1 better ear/worse ear weighting scheme was arbitrary and not based upon scientific evidence (Ginnold, 1979).

Reflecting on the research evidence, NIOSH rejected the AAOO-1959 method and adopted the criterion that speech communication difficulty begins when average hearing levels at 1000, 2000 and 3000 Hz exceed 25 dB (NIOSH, 1972). Kryter argued that instead of changing the frequencies involved, the fence should be lowered to 15 dB, corresponding to almost perfect intelligibility for normal speech (Kryter, 1973). The better ear/worse ear correction simply remained a point of argument.

Responding to these arguments, the AAOO revised its formula in 1978 to include 3000 Hz (AMA, 1979). This new formula specifies that hearing impairment begins when the average of the hearing levels at 500, 1000, 2000 and 3000 Hz exceeds 25 dB. Although some people felt that the inclusion of 3000 Hz was a step in the right direction, there was still evidence to support the complete elimination of 500 Hz from the definition (Suter, 1978). As a result, the new OSHA guidelines specify that hearing impairment begins when the average of hearing levels at 1000, 2000 and 3000 Hz exceeds 25dB (OSHA, 1981).

Beyond these basic measurement and definitional issues, other practical stumbling blocks have stymied the research on the effects of noise. Although the short-term effects of noise (e.g., temporary threshold shift and the momentary startle reflex) may be studied in a clinical setting, both logistics and the rights of human subjects prevent such clinical studies of the long-term effects on humans. Thus, much of the existing evidence comes from field studies of people who have been routinely exposed to excess noise either at the workplace or at home. Unfortunately, although some of these field studies have been prospective in nature, the vast majority of them have been retrospective, and have been plagued with methodological problems endemic to such investigations. In particular, many studies have come under attack because they have been based on poor experimental designs, have used inappropriate statistical techniques and have failed to adequately control for factors other than noise that are known to affect hearing and health (Thompson, 1981). Other criticisms have stemmed from the routine use of small, nongeneralizable populations (Taylor et al., 1980). But given that the most recent available data on the hearing status of the United States population date back to 1962 (NCHS, 1965), how is a researcher to determine if a sample of subjects is representative of the overall population?

Precisely these types of concerns have led to the present study. Under the authority of the Noise Control Act of 1972, the Environmental Protection Agency (EPA) is charged with conducting research on the effects of noise. The resulting information is to be used for developing and refining criteria, which in turn are used for setting standards and regulations, advising other Federal agencies, giving technical assistance to local communities, and educating the general public, all for the general purpose of protecting the public against the adverse effects of noise. Although much research has already been conducted under this mandate, EPA has still noted in their most recent Detailed Research Plan that the need to document noise exposure as a risk factor associated with hearing impairment and other health conditions remains acute (EPA, 1981). This research goal has been seconded by several other concerned groups, including those at the 1978 International Congress on Noise as a Public Health Problem and those on a 1978 National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) panel. In addition, today's researchers still lack a complete up-to-date profile of the hearing status of the United States population, a prerequisite to determining the representativeness of any study sample. To help meet these needs, the Environmental Protection Agency sought to identify a current, generalizable data set that could be used for these purposes. Towards this end, the First National Health and Nutrition Examination Survey (NHANES I) was selected for study.

NHANES I was designed to characterize the overall health and nutritional status of the U.S. civilian non-institutionalized population aged 1-74 years and to permit examination of the prevalence of specific health conditions on a subsample of adults aged 25-74 years. During the period from 1971-1975, a national probability sample of 23,808 persons aged 1-74 years was interviewed and examined.

As part of this examination, audiometric data were collected on a national probability subsample of 6913 adults aged 25–74 years; in addition, data on hypertension and general well-being, as well as on a variety of health and background characteristics, were gathered for these examinees. Although no specific data were collected on noise exposure, a detailed description of each examinee's occupation was obtained using the U.S. Bureau of the Census Industry and Occupation Classification Codes (U.S. Bureau of the Census, 1971). This information was used in the present study to estimate approximate eight-hour noise levels for each examinee reported to be in the workforce.

Based on these data, the present study was designed with four primary objectives in mind:

- to provide a broad generalizable profile of the hearing status of the U.S. adult population;
- to estimate the number of adults having a hearing impairment;
- to investigate the auditory correlates of noise exposure; and
- to investigate the nonauditory correlates of noise exposure.

With respect to the first two objectives, specific emphasis was placed on updating the information published as a result of Cycle I of the Health Examination Survey, a predecessor of NHANES I (NCHS, 1965, 1967b, 1968a, 1968b). In particular, data on air and bone conduction hearing levels, speech discrimination ability, self-assessment of hearing and the prevalence of hearing impairment under a wide variety of alternative definitions for the full representative sample of 6913 adults were examined. In addition, the interrelationships among these measures were investigated.

With respect to the last two objectives, analyses were conducted on the sample of 3842 adults aged 25-74 years in the workforce. Emphasis here was placed on documenting the associations between occupational noise exposure and hearing status, hypertension, general well-being and a variety of other indices of heath status. To the extent possible, an effort was made to statistically control for the extraneous and potentially misleading effects of background characteristics such as age, sex, race, socioeconomic status and lifestyle.

The body of this report comprises a description of the NHANES I survey and the data collection methods (Chapter Two), a description of the hearing status of the United States and the prevalence of hearing impairment under alternative definitions (Chapter Three), an examination of the auditory and nonauditory correlates of noise (Chapters Four and Five) and a discussion of the study findings in light of previous research (Chapter Six). Three appendices supplement the report. Appendix I presents the survey design and analytic approach. The noise exposure classification system is presented in Appendix II. Appendix III, which consists of the detailed tables referred to throughout the main report, is bound separately in a companion volume.

CHAPTER TWO: DATA SOURCES

The National Health and Nutrition Examination Survey was an outgrowth of the National Health Survey Act of 1956. Under authority of this act, the National Center for Health Statistics instituted the National Health Examination Survey to characterize the health status of a nationwide probability sample and to estimate the prevalence of certain medically defined illnesses for the population under study. Ten years later, measures of nutrition were added to the survey, and the National Health and Nutrition Examination Survey (NHANES) was formed.

The first NHANES program (NHANES I), conducted from 1971 to 1975, was designed to measure the nutritional status of the U.S. civilian noninstitutionalized population aged 1-74 years, to obtain some limited information on the general health status of that entire age group, and to obtain more detailed information on the health status and medical care needs of adults aged 25-74 years. To standardize data collection as much as possible, several full-time medical teams, trained to administer a uniform health examination using the same equipment in the same surroundings, traversed the country in mobile examination centers, spending between three and six weeks in each of 100 data collection sites.

The survey was originally divided into two components: a general component and a detailed component. As part of the general component, 20,749 persons aged 1-74 years were interviewed and examined from 1971 to 1974. Every participant was given a nutrition interview, a medical history questionnaire and general medical, dental, dermatological and ophthalmological examinations. Samples of whole blood serum, plasma and urine were taken for laboratory analysis, anthropometric data were taken by trained technicians, and demographic data were obtained by interviewers from the U.S. Bureau of the Census. As part of the detailed component, a one-fifth subsample of 3854 adults aged 25-74 years were further interviewed and examined. In addition to the protocols and procedures outlined above, these participants were administered a medical history supplement, supplements for arthritis, cardiovascular disease and respiratory conditions, questionnaires on health care needs and general well-being, more extensive medical and laboratory screenings and a pure tone audiometric examination.

It had originally been anticipated that the detailed component would be continued into a second NHANES program to produce a sample size adequate for analysis by smaller demographic groupings. However, to provide more time for planning this second NHANES program, it was decided to devote the 15-month period from July 1974 through September 1975 to additional detailed component data collection as part of NHANES I. As part of this third component (the augmentation component), 3059 adults aged 25-74 years were interviewed and examined. Participants in the augmentation component did not receive the majority of protocols given to participants in the general component (i.e., nutrition interview, general medical history questionnaire, general examinations, basic laboratory determinations), although complete body measurements were obtained and the demographic questionnaire was administered. Instead, these participants received the extensive set of protocols given to those persons in the detailed component as well as additional laboratory procedures and medical examinations.

Each of these three samples--for the general component, the detailed component and the augmentation component--is a national probability sample. In addition, the data from the latter two samples may be combined to form a fourth national probability sample consisting of 6913 adults aged 25-74 years. Because it is this sample for which the audiometric data as well as the detailed information on general well-being and hypertension are available, these 6913 persons form what has been labeled the analytic sample.

The remainder of this chapter presents an overview of the data collection procedures used to gather information from these 6913 adults in each of the four major areas relevant to the present study: audiometric tests; data on health conditions; data on noise exposure; and data on background characteristics. Additional detail on the NHANES I survey design may be found in Appendix I.

2.1 Audiometric Data

Air conduction hearing thresholds for the right and left ear of each examinee were determined individually using a standard audiometer at each of four frequencies: 500, 1000, 2000 and 4000 Hz. Bone conduction hearing thresholds at each of these frequencies in both ears were then determined for examinees in the detailed component. For examinees in the augmentation component, a Speech Discrimination Test was administered immediately following the air conduction test. All examinees were given an extensive questionnaire related to their general hearing status; examinees in the augmentation component (i.e., those who received the Speech Discrimination Test) were also administered a questionnaire on their ability to hear and understand speech.

2.1.1 Air Conduction Test

Air conduction hearing thresholds were determined monaurally and individually by trained technicians in an acoustically treated booth within the mobile examination center. Within the testing booth, ambient noise was generally attenuated well below acceptable standards.* Quality of the test results was further controlled by periodic factory calibration of the audiometers and daily field checks. Calibration was done in accordance with 1969 American National Standards Institute (ANSI) specifications. Hence, the zero sound hearing level as reported corresponds to the 1969 ANSI reference zero.

Each adult was tested at the four frequencies in the following order: 1000, 2000, 4000, 500 Hz. At the completion of this sequence in a given ear, the 1000 Hz frequency was repeated a second time as a test of reliability. Alternation of presentation to left and right ears was varied systematically among examinees to guard against bias in testing.

The threshold recorded for each frequency was the lowest decibel level at which 50 percent or more of the responses were obtained, that is, in two out of three or three out of five trials. Masking for the non-test ear was done when there was a 40 dB difference or more in the thresholds for the two ears. Standardized testing procedures were used to ensure that test results were as consistent as possible throughout the survey (NCHS, 1972a).

The data were recorded using 5-dB intervals, beginning with -10 dB and running in 5-dB increments to 95 dB. Thus, a recorded air conduction threshold of -10 dB indicates a "true" threshold of -10 dB or less (i.e., -10 dB or less), a recorded threshold of -5 dB indicates a "true" threshold in the range of -9 through -5 dB, and so on.

*Maximum allowable sound pressure levels at selected frequencies were: 35 dB at 31.5, 63, 125, 250, 500 and 1000 Hz; 42 dB at 2000 Hz; 52 dB at 4000 Hz and 62 dB at 8000 Hz.

Individuals with air conduction thresholds of 96 dB or more were recorded as having a threshold of 99 dB. Table 2.A presents the corresponding "true" threshold ranges for each of the recorded values.

Table 2.A

True Ranges for Recorded Values in Pure Tone Audiometry

Recorded Value	True Range	Recorded Value	True Range
-10	-10 or less	50	46 thru 50
- 5	- 9 thru -5	55	51 thru 55
0	- 4 thru 0	60	56 thru 60
5	1 thru 5	65	61 thru 65
10	6 thru 10	70	66 thru 70
15	11 thru 15	75	71 thru 75
20	16 thru 20	80	76 thru 80
25	21 thru 25	85	81 thru 85
30	26 thru 30	90	86 thru 90
35	31 thru 35	95	91 thru 95
40	36 thru 40	99	96 or more
45	41 thru 45		

2.1.2 Bone Conduction Test

Individuals in the detailed sample were administered a bone conduction test immediately following the air conduction test. Testing procedures for the bone conduction test were identical to those for the air conduction test with two exceptions: (a) during bone conduction, masking was done routinely in the non-test ear according to the plateau formula; and (b) the maximum hearing level recorded was 55 dB.

2.1.3 Speech Discrimination Test

Individuals in the augmentation sample were administered the Speech Discrimination Test immediately following the air conduction test. The Revised Central Institute for the Deaf (RCID) Lists were used, recommended by a working group of the Committee on Hearing and Bioacoustics (CHABA) of the National Research Council (Elkins, 1971).

Each subject was asked to repeat lists of 10 sentences, each list containing 50 key words, beginning at a sensation level (SL) of 10-15 dB below the air conduction threshold at 1000 Hz. When the air conduction threshold was 35 dB or lower, the first list was presented at 20 dB SL. If the examinee missed six key words or more (i.e., scored less than 90 percent), the next list was presented at a sensation level 10 dB higher. Testing was continued until the subject missed five key words or less or until the ear had been tested at 80 dB SL. Each ear was tested this way beginning with the list immediately following the last list used for the previous examinee.

The Speech Discrimination Score (SDS) used in this report is the percentage of key words correctly repeated at a sensation level of 20 dB. If the examinee had an air conduction threshold in excess of 35 dB at 1000 Hz, he or she was not tested at 20 dB SL and thus the SDS is considered missing. A total of 62 examinees (2.2 percent) who received the speech discrimination test were not tested at 20 dB SL. As a result, the data presented in this report may be an overestimate of the speech discrimination ability at 20 dB SL of the U.S. population. Moreover, since the administration procedures used differ somewhat from those more commonly employed in tests of this type, comparisons between the data presented herein and other studies may not be straightforward.

2.1.4 Self-Assessment of Hearing

As part of the general medical history supplement given to persons in the detailed sample or the supplement given to persons in the augmentation sample, examinees were asked a series of questions pertaining to their hearing. In particular, they were asked: if they had noticed ringing or other "funny noises" in their ears during *the past few years* and, if so, how often it had bothered them; if they had *ever* had a running ear or any other discharge from their ears, not including wax; if they had *ever* had deafness or trouble hearing in one or both ears, and, if so, the cause of it; and, how they would rate their hearing in each ear--good, a little decreased, severely decreased, or deaf.

For examinees in the augmentation sample, the above protocol was followed by the administration of a ranked set of seven questions focused on the types of speech and sounds that the examinee could hear and understand as shown below.

Without a hearing aid, can you usually . . .

1. Hear and understand what a person whispers to you from across a quiet room?
2. Hear and understand what is said if a person talks in a normal voice to you across a quiet room?
3. Hear and understand what is said if a person shouts to you from across a quiet room?
4. Hear and understand a person if that person speaks loudly into your better ear?
5. Tell the sound of speech from other sounds and noises?
6. Tell one kind of noise from another?
7. Hear loud noises?

This series of questions was administered as an unidimensional Guttman scale, in that once the examinee responded "yes," no more questions were asked, as it was logically assumed that the responses to the subsequent questions which required lesser hearing ability would be affirmative. This hearing scale is virtually identical to that used in the National Census of the Deaf Population (Schein and Delk, 1974).

2.2 Data on Health Conditions

Data related to a variety of health conditions were collected through several protocols used during NHANES I. Presented below are the primary sources of information used to gather data specifically on hypertension and stress and generally on a variety of other health conditions.

2.2.1 Hypertension

Hypertension was addressed through three data collection techniques in NHANES I: blood pressure measurements, a medical history and a medical examination.

Blood Pressure Measurements. Three blood pressure measurements were obtained for all adults in the analytic sample. The first reading was taken by the physician with the examinee sitting; the second and third readings were taken by a nurse, once with the examinee sitting and once with the examinee recumbent. For all three measurements, blood pressure was measured indirectly with a standard clinical sphygmomanometer in close accordance with guidelines outlined in the American Heart Association's "Recommendations for Human Blood Pressure Determinations by Sphygmomanometers" (AHA, 1951).

Medical History. As part of the medical history administered by a trained interviewer, each examinee in the analytic sample was asked if he or she had ever been told by a doctor that he or she had high blood pressure or hypertension and whether he or she had used any medication for high blood pressure or hypertension within the preceding six months.

Medical Examination. Immediately following a structured physical examination which included an inspection of the head, eyes, ears, nose and throat as well as thyroid, cardiovascular, abdominal, respiratory, musculoskeletal, neurological, and skin evaluations, the examining physician was instructed to make a tentative diagnosis using the Eighth Revision of the International Classification of Diseases (ICD) codes (NCHS, 1972). In addition to the information gathered during the examination, the physician had access to the examinee's medical history, laboratory tests and x-rays. If any form of hypertension was noted, the physician recorded one of the five ICD codes for hypertension (400-404).*

2.2.2 Stress

Signs and symptoms of psychological stress were measured through three NHANES I protocols: the General Well-Being Questionnaire; the Medical History; and the Medical Examination.

General Well-Being Questionnaire. This questionnaire, administered to all persons in the analytic sample, was the only explicitly psychological component in the NHANES I. The total score on this questionnaire is intended to serve as an indicator of overall adjustment; a higher score reflects a higher degree of psychological well-being.

*The five hypertensive disease ICD codes are: 400--Malignant hypertension; 401--Essential benign hypertension; 402--Hypertensive heart disease; 403--Hypertensive renal disease; and 404--Hypertensive heart and renal disease.

Table 2.B

Composition of Constructs for Global Health Status

Health Domain	Conditions from Medical History	Conditions From Medical Examination (ICD Codes)
Cardiovascular	Stroke Heart Failure Heart Attack	Diseases of the Circulatory System (390-458)
Heart Disease	Heart Failure Heart Attack	Ischemic Heart Disease (410-414) Other Heart Disease (420-429) Diseases of Arteries, Arterioles, and capillaries (440-448) Diseases of Veins and Lymphatics and Other Diseases of Circulatory System (450-458)
Respiratory	Asthma Bronchitis Hay Fever	Diseases of the Respiratory System (460-519)
Musculo-skeletal	Arthritis Gout	Diseases of the Musculo-skeletal System (710-738)
Gastrointestinal	Ulcers Enteritis Colitis Gallstones Hernia	Diseases of the Digestive System (520-577)
Metabolic	Thyroid Disease Diabetes	Endocrine, Nutritional and Metabolic Disorders (240-279)
Infections	Tuberculosis Hepatitis Polio	Infective and Parasitic Disorders (100-136)
Neoplasms	Malignant Tumors Benign Tumors	Neoplasms (140-239)
Nervous System	No equivalent group	Diseases of the Nervous System and Sense Organs (320-389)
Genito-Urinary	No equivalent group	Diseases of the Genito-Urinary System (580-629)
Accidents	No equivalent group	Accidents, Poisonings and Violence (800-999)
Skin	No equivalent group	Diseases of the Skin and Subcutaneous Tissues (680-709)

The scale also has six subscales, one of which is intended to measure the degree to which the examinee is tense/anxious versus relaxed. This subscale ranges from 0 to 25; a score of 0 indicates a high degree of tension and a score of 25 indicates little or no tension. Because this subscale is a component of the overall scale, these two measures cannot be viewed as independent assessments of general well-being; in fact, the correlation between the two measures is .88.

Medical History. As part of the medical history, each examinee was asked if during the past six months, he or she had regularly used medicine, drugs or pills for any of the following conditions: sleep problems or insomnia; upset stomach or indigestion; nerves; high blood pressure; or bowel trouble.

Medical Examination. At the completion of the medical examination, the physician had the opportunity to note any mental disorders using the ICD codes 290-315 which include psychoses, neuroses, personality disorders, other nonpsychotic disorders, and addictions.

2.2.3 Other Health Conditions

To examine the myriad of remaining health conditions which might be associated with auditory functioning or noise exposure, the conditions found on the medical history and during the medical examination (as described with ICD codes) have been grouped into eleven global categories presented in Table 2.B. In addition, the physician's summary diagnostic impression of the examinee (normal/abnormal) has been analyzed separately.

2.3 Data on Noise Exposure

As no direct, precise estimates of noise exposure were collected during NHANES I, a proxy measure based upon the curent occupation of the examinee was developed for the purpose of this study. Although it would have been desirable to also include information on prior work history, especially military experience, these data were not collected during NHANES I. Nevertheless, classifications based only on current employment have been used successfully in prior epidemiological investigations of occupational risk and have been shown to provide reasonable estimates of average exposure. (See, e.g., Gamble, et al., 1976 and Hoar, et al., 1980.)

Data on occupation comes from information coded using the Census Index of Industries and Occupations (Bureau of the Census, 1971). The occupational classification system has 417 separate categories grouped into 12 major sets: professional, technical and kindred workers; managers and administrators (except farm); sales workers; clerical and kindred workers; craftsmen and kindred workers; operatives (except transport); transport equipment oepratives; laborers (except farm); farmers and farm managers; farm laborers and farm foremen; service workers (excluding private household workers); private household workers.

Two independent raters--Dr. Joseph McGuire, University of Michigan and Dr. Larry Royster, North Carolina State University--whose combined experience covers several of the major manufacturing regionsl in this country, assigned an average eight-hour dBA noise exposure level to each of the 417 occupations as follows: (1) $\leq$ 70 dBA; (2) 71-75 dBA; (3) 76-80 dBA; (4) 81-85 dBA; (5) 86-90 dBA; (6) 91-95 dBA; (7) $\geq$ 96 dBA. Although many of the assignments were based upon individual experience with workers in particular occupations and industries, several references were also used in this process including: Karplus and Bonvallet (1953); Jones and Church (1960); Intersociety Guidelines for Noise Exposure (1967); EPA (1973); Olishifski and Hartford (1975); Ward (1975); Reltinger (1977); Yerg, Sataloff, Glorig and Menduke (1978); Royster, et al., (1980); McGuire (1981).

Comparisons of the ratings on a code-by-code basis show that there was perfect agreement on 34.3 percent of the codes; the two raters were one category apart on an additional 44.0 percent of the codes, two categories apart on an additional 17.1 percent of the codes, and three or more categories apart on the remaining 4.6 percent of the codes, (see Appendix II, Table II.1). Moving from a code-by-code comparison to a case-by-case comparison, the level of agreement between the two raters increased. The two raters classified 43.1 percent of the examinees into the same category and 44.5 percent of the examinees into adjacent categories; the ratings for an additional 11.6 percent of the examinees were two categories apart, and the ratings were three categories apart for only 1.8 percent of the examinees (see Appendix II, Table II.2). The final classification scheme, as presented in Appendix II, Table II.3, was made by averaging the two ratings.

It is not known if the NHANES I examinees were actually exposed to the particular noise levels assigned to them. Moreover, it has not been established whether such estimated noise levels can even be directly related to the more generally accepted time-weighted noise exposure levels. It would have been impossible, however, to derive time-weighted noise exposure levels for the 417 occupational descriptors used in the present study, largely because time-weighted noise exposure levels vary substantially more than average noise levels. Variations in worker time-

Table 2.C

Demographic Characteristics and Their Description

Variable	Variable Description
Age	Age at examination (in years)
Sex	(1) Male (2) Female
Race	(0) White (1) Black (2) Other
Income	(0) < \$5,000 (1) \$5,000 - \$9,999 (2) \$10,000 - \$14,999 (3) > \$15,000
Currently Married	(0) Not Currently Married (1) Currently Married
Size of Place	(0) Urban—3 million persons or more (1) Urban—1-3 million persons (2) Urban—250,000-1 million persons (3) Urban—less than 250,000 persons (4) Outurban—25,000 persons or more (5) Outurban—10,000-25,000 persons (6) Outurban—less than 10,000 persons (7) Rural
Standard Metropolitan Statistical Area (SMSA)	(0) not in SMSA (1) SMSA, not in Central City (2) SMSA, Central City
Farm	(0) Farm (1) Not Farm
Region	(0) Northeast (1) Midwest (2) South (3) West
Education	Years of education
Poverty Income Ratio	Ratio of total household income to the income necessary to maintain a family with its characteristics on a nutritionally adequate food plan
Internal Density	Ratio of the number of rooms in the house to the number of persons in the house

weighted noise exposure levels of as much as 10 dB at the same location are not uncommon. To compensate for this variability, OSHA recommends that at least ten eight-hour noise dosimeter exposure measurements be taken to establish a single location exposure level for compliance purposes (OSHA, 1981). However, no single data base currently exists with such detailed information for the broad range of occupational titles collected during NHANES I. Average noise levels were used in the present study due to their availability and lower variance.

2.4 Data on Background Characteristics

Two types of background characteristics were examined: demographic characteristics and physical characteristics/habits. As shown in Table 2.C, demographic characteristics include basic personal information concerning the examinee, indicators of his or her family's socioeconomic status and descriptors of the community in which he or she resides. Physical characteristics and habits encompass background measures relating to an individual's health, lifestyle and appearance. As shown in Table 2.D, these include indicators of drug use, smoking, alcohol use, physical activity at work and at home, eye color, height, weight and skinfold thickness.

Table 2.D

Physical Characteristics and Habits and Their Description

Variable	Variable Description
Drugs for Infections	During the past six months, have you used medicine, drugs or pills for infections (antibiotic or sulfa pills or shots)? (0) No (1) Yes
Aspirin Use	Have you taken aspirin the past 30 days? (0) No (1) Yes
Birth Control Pill Use	Have you taken birth control pills in the past 6 months? (0) No (1) Yes
Hyptertension Medication Use	Have you taken medication for hypertension or high blood pressure in the past 6 months? (0) No (1) Yes
Cigarette Smoking	(0) Non-Smoker (1) Ex-Smoker (2) Smoker
Alcohol Use	(0) None (1) 1-2 Drinks/Day (2) 3-4 Drinks/Day (3) 5 or more Drinks/Day
Activity Level (Recreation)	(0) Inactive (1) Active
Activity Level (Work)	(0) Inactive (1) Active
Eye Color	(0) Brown (1) Blue (2) Grey, Green, Hazel (3) Other
Skinfold Thickness	Index of Relative Fatness (sum of rightside subscapular and triceps skinfolds)
Height	Height (in centimeters)
Weight	Weight (in kilograms)

CHAPTER THREE: HEARING STATUS OF THE U.S. POPULATION

In this chapter, we present descriptive information on the hearing status of the United States population using air and bone conduction data as well as speech discrimination scores and self-assessment information. Prevalence estimates of hearing impairment under a broad range of alternative definitions are also displayed. The chapter closes with a discussion of the interrelationships among the various indices of hearing status.

Tabular results are presented for the left, right, better and worse ears (Tables 3.1 through 3.128 may be found in Appendix III, bound in a separate volume). These displays include percent distributions, means and sample sizes for the air conduction, bone conduction and speech discrimination data as well as estimates of the prevalence of and number of persons (in thousands) with hearing impairment and selected self-report conditions. Standard errors of these estimates, design effects and significance tests of age, sex and race differences are presented for the left and right ears.* Correlation coefficients among the indicators of hearing status also are presented for the left and right ears.** Figures presented in the text are based upon the left ear data, unless otherwise indicated.

3.1 Air Conduction Hearing Levels

3.1.1 Patterns Among Hearing Levels

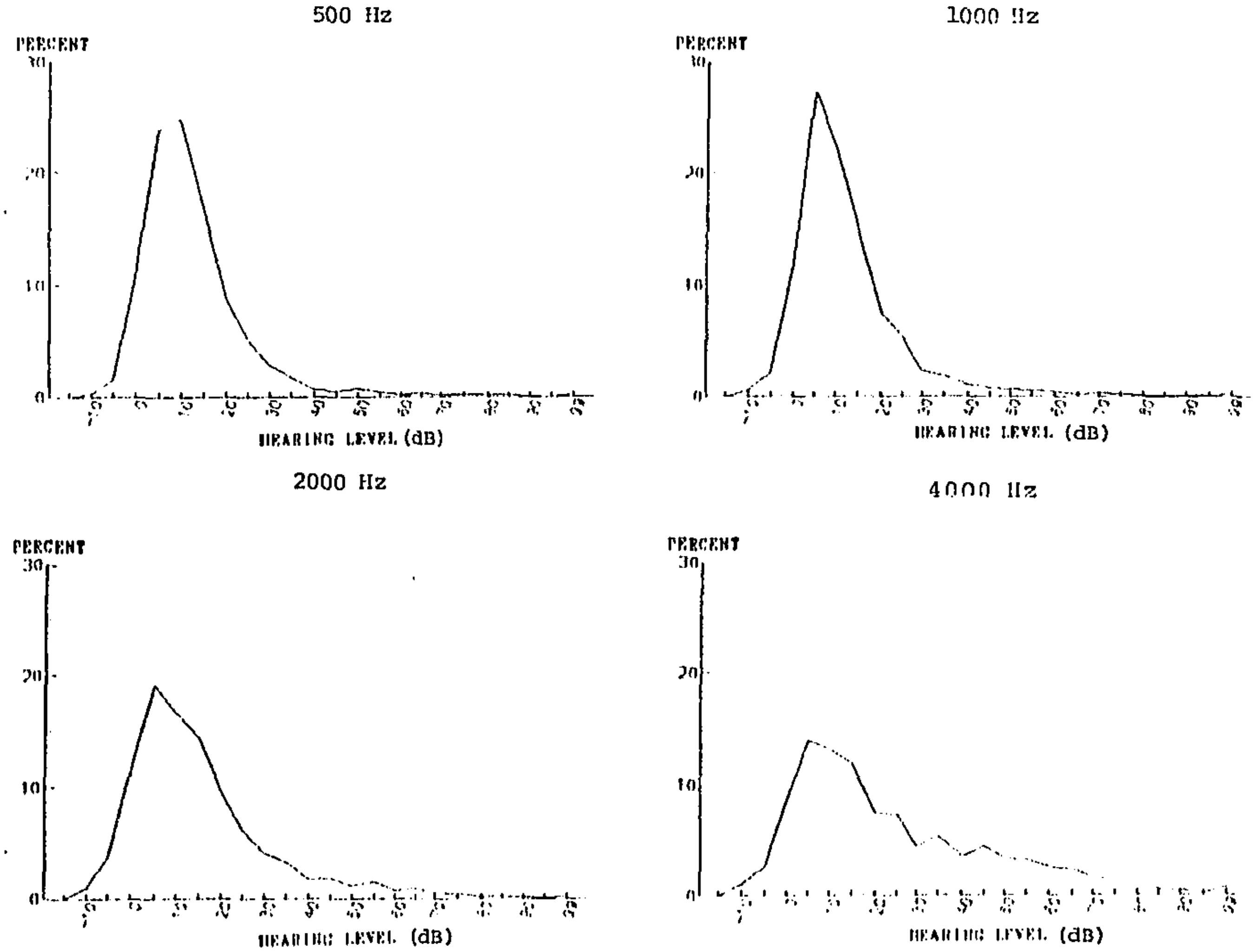
Figure 3.A presents the distribution of air conduction hearing levels at each of four frequencies tested.

* Statistical details outlining the methods used to calculate these estimates are presented in Appendix I.

**All correlation coefficients presented in this report are zero-order Pearson correlations.

Figure 3.A

Distribution of Air Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hz in the Left Ear

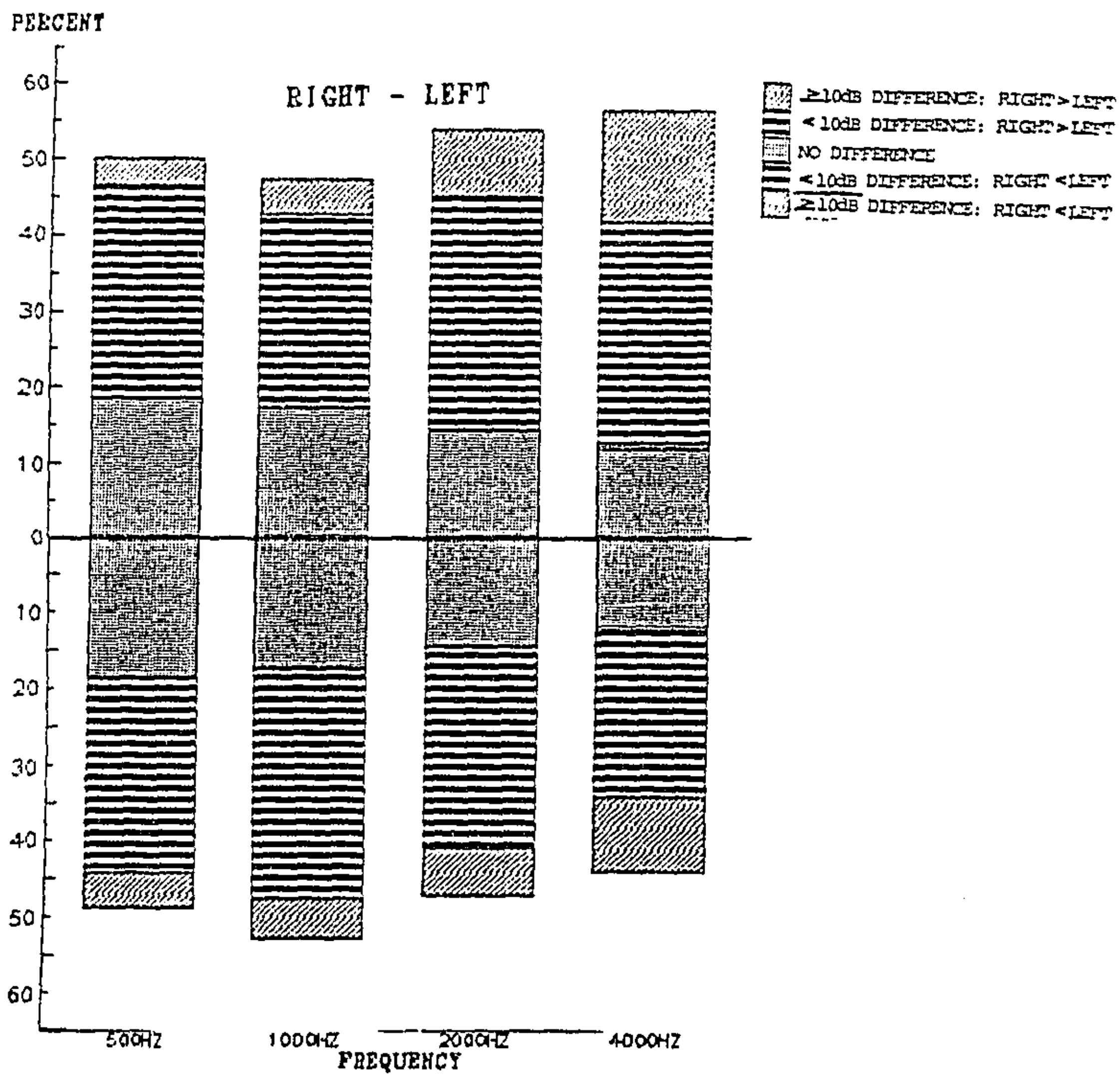


(See also Table 3.1.) For both the left and right ears, the median threshold at 500, 1000 and 2000 Hz is 10 dB (i.e., in the range from 6 to 11 dB), while at 4000 Hz it is 15 dB (i.e., in the range from 11 to 16 dB). At all frequencies, the distribution of hearing levels is markedly skewed to the right, although the degree of skewness decreases with increasing frequency. Also note that more people have poorer hearing at the mid and high frequencies than at the low frequencies. For example, examination of the percent of persons with hearing levels of 26 dB or more at each frequency shows that the prevalence (for the left ear) is 8.2 percent at 500 Hz, 8.8 percent at 1000 Hz, 17.1 percent at 2000 Hz and 34.5 percent at 4000 Hz. Clearly, hearing sensitivity decreases with increasing frequency.

This is not to say, however, that for a given ear, hearing levels at one frequency are not related to hearing levels at another frequency. As shown in Table 3.2, the correlations among air conduction hearing levels for both the left and right ears at all tested frequencies are strong and highly significant, ranging from .48 to .82. The magnitude of the correlation between any two frequencies varies in two ways as a function of the two frequencies being compared: (a) correlations are stronger between frequencies that are closer together than they are between frequencies that are separated by several octaves; and (b) correlations are stronger among the lower frequencies than they are among the higher frequencies. Thus, for example, the correlation between any pair of hearing levels is strongest for the 500 Hz/1000 Hz comparison and weakest for the 500 Hz/4000 Hz comparison. Nevertheless, hearing sensitivity at any one frequency within the 500-4000 Hz range is directly related to hearing sensitivity at all other frequencies in this range in the same ear.

Figure 3.B

Distribution of Difference Between
Right and Left Air Conduction Hearing
Levels at 500, 1000, 2000 and 4000 Hertz



Air conduction hearing levels at any individual frequency for a given ear are also closely related to hearing sensitivity at that frequency in the other ear (Table 3.3 and Figure 3.B). At every frequency tested, hearing levels for the right and left ears of a given individual are within 10 dB of each other for over three-quarters of the adults in this country. However, the extent of agreement diminishes with an increase in frequency, from 90.0 percent at 500 Hz to 75.7 percent at 4000 Hz. When the hearing levels for the two ears do differ by more than 10 dB, the left ear is found to be less sensitive more often than the right ear at the higher frequencies (2000 and 4000 Hz). Note that this difference was found even when masking was done in those cases in which the discrepancy between the hearing thresholds in the two ears was 40 dB or more. Moreover, this difference is not due to practice effects, as shown by the randomization of the order of presentation.

3.1.2 Differences by Age, Sex and Race

Air conduction hearing levels vary significantly by age, sex and race. (Tables 3.4-3.27 present means and standard errors; results of significance tests are presented in Table 3.28.) As shown in Figure 3.C, hearing sensitivity declines substantially with increasing age. This decline is significant for both ears at all four tested frequencies, but the age differential, as represented by the slope of the line in Figure 3.3, is greater as the frequency increases. For example, the mean air conduction hearing level at 500 Hz for the left ear among persons ages 25-34 years differs from that for persons ages 65-74 years by 12.5 dB; the identical contrast in hearing levels at 4000 Hz produces a difference more than twice as large--32.8 dB.

Although little consistent difference between the hearing sensitivity of men and women is found at the lower

Figure 3.C

Mean Air Conduction Hearing Levels at
500, 1000, 2000 and 4000 Hertz in the
Left Ear By Age

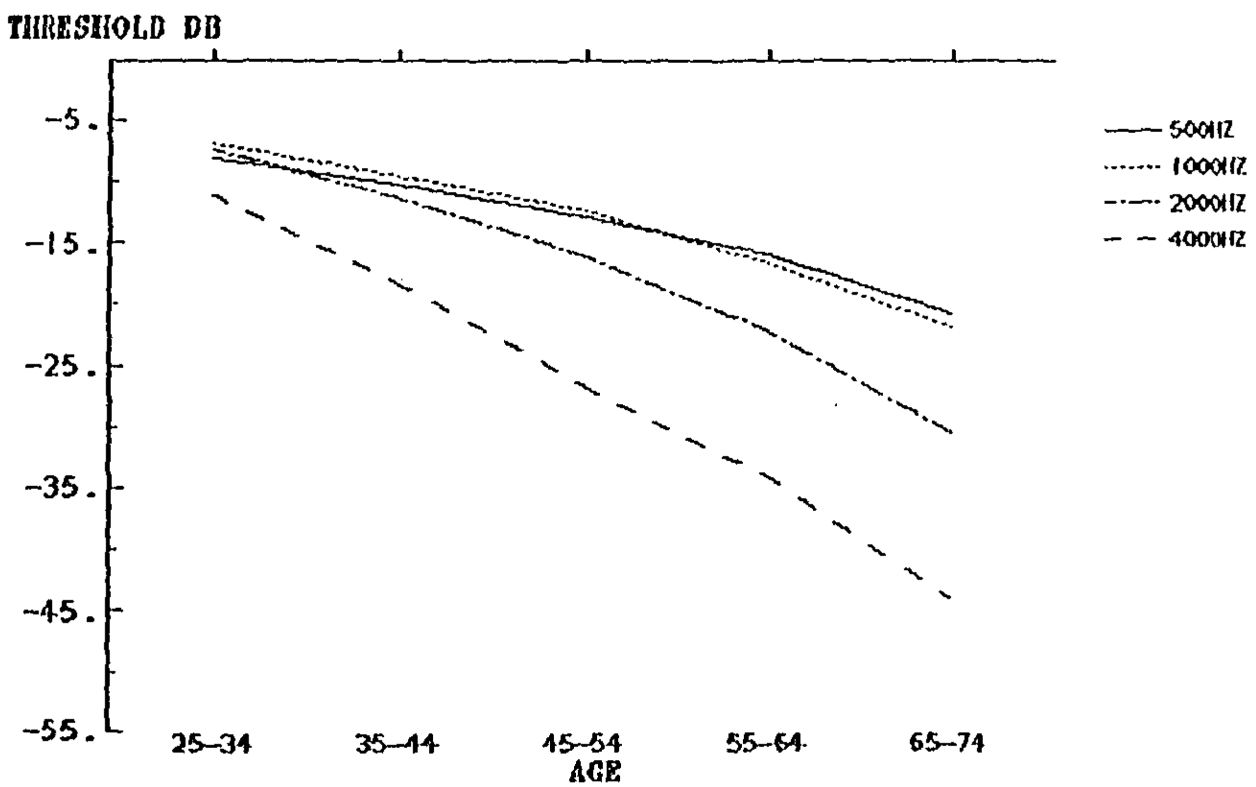


Figure 3.D

Mean Air Conduction Hearing Levels at
500, 1000, 2000 and 4000 Hz in the Left Ear By Age and Sex

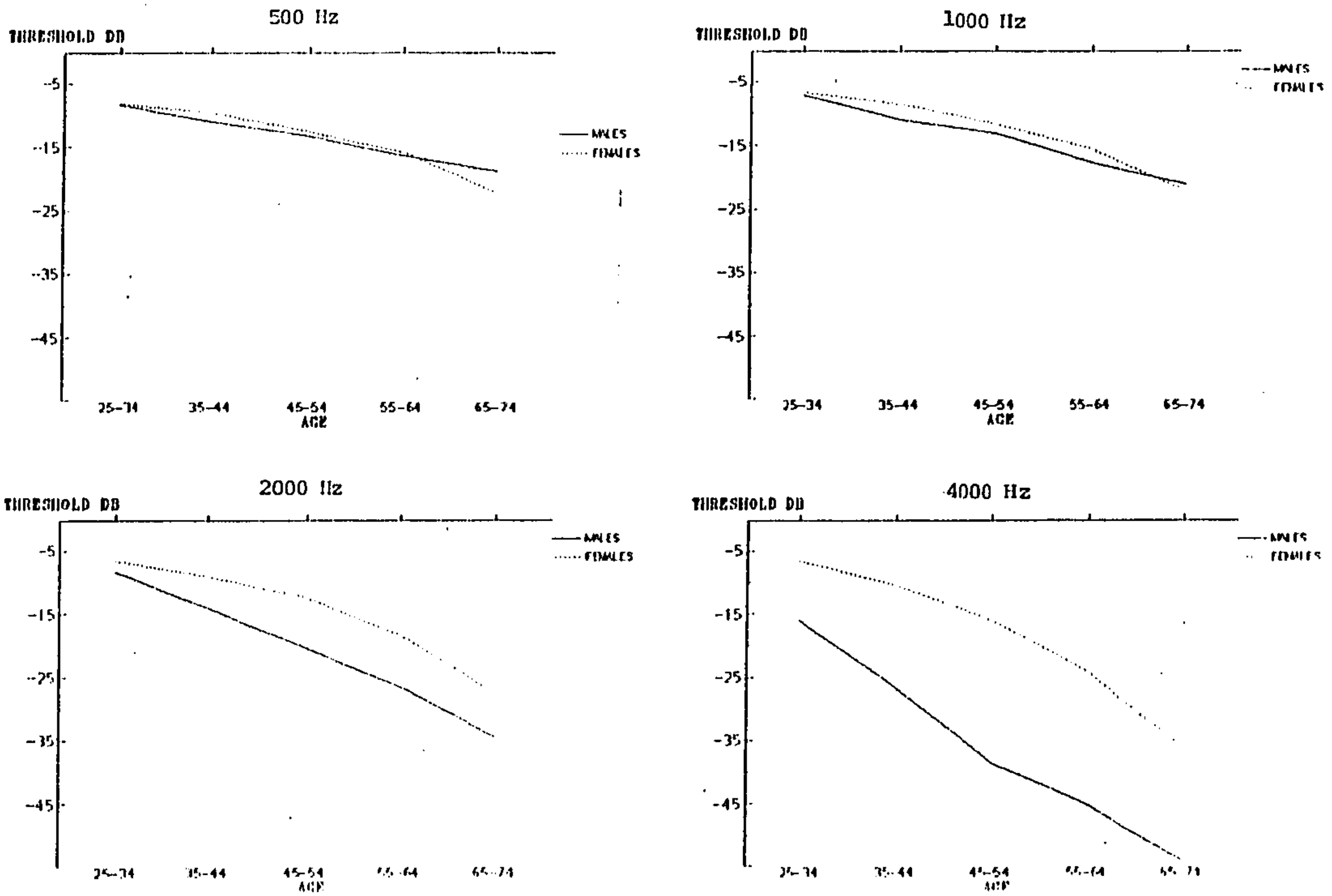
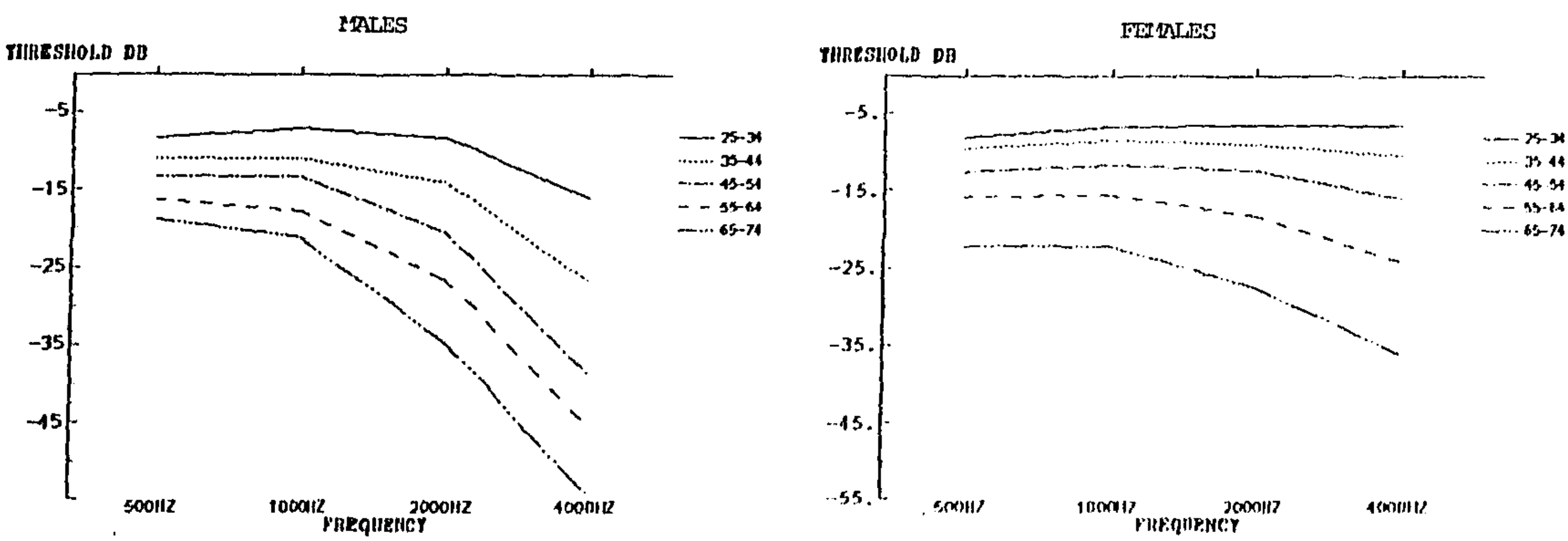


Figure 3.E

Mean Air Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hz
in the Left Ear By Age for Males and Females



frequencies, at 2000 and 4000 Hz women have far better hearing than men of the same age (Figure 3.D). These sex differences in hearing sensitivity result in mean air conduction profiles by age that vary dramatically by sex (Figure 3.E). Whereas for men, increasing age is associated with an extremely marked decline in hearing sensitivity at all frequencies, but especially at 2000 and 4000 Hz, the declines for women are far less pronounced, even at the mid and high frequencies. Moreover, the steep decline found in the mean audiometric profile for men of all ages is far less pronounced among women of all ages. Indeed, it is only among women 55 years of age and older that there is a hint of a sharp decrease.

The relationship between race and hearing sensitivity differs by frequency and sex. At 500, 1000 and 2000 Hz, little consistent difference is found in the hearing levels of white and black men and women of all ages. At 4000 Hz, black men have significantly better hearing than white men of the same age; no parallel significant difference in hearing sensitivity at 4000 Hz was found for women.

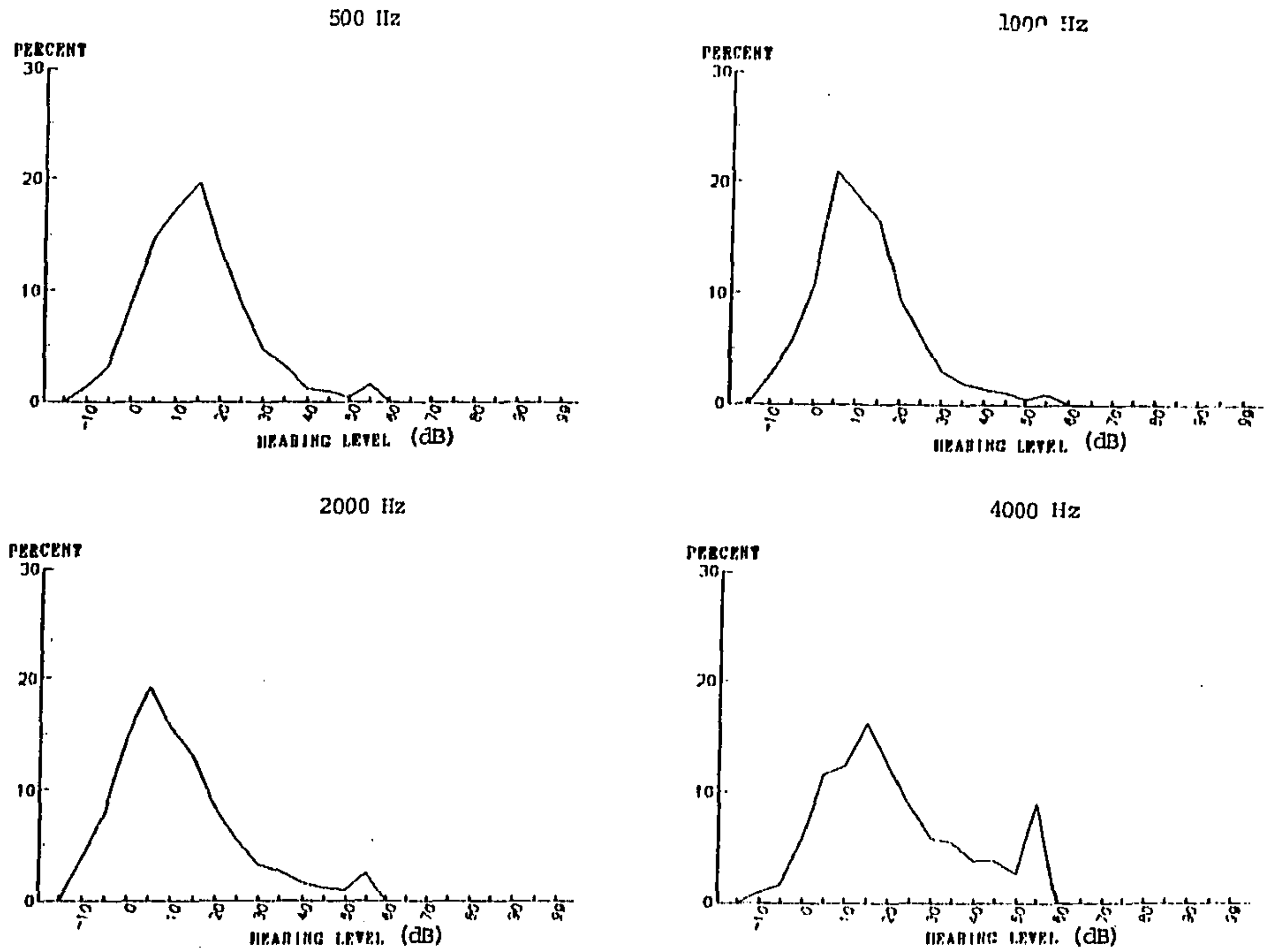
3.2 Bone Conduction Hearing Levels

3.2.1 Patterns Among Hearing Levels

Figure 3.F presents the distribution of bone conduction hearing levels at each of four frequencies tested. (See also Table 3.29.) For both the left and right ears, the median thresholds at 500 and 1000 Hz are 15 and 10 dB, respectively; at 2000 Hz, the median threshold for the left ear is 10 dB, while for the right ear it is 5 dB; at 4000 Hz, the median threshold for the left ear is 20 dB, while for the right ear it is 15 dB. At all frequencies, the distribution of bone conduction hearing levels is mildly

Figure 3.F

Distribution of Bone Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hz in the Left Ear



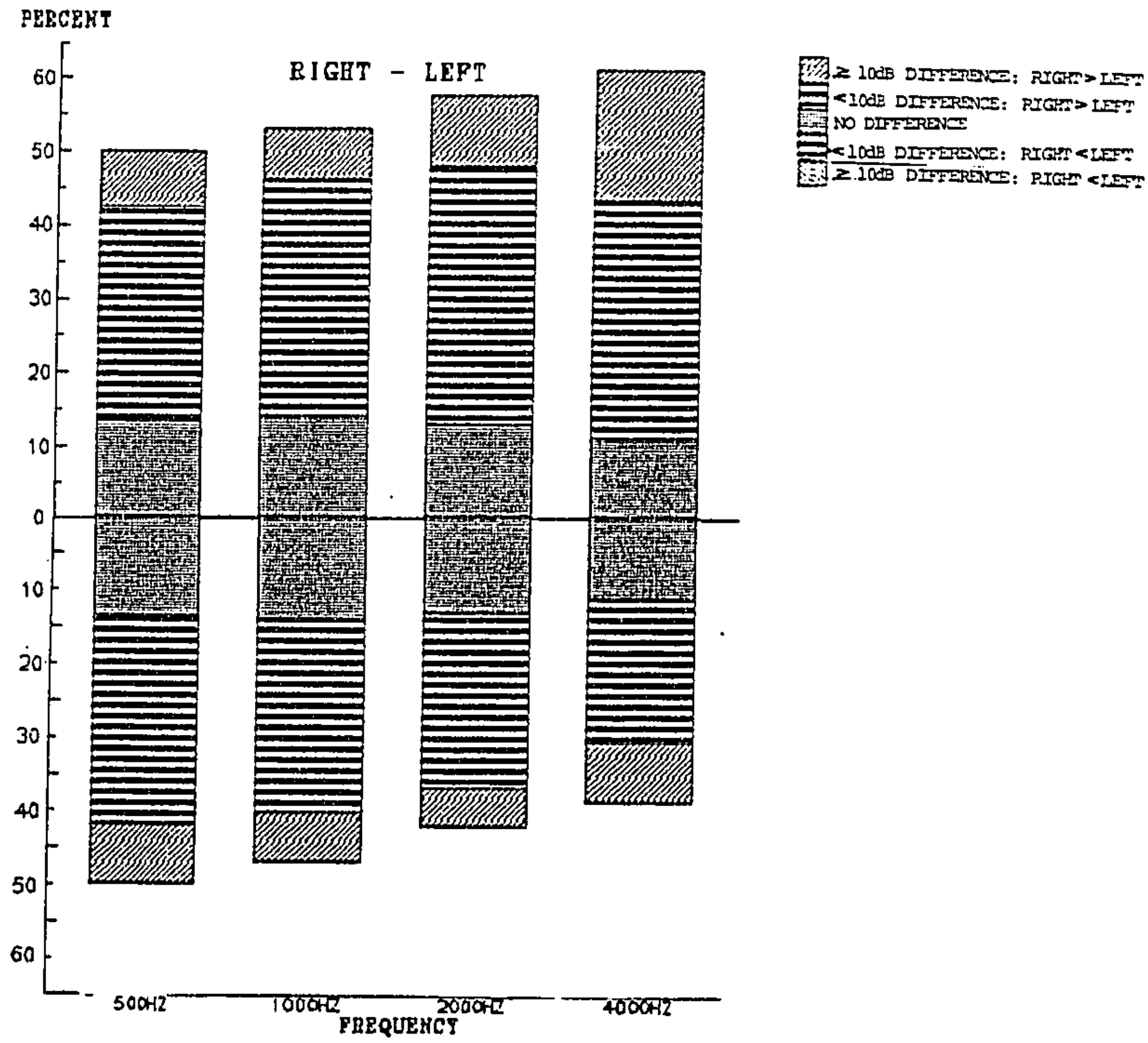
skewed to the right, although the degree of skewness is far smaller than that found for air conduction thresholds. As in the air conduction data, the degree of skewness decreases with increasing frequency, so that more people have poorer hearing at the higher frequencies than at the lower frequencies.

Bone conduction hearing levels at one frequency are closely related to those at the other frequencies, although the strength of the association is weaker than that found among the air conduction data. As shown in Table 3.30, the correlations among bone conduction hearing levels for both the left and right ears at all tested frequencies are highly significant, ranging from .36 to .67. The relationships observed for the air conduction data concerning the relative magnitudes of the correlations among thresholds also hold for the bone conduction data.

Bone conduction hearing levels at any individual frequency for a given ear are also closely related to hearing sensitivity at that frequency in the other ear (Table 3.31 and Figure 3.G). At every frequency tested, hearing levels for the right and left ears of a given individual are within 10 dB of each other for the majority of adults in this country. However, the extent of agreement varies with frequency; at 500, 1000 and 2000 Hz, it remains steady at approximately 85 percent, while at 4000 Hz it drops to 73.9 percent. When the bone conduction hearing levels do differ by more than 10 dB, the left ear is found to be less sensitive more often than the right ear at the mid and high frequencies (2000 and 4000 Hz). Note that this difference is neither due to masking, which was routinely done in the non-test ear, nor to practice effects, as shown by the randomization of the order of presentation.

Figure 3.G

Distribution of Difference Between
Right and Left Bone Conduction Hearing
Levels at 500, 1000, 2000 and 4000 Hertz



3.2.2 Differences By Age, Sex and Race

Bone conduction hearing levels vary significantly by age and sex; few significant differences are found by race. (Tables 3.32-3.55 present means and standard errors; results of significance tests are presented in Table 3.56.) As shown in Figure 3.H, hearing sensitivity, as measured by bone conduction, declines substantially with increasing age. This decline is significant at all four tested frequencies, but the age differential is greater as the frequency increases.* For example, the mean bone conduction hearing level at 500 Hz for the left ear among persons aged 25-34 differs from that for persons aged 65-74 by 13.6 dB; the identical contrast in hearing levels at 4000 Hz produces a difference almost twice as large--20.7 dB. Although this pattern is totally consistent with trends in hearing sensitivity, as measured by air conduction, the declines in bone conduction data with increasing age are less severe.

Little consistent difference between the hearing sensitivity of men and women is found at the lower frequencies; at 2000 and 4000 Hz, however, women have far better hearing, as measured by bone conduction, than men of the same age (Figure 3.J). As was found with the air conduction data, these differences result in mean bone conduction profiles by age that differ dramatically by sex (Figure 3.K).

The general pattern of racial differences in hearing sensitivity found in the air conduction data is also found in the bone conduction data; however, because

*The slight decrease in the mean bone conduction hearing level at 4000 Hz observed between ages 55-64 and 65-74 is probably an artifact of a small sample size with a larger standard error, and not reflective of an actual improvement in hearing sensitivity.

Figure 3.H

Mean Bone Conduction Hearing Levels at
500, 1000, 2000 and 4000 Hertz in the
Left Ear By Age

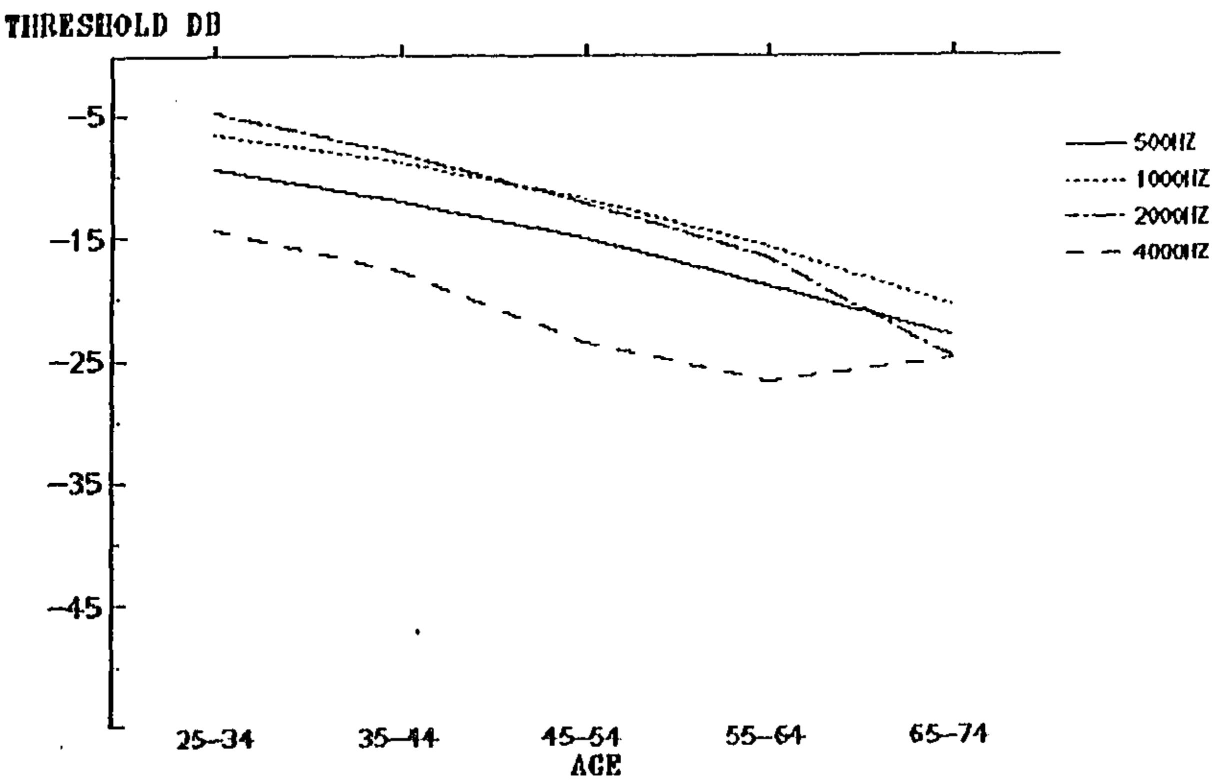


Figure 3.J

Mean Bone Conduction Hearing Levels at
500, 1000, 2000 and 4000 Hz
in the Left Ear By Age and Sex

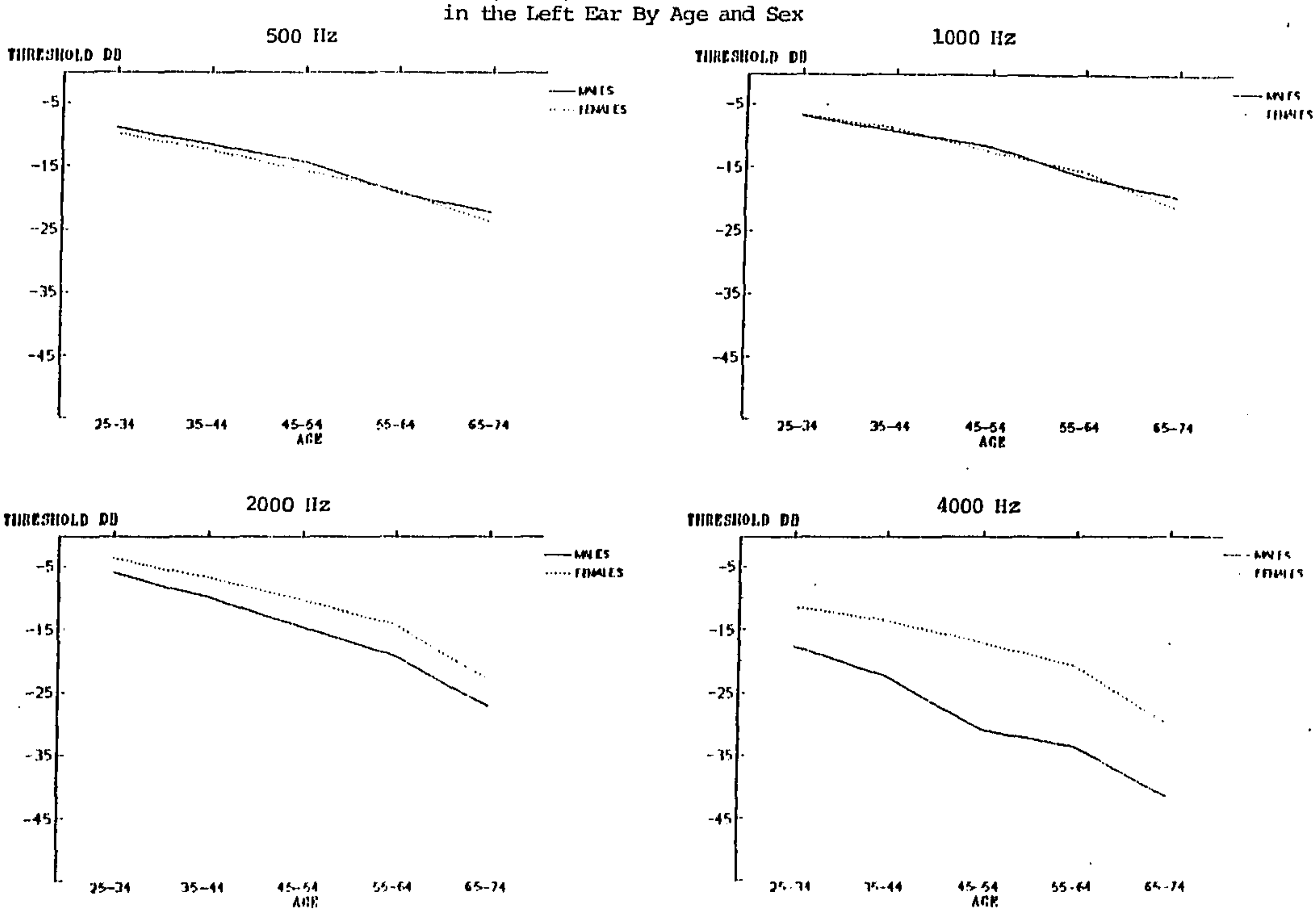
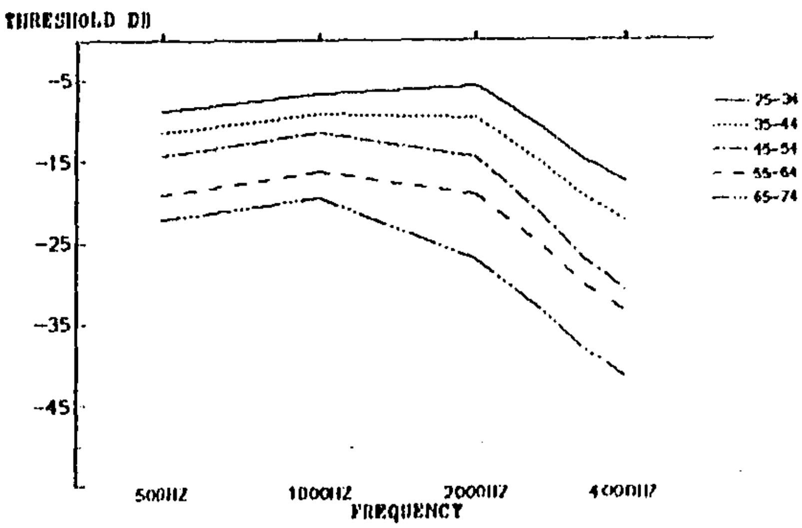


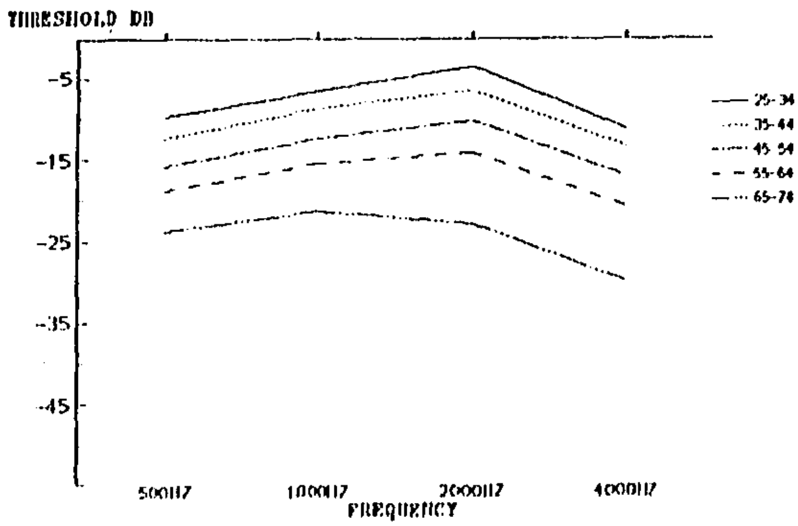
Figure 3.K

Mean Bone Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hz in the
Left Ear By Age for Males and Females

MALES



FEMALES



of the substantially smaller sample sizes, many of the differences found earlier for males at 4000 Hz fail to reach statistical significance. As shown in Table 3.56, little consistent difference is found in the mean bone conduction hearing levels at 500, 1000 and 2000 Hz of white and black men and women of all ages. At 4000 Hz, although black men have consistently lower bone conduction hearing levels than white men, these differences are not statistically significant for all age groups.

3.3 Speech Discrimination Scores

3.3.1 Patterns Among Scores

Table 3.57 presents the distribution of speech discrimination scores at 20 dB SL. Using the criterion that scores of 90 percent or better reflect the ability to hear and understand everyday speech, approximately 70 percent of adults aged 25-74 years passed the speech discrimination test at 20 dB SL. An additional 9.0 percent attained marginal scores of 80-89 percent, and the remaining 21.0 percent were well distributed across the range from 0 to 80 percent.

As in the air and bone conduction data, a direct relationship between speech discrimination ability in the left and right ears is found. The correlation between scores for the two ears is .66, and 74.8 percent of persons had scores for their left and right ears within 10 points of each other. As before, when a difference of more than 10 points was observed, the right ear was found to be more sensitive than the left ear. (See Table 3.58.)

3.3.2 Differences by Age, Sex and Race

Speech discrimination scores at 20 dB SL vary significantly with age; the ability to hear and understand everyday speech declines substantially with increasing age (Tables 3.59-3.65). Although women tend to have somewhat higher speech discrimination scores than men of the same age, this difference is not often statistically significant. Given that speech discrimination in a quiet testing environment relies predominantly on hearing sensitivity at the lower frequencies, and given that sex differences in hearing sensitivity did not emerge until the mid and high frequencies, the observed equivalence across sexes is not unusual. No consistent racial differences in speech discrimination were observed.

3.4 Self-Assessment of Hearing

3.4.1 Patterns Among Responses

In addition to the objective audiometric assessments discussed above, examinees were asked a series of questions pertaining to their perception of their hearing ability and any hearing problems they might have. In response to the question: "How would you rate your hearing in your right (and left) ear--good, a little decreased, severely decreased or deaf?", an estimated 86.1 percent of the adult population (91.6 million) considers their hearing to be good in both ears, and the remaining 13.9 percent (14.8 million) report that their hearing in at least one of their ears is a little decreased or worse. These 14.8 million adults, who report some problem with one or both ears, are distributed as follows: 6.5 percent (6.9 million) consider one ear good but the other worse; 6.4 percent (6.8 million) consider one ear slightly impaired and the other ear the same or worse; 1.0 percent (1.0 million) consider one ear severely impaired and the other ear the same or worse; and the remaining 0.1 percent (100,000) consider themselves deaf in both ears.

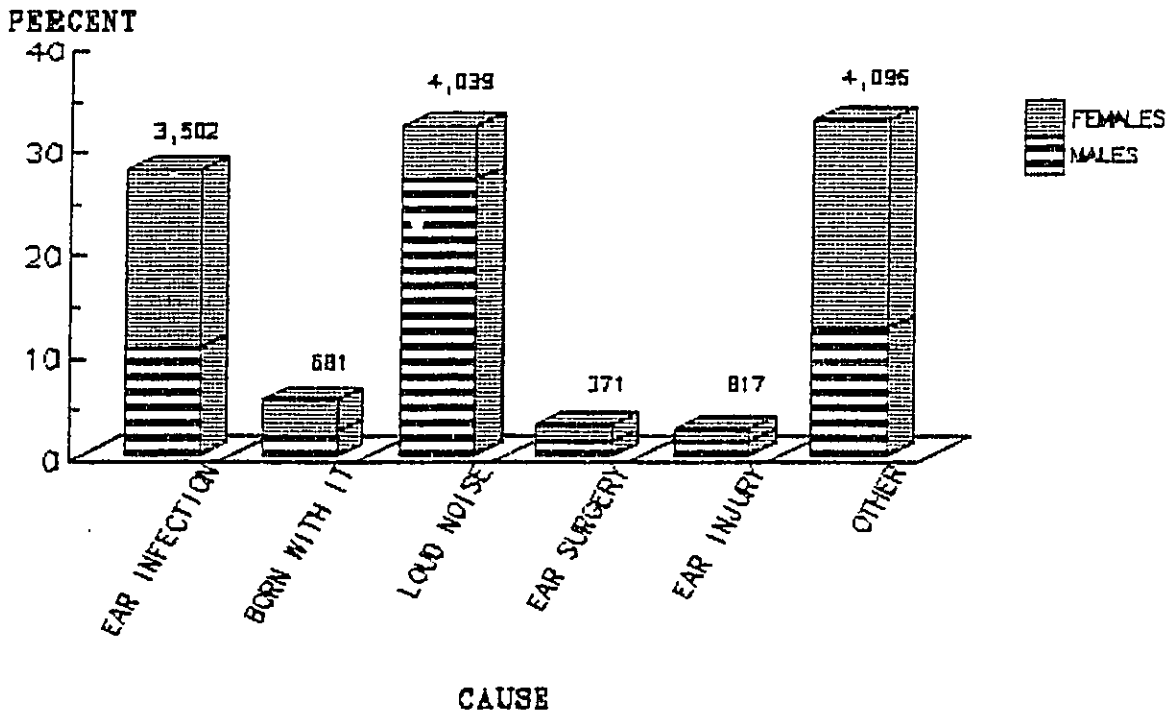
Examinees were also asked if they have ever had deafness or trouble hearing with one or both ears and, if so, the perceived cause. Hearing trouble is reported among an estimated 16.1 percent of the adults (17.2 million);, the remaining 83.9 percent indicate no trouble. Of those adults reporting problems, 32.0 percent (4.0 million) attribute them to exposure to loud noises, 27.8 percent (3.5 million) attribute them to ear infections, 6.5 percent (.8 million) cite ear injury, 5.4 percent (.7 million) report that it was congenital, and 2.9 percent (.4 million) cite ear surgery; the remaining 32.6 percent (4.1 million) cite other reasons, not specified in the NHANES I questionnaire.

With regard to other possible ear problems, examinees were asked if they had ever experienced running or ringing in their ears. A total of 11.2 percent (11.9 million) adults report having had a running ear or some other type of discharge from their ear, not including wax. Considerably more people have had ringing in their ears; an estimated 26.1 percent (27.5 million persons) report experiencing ringing at some point in the past few years. When further queried as to the frequency of ringing, 32.8 percent (9.0 million) of those reporting any ringing indicate that it occurs every few days.

Finally, examinees who were given the speech discrimination test were asked a series of questions relating to their ability to hear and understand speech and sounds. When asked how loudly a person would have to speak to them from across a quiet room for them to hear and understand what was being said, 78.8 percent (85.4 million) report that a whisper is sufficient, 18.2 percent (19.7 million) report a normal voice, 2.6 percent (2.9 million) require a shout and the remaining 0.4 percent (400,000) require additional amplification or closer contact with the speaker.

Figure 3.L

Percent Distribution & Estimates of
Numbers of Persons (in Thousands) with Reported
Causes of Deafness or Trouble Hearing



3.4.2 Differences by Age, Sex and Race

Just as the objective assessments of hearing ability vary across age, sex and race, the subjective assessments vary as well. (Tables 3.66-3.70 present prevalences; Tables 3.71-3.75 present estimates of number of persons affected; results of significance tests are presented in Tables 3.76-3.79.) Under every general hearing evaluation question asked, older persons report poorer hearing sensitivity more often than younger persons. For example, only 9.5 percent of adults aged 25-34 report ever having deafness or trouble hearing, whereas this is true for 17.2 percent of adults aged 45-54 years and for 27.2 percent of adults 65-74 years old. However, no significant age differential is found in either the causes of the reported hearing trouble or in the prevalence of running ear or ringing in the ear.

Men are significantly more likely than women to report poorer hearing or trouble hearing; for example, approximately 5 percent more men report deafness or trouble hearing at every age. In addition, the reported causes of hearing loss vary by sex (Figure 3.L). Among men, noise is clearly perceived to be the predominant cause, with an estimated 48.5 percent of men (3.6 million) reporting exposure to loud noises, blasts or gunfire as the source of their hearing loss. Among women, in contrast, noise exposure is mentioned in only 9.4 percent of the identified problems (.5 million); instead, women were more likely to cite ear infections (36.2 percent) or "other" causes (41.9 percent). Although there is a tendency for women to report ringing in their ears more often than men, and for men to report more frequent ringing than women, these differences are not statistically significant at every age. No significant sex difference was found in the prevalence of running ears.

Few consistent differences in the self-assessment of hearing are found across races. In general, black and white adults are equally likely to report decreased hearing sensitivity or trouble hearing. A tendency is found, however, for black males to report loud noise as the perceived cause of their hearing loss significantly more often than white males (58.7 percent vs. 35.1 percent). In addition, white men and women tend to report running or other types of ear discharge more often than black men and women.

3.5 Prevalence of Hearing Impairment

As discussed in Chapter One, many criteria have been used in the past 25 years to determine on the basis of a single audiometric examination whether or not an individual has a hearing impairment. In general, the prevalence of hearing impairment in a population has been determined by averaging a set of hearing levels at preselected frequencies and then computing the percentage of persons whose average hearing level exceeds a given value (low fence). However, there is still disagreement in the field as to which frequencies should be used, what the low fence should be for a given set of frequencies, how the results for both ears should be incorporated and, whether or not a correction for presbycusis should be employed. Rather than adopt a single definition that would reflect only one perspective on these issues, the present chapter considers an array of alternative definitions that, taken together, span the spectrum of viewpoints on these issues.

A brief survey of the hearing impairment definitions currently used by researchers, clinicians, regulators and compensation boards reveals that the primary source of disagreement is in the choice of frequencies. (See Suter, 1978) for a useful review of the literature.) Although most agree with the premise that the frequencies selected should correlate well with "the ability to hear and understand everyday speech under everyday conditions," there are differing interpretations of the research evidence concerning which frequencies do, in fact, correlate well with this construct. At the heart of the issue is whether low frequency (500 Hz) hearing ability should be included or whether high frequency (3000 or 4000 Hz) hearing ability is more important. Workmen's compensation laws in many states, for example, use the AAOO-1959 formula that labels 500, 1000, and 2000 Hz the speech frequencies (Ginnold, 1979), whereas NIOSH (1975), EPA (1980), and most recently, OSHA (1981) believe that 500 Hz should be dropped from the criterion and 3000 Hz should be added. The AAOO-1978 position is a compromise of these two views--it includes 500, 1000, 2000 and 3000 Hz (AMA, 1979).

To adequately span the spectrum of viewpoints, it is obvious that all three of these positions should be investigated. However, no hearing levels were obtained at 3000 Hz. Rather than dispense with the incorporation of high frequency hearing ability into any definition, we have substituted hearing levels at 4000 Hz because it is reasonable to assume that hearing levels at these two fequencies should be highly correlated.* Thus, three sets of frequencies are considered:

- 500, 1000 and 2000 Hz;
- 500, 1000, 2000 and 4000 Hz; and
- 1000, 2000 and 4000 Hz.

Given these sets of frequencies, the next major issue is what the low fence, which defines the beginning of hearing impairment, should be. Since air conduction hearing

*We recognize the possible implications of this substitution on computed prevalence rates. However, we have decided that such an approximation is better than no estimates at all.

levels vary dramatically by frequency, the resolution of this issue must be treated separately for each set of average hearing levels.

When using the average of hearing levels at 500, 1000 and 2000 Hz, the AAOO-1959 formula uses a 25 dB low fence. Kryter (1973), in criticizing this formula, advocated the use of a 15 dB low fence. We have therefore applied both these fences, as well as a compromise position--a 20 dB low fence.

Selection of the low fences for the remaining two sets of frequencies is less straightforward because the use of 4000 Hz in lieu of 3000 Hz may necessitate an alteration of the fence typically employed. Let us consider the average of 1000, 2000 and 4000 Hz first. The OSHA (1981) recommendation is for a 25 dB low fence with the average of 1000, 2000 and 3000 Hz. Converting this fence to an appropriate number when substituting 4000 Hz for 3000 Hz, one may either make no changes or raise the fence (say, to 30 dB) under the assumption that the hearing level at 4000 Hz will be slightly higher than that at 3000 Hz. In accordance with the philosophy of maintaining a broad spectrum of definitions, both 25 and 30 dB low fences are used for the average of hearing levels at 1000, 2000 and 4000 Hz. Taken together, these two definitions should bracket the prevalence of "material impairment of health or functional capacity" under the recent OSHA definition (OSHA, 1981).

This type of fence adjustment becomes more complex when considering the average of hearing levels at 500, 1000, 2000 and 4000 Hz. The current AAOO recommendations call for a 25 dB low fence for the average of 500, 1000, 2000 and 3000 Hz. As above, one can simply apply this fence regardless of the frequency substitution, or one can consider raising it slightly to compensate for the probably higher hearing level at 4000 Hz. The decision to raise it, however, calls to mind two issues: (1) How much should it be raised since the hearing level at 4000 Hz only contributes 1/4 weight to the average hearing level; and, (2) If 25 dB is the correct fence for the average of 1000, 2000 and 3000 Hz, isn't 25 dB too high if 500 Hz is included in the definition? With respect to the first issue, the difference between hearing levels at 3000 and 4000 Hz would have to be 20 dB or more to justify raising the low fence 5 dB; even for an individual with a substantial noise-induced hearing impairment such a gap would be large. As a result, we did not consider raising the fence above 25 dB. With respect to the second issue, we dropped the fence to 20 dB as well. We therefore present findings using a 20 dB and a 25 dB low fence when examining the average of hearing levels at 500, 1000, 2000 and 4000 Hz. The prevalence rates computed using the 25 dB are those which will most closely approximate the AAOO-1978 definition. However, these estimates will tend to be slightly higher than those we would have produced if data at 3000 Hz were available.

These considerations produce a total of seven alternative definitions of hearing impairment:

- average of hearing levels at 500, 1000 and 2000 Hz with low fences of 15 dB, 20 dB and 25 dB;

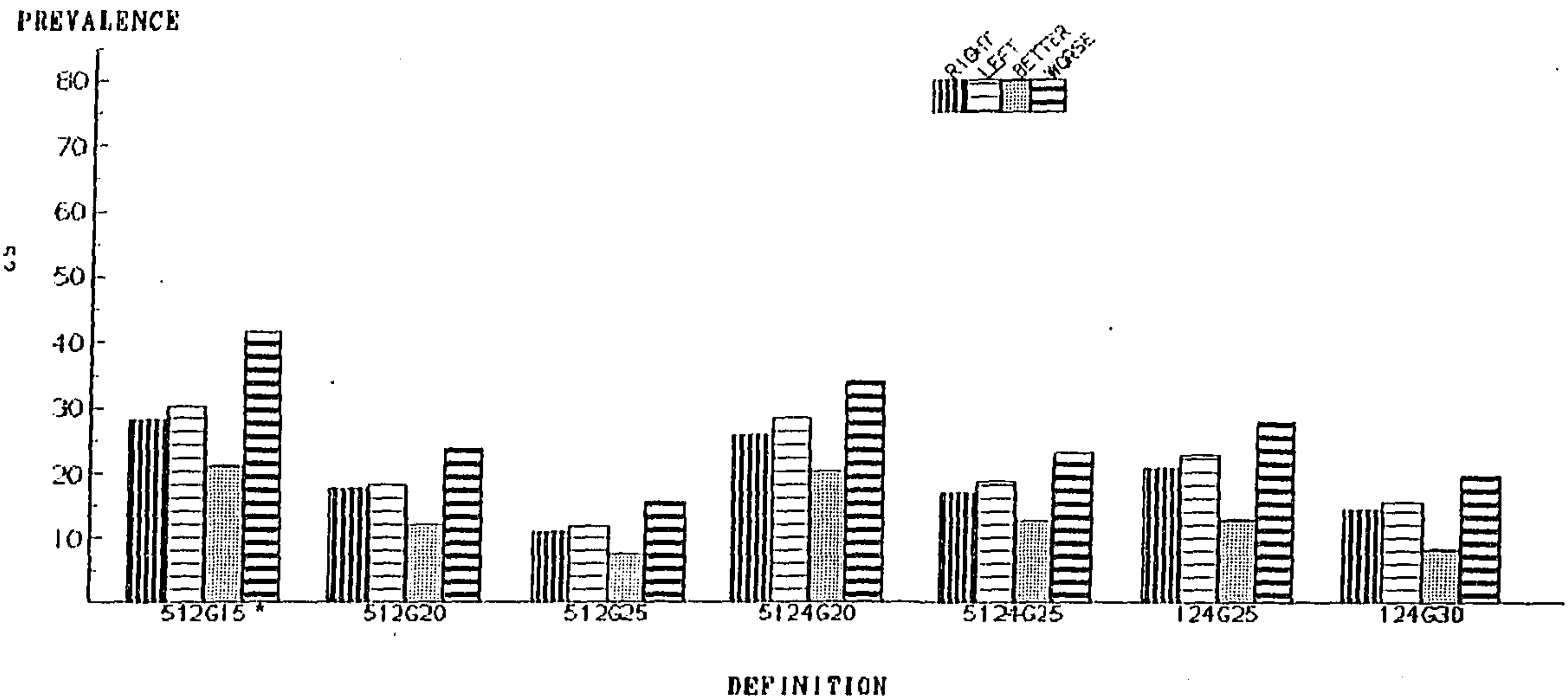
- average of hearing levels at 500, 1000, 2000 and 4000 Hz with low fences of 20 dB and 25 dB; and

- average of hearing levels at 1000, 2000 and 4000 Hz with low fences of 25 dB and 30 dB.

Rather than employ artificial better ear/worse ear weighting schemes, results are presented for the right, left, better

Figure 3.M

Prevalence of Hearing Impairment & Estimates of Number of Persons Affected Under Seven Alternative Definitions in the Right, Left, Better and Worse Ears



* In this figure, as well as in those that follow, abbreviations such as 512G25 have been used to indicate a particular definition of hearing impairment. The digits to the left of the 'G' specify the frequencies averaged (5=500 Hz; 1=1000 Hz; 2=2000 Hz; and 4=4000 Hz.) The number to the right of the 'G' is the low fence.

and worse ears separately. In addition, no attempt has been made to employ a presbycusis correction; instead, results are presented by age.

3.5.1 Patterns Among Prevalence Rates

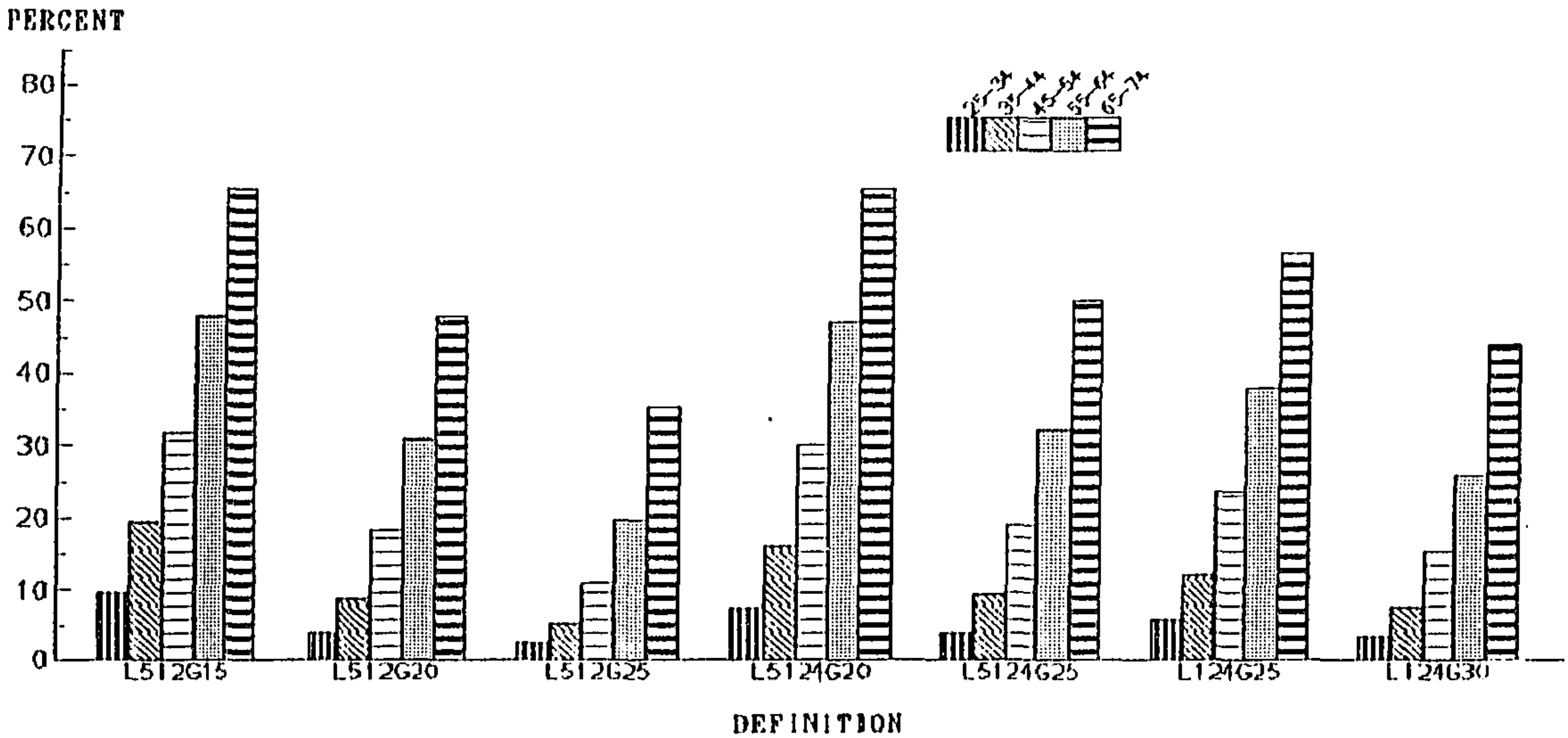
Figure 3.M presents the prevalence of hearing impairment under each of the seven definitions. Depending upon the criterion adopted, the prevalance of hearing impairment ranges from a low of 7.4 percent or an estimated 7.7 million persons (better ear average of 500, 1000 and 2000 Hz > 25 dB) to a high of 41.5 percent or an estimated 43.5 million persons (worse ear average of 500, 1000 and 2000 Hz > 15 dB). Moving in from these extremes, the OSHA (1981) criterion would yield a prevalence in the range from 8.4 percent or an estimated 8.7 million persons to 27.8 percent or an estimated 29.1 million persons. And the AAOO-1978 criterion would yield an even more narrow range--from just under 12.8 percent or an estimated 13.3 million persons to just under 23.3 percent or an estimated 24.4 million persons. Clearly, the choice of a particular definition has direct implications for the magnitude of the prevalence.

Examination of the variations among the prevalance rates reveals certain consistent patterns. First, of course, by definition, for a given set of frequencies in a particular ear, the higher the low fence, the lower the prevalence rate.

Second, the prevalence of hearing impairment varies depending upon the ear used. Of course, the prevalence based upon an individual's better ear is always the lowest of the four rates, and that based upon an individual's worse ear is always highest. The effect of this difference is often dramatic; the prevalence based

Figure 3.N

Prevalence of Hearing Impairment Under
Seven Alternative Definitions
in the Left Ear By Age



upon the worse ear is often twice as high as that based upon the better ear. At its most dramatic, the difference between the better and worse ear rates is 20.2 percent or 21.3 million persons (average of 500, 1000 and 2000 Hz > 15 dB); at its most conservative, the difference is 8.2 percent or 8.7 million persons (average of 500, 1000 and 2000 Hz > 25 dB). In addition, in keeping with the earlier finding that at the higher frequencies, air conduction hearing levels in the left ear are higher than those in the right ear, the prevalence rates for the right ear are consistently lower than those for the left.

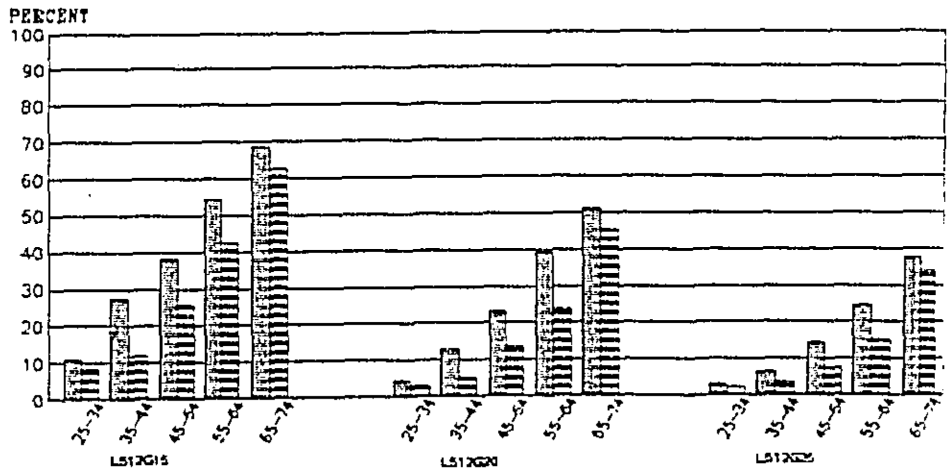
Third, the frequencies selected have a substantial impact upon the prevalence. For a given low fence, the prevalences based upon the average of hearing levels at 500, 1000 and 2000 Hz are consistently the lowest; those based upon the average of hearing levels at 1000, 2000 and 4000 Hz are consistently the highest; and those based upon the average of hearing levels at 500, 1000, 2000 and 4000 Hz fall between these two extremes. This variation is to be expected because hearing levels at 500 Hz are generally substantially lower than those at 4000 Hz; thus, the inclusion of 500 Hz and exclusion of 4000 Hz lowers the prevalence, the exclusion of 500 Hz and inclusion of 4000 Hz raises it, and when both are included, they tend to balance each other.

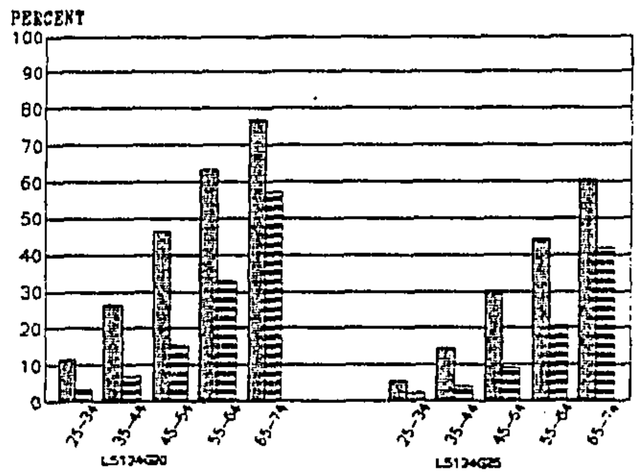
3.5.2 Differences by Age, Sex and Race

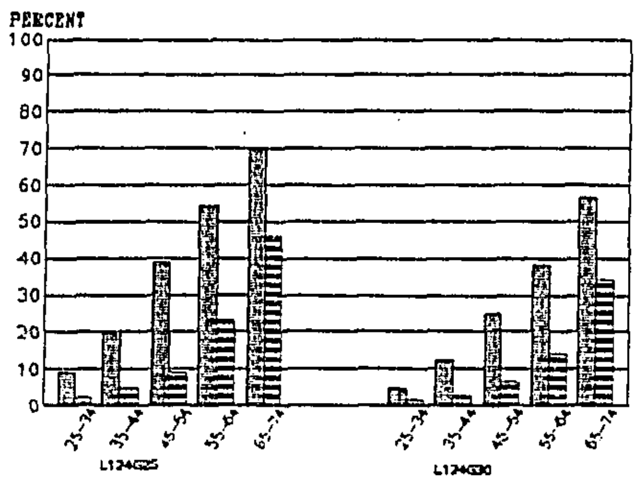
The prevalence of hearing impairment under many definitions varies significantly by age and sex; fewer significant differences are found by race. (Tables 3.79-3.86 present prevalences; Tables 3.87-3.94 present estimates of number of persons affected; results of significance tests are presented in Tables 3.95 and 3.96.) As shown in Figure 3.N, under all definitions, the prevalence of hearing impairment increases substantially with advancing age. At

Figure 3.P

Prevalence of Hearing Impairment Under
Seven Alternative Definitions in the
Left Ear by Age and Sex







ages 25-34 years, the prevalence hovers around 5 percent and rarely exceeds 10 percent; at ages 45-54 years it hovers around 20 percent and rarely exceeds 30 percent; by ages 65-74 it generally exceeds 50 percent, regardless of the criterion used. This is not to say, however, that hearing impairment is a condition found only among the elderly. Based upon the OSHA (1981) definition, for example, even the most conservative (better ear) estimates suggest that between .7 and 1.5 million persons aged 25-44 have a hearing impairment, while more liberal (worse ear) estimates under this definition range from 3.3 million to 5.4 million.

Not only the prevalence of hearing impairment varies by age; the relationships among the prevalences for the better, worse, left and right ears under a given definition also vary by age. Among persons aged 25-34 years, the differences in the prevalences computed for the better and worse ears average to approximately 6 percent; at ages 45-54 years this difference has risen to almost 14 percent; and by ages 65-74 years, this difference is often as large as 20 percent. Thus, among younger persons, choice of a particular ear for computing the prevalence of hearing impairment has little effect upon the estimates made; among older persons, in contrast, such a choice may have dramatic implications for the magnitude of the estimated prevalence.

Men are more likely, in general, to have a hearing impairment than women of the same age; the magnitude of the difference, however, varies with the definition of hearing loss chosen and the age group under examination (Figure 3.P). Using the average of the hearing levels at 500, 1000 and 2000 Hz, men aged 35-64 years are significantly more likely to have a hearing impairment than women of the same age; among the youngest age group (25-34 years) and oldest age group (65-74), in contrast, the observed sex differential is not statistically significant. If the hearing level at

4000 Hz is incorportated into this definition, however, the magnitude of the sex differential increases substantially and is statistically significant at almost all ages examined. And if 500 Hz is then dropped from the definition, the gap between the prevalence rates for men and women widens; using the average of the hearing levels at 1000, 2000 and 4000 Hz, men are approximately twice as likely as women to have a hearing impairment. These variations are attributable to the fact that average hearing levels at 500 and 1000 Hz for men and women are virtually identical, whereas at the higher frequencies, women have significantly better hearing sensitivity than men.

Prevalence rates of hearing impairment in the white and black populations are approximately equal under most definitions examined; the major exception to this pattern is the higher prevalence of hearing impairment as measured by the average of hearing levels at 1000, 2000 and 4000 Hz among white males aged 35-64 years.

3.6 Relationships Among Measures of Auditory Functioning

Each of the measures profiled in this chapter constitutes an independent source of information on the same construct--an individual's level of auditory functioning. It is therefore not surprising that strong direct associations are found both among the objective indices (air and bone conduction hearing levels as well as speech discrimation scores) and between these objective measures and an individual's own assessment of his or her auditory functioning.

3.6.1 Air Conduction, Bone Conduction and Speech Discrimination

Table 3.97 presents correlation coefficients between air conduction hearing levels and both bone conduction hearing levels and speech discrimination scores at 20 dB SL.* Correlations among air and bone conduction hearing levels for both the left and right ears at all tested frequencies are strong and highly significant, ranging from .28 to .85. The magnitude of the correlation between the air and bone data for any two ears at any two frequencies consistently varies as a function of the ears and frequencies selected. Not surprisingly, correlations are stronger for comparisons of the air and bone data in the same ear than they are for comparisons based on different ears; in addition, correlations are slightly stronger for the right ear data than they are for the left ear data. With regard to the effect of the choice of frequencies, correlations are stronger for the same frequency than for different frequencies; in addition, correlations are stronger among the mid and high frequencies than among the lower frequencies. Thus, in terms of overall magnitude, in comparing air and bone conduction data, the strongest correlations are found for the right ear/right ear comparisons, next strongest are those for the left ear/left ear comparisons and finally the weakest are those for the right ear/left ear comparisons. Within a particular set of overall comparisons, the 4000 Hz/4000 Hz comparison is the strongest and the 500 Hz/4000 Hz comparison is the weakest.

Air conduction hearing levels at all tested frequencies are also closely related to speech discrimination ability at 20 dB SL, with correlations ranging from -.38 to -.62.* As was found for the relationship between air

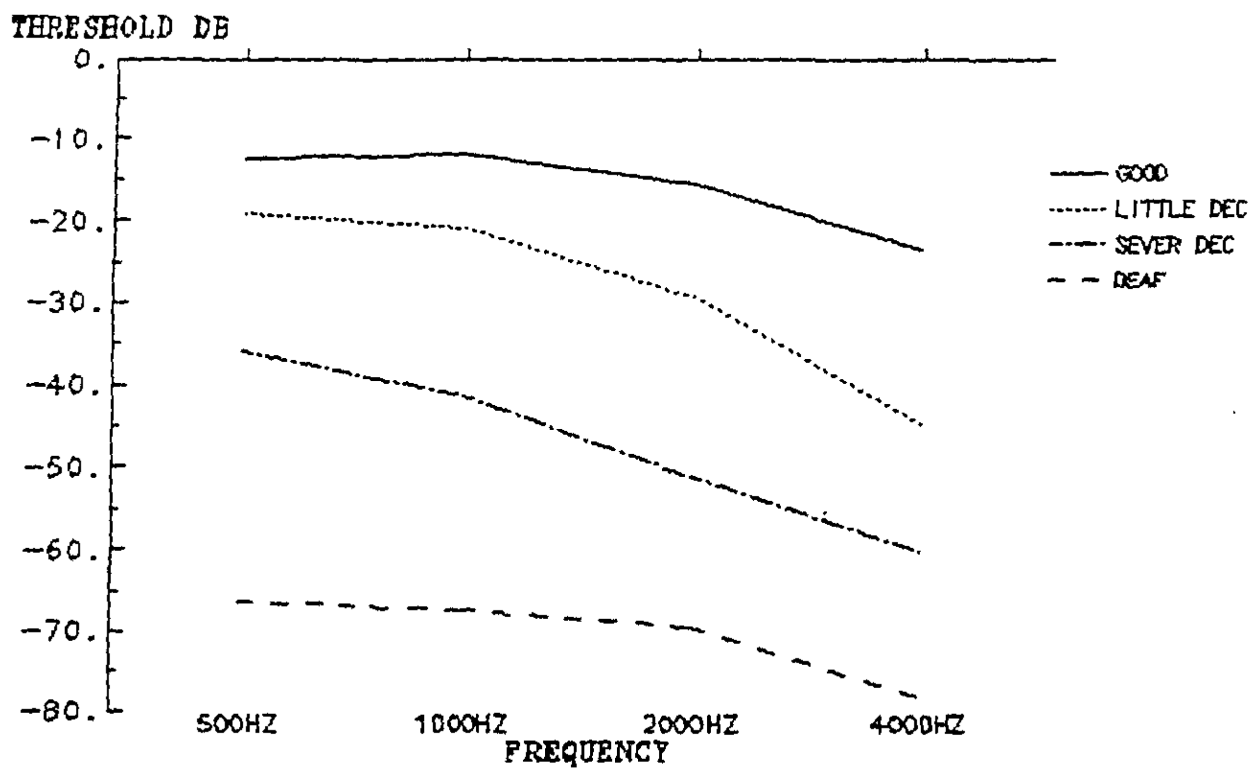
---

*No correlations can be computed between bone conduction hearing levels and speech discrimination scores because these two tests were administered to completely independent samples.

**Note that the correlations are negative because the relationship between each data source and hearing acuity is different. For air conduction data, better hearing is associated with lower values, whereas for the speech discrimination data, better hearing is associated with higher values.

Figure 3.Q

Mean Air Conduction Hearing Levels at 500, 1000, 2000, and 4000 Hertz By Overall Hearing Rating (Left Ear)



and bone conduction data, the magnitude of the correlation between the air and speech discrimination data for any two ears and any air conduction frequency consistently varies as a function of the ears and frequency selected. As before, correlations are stronger for comparisons of the air and speech discrimination data in the same ear than they are for comparions based on different ears, and slightly stronger for the right ear than for the left ear. More interesting, however, is the fact that correlations are highest for the air conduction threshold at 1000 Hz, slightly lower for the thresholds at 500 and 2000 Hz and substantially lower, but still highly signficant, for the threshold at 4000 Hz. Thus, as other studies have shown, although speech discrimination ability in a quiet background is related to hearing sensitivity at all frequencies, it is the lower frequencies that appear to have the strongest association.

3.6.2 Relationships with Perceived Auditory Ability

Air conduction hearing levels, speech discrimination scores at 20 dB SL and estimates of the prevalence of hearing impairment based upon air conduction data all vary significantly with an individual's perception of his or her hearing ability and with reports of hearing problems. (Tables 3.98-3.109 present data for air conduction hearing levels; Tables 3.110-3.121 present data for prevalence estimates; Tables 3.122-3.124 present data for speech discrimination scores; results of significance tests are presented in Tables 3.125-3.128.) As shown in Figures 3.Q-3.S, hearing sensitivity, as measured by all the objective approaches, varies hand in hand with an individual's overall assessment of his or her hearing as good, a little decreased, slightly decreased, or deaf. For example, examination of mean air conduction hearing levels, using the average rating in the "good" category as a base, shows that

Figure 3.R

Prevalence of Hearing Impairment Under Seven Alternative Definitions in the Left Ear by Overall Hearing Rating

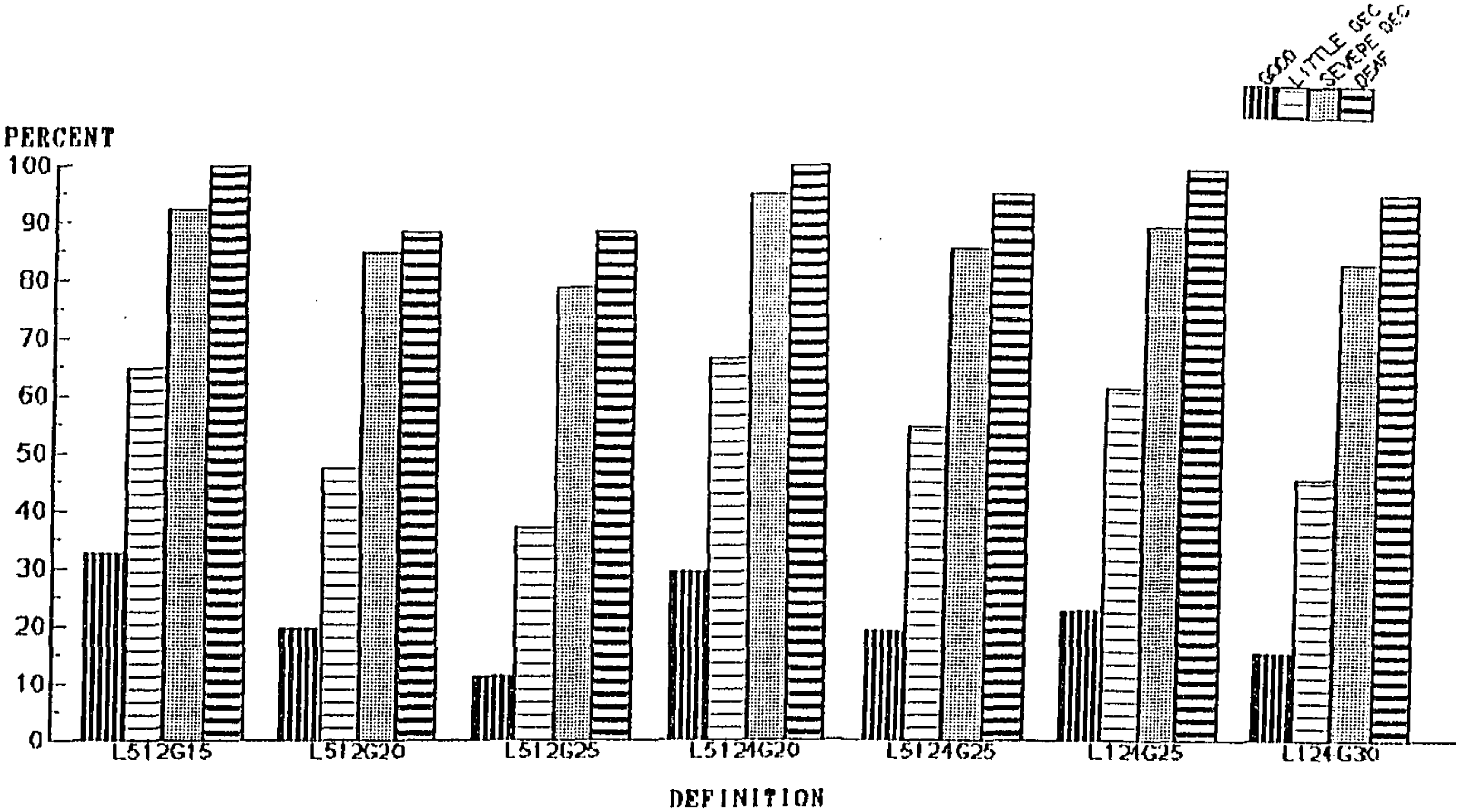
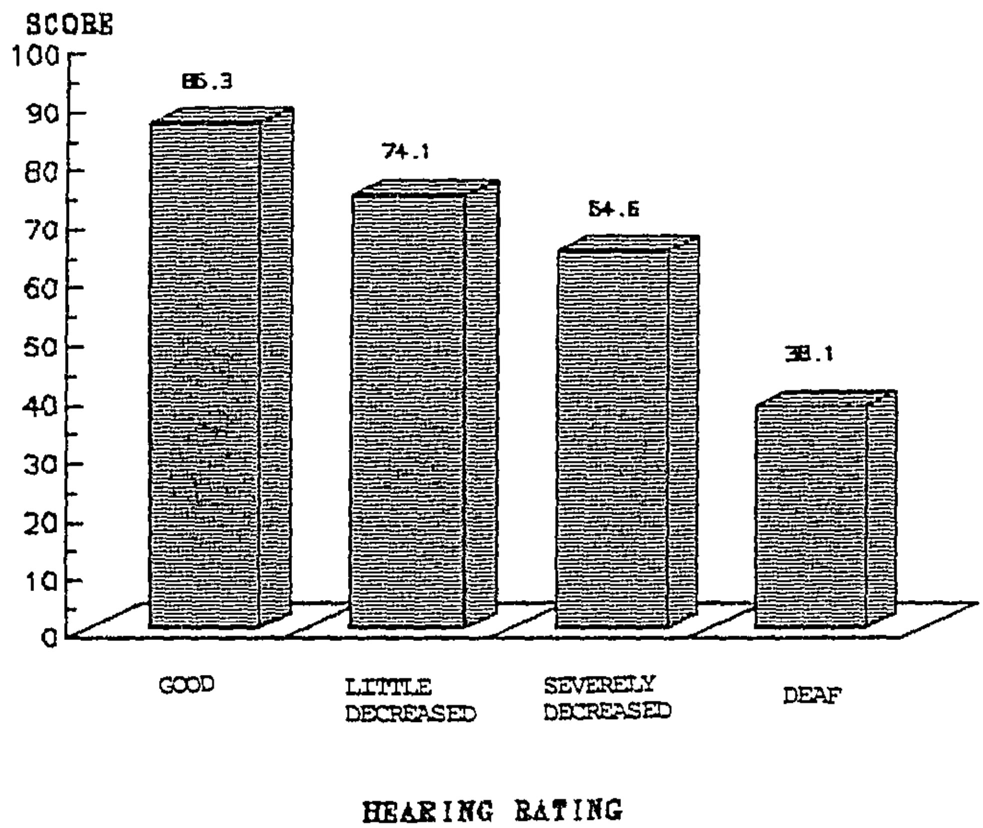


Figure 3.S

Mean Speech Discrimination Score at
20dB SL in the Left Ear
By Hearing Rating



those who rate their hearing as "a little decreased" have average hearing levels almost twice as high, those who rate their hearing as "severely decreased" have average hearing levels almost three times as high, and those who consider themselves deaf have average hearing levels almost four times as high.

Objective assessments of hearing sensitivity also vary with the reporting of deafness or hearing trouble. Individuals who report deafness or trouble hearing have mean air conduction hearing levels almost twice as high as those who do not report trouble; speech discrimination scores are also approximately 20 points lower for persons with hearing trouble. Perhaps the most dramatic evidence of the contrast between those who report trouble hearing and those who do not is the fact that the prevalence of hearing impairment as measured by air conduction hearing levels is between two and four times as high among the former group than among the latter group (depending upon the definition used).

These differences between persons with deafness or hearing trouble and those without these problems are evident regardless of the reported cause of the hearing problem. It is interesting to note, however, that those who report that a loud noise was the cause have the lowest average air conduction hearing levels at 500 Hz and the highest average air conduction hearing levels at 4000 Hz--a pattern totally consistent with the typical profile of noise-induced hearing impairment.

Problems with ear discharges and tinnitus are also associated with objective indicators of hearing status. Individuals who report having had ear discharges have significantly higher mean air conduction hearing levels and speech discrimination scores than those who do not; the prevalence of hearing impairment is also greater among this group. Similarly, those who report hearing ringing or other noises have poorer hearing as measured by all the objective indices than those who do not report ringing. The gap between these two groups enlarges when attention is focused upon those individuals who report ringing every few days. As shown in Figures 3.T-3.V, persons with frequent tinnitus have significantly poorer hearing than those with no ringing at all or with ringing only every few days.

Finally, the ability to hear and understand speech and sounds also varies as expected with air conduction and speech discrimination data as well as with estimates of the prevalence of hearing loss. For example, the prevalence of hearing impairment is generally twice as high among persons who cannot hear a whisper across a quiet room than among those who can.

Figure 3.T

Mean Air Conduction Hearing Levels at 500, 1000, 2000 and 4000 Hertz in the Left Ear By Presence of Ringing in the Ear

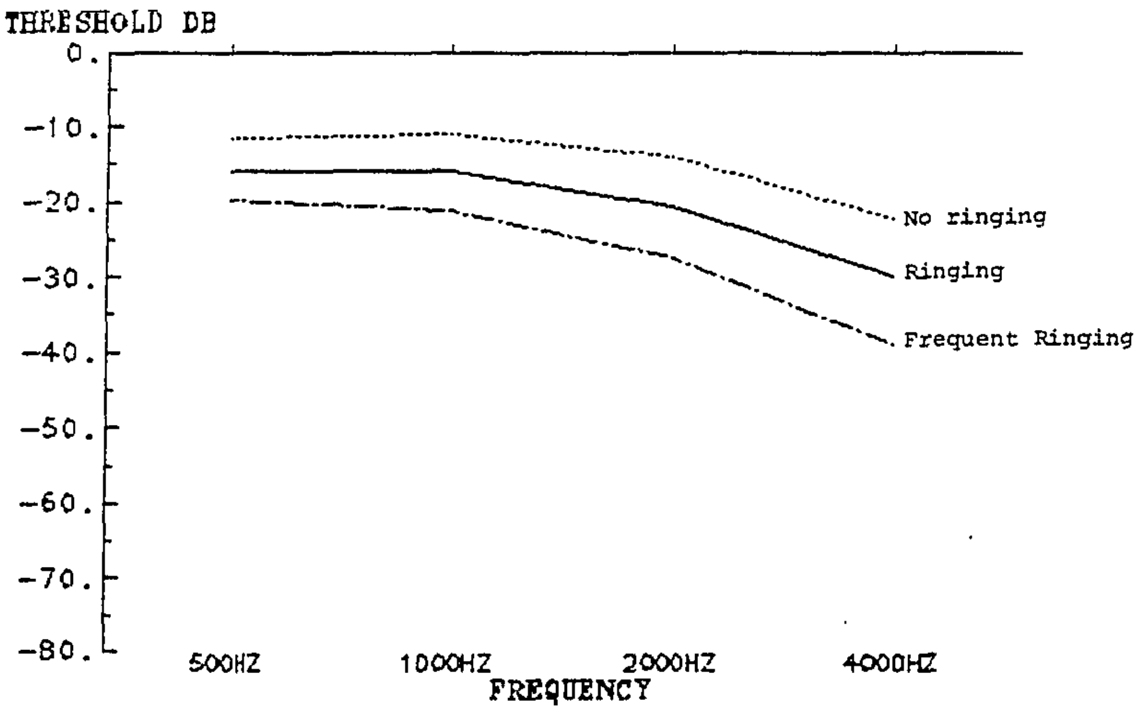


Figure 3.U

Prevalence of Hearing Impairment Under
Seven Alternative Definitions in
the Left Ear by Presence of
Ringing in the Ear

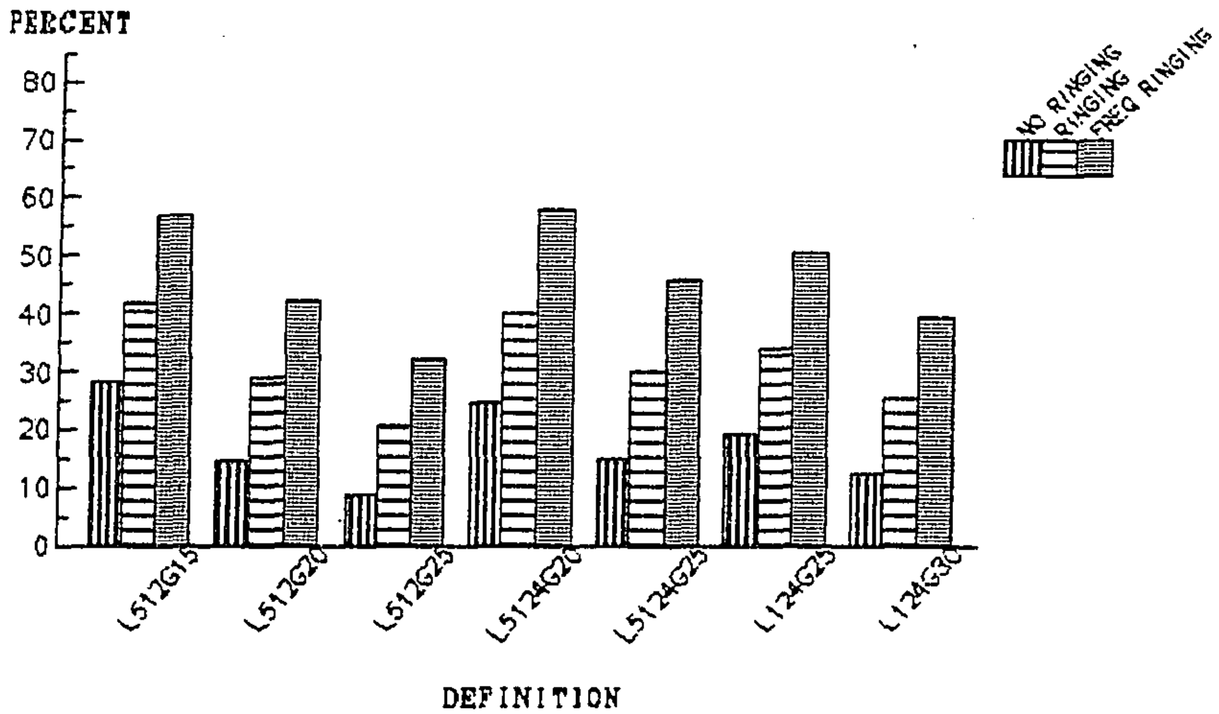
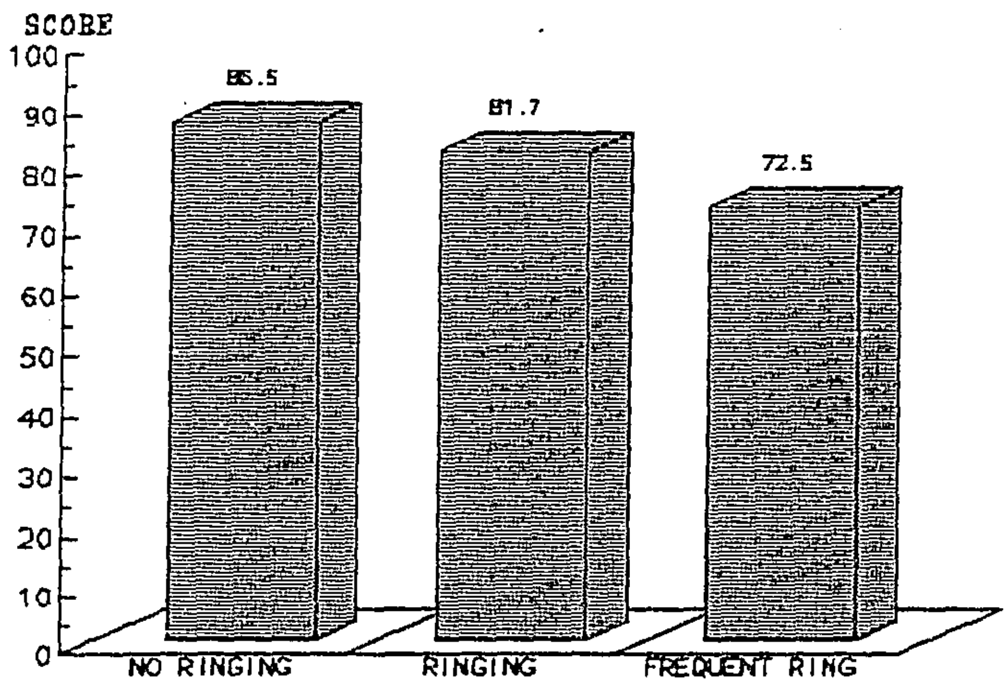


Figure 3.V

Mean Speech Discrimination Scores at
20dB SL in the Left Ear By
Presence of Ringing in the Ear



CHAPTER FOUR: CORRELATES OF AUDITORY FUNCTIONING AND THE AUDITORY EFFECTS OF NOISE

As the previous chapter shows, there is great variability in auditory functioning among adults in the United States. Although the majority of persons have hearing levels well within the generally accepted range of normal, even the most conservative estimates based upon the currently accepted OSHA and AAOO criteria suggest that between 8.7 and 13.5 million persons have a hearing impairment. Perhaps more staggering is the fact that an estimated 17.2 million persons would themselves say that they are deaf or have trouble hearing.

But just what has caused this hearing impairment? Can specific risk factors that contribute to a decrease in hearing be identified? When individuals who reported having hearing problems were queried, many cited exposure to loud noise or ear infections. But many cited other causes as well; more disconcerting is the fact that many simply did not know. And what are the causes of hearing impairment among those for whom objective measurements reveal poor functioning but who do not report having hearing problems?

In this chapter, we attempt to identify the background factors associated with auditory functioning.* Although we have considered a variety of characteristics and their relative contributions to auditory functioning, particular attention has been given to occupational noise exposure. This emphasis arises because: (a) prolonged noise exposure has pronounced measurable and permanent effects on auditory functioning; (b) among persons who

*Analyses presented in Section 5.3 explore the associations between auditory functioning and physical health.

report hearing problems, noise is the most commonly cited specific cause; and (c) of all the potential direct causes of hearing loss (e.g., infection, surgery, noise), noise is the only one for which we have some history for most examinees. As a result, in addition to basic measures of hearing status, we have also examined several dependent measures designed specifically to assess noise-induced hearing impairment.

4.1 Analytic Approach

Ten measures of auditory functioning were considered--five indices of basic hearing status and five indices of noise-induced hearing impairment. Because of the close correspondence between auditory functioning in the left and right ears, the left ear was arbitrarily selected to represent both, in order to avoid needless repetition. From the broad range of measures of basic hearing status profiled in Chapter Three, two were selected for further study: the air conduction hearing levels at 500, 1000, 2000 and 4000 Hz; and the indicator of hearing impairment as measured by the average of hearing levels at 1000, 2000 and 4000 Hz with a low fence of 25 dB.* The choice of the actual air conduction hearing levels is self-explanatory. The particular hearing impairment indicator was selected because it most closely approximates recent recommendations

*Bone conduction and speech discrimination data were not considered for several reasons. First, each was administered to only half the sample, thereby substantially diminishing the power to detect effects. Second, in the case of the bone conduction data, difficulties in testing meant that thresholds were missing for a non-eligible proportion of the examinees for whom there should have been data. Third, in the case of the speech discrimination data, those with extremely poor auditory functioning were not administered the test at 20 dB SL, and thus no data is available on the extremes of the distribution.

made by NIOSH (1975), the International Standards Organization (ISO, 1980) and OSHA (1981) for the assessment of hearing impairment in a noise-exposed population.

Selecting indicators of noise-induced hearing impairment or permanent threshold shift (NIPTS) was not as straightforward. Although hearing levels of individuals with NIPTS follow a well-established pattern, there is no simple standard currently in use to determine if an individual has a NIPTS. Most would agree, however, that an individual with NIPTS has hearing levels well within the range of normal in the low to mid frequencies (500, 1000 and perhaps 2000 Hz) and above the range of normal in the middle to high frequencies, 3000 Hz and beyond. In addition, NIPTS may be accompanied by severe and persistent tinnitus.

Given these basic assumptions, the task was then to develop indicators of NIPTS with the available data. The first measure developed was a simple one--if tinnitus may be symptomatic of NIPTS, ringing in the ear every few days (or more often) may be considered a possible indicator of NIPTS. But tinnitus alone is not a certain indicator of NIPTS; in fact, it may as likely be an indicator of ototoxic drug use (Davis and Silverman, 1970). Therefore, the pattern of air conduction thresholds must also be examined. As no data were collected on hearing levels at 3000 Hz, nor the higher frequencies beyond 4000 Hz, the primary restriction was that any criterion for NIPTS must be based solely upon data at 500, 1000, 2000 and 4000 Hz. Examination of audiograms at these frequencies of individuals with NIPTS reveals that the most salient pattern is the shift in hearing thresholds from normal in the lower frequencies to quite high at 4000 Hz. Therefore, the first indicator developed was the simple difference or absolute shift between the hearing level at 4000 Hz and the average of the hearing levels at 500 and 1000 Hz. Two questions then arose:

Table 4.A

Behavior of Shift Measures Under Selected Audiometric Configurations

Configuration				Shift Measures			
				Absolute Shift to 4000 Hz		Percentage Shift to 4000 Hz	
500 Hz	1000 Hz	2000 Hz	4000 Hz	From 500 & 1000 Hz	From 500, 1000 & 2000 Hz	From 500 & 1000 Hz*	From 500, 1000 & 2000 Hz*
10	10	10	10	0	0	0	0
10	10	10	20	10	10	.33	.33
10	10	20	30	20	16.67	.67	.50
10	30	40	60	40	33.33	1.00	.71
20	20	20	20	0	0	0	0
20	20	20	30	10	10	.25	.25
20	20	20	40	20	20	.50	.50
20	20	40	60	40	33.33	1.00	.71
40	40	40	40	0	0	0	0
40	40	40	50	10	10	.17	.17

*Because the average hearing levels at the lower frequency could be zero, resulting in division by zero, 20 has been added to each threshold to compute percentage shifts.

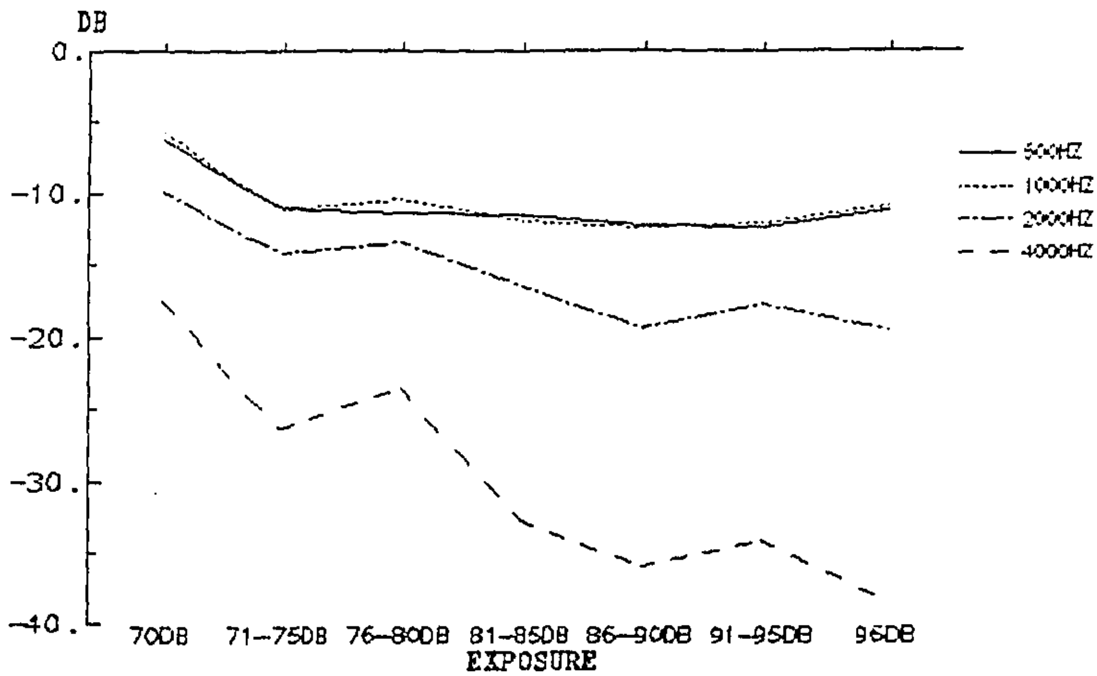
(a) Should 2000 Hz be incorporated into the average low frequency base? (b) What happens in the case of older persons for whom there may be a substantial difference between hearing levels at 4000 Hz and the lower frequencies, but for whom levels even at the lower frequencies are not within the range of normal? In response to the first question, a second indicator was created: the simple difference between the hearing level at 4000 Hz and the average of the hearing levels at 500, 1000 and 2000 Hz. In response to the second question, two additional indicators of NIPTS were created based upon the percentage shift from the average of hearing levels at either 500 and 1000 Hz or at 500, 1000 and 2000 Hz to the hearing level at 4000 Hz.* Use of this percentage shift has the effect of diminishing the size of the shift when hearing levels in the lower (and mid) frequencies are high (i.e., outside the range of normal) and increasing the size of the shift when hearing levels in the lower (and mid) frequencies are low (i.e., well within the range of normal). Table 4.A illustrates the behavior of each of the four shift measures under alternative configurations of hearing levels.

Analyses were conducted on the sample of 3798 black and white men and women who were either currently working, recently out of the job market or currently looking available. Initially, bivariate relationships between auditory functioning and occupational noise exposure were examined. Separate but parallel analyses were performed on men and women because of their dramatically different auditory patterns. These analyses were then repeated, statistically controlling for age and race, to determine whether effects found were artifacts of the differential

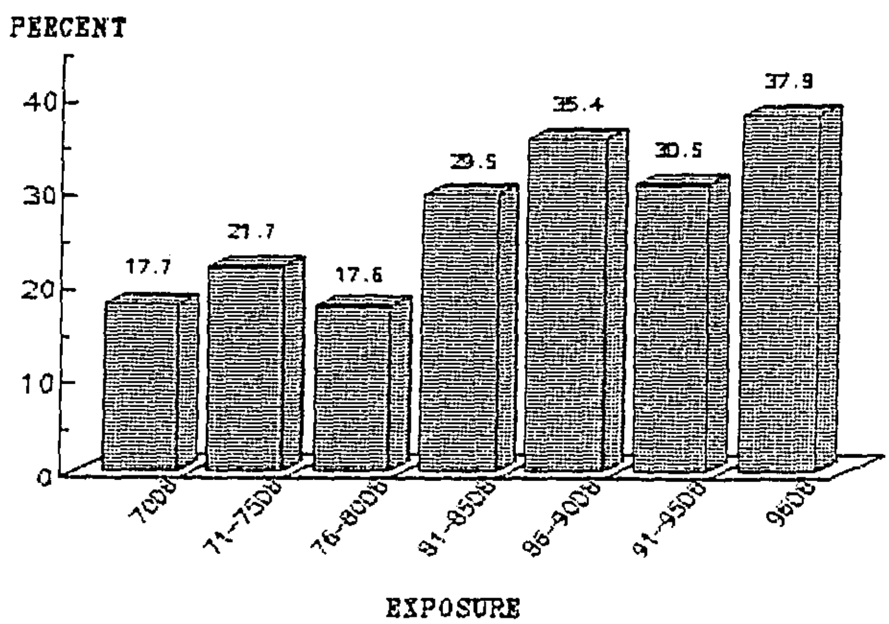
*Because the average hearing levels at the lower frequencies could be zero, resulting in division by zero, 20 has been added to each threshold to compute percentage shifts.

Figure 4.A

Mean Air Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hertz
in the Left Ear By Occupational
Noise Exposure (Males)



Prevalence of Hearing Impairment
in the Left Ear by Occupational
Noise Exposure (Males)



distributions of age and sex in the occupational groups. Bivariate relationships between auditory functioning and the extensive set of independent measures presented in Section 2.4 were similarly examined, both alone and statistically controlling for age and race. On the basis of these results, a smaller set of independent measures was selected to be examined in conjunction with occupational noise exposure in a multivariate framework. A detailed description of the statistical approach is presented in Appendix I.

4.2 Auditory Functioning and Occupational Noise Exposure

Bivariate relationships between the ten measures of auditory functioning and occupational noise exposure were examined first, separately for men and women. Table 4.1 presents results for men. (See also Figure 4.A.) Estimates of the mean and standard error of each measure are presented for each of seven levels of occupational noise exposure. For example, the average air conduction hearing level at 500 Hz for men working in occupations with noise exposure rated less than or equal to 70 dB is 6.30, and it increases to 11.18 for those exposed to noise levels of 96 dB or greater.

The behavior of each of the 10 measures of hearing sensitivity reflects a deterioration in auditory functioning with increasing levels of occupational noise exposure among men. That is, mean air conduction hearing levels increase with increasing exposure, as do the prevalence of hearing impairment, the shifts in hearing levels from low to high frequencies, and the prevalence of tinnitus.

This deterioration in auditory functioning is far more dramatic at the mid and high frequencies than the low frequencies. The differential effect can best be seen by

Table 4.B

Selected Percentiles from the Distribution of Air Conduction Hearing Levels at 500, 1000, 2000 and 4000 Hz by Occupational Noise Exposure

MALES

Frequency	Percentile	≤70 dB	71-75 dB	76-80 dB	81-85 dB	86-90 dB	91-95 dB	≤96 dB
500 Hz	75th	10	15	15	15	15	15	15
	50th	5	10	10	10	10	10	10
	25th	5	5	5	5	5	5	5
1000 Hz	75th	10	15	15	15	15	15	15
	50th	5	10	10	10	10	10	10
	25th	0	5	5	5	5	5	5
2000 Hz	75th	15	20	20	25	30	25	25
	50th	10	10	10	15	15	15	15
	25th	5	5	5	5	5	5	5
4000 Hz	75th	30	40	40	55	55	50	65
	50th	15	25	20	35	30	30	40
	25th	5	10	10	15	15	15	20

examining the behavior of the four shift measures. For each measure, the average shift (both absolute and relative) is more than twice as large for men working in occupations rated 96 dB or more than those in occupations rated 70 dB or less. Since noise-induced hearing impairment tends to become evident at higher frequencies rather than at lower frequencies, the patterns shown here may be considered indicative of noise-induced hearing impairment.

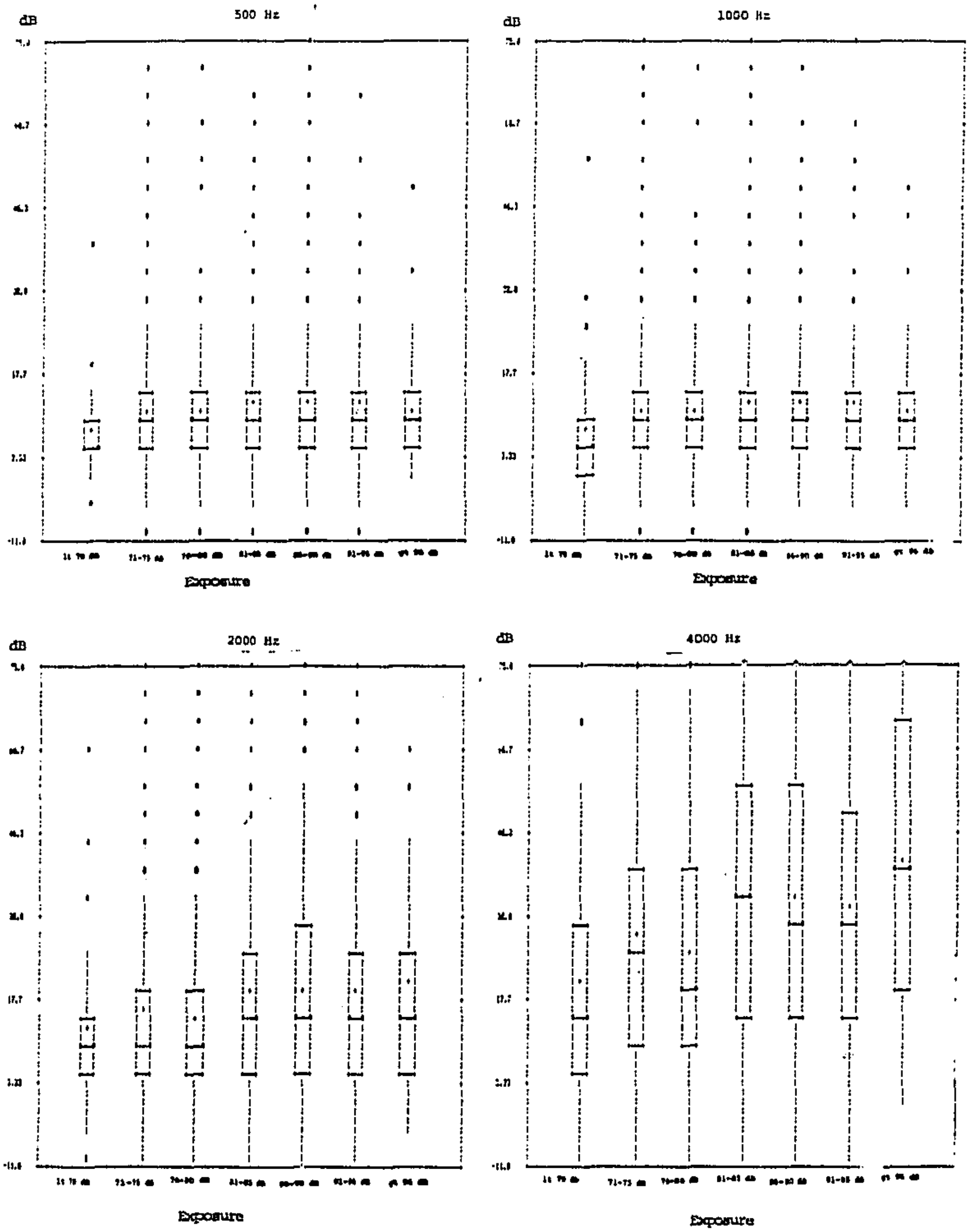
Not only do the mean air conduction hearing levels vary by occupational exposure, but, in fact, the entire distribution of hearing sensitivity varies as well (Table 4.B). Schematic plots for the four air conduction hearing levels are shown in Figure 4.B. The boxes extend from the lower to the upper quartiles of the data for each of seven levels of occupational noise exposure. The dashed line inside each box represents the median, and the point marked with a "+" represents the mean. Dashed lines extending from the upper and lower quartiles indicate the nearest portions of the tails of the distribution, and those groups of data points which are well outside of the central part of the distribution are indicated with zeros and asterisks. (See Tukey [1977] for a more complete discussion of schematic plots.) Arrows at the top and bottom of some of the graphs indicate that these schematic plots extend beyond the limits of the display.

All four measures are heavily skewed positive; that is, the majority of respondents have hearing well within the range of normal at all levels of occupational noise exposure. Although the mean increases somewhat, there appears to be little change in the distribution of air conduction hearing levels at 500 and 1000 Hz by noise exposure. At the mid and high frequencies, in contrast, the distributions of hearing levels do shift upward with increasing noise exposure. With increasing levels of

Figure 4.B

Distribution of Air Conduction Hearing Levels at
500, 1000, 2000 and 4000 Hz
by Occupational Noise Exposure

MALES



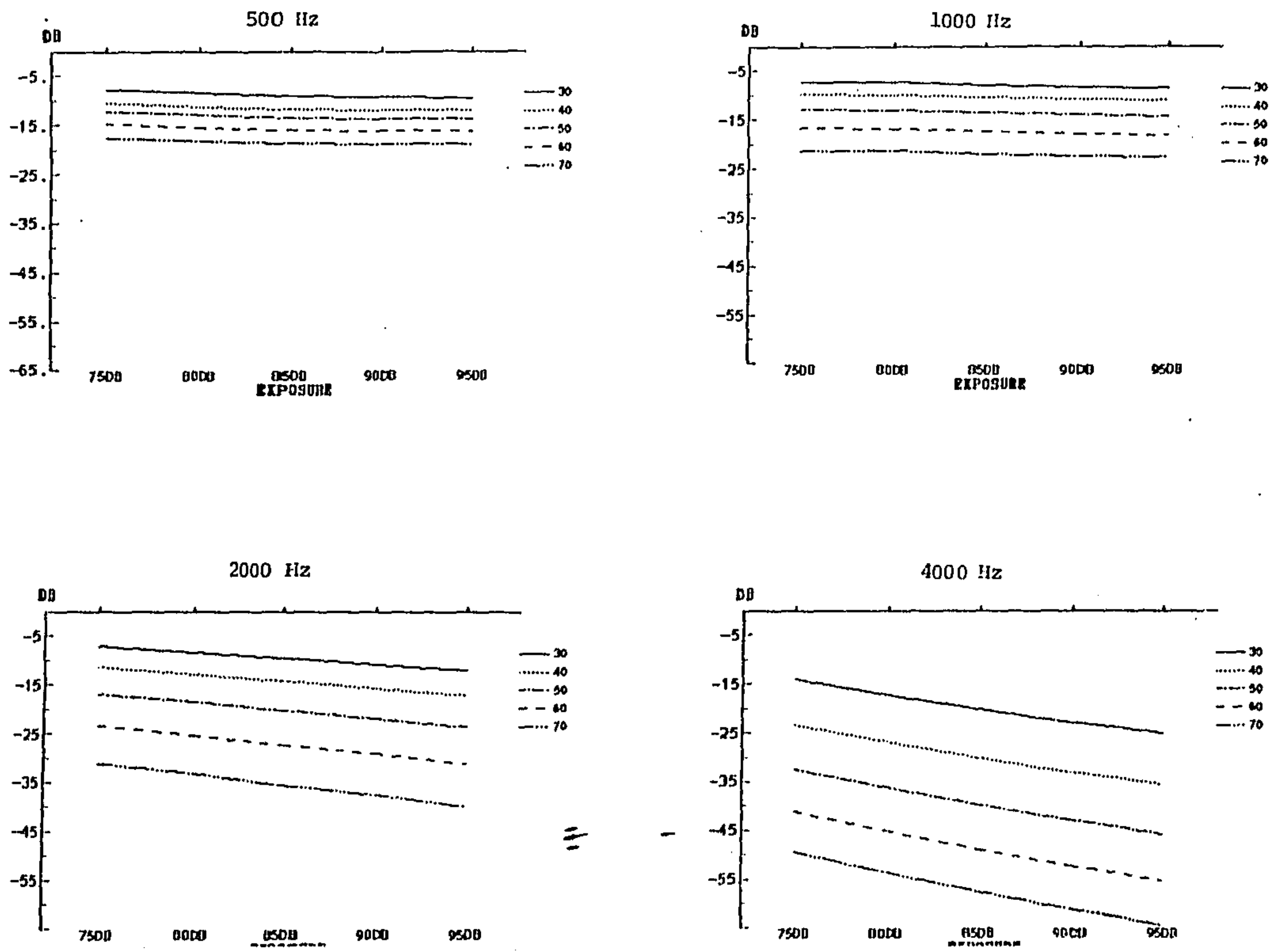
noise exposure, the spread of distributions of hearing levels at higher frequences increases and the positive tails become heavier and longer, indicating a greater preponderance of individuals with impaired hearing.

Although these graphic displays provide evidence that hearing acuity decreases with increasing noise exposure, they cannot be used to determine if the differentials might be due to chance alone. To provide this objective determination, two sets of F-statistics for testing the significance of the relationship between auditory functioning and noise exposure are presented in Table 4.1. The first of these, labeled "uncontrolled," tests the simple linear relationship. For men, all of the auditory variables (with the exception of the measure of tinnitus) are significantly related to noise exposure.

However, as was shown in Chapter Three, auditory functioning is also closely related to age and race. These significant relationships might, therefore, be due to differential distributions of age (or race) by noise exposure. Various methods for correcting or adjusting for such differing age distributions have been used in previous studies of noise-induced hearing impairment. Many employ external corrections based on data from individuals who have been screened for noise exposure and otological abnormalities (see, for example, Corso, 1976). However, the corrections available from a particular study may not accurately reflect the presbycusic patterns in the populations being examined. Other researchers have, therefore, recommended an "internal" presbycusis correction (Robinson, 1976; ISO, 1980). In general, these approaches have examined the <u>distribution</u> of hearing levels among persons in the data base with low levels of exposure (say 70-75 dBA), computed percentiles separately for men and women by age in this "non-noise-

Figure 4.C

Fitted Mean Air Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hz in the Left Ear By
Age and Occupational Noise Exposure (MALES)



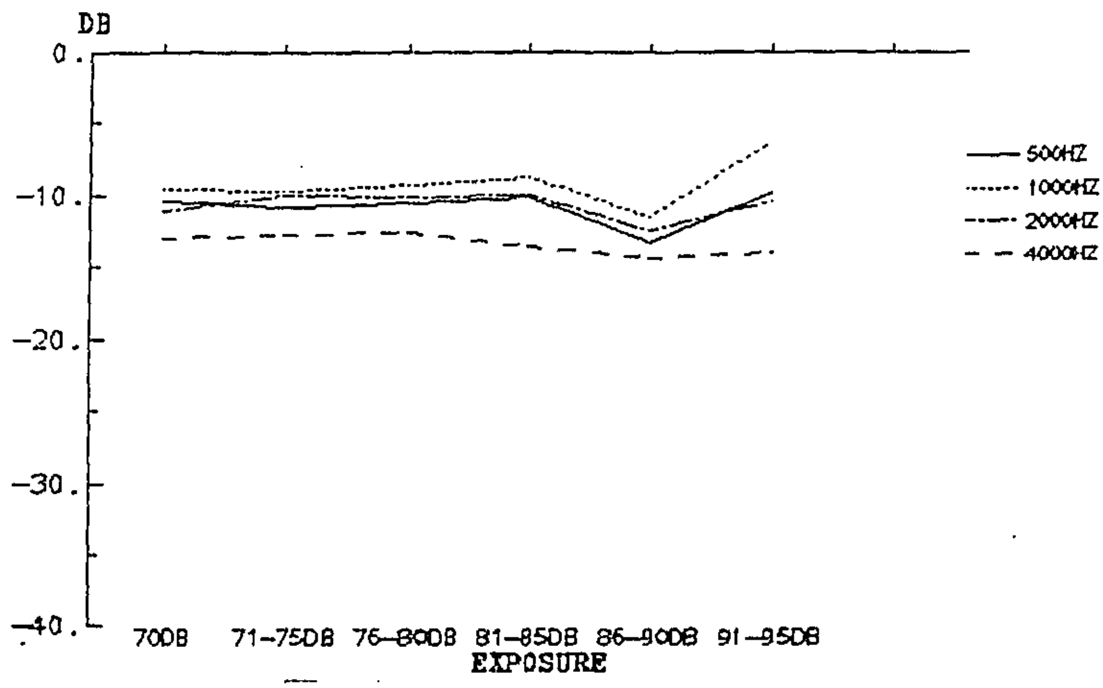
exposed" population, and subtracted these values from the relevant percentiles in the noise-exposed groups. Unfortunately, accurate estimation of these percentiles is totally dependent upon an adequate sample size within each age-by-sex-by-noise exposure category, a requirement which cannot be met in the present study. (See Table II.4 in Appendix II for the sample sizes by age, sex and occupational noise exposure.) To circumvent this problem, we have chosen to develop an internal linear presbycusis correction which examines the trends across the entire data set and thus does not require a sufficient sample size in each cross-classification. This approach simply requires that age (and race) be entered as linear covariates in all subsequent analyses. The net effect of this strategy is to "subtract out" the variation in hearing sensitivity due to age and race, so that the residuals left over can be explored for their relationships with other measures, especially occupational noise exposure.

Before routinely applying this approach, its appropriateness requires further examination. In particular, the assumptions of linearity in age, linearity in noise exposure and non-interactiveness of age and noise exposure must be investigated. Figure 4.C presents fitted curves for average air conduction hearing levels by occupational noise exposure for males at ages 30, 40, 50, 60 and 70 for each of the four frequencies included in this study. These curves include linear <u>and</u> quadratic terms for age and occupational noise exposure, as well as a multiplicative interaction term. The regression coefficients and fitted data points upon which these curves are based are presented in Table 4.2.

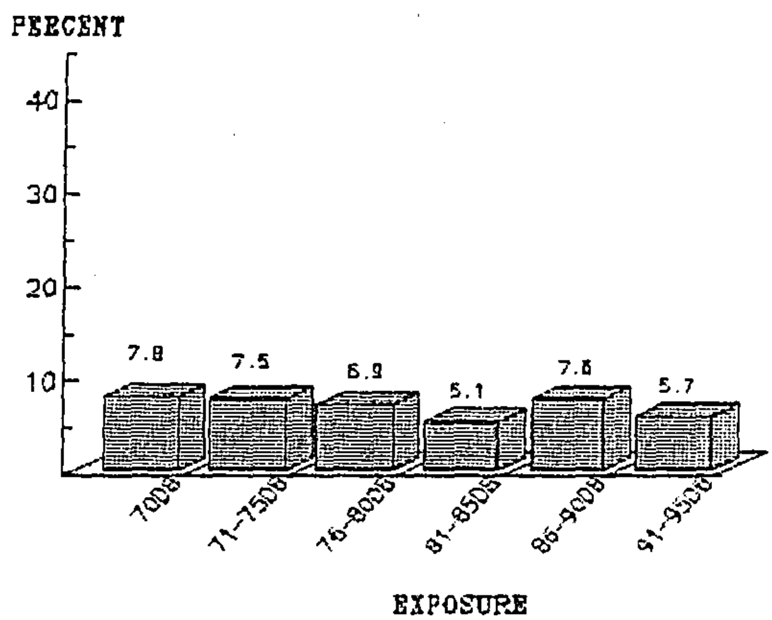
None of these curves shows any substantial departure from linearity. With regard to noise exposure, only at 500 Hz does the effect of increasing exposure appear to taper off at higher levels; however, as already noted, the effect

Figure 4.D

Mean Air Conduction Hearing Levels
at 500, 1000, 2000 and 4000 Hertz
in the Left Ear by Occupational
Noise Exposure (Females)



Prevalence of Hearing Impairment
in the Left Ear by Occupational
Noise Exposure (Females)



of noise at 500 Hz is minimal in any case. With regard to age, only at 2000 Hz is some nonlinearity evident, with the effect of age being slightly steeper at older ages than younger ages; however, this effect is also not substantial. There is some evidence of a small interaction between noise exposure and age at the higher frequencies. The spread between the 10-year interval curves is slightly wider at high noise exposures than at low ones, indicating a somewhat larger effect of aging at higher noise exposure levels. Again, this departure from strictly non-interactive linearity in age and noise exposure is minimal. On the whole, these graphs seem to indicate that a strictly additive model of occupational noise exposure and age may be used as a reasonable approximation with which to summarize the data and investigate relationships. This approximation has therefore been adopted for all further analyses.

Using this approach, it is now possible to test the alternative hypotheses that the observed relationships shown in Table 4.1 are artifacts of the differential age distributions and/or of the differential race distributions among the occupational categories. The second column of F-statistics, labeled "controlling for age and race" presents the results of this exercise. For men, the F-statistics for the linear relationships between all of the auditory functioning variables are actually <u>increased</u> by statistically controlling for age and race. Just as with the uncontrolled test, the linear relationships between auditory functioning and occupational noise exposure are statistically significant (with the exception of tinnitus).

The same information reported for males in Table 4.1 is shown for females in Table 4.3. (See also Figure 4.D.) In comparing these two tables, one should keep in mind that there are only 1442 females in this analysis as opposed to 2356 males. Thus, estimates for females in Table

4.3 are somewhat more variable than those for males in Table 4.1. In addition, one would expect F-statistics for testing relationships for females to be somewhat smaller than those for males, even if the strengths of the relationships were the same, simply because the sample sizes for females are smaller.

Note first in comparing the two tables that, in general, auditory functioning as measured by all but the tinnitus indicator tends to be worse for men than for women regardless of occupational noise exposure. Secondly, the relationship between occupational noise exposure and hearing for females is dramatically different from that for males: it is much weaker for females, and is only statistically significant for the air conduction hearing level at 500 Hz. Furthermore, the strength of the relationship between occupational noise exposure and each of the auditory functioning measures is <u>reduced</u> by statistically controlling for age and race. In fact, the one statistically significant finding for females--the air conduction hearing level at 500 Hz--is eliminated after controlling for age and race.

These sex differences are perhaps best illustrated by comparing the linear regression coefficients and associated standard errors obtained by regressing each of the auditory functioning measures on age, race, and occupational noise exposure separately for males and females (Table 4.4). These are the regression equations upon which the F-statistics for the relationships with occupational noise exposure controlling for age and race, reported in Tables 4.1 and 4.3, are based.

As discussed in Chapter Three, (Tables 3.4-3.28), Table 4.4 shows that the effect of age on air conduction hearing levels increases with increasing frequency for both men and women, although this phenomenon is more dramatic for men than women. At 500 Hz, for example, the effect of age is approximately equal for men and women; for both, the average hearing level increases about .2 dB each year. At 4000 Hz, in sharp contrast, the effect of age is almost twice as large for men (one dB per year) as for women (.5 dB per year). This contrast can be seen more clearly by examining the age coefficients for the four shift measures; all four are approximately twice as large for men as women. This finding confirms the earlier observation that men suffer from presbycusis and the cumulative effects of non-occupational losses (sociocusis) more than women, even when controlling for occupational noise exposure.

The magnitude of racial differences similarly varies by sex and frequency.* At the low and mid frequencies (500, 1000 and 2000 Hz), no race differentials are noted for either sex, even when controlling for occupational noise exposure. At 4000 Hz, black men have significantly better hearing than their white counterparts with an average difference of 11 dB; however, no similar differential is noted for women. This again can be seen more clearly in the race coefficients for the shift measures. In each case, the shift in air conduction hearing levels from low and mid to high frequencies, both absolute and relative, is substantially larger for white males than black males. This is consistent with results reported elsewhere that blacks are more resistant to noise-induced hearing impairment than whites, and thus are likely to show smaller shifts in hearing levels from lower to higher frequencies (Bunch and Raiford, 1931; Karsai, Bergman and Choo, 1971; Royster, Thomas, Royster and Lilley, 1978; Royster, Royster and Thomas, 1980).

*The coefficients reported for race are the average differences between whites and blacks. For example, white males on average have air conduction hearing levels at 500 Hz which are .8 dB higher than those of black males, after controlling for age and occupational noise exposure.

Finally, as illustrated by examining the means in 5 dB increments, it is evident that the effects of occupational noise exposure are substantial for men and minimal for women.* For example, the noise exposure coefficients for each of the four shift measures are approximately ten times larger for males than they are for females. None of the noise exposure coefficients for women is statistically significant; with the exception of the tinnitus indicator, all are significant for men.

Because of these dramatic differences in the relationships for males and females, all subsequent analyses for auditory functioning have been conducted separately by sex. For both males and females, a number of additional background measures and their relationship with the auditory functioning measures were considered, statistically controlling for age and race. For males, those background variables which showed significant relationships with any of the auditory functioning variables were used as covariates in a further investigation of the relationship between occupational noise exposure and auditory functioning. For females, since noise exposure had no detectable relationship with auditory functioning, no further investigation into that relationship was conducted.

4.3 Selection of Independent Measures

Relationships between the set of demographic and physical characterisics and habits identified in Section 2.4 and the 10 measures of auditory functioning were examined next. The purpose of these analyses was to identify additional factors which could influence auditory functioning and which

---

*The occupational noise exposure variable was obtained by grouping occupations in ranges of 5 dB of noise exposure. Thus, for example, for males we know that average air conduction hearing level at 500 Hz increases .2 dB for each 5 dB increase in occupational noise exposure.

therefore should be controlled for when investigating the effect of occupational noise exposure.

Again, we assumed linearity in testing for significant relationships and estimating regression coefficients and effects. Analyses have been performed separately for males and females. Estimated regression coefficients obtained by separately regressing each independent variable together with age and race are reported along with the results of the associated significance tests. Results of significance tests are presented in Tables 4.5 and 4.6. The corresponding estimated regression coefficients are displayed in Tables 4.7-4.10.

For both men and women, demographic characteristics seem to have somewhat more influence on auditory functioning than do physical characteristics and habits. For men, each of the 10 demographic measures examined was related to at least one indicator of auditory functioning, some dramatically so; and for women, the same was true for all measures with the exception of SMSA.

Three of the demographic measures--income, years of education and poverty income ratio--are components of socioeconomic status (SES). It is, therefore, not surprising that each exhibits a similar relationship to hearing sensitivity for both sexes: with the exception of tinnitus, men and women at higher SES levels have better hearing than those at the lower levels. Note, however, that the magnitude of the effect is somewhat larger for men than for women. For example, men in the lowest income category have air conduction hearing levels at 4000 Hz 7.2 dB higher than men in the highest income category; the difference between the same two categories among women, on the other hand, is only 4.3 dB. Of the three SES variables, years of education shows the strongest and most consistent relationship with the dependent hearing variables, and it was therefore used in further analyses as a covariate.

Two demographic variables--size of place and SMSA--relate to an urban-rural continuum.* Generally, for both, there is indication of a positive relationship between auditory functioning and urbanization. Respondents, both male and female, who live in more urbanized areas have better hearing than their rural counterparts of the same age and race. Again, however, the tinnitus indicator is the one hearing measure which behaves in the opposite manner: the more urbanized respondents report <u>more</u> tinnitus. As was found for the SES variables, the majority of the relationships between urbanization and hearing are more pronounced for men than for women. Since, of the two urban-rural variables, size of place exhibited a marginally stronger relationship, it was selected for use as a covariate in further analyses of occupational noise exposure.

The variable "farm" indicates whether or not any substantial amount of commercial farming occurs at the respondent's residence, where "substantial" is defined rather liberally. It may therefore be more reasonably considered as an indicator of a respondent's domestic environment. For most agricultural workers, however, it may also relate to their occupational noise exposure. For both males and females, significant relationships between farm residence and hearing sensitivity are found; however, these relationships are in <u>opposite</u> directions for the two sexes. Generally, for men, respondents living on farms have substantially worse hearing than those who do not. This is especially true for the shift measures, where, for example, farm dwellers show an average of 6.5 dB greater shift from the

*The categories of size of place are in decreasing order by size.

average of hearing levels at 500 and 1000 Hz to 4000 Hz than do non-farm dwellers. For women, the relationship is reversed: female farm dwellers experience smaller shifts in hearing levels from low to high exposures than do non-farm dwellers.

Coefficients for marital status reflect average differences in hearing between respondents who are currently married and those who are not. The measures of shift in hearing are significantly related to marital status for both sexes. Here again, though, the direction of the relationship for men is reversed for women: currently married men have somewhat higher shifts than single men and currently married women somewhat lower shifts than single women.

The last demographic variable considered was region. Among women, air conduction hearing levels seem to be somewhat lower (i.e., better) in the West than in the rest of the country. Relationships with shift measures, however, are not large. For men, although region was not significantly related to the absolute thresholds, Westerners appear to be somewhat worse off with regard to the measures of shift in hearing levels.

On the basis of these analyses, marital status, size of place, farm, region and years of education were selected as demographic covariates for further study of the relationship between occupational noise exposure and auditory functioning among men.

In contrast to the strong findings for the demographic characteristics, the results of analyses linking hearing sensitivity with personal habits yielded only scattered significant results. The most striking and consistent of these were the relationships between hearing sensitivity and both alcohol use and the amount of occupational physical activity. For males, alcohol consumption is related to hearing levels at 2000 and 4000 Hz, the overall prevalence of hearing impairment, and three of the four shift measures; for females, all auditory functioning measures except the hearing level at 2000 Hz are related. The direction is the same for both sexes: non-drinkers have slightly worse hearing, on average, than do drinkers.

For males, the amount of physical activity at work is also related to all measures of auditory functioning except the hearing levels at 500 and 1000 Hz; however, it is not related for females. Men with higher levels of physical activity have on the average poorer hearing. This variable may be an indicator of blue collar/white collar job differentials and may primarily reflect differences in occupational noise exposure, rather than activity level.

The remaining characteristics in this group showed only a smattering of significant relationships. Of these, we consider here only those which show some significant relationship with auditory functioning for males, thus identifying covariates for further multivariate analyses. They are drugs for infection, aspirin use, cigarette smoking, alcohol use, and activity level.

Finally, four physical characteristics were considered as possible correlates of auditory functioning. Eye color was considered because there is some evidence from previous research that it is related to hearing. (See, e.g., Carlin and McCroskey, 1980; Carter, 1980; Hood, Poole, Freedman, 1976). Three anthropometric variables--height, weight and skinfold thickness, an indicator of subcutaneous fat thickness--were also included.

Previous studies have indicated that persons with brown eyes are somewhat less susceptible to hearing loss than others; no comparable difference was found in these data. Eye color does not appear to be related to hearing for men at all. Although there are significant differences among the various eye color groups for females, there does not appear to be any evidence that brown-eyed women have any better hearing than any other eye color groups. Since further multivariates analyses including occupational noise exposure were carried out for males only, eye color was dropped from further consideration.

Skinfold thickness, or relative fatness, appears to be related to auditory functioning in both males and females.* Again, the pattern is different for the two sexes. Among males, of all the air conduction hearing levels examined, only that taken at 4000 Hz is related to skinfold thickness: relatively fatter men have better hearing at 4000 Hz. However, each of the four shift measures _is_ related to skinfold thickness. Again, fatter men suffer less from a shift in hearing levels from low (and mid) to high frequencies. This may well be related to differential noise exposure levels, either environmental or occupational, or socioeconomic differences.

For females, no relationship between skinfold thickness and shift in hearing is evident. However, there does seem to be a relationship between skinfold thickness and air conduction hearing levels. Furthermore, this relationship is in the opposite direction from that which is evident for males: at each of the four frequencies, hearing levels for females _increase_ with increasing skinfold thickness.

Finally, weight (measured in kilograms) does not appear to be related to auditory functioning among men. For

---

*Skinfold thickness is the sum of the triceps and subscapular skinfolds, measured in millimeters.

women, however, the air conduction hearing levels are all related to weight. Furthermore, the direction of the relationship is the same as for skinfold thickness, a parallelism that is not surprising given the correlation between skinfold thickness and weight. Since there is no evidence of a relationship for males, weight was not considered as a covariate of auditory functioning in the remaining analyses of the effect of occupational noise exposure on hearing. Therefore, of the four physical characteristics, skinfold thickness and height were the only measures used as covariates in subsequent analyses.

4.4 Auditory Functioning and Occupational Noise Exposure: Adjusting for Other Covariates

In Section 4.3, a set of 12 variables was identified as being related to or correlates of at least one of the 9 auditory functioning variables related to occupational noise exposure among men. Each of these variables was then employed in turn as a covariate in the analysis of the relationship between auditory functioning and occupational noise exposure. The results of this regression exercise are displayed in Tables 4.11-4.19.

The first line of Table 4.11 presents the coefficients of noise exposure for each of the thirteen models considered for predicting air conduction hearing levels at 500 Hz. For the most part, the noise exposure coefficients are stable at approximately a .12 dB increase in hearing level per 5 dB increase in occupational noise exposure. However, when the SES indicator, years of education, is used as a covariate (Model 6), the noise exposure coefficient is more than halved. In fact, it is no longer significantly different from zero.

A similar phenomenon occurs with hearing levels at 1000 Hz. Table 4.12 shows that occupational noise exposure coefficients average about .14 dB per 5 dB increase in exposure for all but Model 6. As before, the introduction of education into the model more than halves the occupational noise exposure coefficient, to about .06. At this reduced level, this observed coefficient is no longer statistically different from zero. Thus, for low frequencies, the relationship between noise exposure and air conduction hearing levels is explained away, statistically, by controlling for years of education.

At the mid and high frequencies, however, the effects of occupational noise exposure persist, even when controlling for years of education (Tables 4.13 and 4.14). Although the noise exposure coefficients are reduced somewhat by controlling for education, in neither case is it as drastic a reduction as for hearing levels at low frequencies. Furthermore, for the mid and high frequencies, the noise exposure coefficients remain highly significant. At 2000 Hz, the noise exposure coefficient, which was relatively stable at around .37, is reduced to .24 by controlling for education. Similarly, at 4000 Hz, the reduction is from about .80 to .59.

Regression coefficients for predicting prevalance of hearing impairment are presented in Table 4.15. Since this measure is an derived from an average of hearing levels at 1000, 2000 and 4000 Hz, the effect of adding covariates to the model is somewhere in between that for low and high frequencies. There is some reduction in the noise exposure coefficient after controlling for education, but it is not great, and the coefficient remains statistically significant.

In Tables 4.16-4.19, coefficients for predicting each of the four measures of shift in hearing levels are presented. In each case, the noise exposure coefficients are not greatly affected by the introduction of additional covariates, except for education. By statistically controlling for education, the effect of noise exposure on the shifts in hearing levels is reduced by about 20 percent. However, the effect of noise exposure remains relatively large and highly significant.

In summary, the associations of occupational noise exposure with various measures of auditory functioning remain relatively stable when controlling for each of the covariates identified in the previous section, with the exception of years of education. When controlling for education, the observed association between occupational noise exposure and air conduction hearing levels at low frequencies disappears. At the mid and high frequencies, while the association is reduced somewhat by controlling for education, it remains quite strong. The same pattern is also observed for the shifts in hearing levels, measures which are designed to reflect hearing patterns associated with noise-induced hearing impairment.

CHAPTER FIVE: THE NONAUDITORY CORRELATES OF NOISE

Excessive noise exposure may have deleterious effects on human health over and above the decreases in hearing sensitivity discussed in the last chapter. In particular, noise has been associated with transient changes in blood pressure, heart rate and respiration, with alterations in hormonal levels and with gastrointestinal disorders. (See, e.g., Ahrlin and Ohrstrom, 1978; Carlestamn, Karlsson and Levi, 1973; Graff, Bockmuhl and Tietze, 1968; Parvizpoor, 1976; Welch, 1979; Thompson, 1981.) In some instances, the effect is of short duration; for example, the "startle" reflex displayed when an individual in a quiet room suddenly hears a loud noise. In other instances, however, the effects may be long-term, producing profound and perhaps irreversible damage. The physiological factor hypothesized to produce these long-term reactions is stress; that is, exposure to noise produces physiologic stress, which in turn produces other physiological and perhaps psychological changes. These long term extra-auditory effects of noise on human health are the focus of the present chapter.

As alluded to above, the health domains which noise has been postulated to affect are wide-ranging; as a result, we have not limited attention to a handful of specific conditions, but have explored a variety of aspects of human health. At the same time, it is important not to overlook the strong research evidence suggesting that of all the extra-auditory effects of noise, it is the relationship between noise and elevated blood pressure that is most likely to exist (MIT, 1976; Cohen, 1979). We therefore first consider the relationship between noise and hypertension (Section 5.1) and then investigate associations between the remaining health conditions and noise (Section

5.2). In addition, the relationship of all these health conditions to auditory functioning is explored in Section 5.3.

5.1 Hypertension and Noise

Hypertension, often called high blood pressure, is one of the more prevalent chronic conditions among adults in the United States. Estimates of the number of Americans with hypertension range from 23 million to as many as 60 million, depending on the criteria used for defining presence of the condition and the age range of individuals included in the calculations (NCHS, 1980). Epidemiological studies have shown that elevated blood pressure is a major risk factor contributing to death from cardiovascular disease (Kannel, Wolf and Dawber, 1978). Hypertension has also been linked to cerebrovascular disease (stroke), the third-ranked cause of death in the United States.

An association between noise exposure and elevated blood pressure has been documented in several cross-sectional epidemiologic research efforts (See, e.g., Shatalov et al., 1969; Parvizpoor, 1976; Mosskov and Ettema, 1977.) In fact, in a recent review of the literature, Thompson (1981) found that of 55 studies of the relationship between noise and blood pressure, 44 (80 percent) found positive associations. Although she concluded that such consistency of findings strengthens an inference of a causal connection, she cautions that many of these studies were conducted on nongeneralizable samples and did not adequately control for factors such as smoking and overweight, characteristics which have a well-established association with hypertension. In the present study, we attempted to investigate these associations on a generalizable sample while statistically controlling for relevant background characteristics.

5.1.1 Analytic Approach

Nine measures of blood pressure were examined--three measures of actual blood pressure levels, three measures of the variability of these blood pressure levels and three measures of hypertension. These variables were derived from the two individual sitting blood pressure measurements taken during the physical examination,* from the physician's diagnostic impression, and from information gathered during the medical history on the history of hypertension and use of hypertension medication.

The three measures of actual blood pressure were derived by computing the mean systolic blood pressure and mean diastolic blood pressure, as well as by computing mean average blood pressure. (Average blood pressure for a given reading was defined as 2/3 diastolic pressure + 1/3 systolic pressure.)

The three measures of variability in blood pressure were derived by computing the difference (in absolute value) between the systolic, diastolic and average blood pressures at each of the two readings. These measures of shift reflect the stability (or lack thereof) in an individual's blood pressure. Since the development of hypertension may be gradual, often first evidenced by erratic blood pressure readings, these measures of shift were intended to indicate possible labile hypertension.

The remaining three variables were intended to assess the presence of hypertension per se. The first of

---

*Although a third blood pressure reading was taken during the physical examination, the examinee was recumbent during the procedure. Since recumbent blood pressure differs systematically from seated readings and is not generally used to assess hypertension, this reading was not incorporated into the derived variables.

these measures, history of hypertension, was derived from medical history questions. Any individual who reported being told by a physician that he or she had hypertension or high blood pressure was coded as having hypertension under this measure. Because this variable includes many persons who were told that they were hypertensive some time ago as well as excluding many people who may truly have hypertension but who have not been undiagnosed, this variable was expected to have low reliability relative to the more objective measures. The second measure of hypertension was based upon the diagnostic impression of the NHANES I physician. Although this measure was expected to be more reliable than the self-report measure, it too may be considered a somewhat inconclusive measure. This is because the medical examination was not targeted at collecting data on hypertension per se; the condition was only recorded if the particular physician noted it (from his <u>single</u> blood pressure reading) or had cause to suspect it, and thus followed up on it.

The last indicator of hypertension was based on the two actual blood pressure readings and information from the medical history on the use of hypertensive medication. This variable, which classifies individuals into one of five categories--normotensive, labile hypertensive, borderline hypertensive, definite hypertensive, and on medication--was believed to be the most reliable indicator of high blood pressure. Initially, each examinee was tentatively classified into one of three categories based upon their first blood pressure reading:

- <u>tentative definite hypertension</u>--either systolic pressure of 160 mm Hg or more <u>or</u> diastolic pressure of 95 mm Hg or more;

- tentative borderline hypertension--systolic pressure below 160 mm Hg and diastolic pressure below 95 mm Hg, but not both systolic below 140 mm Hg and diastolic below 90 mm Hg; and

- tentative normotension--systolic pressure below 140 mm Hg and diastolic pressure below 90 mm Hg.

Examinees were then classified into these categories a second time based on their second blood pressure reading. Examinees were recategorized by comparing the two tentative classifications and reassigning them as follows:

- confirmed definite hypertension--tentative definite hypertension on both blood pressure readings.

- confirmed borderline hypertension--tentative borderline hypertension on both blood pressure readings or tentative borderline hypertension on one reading and tentative definite hypertension on the other reading;

- labile hypertensive--normotensive on one blood pressure reading and either tentative borderline or tentative definite hypertension on the other reading; and

- confirmed normotension--tentative normotension on both blood pressure readings.

The final classification scheme was developed by reclassifying any examinee who had taken hypertension medication into a fifth category--medication--regardless of his or her blood pressure readings.* This has been done both because anyone

*Note that for analytic purposes, this last measure was considered as five separate variables: the prevalence of normotension, prevalence of labile hypertension, prevalence of borderline hypertension, prevalence of definite hypertension and prevalence of hypertension medication.

who is on hypertension medication is likely to be hypertensive (as judged by the personal physician) regardless of what the objective readings indicate and because if the medication is truly effective, the objective assessments do not reflect the individual's true blood pressure, but a regulated one.

Analyses were conducted on the sample of 3842 persons who were either currently working, recently out of the job market or currently looking for a job, and for whom an occupational description was available. Initially, bivariate relationships between measures of blood pressure/ hypertension and occupational noise exposure were examined. Separate but parallel analyses were performed on men and women because of the established differences in blood pressure levels and the differences in occupational noise exposure in our analytic sample.* These analyses were then repeated, statistically controlling for age and race, to examine whether effects found were artifacts of the differential distributions of age and race in the occupational groups. The goal of these analyses was to identify a smaller set of dependent measures which, at least on the surface, were associated with occupational noise exposure. Bivariate relationships between the identified measures and the extensive set of background characteristics presented in Section 2.4 were similarly examined, statistically controlling for age and race. On the basis of these results, a smaller set of independent measures was selected to be examined in conjunction with occupational noise exposure in a multivariate framework.

*Although race has also been shown to be strongly associated with hypertension and elevated blood pressure, separate analyses were not performed on the white and black populations, because of the relatively small number of black persons in the analytic sample. Race was used as a covariate in all but the initial analyses, however.

5.1.2 Hypertension and Occupational Noise Exposure

Bivariate relationships between blood pressure/ hypertension and occupational noise exposure were initially examined separately for men and women. (Table 5.1 presents results for men; Table 5.2 presents results for women; Figures 5.A and 5.B display the most salient findings.) Analyses for men yielded four significant relationships: mean diastolic blood pressure; mean average blood pressure; physician's diagnosis of hypertension; and the prevalence of normotension. Men in the lowest occcupational noise exposure category ($\leq$ 70 dB) had a mean average diastolic blood pressure of 79.7 mm Hg and a mean average blood pressure of 94.3 Hg; men in the highest noise exposure category ($\geq$ 96 dB) had means of 85.4 mm Hg and 100.6 mm Hg, respectively. More strikingly, the prevalence of hypertension (as noted by the physician) was 6.4 percent in the 70 dB and under group and almost three times as high (at 17.7 percent) in the 96 dB and above group. Similarly, the prevalence of normotension (using the actual blood pressure readings) differed dramatically with respect to occupational noise exposure: 67.5 percent of the men in the 70 dB and below group were normotensive as compared with only 47.4 percent of those in the 96 dB and above group.

Analyses for women also yielded four significant relationships. As with men, significant differences in mean average diastolic pressure, mean average blood pressure and prevalence of normotension were found. In addition, the prevalence of labile hypertension significantly increased with increasing occupational noise exposure. Women in the lowest occupational noise category ($\leq$ 70 dB) had a mean diastolic blood pressure of 80.5 mm Hg and a mean average blood pressure of 95.4 mm Hg; women in the highest noise

Figure 5.A

Mean Systolic, Diastolic and
Average Blood Pressure By
Occupational Noise Exposure

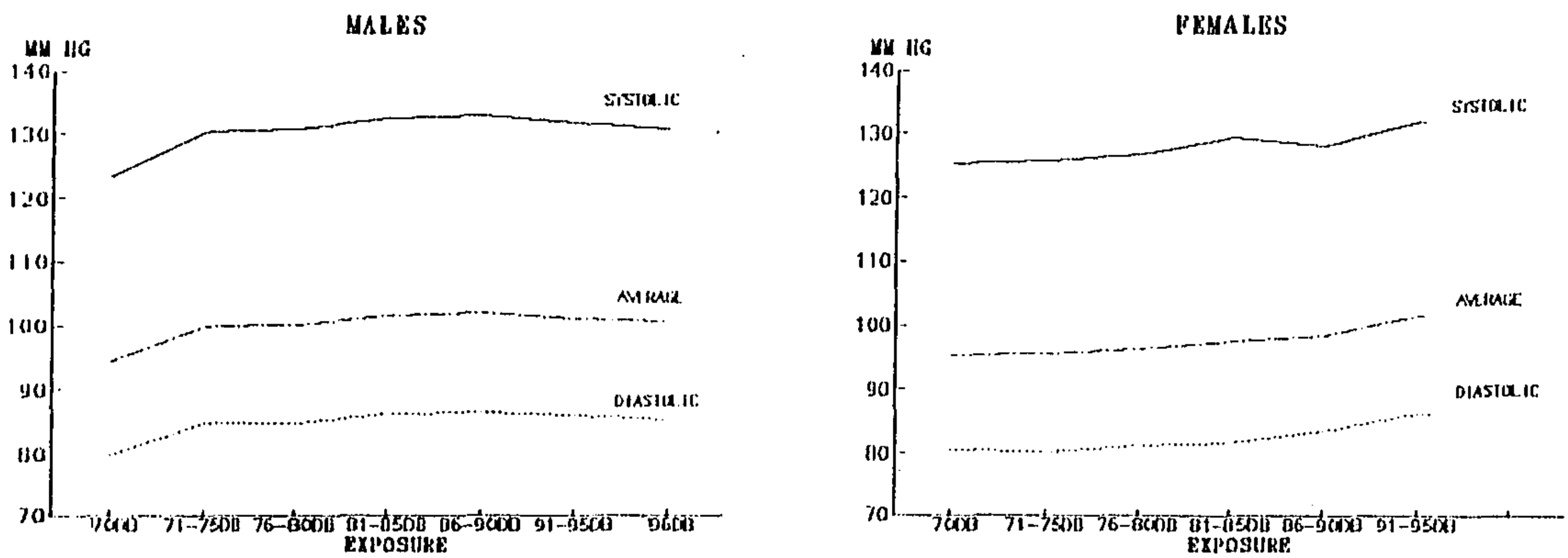
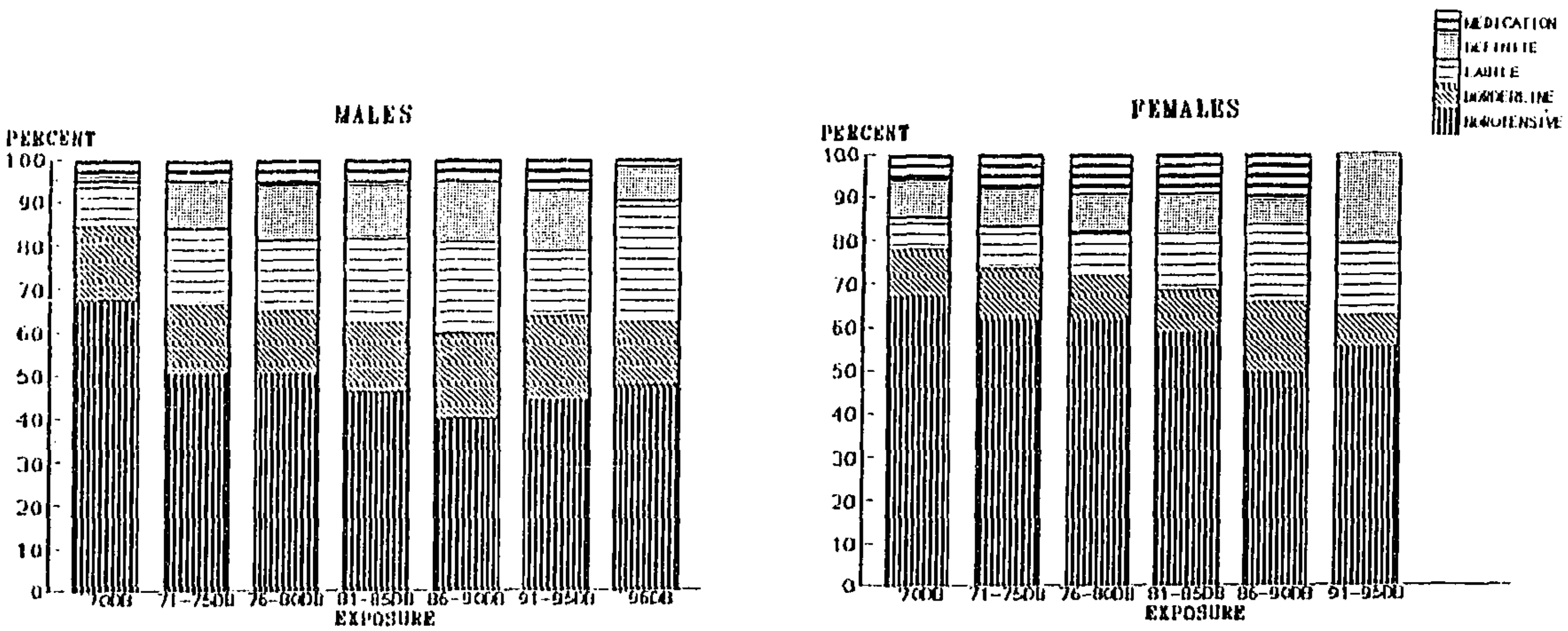


Figure 5.B

Distribution of Hypertension Based on Blood Pressure Readings By Occupational Noise Exposure



exposure category (91-95 dB, for women*) had means of 86.3 mm Hg and 101.6 mm Hg, respectively. The prevalence of normotension dropped 12.0 percent from the lowest to the highest noise exposure categories (from 67.0 to 55.0); this was reflected by an increase of almost 10 percent in the prevalence of labile hypertension (from 7.2 to 17.0).

The above analyses were then repeated, statistically controlling for age and race to determine whether any significant findings were artifacts of the differential distributions of age and race in the occupational noise exposure categories. (Significance tests are reported in the final columns of Tables 5.1 and 5.2; regression equations are presented for both men and women in Table 5.3.) For men, differences in mean diastolic blood pressure, mean average blood pressure and the prevalence of normotension remained significant; differences in the prevalence of the physician's diagnosis of hypertension were no longer significant. For women, only the relationships between noise exposure and mean diastolic blood pressure and prevalence of labile hypertension remained significant.

The regression equations presented in Table 5.3 can be used to compare the relative magnitudes of the effects of age, race and occupational noise exposure for men and women. Age appears to play a stronger role in elevated blood pressure for women than for men. The coefficients for age for the actual blood pressure readings, the measures of shift, and the history of and physician's diagnosis of hypertension are all approximately twice as large for women as for men. For example, for every year of age, a man's

---

*No stable estimates could be obtained for the 96 dB and above category for women, because only three people in the sample were classified into this cell. Subsequent analyses using occupational noise exposure as a continuous variable have included these three women, however.

mean systolic blood pressure is raised about a half a point; for women, the increase is almost a full point. The race differential (blacks have consistently higher blood pressure than whites) is approximately equal for both sexes. Although the coefficients for occupational noise exposure are generally higher for women than for men, these differences are not statistically significant.

Based on these bivariate relationships, four measures of blood pressure/hypertension that were significantly associated with occupational noise exposure for men or women (when statistically controlling for age and race) were selected for further study: mean diastolic blood pressure; mean average blood pressure; prevalance of normotension; and prevalence of labile hypertension.

5.1.3 Selection of Independent Measures

Relationships between the extensive set of demographic characteristics and physical characteristics and habits identified in Section 2.4 and the four selected measures of blood pressure/hypertension were then examined. The purpose of these analyses was to identify additional factors which might contribute to elevated blood pressure, and which therefore should be controlled for in examining the relative contribution of occupational noise exposure. As before, analyses were conducted separately for men and women, statistically controlling for age and race. Results of significance tests are presented in Table 5.4. Regression coefficients are presented in Table 5.5.

For both men and women, physical characteristics and habits played a substantially stronger role in contributing to elevated blood pressure than did socioeconomic and demographic characteristics. (Note that this is a complete reversal of the findings for auditory functioning.) For men, of all the demographic characteristics examined, only years of education was significantly associated with elevated blood pressure, and even this effect was rather small. A college graduate had a mean diastolic pressure .6 mm Hg lower than a high school graduate of the same age and race, and a mean average blood pressure that was .8 mm Hg lower. For women, the two measures of income (total income and the poverty income ratio) and size of place were the only demographic characteristics that were significantly associated with those measures of elevated blood pressure that were significantly associated with occupational noise exposure. In general, the higher the income, and the larger the community, the lower the blood pressure. But as with men, these effects were relatively small.

In direct contrast, the effects of physical characteristics and habits upon blood pressure were quite dramatic for both men and women. First and foremost of the relationships was the expected one found for hypertension medication: men and women on hypertension medication have substantially higher diastolic and average blood pressure than those not on hypertensive medication. For both sexes, the effect on average blood pressure was approximately 10 mm Hg; for men the effect on diastolic pressure was also about 10 mm Hg, but for women it was just under 6 mm Hg. The effects of weight, skinfold thickness and, to a lesser extent, height were also dramatic for both sexes. As many epidemiological studies have demonstrated, the more overweight the individual, the higher the blood pressure. For example, a difference of 10 kg in weight represents an approximate difference of 3 mm Hg in mean average blood pressure for men and 4 mm Hg for women. Alcohol use was also found to be associated with increased risk of hypertension for both men and women. For example, the prevalence of normotension was approximately 5 percent higher among men who did not drink at all or who averaged only 1 to 2 drinks per day than it was among men who drank 5 or more drinks per day. Finally, cigarette smoking was also associated with blood pressure especially among women; female smokers had mean diastolic and average blood pressure approximately two mm Hg lower than their age and racial counterparts who never smoked.

Based on these bivariate findings, a set of eight background characteristics was selected for examination in conjunction with occupational noise exposure in a multivariate framework. For men, this set was composed of the single demographic characteristic, years of education, and five physical characteristics or habits: skinfold thickness, weight, height, hypertension medication and alcohol consumption. For women, this set was composed of three demographic characteristics (income, poverty income ratio and size of place) and a related set of five physical characteristics or habits: skinfold thickness, weight, hypertension medication, alcohol consumption and cigarette smoking.

5.1.4 Multivariate Analyses

The next stage in the analysis was to examine the variables identified above in a multivariate framework including age, race and occupational noise exposure. Our goal in this work was not to model hypertension per se, but to examine the relationship between noise and hypertension. Although some might argue that the analyses presented in Section 5.1.2 validate this relationship, such research evidence is not sufficient. It is possible, for example, that a significant relationship found earlier is simply an artifact of the confounding of occupational noise exposure with an important underlying factor. Thus, these analyses were designed with the sole intent of determining if occupational noise exposure retained its significance in the presence of the identified independent variables, or if the effects found earlier might be inconclusive, largely due to a confounding of noise with other relevant factors.

Analyses were conducted separately for men and women using a modified forward stepwise approach. In each case, interest lay in examining the effects of the inclusion of other variables in addition to age, race and occupational noise exposure on the predictive power of the latter variable. Because use of hypertensive medication artificially alters an individual's blood pressure, this variable was included in all models which analyzed the continuous blood pressure measures. (Because this variable is a component of the categorical hypertensive measures, this was not necessary for these models.)

As shown in Section 5.1.2, occupational noise exposure was significantly associated with three indicators of blood pressure among men: mean diastolic blood pressure, mean average blood pressure and prevalence of normotension. Results of multivariate analyses of these measures are summarized in Tables 5.6, 5.7 and 5.8, respectively.

Initially, each indicator of elevated blood pressure was examined in a model with age, race, occupational noise exposure and hypertension medication (where appropriate). In every case, all variables were statistically significant. Anthropometric measures were then added to the model. These models first examined the relative roles of skinfold thickness and weight, by including skinfold thickness alone (Model 1), weight alone (Model 2), and skinfold thickness in conjunction with weight (Model 3). When skinfold thickness and weight are considered separately, each is statistically significant, although the equation with weight (Model 2) has a higher overall F-statistic (more predictive power). When both measures of stature are examined simultaneously, however, skinfold thickness is no longer statistically significant.* A parallel set of models was constructed including height in each combination (Models 4-6). Although height remained significant in each model, skinfold once again was nonsignificant when entered in conjunction with weight. Weight and height were therefore selected as the relevant anthropometric measures for subsequent work.

Alcohol consumption and years of education, the two remaining independent variables, were then examined in conjunction with age, race, occupational noise exposure, hypertension medication (where appropriate), weight and height (Models 7 and 8). Alcohol consumption remained statistically significant for each dependent variable and did not reduce substantially the predictive power of any of the other variables. The same was not true of years of education, however. As was found with analyses linking noise exposure with hearing, inclusion of years of education weakened the predictive power of occupational noise exposure. Although noise exposure remained significant for the analysis of normotension (at a greatly reduced level), it was nonsignificant in models of mean diastolic pressure and mean average pressure when years of education was included in the model. When both alcohol consumption and years of education were entered into the model (Model 9), alcohol consumption remained significant in all cases, years of education remained significant for mean average blood pressure but for no other variable, and occupational noise exposure was only significant for the prevalence of normotension, although at a reduced level. Thus, it is only possible to conclude that a weak, but nevertheless significant, association exists between the prevalence of normotension and occupational noise exposure among men.

*When weight and skinfold both enter as predictors, after eliminating the shared covariance, an estimate of lean body mass remains.

Analyses for women were somewhat more conclusive (Tables 5.9 and 5.10). As shown in Section 5.1.2, two measures of blood pressure were significantly associated with occupational noise exposure among women: mean diastolic blood pressure and the prevalence of labile hypertension. Each indicator was initially examined in a model with age, race, occupational noise exposure and hypertension medication (where appropriate). As was found for men, all variables were statistically significant. Anthropometric measures were then considered, but because height was never significantly related to measures of elevated blood pressure in women, these analyses were limited to weight and skinfold thickness. Once again paralleling the findings for men, skinfold thickness alone (Model 1) and weight alone (Model 2) are both significant predictors of hypertension. When both are entered simultaneously, however, weight retained far more predictive power (Model 3). In all instances, occupational noise exposure was statistically significant in the presence of the anthropometric measures.

No other independent measure was signficantly related to mean diastolic blood pressure; analyses of this variable therefore stopped at this point. Two other independent variables did remain to be tested in conjuction with labile hypertension: alcohol consumption and income. As shown in Models 4 and 5 in Table 5.10, both are significantly associated with labile hypertension, but the presence of either or both does not have any measurable effect upon the predictive power of occupational noise exposure.

In sum, a weak association was found between occupational noise exposure and elevated blood pressure in men, and a somewhat stronger relationship was found for women.

5.2 Other Health Conditions and Noise

Noise has been postulated to have an effect on many diverse aspects of human health ranging from fetal abnormalities to psychological stress. Although many studies have isolated a specific condition and then examined linkages with noise, the present study has adopted a broader approach of looking at the array of health data collected as part of NHANES I. Although this approach provides a great deal of opportunity for spurious findings (the 5 tests out of 100 that will be significant by chance alone at the .05 level), it also provides an opportunity to ensure that little will be overlooked.

5.2.1 Analytic Approach

In all, 25 indicators of health were examined--2 measures of overall health, 3 measures of psychological stress and 20 indicators of specific health conditions. These variables were derived from responses to questions asked during the medical history, from the physician's physical examination and from the general well-being questionnaire.

The two measures of overall health were intended to represent two distinct, but related, aspects of health--physiological well-being and psychological well-being. The only available indicator of general physiological well-being was the physician's diagnostic impression of the examinee as normal or abnormal. Psychological well-being was assessed through the total score on the general well-being questionnaire.

The three measures of psychological stress were derived from three distinct sources, each having its own associated unreliability. The first of these measures is probably the most reliable indicator: the examinee's score on the relaxed/tense subscale of the general well-being questionnaire. The second of these measures is the use of drugs for relieving symptoms of stress during the preceding six-month period. The third of these measures is probably the least reliable: the physician's diagnosis of mental disorders. This includes suspected neuroses, psychoses and assorted addictions, such as drug dependence or alcoholism.

The remaining 20 variables were intended to assess the presence of specific health conditions. Whenever possible, information was gathered from both the physician's examination and the examinee's report of his or her medical history. The complete list of health conditions was presented in Table 2.B.

Analyses were conducted on the sample of 3842 persons who were either currently working, recently out of the job market or currently looking for a job and for whom an occupational description was available. Initially, bivariate relationships between measures of health and occupational noise exposure were examined. Separate but parallel analyses were performed on men and women. These analyses were then repeated, statistically controlling for age and race, to determine whether effects found were artifacts of the differential distributions of age and race in the occupational groups. The goal of these analyses was to identify a smaller set of health conditions, which, at least on the surface, was associated with occupational noise exposure. Bivariate relationships between the identified measures and the extensive set of background characteristics were similarly examined, both alone and statistically controlling for age and race. On the basis of these results, a smaller set of independent measures was selected to be examined in conjunction with occupational noise exposure in a multivariate framework.

5.2.2 Health Conditions and Occupational Noise Exposure

Bivariate relationships between health and occupational noise exposure were initially examined separately for men and women. (Table 5.11 presents results for men; Table 5.12 presents results for women; Figures 5.C and 5.D display the most salient findings.) Analyses for men revealed that only the two measures of overall health--physician's diagnostic impression and general well-being score--were significantly associated with occupational noise exposure. Although some irregularities were found, men in the lower noise exposure occupations were found to have generally higher well-being scores than those in the higher noise exposure categories. The magnitude of this difference, however, is rather small. More strikingly, the prevalence of abnormal findings on the physician's diagnostic impression is only 34.8 in the 70 dB and below group and yet it always exceeds 50 percent in any other noise exposure group.

Analyses for women similarly yielded few significant findings; of the 25 health conditions examined, only 4 were significantly associated with occupational noise exposure. As for men, significant differences in the general well-being score were found. Parallel with this finding, significant differences in the relaxed/tense subscale were also noted for women. The remaining two significant variables were physician's diagnosis of infections and physician's diagnosis of skin conditions. It is difficult to determine from the mean prevalences, however, the direction of these relationships.

The above analyses were then repeated, statistically controlling for age and race, to examine whether any significant findings were artifacts of the differential distributions of age and race in the occupational noise exposure categories. (Significance tests are reported in

Figure 5.C

Distribution of Physician's
Diagnosis of Abnormal Findings By
Occupational Noise Exposure

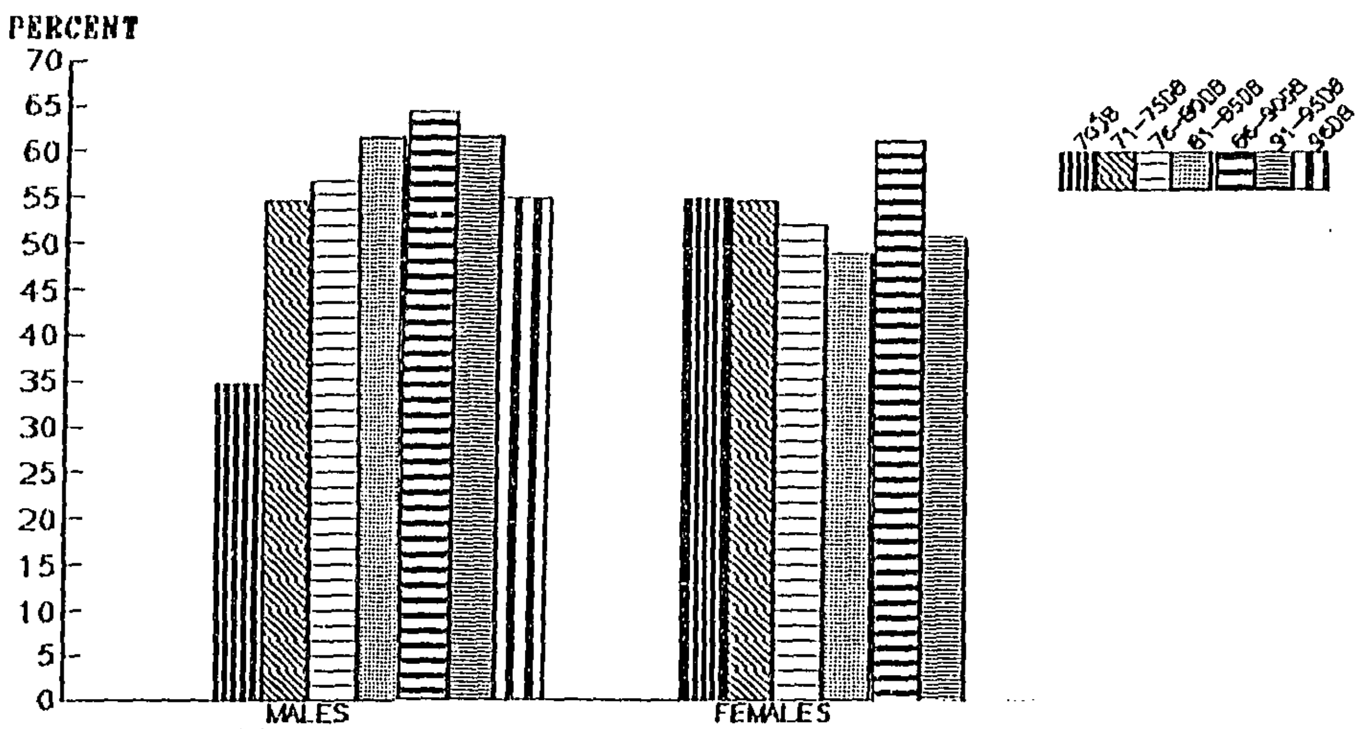
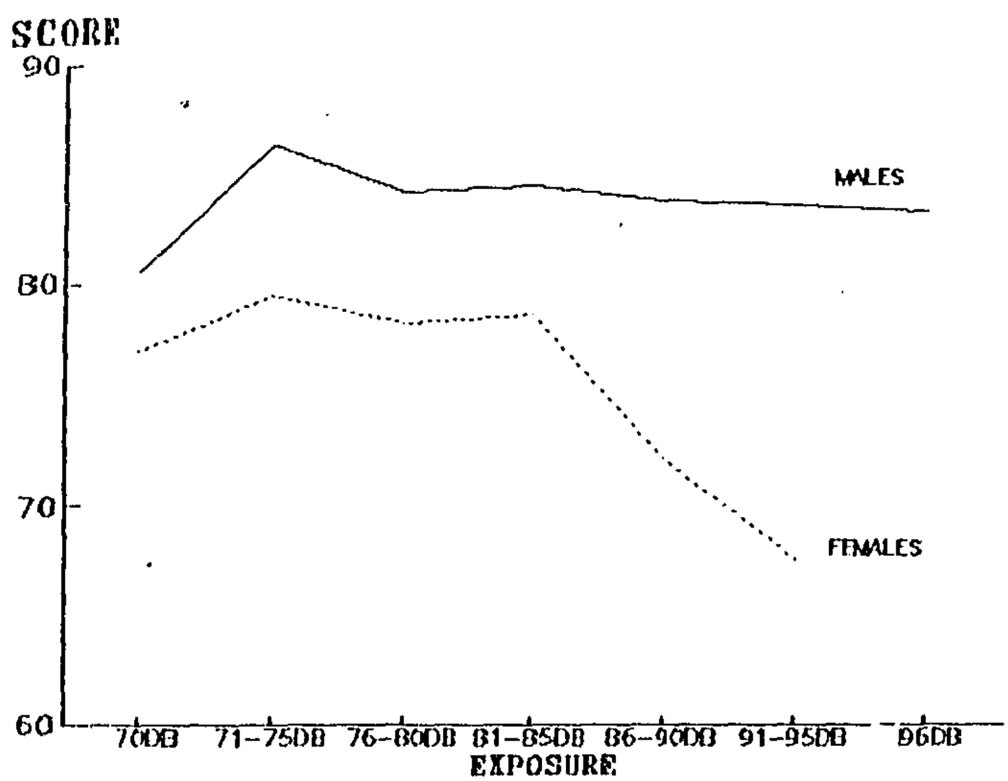


Figure 5.D

Mean General Well Being Score
By Occupational Noise Exposure



the final columns of Tables 5.11 and 5.12; regression equations for significant variables are presented for both men and women in Table 5.13.) Findings for both men and women remained completely stable in these analyses.

The regression coefficients presented in Table 5.13 can help elucidate the direction of the effects of occupational noise exposure in the case of the two specific health conditions for women. Although the direction of the effect is as expected for skin conditions (the higher the noise exposure, the higher the prevalence), it is in the opposite direction for infectious and parasitic diseases. That is, increased noise exposure is associated with a <u>decrease</u> in the prevalence of infections among women. While this result is significant, it has been set aside from all further analyses because it makes little sense and thus is more likely than the other findings to have been due to chance alone.

Based on these bivariate relationships, four measures of health were selected for further study: physician's diagnostic impression, general well-being score, relaxed/tense subscale score and physician's diagnosis of skin conditions.

5.2.3 Selection of Independent Measures

Relationships between the extensive set of background characteristics and the four selected measures of health were then examined.* The purpose of these analyses

*Use of hypertensive medication was set aside from these analyses because in this particular instance, it is simply another measure of the dependent variable. That is, if the examinee was on hypertensive medication, the physician was likely to give an overall diagnosis of "abnormal" simply because of the use of medication. Thus, this measure does not provide independent information for the purposes of these analyses.

was to identify additional factors which might contribute to the prevalence of these health conditions and which therefore should be controlled for in examining the relative contribution of occupational noise exposure. Analyses were conducted separately for men and women, statistically controlling for age and race. Results of significance tests are presented in Table 5.14. Regression coefficients for variables found to be significant for any dependent measure are presented in Table 5.15.

As was found for analyses of elevated blood pressure, physical characteristics and habits were more likely to be significant predictors of health conditions than were measures of demographic characteristics, although, as before, the magnitude of the differential varied by sex. For men, of all the demographic characteristics examined in relationship to overall health, only years of education was found to have an effect, and only for general well-being. A male college graduate had a total general well-being score one point higher on average than a male high school graduate of the same age and race. For women, on the other hand, several measures of socioeconomic status were strongly associated with both the total well-being score and the relaxed/tense subscore. In particular, total income, marital status and years of education were all significantly associated with these psychological well-being measures. Women with lower annual incomes, or who were single, or who had fewer years of education had lower general well-being scores (therefore, were less well overall) and lower relaxed/tense subscale scores (i.e., more tense). The size of these effects was often quite large; for example, a woman with a household income of $5,000 a year or less had a total well-being score a full nine points lower than a woman from a family with an annual income of $15,000 a year or more. Whether these dramatic relationships reflect true associations with psychological well-being or the ability of better-educated women of higher socioeconomic status to respond "appropriately" to the questionnaire, is difficult to determine, however.

Overall health was far more sensitive to measures of physical characteristics and habits. Of the 10 measures of this type examined, only 3 did not bear any relationship to the measures of health for men or women: use of drugs for infection, oral contraceptive use (women only) and height. The physician's diagnostic impression was only related to weight and skinfold thickness. As both these measures may indicate obesity, and obesity has been one of the more common specific conditions cited by physicians as indicative of poor health, this association is not unusual. The two indicators of psychological health, on the other hand, were not directly related to obesity but to the majority of lifestyle indicators: aspirin use, cigarette smoking, and activity level both on and off the job. Men and women who take aspirin have lower general well-being scores and are more stressed than those who do not; however, the direction of causality here is probably in reverse--those who are less well psychologically are more likely to take aspirin. Cigarette smoking also had its expected relationship to psychological well-being; smokers have the lowest general well-being and relaxed/tense subscale scores, ex-smokers are somewhat higher, and non-smokers have the highest scores. Activity both on and off the job is positively associated with well-being; for example, men and women who report that they get at least a moderate amount of exercise have general well-being scores that are 4 and 6 points higher, respectively, and relaxed/tense subscores that are on average approximately one point higher.

Based on these bivariate findings, a varied set of background characteristics was selected for examination in conjunction with occupational noise exposure in a multivariate framework. As the set of variables related to each particular health measure varied substantially from measure to measure, it was not possible to identify parallel sets of variables, as has been done in past sections. For the analyses of the physician's diagnostic impression, which was significantly associated with noise for men only, only two variables were carried forward--skinfold thickness and weight. For analyses of the physician's diagnosis of skin conditions, which was significantly associated with noise only for women, only alcohol use was included in subsequent work. For analyses of the general well-being score (for both sexes) and the relaxed/tense subscore (for women only), different independent variables were included for each sex. For men, this set was composed of years of education, aspirin use, smoking and the two indicators of activity. For women, this set was composed of total income, marital status, years of education, smoking and activity level in recreation.

5.2.4 Multivariate Analyses

The next stage was to examine the variables identified above in a multivariate framework including age, race and occupational noise exposure. Analyses were conducted separately for men and women using a modified stepwise approach. Results are presented for each dependent variable separately.

Physician's Diagnostic Impression. Analyses presented in earlier sections have determined that the diagnostic impression was associated with both occupational noise exposure and measures of obesity (skinfold thickness and weight) among men in the study sample. The question to be investigated here is whether or not noise exposure remains a significant predictor in the presence of the measures of overweight.

Table 5.16 (part A) presents results of three multivariate models which address this issue. Although the coefficient for skinfold thickness is nonsignificant when included in a model with weight, as was found for analyses of hypertension, occupational noise exposure remained significant regardless of the other variables in the model. Thus, controlling for age, race, weight and skinfold thickness, occupational noise exposure is associated with the physician's diagnostic impression for males.

Physician's Diagnosis of Skin Conditions. Alcohol use was the only background characteristic identified in the previous section to be associated with the physician's diagnosis of skin conditions for women. As shown in Table 5.16 (part B), occupational noise exposure is nonsignificant when entered in conjunction with alcohol consumption. It is therefore not possible to conclusively state that occupational noise exposure is associated with a higher prevalence of skin problems in women.

Relaxed/Tense Subscale. The relaxed/tense subscale, which was significantly associated with occupational noise exposure for women only, was also associated with years of education, income, marital status, aspirin use, cigarette smoking and exercise outside of work. Because earlier analyses had determined that years of education was most likely to weaken the predictive power of noise exposure, this variable was entered first into a multiple regression with age, race, and occupational noise exposure. As shown in Table 5.16 (part C), occupational noise exposure is no longer a significant predictor of a woman's score on the relaxed/tense subscale when examined in conjunction with years of education.

General Well-Being. This measure of general psychological status was associated with occupational noise exposure for both men and women, although the degree of the relationship was far stronger for women than for men. For women, each 5 dB increase in noise exposure (in the range from 70 to 100 dB) was associated with an approximate 2 point decline in the overall score, whereas for men, a 5 dB increase was only associated with a half-point decline. This measure was also associated with a host of background characteristics for both sexes, and thus the conclusiveness of the findings remained to be tested.

Of all the background characteristics identified in the previous section, years of education was most likely to diminish the predictive power of noise exposure, so it was entered into the model first. As shown in Table 5.17, although noise exposure was no longer a significant predictor of general well-being for men, the relationship for women was not severely attenuated. Analyses for men were therefore concluded at this point* and models for women were further explored.

Four background variables remained to be tested: two measures of socioeconomic status (income and marital status) and two lifestyle measures (cigarette smoking and activity level outside of work). Socioeconomic factors were examined first. When either income or marital status was examined alone in conjunction with occupational noise exposure, both the variable itself and noise exposure remained significant (Models 2 and 3). Addition of years of education to the models did not significantly alter this picture, although the coefficient for noise exposure was diminished somewhat (Models 4 and 5). However, when income

*The general well-being score was also examined in conjunction with the physical characteristics and habits identified in the previous section, such as activity level and cigarette smoking. Although noise remained significant in the presence of these predictors, once years of education was entered, it was no longer significant.

and marital status were considered in the same model without years of education, marital status was nonsignificant (Model 6), and when they were considered in the same model with years of education, both were nonsignificant (Model 7). These variations are due to the correlation between marital status and income in our sample of working women, a correlation that is not surprising given that women who are married are more likely to be in two-income households (generally with higher total incomes) and those who are single are probably the only wage earner. Based on these results, years of education and income were selected for further examination.

The relative roles of the two lifestyle characteristics were examined next. When activity level and cigarette smoking were examined in conjunction with age, race and occupational noise exposure, all variables remained significant (Models 8 and 9). Similarly, little changed when both these lifestyle measures were examined simultaneously with noise exposure (Model 10).

As a final step, the identified socioeconomic characteristics were entered simultaneously with the lifestyle descriptors (Model 11). All variables, including occupational noise exposure, remained significant, thus suggesting that its effect is over and above the other variables entered in the model. Note, however, that the magnitude of the coefficient was reduced substantially through the addition of background characteristics. Controlling for age, race, education, income, activity level and smoking, a 5 dB increase in occupational noise exposure is associated with a one-point decrease in the general well-being score, as opposed to the two-point uncontrolled decrease.

5.3 Auditory Functioning and Selected Health Conditions

In addition to the individual investigations of auditory functioning and health as they related to noise exposure, the relationship of auditory functioning to the extensive set of health conditions was analyzed. Toward this end, linear regressions of the 10 measures of auditory functioning on each of the health conditions were conducted separately for males and females, adjusting for age and race. Table 5.18 indicates which diseases were found to be significantly related to auditory functioning. The associated regression coefficients are displayed in Tables 5.19 and 5.20. It should be emphasized that no causal relationship between these two sets of variables is postulated here. Significant findings may well be due to common causes, drug treatment or some more complicated causal linkage. The information presented here is merely intended to be descriptive of some concomitants of auditory functioning.

Among the measures, tinnitus seems to be most consistently associated with the health conditions. (As has been noted in Chapter Four, tinnitus also stood out as distinctive from the nine other measures of auditory functioning on analyses of occupational noise exposure.) In fact, for males, while some health conditions are related to air conduction hearing levels and others to tinnitus, it is only the physician's impression of overall health which is related to both tinnitus and hearing levels. For males, the reported prevalence of tinnitus is positively related to the prevalence (either reported or diagnosed) of respiratory, muscular-skeletal and gastrointestinal disorders, the reported use of drugs for stress and the physician's overall diagnostic impression. In addition, the prevalence of tinnitus is negatively related to the two scores indicative of the signs and symptoms of stress. That is, those men whose scores suggest low stress were <u>less</u> likely to report tinnitus.

For females, the results for tinnitus are not as consistent. Prevalence of tinnitus was found to be positively related to the prevalence of respiratory disorders (either physician-diagnosed or self-reported) as well as the use of drugs for stress. In addition, just as was found for their male counterparts, there was a negative association between the two stress scores and the prevalence of tinnitus: Those women whose scores indicate low stress were less likely to report tinnitus. On the other hand, tinnitus was found to be negatively associated with the prevalence of infections and genito-urinary disorders; women who reported tinnitus were less likely to have these conditions. More perplexing, reported and diagnosed prevalence of neoplasms have associations with tinnitus in opposite directions.

More scattered results were found for the air conduction hearing levels, one or more of these measures were positively related with the physician's overall diagnostic impression, neoplasms, nervous system disorders and mental conditions. That is, the reported or diagnosed presence of one of these conditions was found to be associated with elevated hearing threshold levels at one or more frequencies. Of these relationships, the two conditions showing the largest effects were mental conditions and nervous system disorders. This latter finding is of particular importance because the diseases of the ear and mastoid process (ICD codes 380-389) constitute the largest component of this overall construct. As a result, persons with positive nervous system findings are more likely to have auditory problems, especially conductive impairments, such as otitis media, resulting from diseases. Such conductive impairments generally produce rather flat audiograms with approximately equal impairment at all frequencies, all usually outside the range of normal. The contrast discussed here compares these individuals, many who have conductive impairments, with the rest of the male population, whose hearing levels are generally low and within the range of normal at the low frequencies, but considerably higher at the higher frequencies. As a result, a significant relationship is found between the presence of such nervous system disorders and hearing levels at 500, 1000 and to a lesser extent 2000 Hz but not at 4000 Hz.

One condition, genito-urinary disorders, was negatively associatd with hearing levels. Those men diagnosed as having disorders of this type had, on average, lower hearing thresholds (i.e., better hearing) at all four frequencies. Furthermore, the effects were relatively large: average hearing levels at 4000 Hz, for example, were 11 dB lower for those with diagnosed genito-urinary disorders.

The shift measures were associated with the physician's overall diagnostic impression, diagnosed mental conditions, and nervous system disorders; however, for the latter two measures, the association was in a negative direction. That is, persons with these health conditions had <u>lower</u> shifts than those without these conditions. Although this may at first appear counterintuitive, it is simply a function of the earlier finding of significant differences in hearing levels at the lower frequencies but not at 4000 Hz with regard to the presence of these conditions. When these lower frequency hearing levels are increased, without corresponding increases in hearing levels at 4000 Hz, the shift in hearing levels is reduced. As a result, these people have lower shifts relative to the majority of males in the population. These significant differences should <u>not</u> be taken to mean that these health conditions are associated with better hearing. Rather, these conditions are associated with hearing impairment, but of a different type, that of functional impairment at the lower frequencies.

The associations for females are again contradictory. Here, too, a positive association between the physician's diagnostic impression and hearing levels was found, though the association was at higher frequencies whereas for men it was at lower frequencies. For women as for men, the average differences were relatively small, less than 2.5 dB at 4000 Hz. On the other hand, four other conditions--respiratory, muscular-skeletal, gastrointestinal and infections*--were all negatively associated with hearing levels at one or more frequencies. That is, those females diagnosed as or reporting having these disorders had, on average, better hearing than other women.

Having noted these somewhat preplexing results, it should be re-emphasized that no causal relationships are suggested here. These associations could be due to any one of a number of confounding variables not included in these analyses. In addition, the problem of multiple comparisons in statistical inference should be recalled. Numerous statistical tests have been conducted in this analysis. If they were all statisticallly independent (which they are not) one would expect to find "statistically significant" results at least 5 percent of the time even if there were no true associations. Almost surely, some of the results noted here are indeed spurious.

---

*The direction of this finding, with respect to infectious disease, parallels that for noise exposure in women; women who were exposed to for higher levels of noise had a lower prevalence of infectious diseases.

CHAPTER SIX: DISCUSSION

Hearing impairment is believed to be a major health problem in the United States today (NCHS, 1975a; NCHS, 1981). Estimates of the prevalence are as numerous as the studies conducted, but there has been general agreement that the overall rate is between 5 and 10 percent (NCHSb, 1968, NCHS, 1975b). One of the primary causes of these impairments is postulated to be noise exposure; long-term exposure to excessive noise has been shown to have marked deleterious effects upon hearing and the ability to understand speech, especially in a noisy environment (Passchier-Vermeer, 1968; Robinson, 1970; Baughn, 1973; Suter, 1978). Both small-scale clinical studies and larger field investigations have also suggested that excessive noise may be linked to other aspects of overall health and well-being including specific ailments such as hypertension, cardiovascular disease and stress (see e.g., Parvizpoor, 1976; Cohen, 1973; Welch, 1979; Thompson, 1981).

The results of the present study generally support this earlier research. However, they also depart from these findings in several respects. First, the present study shows that not only is hearing impairment a major problem in the United States, but that previous estimates of its prevalence may, in fact, have been overly conservative. This difference is not due to a decrease in the hearing sensitivity of Americans, but rather to recent changes in the criteria by which such rates are computed. Second, although occupational noise exposure was found to be a major contributing factor associated with auditory functioning among men, no parallel relationship was found among women. This lack of findings for women is probably attributable to differences in current noise exposure and noise exposure histories between men and women. Third, significant associations between both hypertension and physical health and noise exposure were noted for men, as were linkages between noise and both hypertension and psychological well-being among women; however, these relationships were weak in general. In addition, no conclusive relationships were found with the majority of indicators of specific health conditions for either sex. Whether the fact that only scattered findings were uncovered in the nonauditory domain is reflective of a true lack of relationships or whether it is due to the inability to isolate the effects of noise exposure from other characteristics can only be a point of speculation in the present study.

6.1 Prevalence of Hearing Impairment

Determination of the prevalence of hearing impairment in this country is entirely dependent upon the method and assessment criterion used to classify individuals into normal and impaired groups. Two general approaches were used in the present study--self-assessment and pure-tone audiometry--and for each approach a varied set of criteria were used.

An estimated 16.1 percent (17.2 million) of the adults aged 25-74 years reported that they have had deafness or some other trouble hearing at some point in their lives. An alternative view of the prevalence of perceived hearing impairment is that 13.9 percent (14.8 million) feel that their hearing acuity in at least one of their ears is a little decreased (or worse) and 7.4 percent (7.9 million) feel that even the hearing in their better ear is a little decreased (or worse).

Similar questions have been included in several large-scale studies during recent years. Reference here is limited to four which were conducted on national probability samples and thus can be used to generate comparable population estimates. Note, however, that subtle variations in wording may make direct comparisons from one survey to the next difficult.

The earliest of the comparable studies, conducted from 1960 to 1962, was the predecessor to NHANES I--Cycle One of the Health Examination Survey (HES I). Participants were asked to evaluate their own hearing as good, fair or poor and indicate whether or not they have had deafness or other trouble hearing. An estimated 3.4 percent of the adult population aged 25-74 years considered their hearing to be poor, 26.7 percent reported it to be fair, and the remaining 69.9 percent indicated that it was good. Direct comparison between these estimates and those from the present study is virtually impossible, however, because of the change in wording of this overall hearing rating question. It is possible to compare responses to the second question. HES I estimated that 15.6 percent (14.4 million) of the adult population had had deafness or trouble hearing; a number well within the margin of error for the NHANES I estimate of 16.1 percent.

The remaining studies were part of the Health Interview Survey (HIS), an annual survey of some 40,000 to 45,000 households that has collected information on the prevalence of selected impairments three times during the past two decades. The earliest of these surveys, conducted immediately after HES I from 1962 to 1963, estimated that 6.3 percent of the population aged 17 and older had deafness or serious trouble hearing in one or both ears (NCHS, 1967). Although it is obvious that this estimate is far more conservative than those generated from HES I or the present study, the cause of this discrepancy is not clear. One possible explanation is the change in wording of the questionnaire; the 1962-63 estimate of "serious" trouble may, in fact, be comparable to the 7.4 percent in the present study who feel that their hearing in their better ear is slightly decreased. A more likely source of the dramatic difference, however, is respondent error. The HIS surveys have traditionally relied on "any competent family member 19 years of age or older" to serve as a proxy respondent in the absence of any household member. Since it is likely that such a respondent would underestimate the severity of a hearing problem for another household member, or perhaps not even be aware of such a problem, the HIS estimates are probably overly conservative.* The strength of this latter explanation is borne out by examination of the prevalence estimates from the 1971 and 1977 surveys, which eliminated the adjective "serious" from the relevent question (NCHS, 1975; NCHS, 1981). Even while including tinnitus as a possible hearing problem (which neither HES I nor NHANES I did), the 1971 and 1977 surveys estimated that only 10.0 and 10.1 percent, respectively, of the population ages 17 and older had deafness or trouble hearing. Since the 1960-62 survey estimate closely approximates that for the present study, it is unlikely that these decreases during the interim period truly reflect a temporary improvement in the perceived hearing status of the U.S. Thus, although the number of adults with perceived hearing troubles has increased somewhat during the past two decades from 14.4 million to 17.2 million, the prevalence of perceived problems has remained unchanged due to the concomitant increase in the size of the population aged 25-74 during this period.

The relative stability of the hearing sensitivity of the U.S. population over the past 20 years is further

*The difference could also be due to the wider age band used for the HIS prevalence estimate: 17 and older. However, the inclusion of both younger and older persons may balance this problem out to some extent.

reinforced by the comparison of objective indices of hearing handicap from HES I, the last national survey to collect such data, with the present study. Using the AAOO-1959 standard of the average of hearing levels at 500, 1000 and 2000 Hz in the better ear greater than 25 dB (ANSI-1969), the NHANES I estimate of prevalence--7.4 percent--is not significantly different from the HES I estimate of 7.2 percent.

Both of these prevalence rates are dramatic underestimates of the true prevalence of hearing impairment among adults in the United States, however (see Table 6.A). As discussed in earlier chapters, none of the major organizations which have developed criteria for determining the presence of hearing impairment currently use this criterion, because they feel that it does not give adequate weight to high-frequency losses. To accurately estimate the numbers of persons with a hearing impairment we must therefore adopt one of the two more commonly used criteria: the OSHA-1981 criterion based on the average of hearing levels at 1000, 2000 and 3000 Hz with a 25 dB low fence or the AAOO-1978 criterion based on the average of hearing levels at 500, 1000, 2000 and 3000 Hz with a 25 dB low fence. Setting aside the controversial better ear vs. worse ear corrections and employing the conservative (better ear) approach, the OSHA-1981 criterion would produce a prevalence in the range from 8.4 percent to 13.0 percent, while use of the AAOO-1978 standard would yield an estimate just under 12.8 percent. Synthesizing these figures, it seems reasonable to estimate that between 10 and 12 percent of the adult population in this country have a hearing impairment in their better ear.

Perhaps more staggering is the fact that these estimates say nothing of the millions of Americans for whom the loss in one ear is more substantial than the loss in the

Table 6.A

Prevalence of Hearing Impairment and Estimates of Number of Persons Affected Under Alternative Definitions

Definition	Criterion Used in Present Study	Prevalence (in percent)				Number of Persons Affected (in millions)			
		Better	Right	Left	Worse	Better	Right	Left	Worse
AOO-1959 (Average of 00, 1000 & 2000 > 25 B)	Average of 500, 1000 & 2000 > 25 dB	7.4	11.0	12.0	15.6	7.7	11.5	12.5	16.4
SHA-1981 (Average of 000, 2000 & 3000 >25 B)	Average of 1000, 2000 & 4000 > 30 dB	8.4	14.5	15.7	19.6	8.7	15.1	16.4	20.6
	Average of 1000, 2000 & 4000 > 25 dB	13.0	20.8	23.0	27.8	13.5	21.8	24.0	29.1
AOO-1978 (Average of 0, 1000, 2000 and 00 > 25 dB)	Average of 500, 1000, 2000 & 4000 > 25 dB	12.8	17.2	18.9	23.3	13.3	18.0	19.8	24.4

other ear. Recall from the previous discussion that almost as many people felt that their hearing in only one ear was slightly decreased (6.5 percent) as felt that their hearing in their better ear was slight decreased (7.4 percent). Even more substantial differences are found when comparing the more objective criteria. Under every definition considered, twice as many adults have a hearing impairment in their worse ear as have a hearing impairment in their better ear. In particular, the OSHA-1981 definition for the worse ear would produce a prevalence in the range from 19.6 percent to 27.8 percent and the AAOO-1978 definition for the worse ear would yield a prevalence estimate just under 23.3 percent. Synthesizing these figures, it seems reasonable to estimate that between 20 and 25 percent of the adult population in this country have a hearing impairment in their worse ear.

To the casual observer, these differences of a few percent may seem to be trivial, with little practical significance from a public health perspective. But it is precisely the broader perspective that best illustrates the importance of these findings. In point of fact, in national probability surveys such as the present study, percentage estimates can be directly translated into accurate population estimates. For example, in the present report, each percentage point increment in a prevalence rate represents an additional 1.1 million persons aged 25-74 years. Thus, our conservative estimate of the prevalence of hearing impairment in the better ear (10 to 12 percent) translates into a population estimate of between 11.0 and 13.2 million affected persons. And our more liberal estimate of the prevalence of hearing impairment in the worse ear (20 to 25 percent) translates into a population estimate of between 22.0 and 27.5 million affected persons.

It is therefore clear that the oft-cited estimates that between 5 and 10 percent of the adult U.S. population have a hearing impairment are underestimates. Instead, we may now estimate that between 10 and 12 percent of the adult U.S. population have a hearing impairment in their better ear and between 20 and 25 percent have a hearing impairment in their worse ear under the more currently accepted criteria.

6.2 Hearing Sensitivity and Occupational Noise Exposure

The results of the present study clearly demonstrate that men whose current jobs entail exposure to high levels of noise have significantly poorer hearing than those employed in quieter environments. These effects are found across the entire frequency band examined, but are especially pronounced at the mid and high frequencies--2000 and 4000 Hz. Moreover, these mid- and high-frequency losses are found regardless of the age of the individual or his sociodemographic profile. Given that the present study used only approximate indicators of occupational noise exposure, a procedure which would probably lead to the underestimation of true effects, the strength of these relationships is particularly striking. Occupational noise exposure is not significantly related to hearing sensitivity among working women, however.

The finding that occupational noise exposure is associated with decreased hearing sensitivity is not revolutionary. Reports of occupational hearing impairment date back to ancient Egypt, with accounts of hearing difficulties among persons who fished for a living in the cataracts of the Nile. In the past two decades, several investigators have attempted to precisely quantify the relationship between noise exposure on the job and hearing impairment. Passchier-Vermeer (1968) synthesized data from 8 studies conducted from 1954 to 1964 on male and female workers with at least 10 years exposure to constant steady broad-band noise. She demonstrated that although differences in hearing sensitivity at 500 and 1000 Hz did not emerge until work exposure exceeded approximately 90 dBA, functioning at 2000 Hz was appreciably affected by exposures as low as 85 dBA, and performance at 4000 Hz was directly related to all exposure levels greater than 75 dBA.

Baughn (1973) studied the hearing levels of 6835 men exposed to a broad range of levels of continuous eight-hour industrial noise for varying numbers of years. Significant adverse effects were found for men in environments with average noise levels as low as 80 dBA, after several years' exposure. Although more pronounced at the higher frequencies, as one would expect, these differences were even manifested in the prevalence of hearing impairment as defined by the average of hearing levels at 500, 1000 and 2000 Hz $>$ 25 dB.

Burns and Robinson (1970) also collected audiograms and noise histories of a sample of men and women with a wide range of exposure times, noise levels and frequency spectra. Although they too found differences in auditory sensitivity by noise exposure, especially at the higher frequencies, the effects of noise on hearing levels were far smaller in this study than in those of Passchier-Vermeer or Baughn. This is probably because the Burns and Robinson study employed rather rigid subject selection criteria, screening out any cases with hearing losses known or suspected to be due to other causes.

How do the results of the present study compare with the estimates produced by these earlier investigators? Unfortunately, it is virtually impossible to make reasonable direct comparisons because these earlier studies have relied on estimates of lifetime noise exposure and the present study did not have such noise exposure history or even occupation history at its access. As a result, we can only estimate current noise exposure and cannot estimate total lifetime noise exposure without making a series of unrealistic simplifying assumptions. Although it would be possible to make such assumptions, for example, lifetime exposure = age - 18 (the age at which the average worker supposedly enters the labor force), we feel that the inaccuracies which such an approach would introduce to the findings would far outweigh the value they would contribute. However, without generating precise estimates of the magnitude of the effects, we feel it is still possible to accurately conclude that increased noise exposure is associated with poorer hearing acuity among men.

Despite this highly significant relationship between noise exposure and hearing sensitivity among men, no parallel relationship was found for women. Although this differential may have a physiological basis (women's ears have different acoustic properties than men's ears and thus they may simply be less sensitive to noise), it is more probably attributable to differences in current noise exposure and noise exposure histories between men and women. First, although a women may have the same occupational title as a man, it is likely that she will be exposed to less noise than a man would in the same job, due to sex biases in employment and job assignments. Thus, although her job title might assign her to a higher occupational exposure group, this assignment may reflect an overestimate of her exposure. Such errors in assigning individuals to categories make it far more difficult to detect effects. Second, a women of a given age in a given job is likely to have had less experience in that job than a man of the same age, because of the patterns in female labor force participation over the last several decades. Also, some high noise exposure jobs may have only recently have been filled by women. Moreover, a women is less likely than a man to have had exposure to noise in the military. Taken together, these three factors imply that regardless of a women's current job, her total lifetime duration of exposure will probably be lower than that of a man with similar background characteristics. Third, a woman is less likely than a man to have non-occupational exposure to excessive noise through the use of such equipment as power tools or firearms. Thus, although a man and woman may be exposed to the same amount of noise during the worday, the recovery periods available to women may lessen the impact of occupational exposure.

Finally, very few women in the sample under study were employed in occupations typically having high noise exposures; in fact, only three women were assigned to the category 96 dBA and above. Since the ability to detect a relationship is directly influenced by whether or not there are ample data in the extremes of the distribution, these null findings for women may simply be a function of insufficient sample size. Thus, although the present study was unable to demonstrate a relationship between auditory functioning and occupational noise exposure among women, we cannot conclusively state that such a relationship does not, in fact, exist.

6.3 Health and Occupational Noise Exposure

Occupational noise exposure was also found to have a weak, but nevertheless significant, association with several indicators of hypertension for both men and women. In particular, excessive noise exposure was associated with a decrease in the prevalence of normotension among men and an increase in the prevalence of labile hypertension among women; in addition, a direct relationship with elevated diastolic blood pressure was observed, especially for women. In addition, men in higher noise exposure occupations were more likely to be diagnosed by the NHANES I physician as having some physical ailment or abnormality. Although no comparable finding for overall physical health was noted for women, a significant decrease in psychological well-being was found among females in high noise occupations. No other significant difference in the prevalence of specific health conditions, including cardiovascular disease, respiratory conditions or gastrointestinal disorders, was noted.

Many studies have tended to support the existence of a relationship between noise exposure and hypertension. In a recent review of the foreign literature on the extra-auditory effects of noise, Welch (1979) stated that "the dominant and best documented concomitant of prolonged routine noise exposure to intense industrial sound is impaired regulation of blood pressure, the most distinct manifestation of which is an increase in hypertension" (p. 2). Welch supports his thesis by reviewing the results of some 28 investigations. Typical of these studies is the work of Kachny (1977), an examination of approximately 600 young Russian women employed in the weaving industry. Although a trend towards hypotension was initially uncovered, this was transformed to a tendency towards hypertension after 5 to 10 years on the job. Extrapolating from these data, as well as those from other studies, Welch has anticipated that increases in the rate of hypertension will occur in noise-exposed populations over and above the already high rates found in non-noise-exposed populations.

Welch's conclusions are supported by a number of other researchers. For example, in a study of 117 workers involved with heavy machinery emitting noise levels in the range from 95 to 110 dBA, Graff et al. (1968) found a significantly higher prevalence of hypertension among the exposed workers (36 percent) than among controls exposed to relatively low levels of noise (12 percent). Similar findings were noted by Parvizpoor (1976) in his study of 821 weavers exposed to noise levels averaging 96 dBA and 412 controls employed in light industry. Significant differences were observed in the prevalence of normotension, borderline hypertension and definite hypertension between the weavers and the non-noise-exposed controls of similar background. For example, the prevalence of definite hypertension was 8.5 percent among the weavers and only 2.4 percent among the controls. Increased risk of developing hypertension, even at relatively young ages (e.g., 30-39 years), was also found. Although these findings might be due to a self-selection bias influencing employment in weaving (e.g., workers with heart problems might be more likely to take weaving jobs because they can be performed sitting down), the strength of Parvizpoor's findings is nevertheless convincing. And the modest, but significant, increase in labile hypertension among women and decrease in normotension among men in noisier occupations in the present study lends further support to these conclusions.

In addition to changes in prevalence rates of hypertension, simple changes in diastolic blood pressure were noted in the present study. In particular for female workers, an increase in noise exposure was significantly associated with an increase in mean diastolic blood pressure. The fact that changes in diastolic pressure were significant while changes in systolic pressure were not, is of particular importance. Diastolic pressure, the lower of the two blood pressure readings, measures the ambient pressure in the arteries when the heart is relaxing. Thus, pressure in the cardiovascular system is never lower than this level. As a result, if diastolic pressure is high, the minimum presure in the system must necessarily be elevated. Thus, elevated diastolic pressure is a more specific indicator of high blood pressure than elevated systolic pressure might be.

Critics might question the validity of the findings on hypertension for women, since no comparable finding was observed linking occupational noise exposure with auditory sensitivity among females. However, it is indeed possible that an association may be found in the nonauditory domain in the absence of a relationship with hearing sensitivity. This is largely because the mechanisms by which noise affects the body are not well understood; a number of alternative scenarios could therefore produce this seemingly paradoxical result. Suppose, for example, that women's ears are less sensitive to noise than men's ears are, but that their other physiological systems are equally sensitive. In this case, noise exposure would have essentially comparable effects on the regulation of blood pressure, for example, and quite disparate effects on auditory sensitivity. Alternatively, suppose that the effects of moderate noise exposure (in the range from 80 to 90 dBA) on hearing develop more gradually than comparable effects on other systems. Although this may seem implausible at first, consider how little noise it takes to startle an individual in a quiet room. Since, as discussed earlier, women have been exposed to less total noise than men of a comparable age, an effect on the regulation of blood pressure, or in any other health domain for that matter, might manifest itself earlier than an effect on hearing. Thus, not only are these hypertension findings for women plausible, but they may also help give insight into the mechanisms by which noise affects human health.

Results of the analyses examining the remaining extra-auditory effects of noise were even less conclusive. Of the 25 measures of health examined, only the two summative measures--physician's diagnostic impression and the total general well-being score--were consistently associated with occupational noise exposure when controlling for background characteristics. One possible explanation of this phenomenon is that a summary measure such as the physician's diagnostic impression permits the aggregation of smaller, non-significant effects which when viewed in their entirety reflect a deterioration of health. Although such a conclusion would generally not prove problematic, it may in the present study, for this finding may be directly associated with earlier findings for hypertension. Examination of the most common diagnoses made by the examining physicians in NHANES I reveals that hypertension is the single most common disorder cited, accounting for 14.1 percent of the diagnoses made.* Even though many other diagnoses are also included in this measure, its direct relationship to hypertension cannot be ignored.

The inconclusiveness of the present study's findings is in accordance with the state of research on these extra-auditory effects of noise. Much of the previous research has been conducted in the form of community surveys of environmental noise. Fiedler and Fiedler (1975) and Graeven (1974), for example, both investigated the relationship between aircraft noise in the community and self-report of selected health outcomes; neither study was able to demonstrate any significant differences, although the latter study's lack of findings may have been due to serious methodological flaws. Similarly, Lader (1971) concluded that noise exposure generally does not increase the frequency of psychiatric disorders; however, he also stated that it might play an etiologic role in neurotic or anxious individuals.

---

*In descending order of frequency, the distribution of specific health conditions cited by the physicians is: hypertension, 14.1 percent; osteoarthritis, 12.3 percent; cardiovascular conditions, 8.6 percent; bronchitis, emphysema, asthma, 6.1 percent; varicose veins of the lower extremities, 6.1 percent; other diseases of the musculoskeletal system, 6.1 percent; obesity, 6.0 percent; conditions of the ear and mastoid process, 3.4 percent; other, 37.3 percent.

But several studies _have_ demonstrated a relationship between community noise and stress-related disorders, especially among women. Abey-Wickrama et al., (1969) found a trend towards increased first admissions to mental hospitals among women in areas exposured to aircraft noise. Although this study too had methodological flaws, Herridge (1974) and Herridge and Low-Beer (1978) were nonetheless able to replicate these findings. Knipschild (1977) similarly found a higher prevalence of hypertension and a greater use of cardiovascular drugs among women who lived in noisy areas near an Amsterdam airport. In addition, the results of a pilot study conducted by Tarnopolsky (1978) suggest that some groups may be particularly vulnerable to adverse mental health outcomes from noise, particularly younger people, higher socioeconomic status individuals and women. Since the present study found an association between general well-being and occupational noise exposure among women, perhaps the same mechanism operating in these studies of aircraft noise is operating in the workplace.

It is difficult to equate the effects of aircraft noise in a community with the effects of industrial noise in the workplace, however. Noise exposure from these two diverse sources may affect workers and residents in entirely different ways. Moreover, although it is possible for residents to attempt to buffer environmental noise by remaining inside or closing doors and windows, the worker in a noisy environment often has no recourse, especially if no hearing conservation program is in force at his or her place of work.

Unfortunately, the research on the extra-auditory effects of industrial noise over and above those on hypertension and cardiovascular disease is even more sketchy. Chronic diseases may have a multiplicity of causes. Findings presented in the literature are contradictory and often difficult to evaluate due to serious methodological flaws. Perhaps the best known of the available studies are the Raytheon investigations of industrial noise and medical, absence and accident reports (Cohen, 1973; Cohen, 1976). In the first study, which was a retrospective record review, Cohen noted differences in all of these outcome domains between high-noise-exposed workers and low-noise-exposed workers in a nuclear vessel plant; however, this study, and others of its type, have failed to control for other adverse workplace conditions or job factors that might occur hand in hand with high levels of noise. For example, environments with higher noise levels are also more likely to have such occupational risks as excessive heat, toxic materials and a polluted atmosphere, conditions which are all associated with higher health risks. The second study was able to overcome these methodological difficulties by examining the same set of workers before and after the implementation of a hearing conservation program. Using this longitudinal approach, Cohen was able to more conclusively demonstrate a relationship between occupational noise exposure and job injuries, medical problems and absences. But as Cohen suggested, more research is needed to more precisely quantify and understand these relationships.

6.4 Summary

Our analyses have demonstrated that hearing impairment is a widespread health problem in the United States with approximately 11.0 to 13.2 million adults aged 25-74 having some degree of impairment in their better ear and 22.0 to 27.5 million having some degree of impairment in their worse ear. Occupational noise exposure has been identified as a major factor associated with the prevalence of hearing impairment among men, although no comparable finding was obtained for women. Weak but nevertheless significant associations between both hypertension and overall physical health were also noted for men, as were parallel linkages between noise and both hypertension and psychological well-being among women. No conclusive relationships were found, however, between noise exposure and the remaining indicators of specific health conditions.

Although the above paragraph represents what we feel to be an accurate summary of the study's major findings, two caveats are nevertheless in order. First, the associations we have reported are just that--associations. There is no way of determining, from the present data base alone, whether the relationships we have found are causally based. Of course, a compelling argument can be made that noise does indeed cause the physiological conditions found, especially in the domain of hearing impairment; however, the cross-sectional nature of the data base analyzed precludes such definitive interpretations. To make such determinations, and to further explore the associations found, requires the accumulation of not only more epidemiological evidence, but clinical and experimental evidence as well. Although our epidemiological study has generated many interesting hypotheses, these must be more formally examined before causal inferences can be made.

Second, we must caution against misinterpretation of nonsignificant results. When we have stated that a relationship between noise exposure and a specific outcome exists, we feel reasonably confident that the finding is genuine and not due to chance alone. All such relationships hae been rigorously examined in conjunction with many potential confounding factors, and have been reported as significant only when the relationship persisted. However, the same is not true of nonsignificant relationships. Lack of significant findings in the present study does not demonstrate conclusively that excessive noise exposure is not associated with specific health conditions for either sex or hearing impairment among women. Although relationships between these conditions and noise may indeed not exist, or may be confounded by other factors, it is also possible that the measures of noise exposure used were not sensitive enough or that individuals were misclassified into health status or hearing impairment categories.

The utility of noise exposure ratings, such as those used in the present study, is obviously in question. In persuasive defense of the ratings is the strong relationship found with auditory functioning among men. If the ratings were not reasonably correlated with actual exposure, we would not have obtained such clear and precisely ordered results. However, even these relationships were somewhat attenuated at the higher exposure levels, suggesting that the measures are less reliable than one would prefer. Because the ability to detect effects is directly influenced by the reliability of the estimates under study, inability to uncover differences may simply be a function of the measurement method or of the lack of true differences. We nevertheless feel that noise exposure ratings offer great promise in exploring the relationships between occupational exposure and hearing and health for data bases for which it would be difficult or impossible to obtain actual estimates of exposure.

Misclassification, which dilutes the purity of the normal and abnormal groups, may have also affected the ability to uncover relationships, particularly those between the specific indicators of health and occupational noise exposure. Both self-report data and one-time physician's examination data have obvious methodological flaws. If physicians were unable to diagnose a less obvious condition, or if examinees were unaware of the presence of such a condition, the reliability of the dependent measures would be in question. Thus, the unreliability of many dependent variables--the presence or absence of a specific health condition--may have diminished the power to detect effects.

APPENDICES

APPENDIX I: STATISTICAL NOTES

I.1 The Survey Design

The sample design for the first National Health and Nutrition Examination Survey (NHANES I) is basically a three-stage, stratified probability sample of loose clusters of persons in land-based segments. The sample was designed to be representative of the civilian noninstitutionalized population within designated age ranges in the coterminous United States, excluding persons residing on lands set aside for use by American Indians. Successive elements dealt with in the process of sampling were the primary sampling units (PSU), census enumeration district (ED), segment (a cluster of households), household, eligible persons, and finally sample persons.

For the 1971-1974 period (April 1971-June 1974) the design provided for the selection of a representative sample of the target population 1-74 years of age to be given the nutrition component and certain related components, with a subsampling among adults 25-74 years of age who would also receive a more detailed examination that was focused on other aspects of health and health care needs. To increase the size for this subsampling and consequently the usefulness of the data obtained, the design further provided for the selection of an additional nationally representative sample of adults 25-74 years of age in 1974-1975 (July 1974-September 1975) to be given the detailed examination. This extension of NHANES I is also referred to as the "Augmentation Survey."

The starting points in the first stage of this design were the 1960 decennial census lists of addresses and the nearly 1900 primary sampling units (PSUs) into which the entire United States was divided. Each PSU is either a standard metropolitan statistical area (SMSA), a county, or two or three contiguous counties. The PSUs were grouped into 357 strata and subsequently collapsed into 40 superstrata for use in the NHANES I.

From April 1971 to June 1974, 15 of the 40 superstrata which contained a single large metropolitan area of more than 2 million population were chosen in the sample with certainty. The remaining 25 noncertainty strata were classified into four broad geographic regions of approximately equal population (when the large metropolitan areas selected with certainty were included) and cross-classified into four broad population density groups in each region. Then a modified Goodman-Kish controlled-selection technique was used to select two PSUs from each of the 25 noncertainty superstrata with the probability of selection of a PSU proportionate to its 1960 population; proportionate representation of specified State groups and rate of population change classes were maintained in the sample. In this manner a total first-stage sample of 65 PSUs was selected. These 65 sample PSUs are the areas within which a cluster sample of persons was selected for examination at the particular examination location designated within each area. The mobile examining units were moved from one location to the next during this 39-month period (1971-1974) to permit administering those single-time examinations to the cross-sectional sample of the target population.

The 1960 census data were used as the frame for selecting the sample within PSUs for the first 44 of the 65 examination locations in NHANES I; the then-available 1970 census data were used for the remainder. The EDs in each PSU were divided into segments of an expected six housing units each. For large urban EDs, the segments were clusters of six addresses from the 1960 Census Listing Books (later the corresponding books for 1970). For other EDs, area sampling was employed and consequently some variation in the segment size occurred. To make the sample representative of the then-current population of the United States, the address or list segments were supplemented by a sample of housing units that had been constructed since 1960 as described.

Within each PSU a systematic sample of segments was selected. The enumeration districts that fell into the sample were coded into one of two economic classes. The first class, identified as the "poverty stratum," was composed of "current poverty areas" that had been identified by the Bureau of the Census in 1970 (pre-1970 Census), plus other EDs in the PSU with a mean income of less than $3,000 in 1959 (based on 1960 Census). The second economic class, the "nonpoverty stratum," included all EDs not designated as belonging to the "poverty stratum." All sample segments classified as being in the "poverty stratum" were retained in the sample. For those sample segments in "nonpoverty stratum" EDs, the selected segments were divided into eight random subgroups and one of the subgroups was chosen to remain in the NHANES I sample. This procedure permits separate analyses with adequate reliability of those classified as being "below the poverty level" and those classified as being "above the poverty level."

After identifying the sample segments, a list of all current addresses within the segment boundaries was made, and the households were interviewed to determine the age and sex of each household member, as well as other demographic and socioeconomic information.

To select the persons in the sample segments to be examined in NHANES I, all household members aged 1-74 years in each segment were listed on a sample selection worksheet, with each household in the segment listed serially. The number of household members in each of the six age-sex groups shown below were listed on the worksheet under the appropriate age-sex group column. The sample selection worksheets were then put in segment number order and a systematic random sample of persons in each age-sex group was selected to be examined using the following sampling rates:

Age	Sampling rate
1-5 years	1/2
6-19 years	1/4
20-44 years (men)	1/4
20-44 years (women)	1/2
45-66 years	1/4
65-74 years	1

The persons selected in the 65-stand sample of NHANES I comprise a representative sample of the target population and included 28,043 sample persons 1-74 years of age.

For those to also receive the detailed health examination at the first 65 stands of NHANES I, a subsample of those adults 25-74 years of age in the total or "nutrition" sample was then chosen systematically after a random start using the sampling rates shown below:

Age	Sampling rate
25-44 years (men)	2/5
25-44 years (women)	1/5
45-64 years	3/5
65-74 years	1/4

As a result, adults 45-74 years of age in the first 65 PSUs were subsampled for the detailed examination at a somewhat higher rate than those 25-44 years of age.

During the Augmentation Survey period in 1974-1975 (July 1974-September 1975), the sample of adults 25-74 years of age selected for examination in location 66-100 constitute a national probability sample of the target population. Also, when considered jointly with those selected for the NHANES I detailed examinations in locations 1-65, the entire 100-PSU sample is also nationally representative of the target population at that time.

The starting point for the selection of the Augmentation sample was the 1970 decennial census list of addresses and PSUs. The sampling methods for establishing the sample frame were generally similar to those used in the first 65 PSUs. However, only 5 of the 15 superstrata composed of only one very large metropolitan area of more than 2 million population were drawn into the sample for locations 66-100 with certainty. The remaining 10 of these superstrata were collapsed into 5 groups of 2 each, only one which was chosen for the Augmentation Survey with a probability of selection of 0.5. When these latter five locations are considered a part of the 100-PSU design they are selected with certainty.

In this Augmentation Survey, there was no economic axis of stratification and no oversampling among special groups. One of every two eligible persons within sample households (using a random start among those 25-74 years of age) was selected for participation in the survey.

I.2 Nonresponse

In any health examination survey, after the sample is identified and the sample persons are requested to participate in the examination, the survey meets one of its more severe problems. Usually a sizable number of sample persons who are willing to complete the household information and possibly some of the medical hstory will not participate in the examination. Individual participation is determined by many factors, some of which are uncontrollable; therefore, it may be treated as a random event with a particular probability of occurrence. In this situation, the effect of nonparticipation would only reduce the sample size, thereby increasing the sampling variability of examination findings. In practice, however, a potential for bias due to nonresponse exists if nonparticipation is not a random event and if nonparticipants differ from participants. Because of the possibility of bias, intensive efforts are made in NHANES to develop and implement procedures and inducements that would reduce the number of nonrespondents, thereby reducing the potential of bias due to nonresponse. These procedures are discussed in Vital and Health Statistics, Series 1-No. 10a (NCHS, 1973).

Despite response rates at the household interview stage of over 98 percent and intensive efforts of persuasion, 21.1 percent of the sample persons from the first full 65 stands and 28.7 percent from stands 66-100 (or 30.0 percent from the entire 100 locations for the detailed examinations) were not examined. Consequently, the potential for a sizable bias does exist in the estimates in this publication. However, from what is known about the nonrespondents and the nature of nonresponse, the likelihood of sizable bias is believed to be small. For instance, only a small proportion of sample persons from the first 65 examination locations gave reasons for nonparticipation that would lead to the belief that they would never agree to participate in examination sureys and that they may differ from examined persons with respect to the characteristics under examination. Only 15 percent of nonrespondents gave personal illness, physically unable, pregnancy, antidoctor, or a fear of finding something wrong as their reasons for nonparticipation. Typical among the reasons given by the other nonrespondents were: unable because of work, school, or household duties; suspicious or skeptical of the program; just not interested in participating; and private medical care sufficient, or just visited doctor.

An analysis of the medical history data obtained for most nonexaminees as well as for examinees also supports the belief that the likelihood of sizable bias due to nonresponse is small. No large differences were found between the examined and the nonexamined group for the statistics compared. For example, the percent of persons examined who reported ever being told by a doctor that they had arthritis was 20 percent; the percent reporting high blood pressure was 18 percent, and the percent for diabetes, 4 percent. The corresponding percentages for nonexamined persons were: arthritis, 17 percent; high blood pressure, 21 percent; and diabetes, 4 percent.

A procedure (similar to that used in previous National Health Examination Surveys) was used in which the reciprocal of the probability of selection of the sample persons is multiplied by a factor that brings estimates based on sample persons up to a level that would have been attained if all sample persons had been examined. This factor is the ratio of the sum of sample weights for all sample persons with a relatively homogeneous class defined by age, sex, and five income groups (under \$3,000; \$3,000-\$6,999; \$7,000-\$9,999; \$10,000-\$14,999 and \$15,000 or more) within each stand to the sum of sampling weights for all responding sample persons within the same homogeneous class for the same stand. To the degree that homogeneous groups can be defined which are also homogeneous with respect to the characteristics under study, this procedure can be effective in reducing the potential bias from nonresponse. Overall the extent of adjustment for nonresponse among the detailed examinees was 1.45 during the 1971-1974 period and 1.40 in the Augmentation Survey of 1974-1975.

I.3 Missing Data

Examination surveys lose information not only through the failure to examine all sample persons, but also through the failure to obtain and record all items of information for those examined. For a number of examinees, one or more of the audiometric measurements, blood pressure readings or health condition assessments were not available. The extent of these missing measurements is indicated in Table I.1.

The number of missing measurements for the air conduction, self-assessment of hearing, blood pressure and health condition data is small. However, both the speech discrimination and bone conduction data are missing for relatively large proportions of their respective samples.

Table I.1: Number of Examined Persons in NHANES I with Missing Audiometric Measurements, Blood Pressure Readings, or Health Condition Assessments

Domain	Measurement	Total Number of Persons on Sample	Number of Persons with Missing Data	Percent of Persons with Missing Data
Air Conduction	Right Ear 500 Hz	6913	121	1.75
	Right Ear 1000 Hz	6913	108	1.56
	Right Ear 2000 Hz	6913	115	1.66
	Right Ear 4000 Hz	6913	122	1.77
	Left Ear 500 Hz	6913	127	1.84
	Left Ear 1000 Hz	6913	117	1.69
	Left Ear 2000 Hz	6913	116	1.68
	Left Ear 4000 Hz	6913	122	1.77
Averages of Air Conduction Hearing Levels	Right Ear: 500,1000,2000	6913	128	1.85
	Right Ear: 500,1000,2000,4000	6913	138	2.00
	Right Ear: 1000,2000,4000	6913	127	1.84
	Left Ear: 500,1000,2000	6913	130	1.88
	Left Ear: 500,1000,2000,4000	6913	136	1.97
	Left Ear: 100,2000,4000	6913	125	1.81
Bone Conduction	Right Ear 500 Hz	3854	315	8.17
	Right Ear 1000 Hz	3854	246	6.38
	Right Ear 2000 Hz	3854	253	6.57
	Right Ear 4000 Hz	3854	304	7.89
	Left Ear 500 Hz	3854	334	8.67
	Left Ear 1000 Hz	3854	248	6.44
	Left Ear 2000 Hz	3854	254	6.59
	Left Ear 4000 Hz	3854	306	7.94
Speech Discrimination	Right Ear—At any Level	3059	202	6.60
	Left Ear—At any level	3059	216	7.06
	Right Ear—At 20dB SL	3059	264	8.63
	Left Ear—At 20dB SL	3059	278	9.09
Self-Assessment of Hearing	Ringing in the Ear	6913	8	.12
	Running in the Ear	6913	11	.16
	Deafness of Trouble Hearing	6913	8	.12
	Right Ear Hearing Rating	6913	17	.25
	Left Ear Hearing Rating	6913	17	.25
Blood Pressure	First Reading Systolic	6913	26	.00
	First Reading Diastolic	6913	28	.00
	Second Reading Systolic	6913	60	.87
	Second Reading Diastolic	6913	64	.93
	One or Both Systolic Readings	6913	62	.90
	One or Both Diastolic Readings	6913	66	.96
	One or More Systolic or Diastolic Readings	6913	66	.96
Health Conditions	Physician's Diagnosis	6913	21	.30
	General Well-Being	6913	0	.00
	Relaxed vs. Tense/ Anxious Subscale	6913	0	.00

I.4 Small Numbers

In some tables magnitudes are shown for cells for which the sample size is so small that the sampling error may be several times as great as the statistic itself. Obviously in such instances the numbers, if shown, have been included to convey an impression of the overall sense of the table.

I.5 Estimation Methods

All data in the text and detailed tables of this report are based on "weighted" observations (i.e., data recorded for each sample person are inflated to characterize the subuniverse from which that sample person was drawn). The weight, as previously indicated, for each examined person is a product of the reciprocal of the probability of selecting the person, an adjustment for nonresponse (persons not examined), and a poststratified ratio adjustment that increases precision by making the final sample estimates for the population agree approximately with independent controls prepared by the U.S. Bureau of the Census for the civilian noninstitutionalized population of the United States as of November 1, 1972 for the 1971-1974 sample (locations 1-65), February 1, 1974 for the 1971-1975 sample (locations 1-100), and March 1, 1975 for the 1974-1975 Augmentation sample (locations 66-100), as shown in Tables I.2-I.4.

Because the design for NHANES I is a multistage probability sample, complex procedures are required to produce the "weights" needed to inflate the findings for the individual examinees so that they can be used for national or other broad population group estimates. The following three basic operations are involved.

Table I.2: Number of examined persons and estimated population,[1] by race, age and sex of the examinee: United States, 1971-1974

Age at examination and sex	All races[2] Examined persons	All races[2] Population in thousands	White Examined persons	White Population in thousands	Black Examined persons	Black Population in thousands
Both Sexes						
25-74 years	3,854	104,125	3,208	93,030	612	10,243
25-34 years	724	26,740	609	23,615	109	2,936
35-44 years	598	22,193	497	19,573	93	2,376
45-54 years	931	23,317	781	20,906	144	2,294
55-64 years	747	19,187	621	17,440	119	1,518
65-74 years	854	12,688	700	11,497	147	1,118
Male						
25-74 years	1,839	49,332	1,541	44,358	277	4,478
25-34 years	337	12,894	288	11,505	44	1,249
35-44 years	264	10,685	230	9,544	31	998
45-54 years	452	11,145	376	10,025	73	1,067
55-64 years	369	9,130	307	8,336	58	690
65-74 years	417	5,478	340	4,948	71	474
Female						
25-74 years	2,015	54,793	1,667	48,672	335	5,764
25-34 years	387	13,846	321	12,110	65	1,687
35-44 years	334	11,508	267	10,029	62	1,378
45-54 years	479	12,172	405	10,881	71	1,227
55-64 years	378	10,057	314	9,104	61	829
65-74 years	437	7,209	360	6,549	76	645

[1] As of the midpoint of the survey--Nov. 1, 1972.

[2] Includes other racial groups in addition to white and black.

Table I.3: Number of examined persons and estimated population,[1] by race, age and sex of the examinee: United States, 1971-1975

Age at examination and sex	All races[2] Examined persons	All races[2] Population in thousands	White Examined persons	White Population in thousands	Black Examined persons	Black Population in thousands
Both Sexes						
25-74 years	6,913	106,639	5,968	94,886	873	10,656
25-34 years	1,563	28,297	1,362	24,835	175	3,039
35-44 years	1,216	22,302	1,048	19,582	149	2,415
45-54 years	1,613	23,549	1,396	21,053	206	2,358
55-64 years	1,288	19,346	1,118	17,500	161	1,674
65-74 years	1,233	13,145	1,044	11,915	182	1,170
Male						
25-74 years	3,171	50,587	2,744	45,303	390	4,693
25-34 years	672	13,663	587	12,123	72	1,303
35-44 years	528	10,761	469	9,579	52	1,024
45-54 years	746	11,288	642	10,131	99	1,095
55-64 years	626	9,192	544	8,336	76	768
65-74 years	599	5,682	502	5,134	91	504
Female						
25-74 years	3,741	56,052	3,224	49,583	483	5,963
25-34 years	891	14,634	775	12,713	103	1,736
35-44 years	688	11,541	579	10,003	97	1,392
45-54 years	867	12,260	754	10,922	107	1,263
55-64 years	662	10,154	574	9,164	85	906
65-74 years	634	7,463	542	6,781	91	667

[1]As of the midpoint of the survey--Feb. 1, 1974.

[2]Includes other racial groups in addition to white and black.

Table I.4: Number of examined persons and estimated population,[1] by race, age and sex of the examinee: United States, 1974–1975

Age at examination and sex	All races[2]		White		Black	
	Examined persons	Population in thousands	Examined persons	Population in thousands	Examined persons	Population in thousands
Both Sexes 25–74 years	3,059	108,494	2,760	94,406	261	10,595
25–34 years	839	29,524	753	25,868	66	2,765
35–44 years	618	22,411	551	19,643	56	2,382
45–54 years	682	23,540	615	21,083	62	2,324
55–64 years	541	19,550	497	17,606	42	1,860
65–74 years	379	13,469	344	12,206	35	1,264
Male 25–74 years	1,332	51,440	1,203	46,016	113	4,613
25–34 years	335	14,236	299	12,614	28	1,168
35–44 years	264	10,874	239	9,660	21	987
45–54 years	294	11,214	266	10,126	26	1,042
55–64 years	257	9,264	237	8,325	18	854
65–74 years	182	5,852	162	5,290	20	562
Female 25–74 years	1,727	57,054	1,557	50,390	148	5,982
25–34 years	504	15,288	454	13,254	38	1,597
35–44 years	354	11,536	312	9,983	35	1,394
45–54 years	388	12,326	349	10,957	36	1,282
55–64 years	284	10,286	260	9,281	24	1,006
65–74 years	197	7,618	182	6,916	15	702

[1]As of the midpoint of the survey--Mar. 1, 1975.

[2]Includes other racial groups in addition to white and black.

1. Inflation by the reciprocal of the probability of selection. The probability of selection is the product of the probabilities of selection from each step of inflation in the design (PSU, segment, and sample person). The "weights" from this stage are the reciprocal of the resultant probability of selection.

2. Nonresponse adjustment. The "weights" or estimates as obtained at step one above are then inflated by a multiplication factor calculated within each PSU for each of the five selected income groups. The numerator consists of the sum of the "weights" for sample persons (obtained from the reciprocal of their probability of selection), and the denominator consists of the sum of the weights of the examined persons (the latter weights being the reciprocal of the probability of selection for those actually examined).

3. Poststratification by age-sex-race. The final estimates or "weights" are obtained by ratio adjusting within each of 60 age-sex-race cells to an independent estimate, provided by the U.S. Bureau of the Census, of the population in each cell as of the midpoint of the survey. The effect of the ratio-adjusting process is to make the examined sample data more closely representative of that for the total civilian noninstitutionalized population by age, sex, and race, and thereby reduce the sampling variance.

I.6 Sampling and Measurement Error

In the present report, reference has been made to efforts to minimize bias and variability of measurement techniques. The potential for residual bias due to the high nonresponse rate has also been discussed.

The probability design of the survey makes possible the calculation of sampling errors. Traditionally the role of the sampling error has been the determination of how imprecise the survey results may be because they come from a sample rather than from the measurement of all elements in the universe.

The estimation of sampling errors for a study of the type of the National Health and Nutrition Examination Survey is difficult for at least three reasons: (1) measurement error and "pure" sampling error are confounded in the data--it is not easy to find a procedure which will either completely include both or treat one or the other separately; (2) the survey design and estimation procedure are complex, and, accordingly, require computationally involved techniques for the calculation of variances; and (3) hundreds of statistics are presented in the tables in this report, many for subclasses of the population for which there are a small number of sample cases. Estimates of sampling error are obtained from the sample data and are themselves subject to sampling error which can be large when the number of cases in a cell is small or even, occasionally, when the number of cases is substantial.

Estimates of the standard errors for selected statistics used in this report are presented in most of the tables in this report. These estimates have been prepared by a first order Taylor approximation of the deviations of estimates from their expected values. Again, readers are reminded that these estimated sampling errors do not reflect any residual bias which might still be present after the attempted correction for nonresponse. The standard error is primarily a measure of sampling variability, that is, the variations that might occur by chance because only a sample of the population is surveyed. As calculated for this report, the standard error also reflects part of the variation which arises in the measurement process. It does not include estimates of any biases which might lie in the data. The chances are about 68 out of 100 that an estimate from the sample would differ from a complete census by less than the standard error. The chances are about 95 out of 100 that the difference would be less than twice the standard error and about 99 out of 100 that it would be less than two-and-a-half times as large.

I.7 Analytic Procedures

Computer analyses were performed using the Statistical Analysis System package (SAS, 1979). Standard error computations and tests of hypotheses were conducted with the user supplied procedures SURREGR and STDERR from the Research Triange Institute (Holt, 1979 and Shah, 197[illegible]).

Sampling variances and covariances of the estimates of means, proportions and regression coefficients presented in this report have been calculated using the linearization method. Under this method, an asymptotic expansion is used to approximate the variance for functions of random variables in large samples (see, e.g, Kendall and Stuart, 1963). More specifically, one computes a first order Taylor Series approximation of the deviations of estimates from their expected values in the form of an implicit formula built into the algorithm.

In most cases, the effect of the complex sample design is to increase the variances of estimates from what they would be for a simple random sample of the same size. The effects of the samle design including clustering, stratification and unequal probabilities of selection on standard errors can be summarized in a measure known as a design effect. This is defined to be the ratio of the standard error of an estimate obtained from a complex sample design to that which would have been expected from a simple random sample of the same size.

For example, the simple random sample standard error for a mean $\bar{X}$ is calculated by the usual formula,

$$s.e._{SRS}\ (\bar{X}) = S_X/(n)^{1/2},$$

where S_x is the sample standard deviation of $\bar{X}$ and n is the sample size. Thus, the design effect associated with $\bar{X}$ is defined to be

$$\text{Design Effect } (\bar{X}) = s.e.\ (\bar{X})/s.e._{SRS}(\bar{X}).$$

Tables for Chapter 3 pres‹nt standard errors and design effects for a selection of means and proportions. For example, standard errors and de:ign effects for mean air conduction hearing levels in the ri,nt ear at 500 Hz are shown by age, race and sex in Table 3.5. As shown in this table, the standard error of the estimate for all sample persons is 0.24. The associated design effect is 2.44. Thus, the simple random sampling variance associated with a sample of the same size would be expected to be

$$0.24/2.44 = \underline{0.098}.$$

That is, the effect of unequal differential weighting, clustering and stratification is to increase the standard error of this estimate by a factor of 2.44. See Kish (1964) for a more complete discussion of design effects and complex sample designs.

The variances and covariances obtained by the linearization method allow for hypothesis testing in a manner which adjusts for the complex sample design of NHANES I. In Chapter 3, for example, the results of significance tests for differences between means and proportions for various subgroups of the population are reported. These tests were conducted in the following manner: Suppose $\bar{X}_1$ and $\bar{X}_2$ are the sample means of two non-overlapping subgroups. The sampling variance of the difference $(\bar{X}_1-\bar{X}_2)$ is given by

$$\text{Var}\ (\bar{X}_1-\bar{X}_2) = \text{Var}\ (\bar{X}_1) + \text{Var}\ (\bar{X}_2) - 2\ \text{COV}\ (\bar{X}_1, \bar{X}_2).$$

The statistic used for carrying out the hypothesis test is the usual Z-statistic given by

$$Z = \frac{(\bar{X}_1 - \bar{X}_2)}{[\text{Var}\ (\bar{X}_1) + \text{Var}\ (\bar{X}_2) - 2\ \text{COV}\ (\bar{X}_1, \bar{X}_2)]^{1/2}}$$

For reasonably large samples, this ratio can be treated as a normal random variable.

For example, in Table 3.28, results of significance tests of differences in mean air conduction hearing levels by age, sex and race are reported. The Z-statistic for testing the difference in mean air conduction hearing levels at 500 Hz in the right ear between the age groups 25-34 and 35-44 is given as -3.47. This is calculated using the means (reported in Table 3.12), associated standard errors (reported in Table 3.13) and the covariances (not reported) as

$$Z = \frac{(8.3 - 10.3)}{[(.29)^2 + (.48)^2 - 2\ (.0089)]^{1/2}}$$
$$= -3.47$$

The p-value associated with this Z-statistic is less than .001.

Z-statistics for conducting tests of differences in proportions, as reported for example in Table 3.95, were calculated in exactly the same way.

F-statistics associated with tests of significance of regression coefficients are reported in Chapters 4 and 5 and Appendix III. These too make use of the sampling variances and covariances obtained by the Taylor Series approximation.

For testing the significance of a single regression coefficient, given the other variables in the model, one can simply use the estimated coefficient and its standard error. If B is the estimated regression coefficient, then the F-statistic for testing the null hypothesis H_o:B=O is given by

$$F_{1,e} = \left[\frac{B}{s.e.(B)}\right]^2,$$

where 1 and e are the associated degrees of freedom. Here, e is the number of primary sampling units minus the number of strata minus the number of terms in the model (including the intercept).

For example, the coefficient associated with occupational noise exposure in predicting the air conduction hearing level at 500 Hz for males when age and race are also in the model is reported in Table 4.4 to be .2371, with an associated standard error of .0854.

The F-statistic for testing the significance of this coefficient is calculated to be:

$$F_{1,e} = \frac{[.2371]^2}{[.0854]}, = 7.70$$

as reported in Table 4.1. The associated degrees of freedom is calculated to be

$$e = 100 - 40 - 4 = \underline{56}.$$

F-statistics for testing the significance of groups of coefficients, as, for example, in testing the coefficients associated with the levels of a categorical variable, are somewhat more complicated to calculate. They depend on the sampling covariances as well as the variances. This procedure is discussed in most standard textbooks on the linear model, for example, Searle (1971).

APPENDIX II: MEASUREMENT OF OCCUPATIONAL NOISE EXPOSURE

II.1 Development of Noise Exposure Rating Scheme

Table II.1: Joint distribution of the occupational categories classified into noise exposure categories for the two raters.

Rater 2

Rater 1	<70dB (1)	71-75dB (2)	76-80dB (3)	81-85dB (4)	86-80dB (5)	91-95dB (6)	>96dB (7)	Total
<70dB (1)	17	33	9	3	-	-	-	62
71-75dB (2)	4	43	34	18	5	-	-	104
76-80dB (3)	-	15	26	27	13	3	1	85
81-85dB (4)	-	5	12	21	11	7	1	57
86-90dB (5)	-	1	6	19	17	8	1	52
91-95dB (6)	-	-	4	15	21	20	3	63
>96dB (7)	-	-	-	3	1	5	1	10
Total	21	97	91	106	68	43	7	433

Table II.2: Joint distribution of the 3824 persons in the workforce in the NHANES I data into noise exposure categories for the occupational categories.

Rater 2

Rater 1	<70dB (1)	71-75dB (2)	76-80dB (3)	81-85dB (4)	86-80dB (5)	91-95dB (6)	>96dB (7)	Total
<70dB (1)	87	260	60	4	-	-	-	411
71-75dB (2)	25	885	441	124	36	-	-	1511
76-80dB (3)	-	106	123	205	42	2	-	478
81-85dB (4)	-	15	121	110	125	25	4	400
86-90dB (5)	-	3	33	86	186	79	1	388
91-95dB (6)	-	-	27	122	227	179	5	560
>96dB (7)	-	-	-	16	8	49	3	76
Total	112	1269	805	667	624	334	13	3824

Table II.3: Occupational Noise Exposure Ratings

Occupation Code		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
	PROFESSIONAL, TECHNICAL, AND KINDRED WORKERS				
001	Accountants	2	2	2	37
002	Architects	2	1	1.5	4
	Computer specialists				
003	Computer programmers	3	3	3	3
004	Computer systems analysts	3	3	3	3
005	Computer specialists, n.e.c.*	3	3	3	4
	Engineers				
006	Aeronautical and astronautical engineers	5	3	4	4
010	Chemical engineers	6	3	4.5	4
011	Civil engineers	5	4	4.5	12
012	Electrical and electronic engineers	5	3	4	21
013	Industrial engineers	7	4	5.5	4
014	Mechanical engineers	7	4	5.5	12
015	Metallurgical and materials engineers	5	4	4.5	0
020	Mining engineers	6	5	5.5	0
021	Petroleum engineers	6	4	5	2
022	Sales engineers	4	3	3.5	3
023	Engineers, n.e.c.	5	4	4.5	10
024	Farm management advisors	5	3	4	1
025	Foresters and conservationists	3	4	3.5	5
026	Home management advisors	3	3	3	0
	Lawyers and judges				
030	Judges	1	2	1.5	2
031	Lawyers	1	2	1.5	20
	Librarians, archivists, and curators				
032	Librarians	1	1	1	13
033	Archivists and curators	1	1	1	1
	Mathematical specialists				
034	Actuaries	1	2	1.5	0
035	Mathematicians	1	2	1.5	0
036	Statisticians	3	2	2.5	1
	Life and physical scientists				
042	Agricultural scientists	4	3	3.5	1
043	Atmospheric and space scientists	4	2	3	0
044	Biological scientists	3	2	2.5	1
045	Chemists	3	3	3	11
051	Geologists	4	4	4	3
052	Marine scientists	4	4	4	1
053	Physicists and astronomers	3	3	3	1
054	Life and physical scientists, n.e.c.	3	3	3	0
055	Operations and systems researchers and analysts	4	3	3.5	4
056	Personnel and labor relations workers	5	3	4	6

*"n.e.c." means "not elsewhere classified"

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
	Physicians, dentists, and related practitioners				
061	Chiropractors	2	2	2	1
062	Dentists	6	4	5	1
063	Optometrists	2	2	2	0
064	Pharmacists	1	2	1.5	4
065	Physicians, medical and osteopathic	2	2	2	12
071	Podiatrists	2	2	2	0
072	Veterinarians	2	3	2.5	0
073	Health practitioners, n.e.c.	2	2	2	0
	Nurses, dietitians, and therapists				
074	Dietitians	1	2	1.5	2
075	Registered nurses	2	3	2.5	44
076	Therapists	3	2	2.5	6
	Health technologists and technicians				
080	Clinical laboratory technologists and technicians	4	2	3	4
081	Dental hygienists	5	3	4	1
082	Health record technologists and technicians	1	2	1.5	0
083	Radiologic technologists and technicians	3	2	2.5	2
084	Therapy assistants	4	2	3	0
085	Health technologists and technicians, n.e.c.	3	2	2.5	6
	Religious workers				
086	Clergymen	1	1	1	25
090	Religious workers, n.e.c.	1	1	1	2
	Social Scientists				
091	Economists	1	1	1	9
092	Political scientists	1	1	1	0
093	Psychologists	1	1	1	1
094	Sociologists	1	1	1	0
095	Urban and regional planners	2	2	2	1
096	Social scientists, n.e.c.	3	2	2.5	0
	Social and recreation workers				
100	Social workers	2	3	2.5	19
101	Recreation workers	2	4	3	2
	Teachers, college and university				
102	Agriculture teachers	3	3	3	0
103	Atmospheric, earth, marine, and space teachers	3	4	3.5	0
104	Biology teachers	2	2	2	1
105	Chemistry teachers	2	2	2	0
110	Physics teachers	2	2	2	0
111	Engineering teachers	4	3	3.5	1
112	Mathematics teachers	1	2	1.5	1
113	Health specialties teachers	1	2	1.5	3
114	Psychology teachers	1	1	1	2
115	Business and commerce teachers	2	2	2	0
116	Economics teachers	1	2	1.5	0
120	History teachers	1	1	1	0
121	Sociology teachers	1	1	1	1
122	Social science teachers, n.e.c.	1	2	1.5	0

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
123	Art, drama, and music teachers	2	3	2.5	1
124	Coaches and physical education teachers	2	3	2.5	1
125	Education teachers	1	2	1.5	0
126	English teacchers	1	1	1	0
130	Foreign language teachers	1	3	2	2
131	Home economics teachers	2	2	2	0
132	Law teachers	1	2	1.5	0
133	Theology teachers	1	1	1	2
134	Trade, industrial, and technical teachers	5	4	4.5	0
135	Miscellaneous teachers, college and university	2	2	2	2
140	Teachers, college and university, subject not specified	2	2	2	3
	Teachers, except college and university				
141	Adult education teachers	2	2	2	5
142	Elementary school teachers	2	3	2.5	51
143	Prekindergarten and kindergarten teachers	2	3	2.5	44
144	Secondary school teachers	2	2	2	50
145	Teachers, except college and university, n.e.c.	2	2	2	4
	Engineering and science technicians				
150	Agriculture and biological technicians, except health	4	3	3.5	1
151	Chemical technicians	4	3	3.5	3
152	Draftsmen	2	2	2	10
153	Electrical and electronic engineering technicians	3	3	3	11
154	Industrial engineering technicians	4	4	4	2
155	Mechanical engineering technicians	7	4	5.5	0
156	Mathematical technicians	2	2	2	1
161	Surveyors	3	3	3	4
162	Engineering and science technicians, n.e.c.	6	3	4.5	4
	Technicians, except health, and engineering and science				
163	Airplane pilots	7	6	6.5	0
164	Air traffic controllers	5	4	4.5	2
165	Embalmers	3	2	2.5	0
170	Flight engineers	6	5	5.5	0
171	Radio operators	5	4	4.5	2
172	Tool programmers, numerical control	5	4	4.5	0
173	Technicians, n.e.c.	6	4	5	1
174	Vocational and education counselors	5	-	5	8
	Writers, artists, and entertainers				
175	Actors	4	2	3	1
180	Athletes and kindred workers	3	3	3	1
181	Authors	2	1	1.5	0
182	Dancers	5	3	4	0
183	Designers	3	2	2.5	7

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
184	Editors and reporters	3	3	3	3
185	Musicians and composers	6	4	5	2
190	Painters and sculptors	4	2	3	10
191	Photographers	3	2	2.5	7
192	Public relations men and publicity writers	3	2	2.5	4
193	Radio and television announcers	4	3	3.5	0
194	Writers, artists, and entertainers, n.e.c.	5	2	3.5	3
195	Research workers, not specified	4	3	3.5	5
	MANAGERS AND ADMINISTRATORS, EXCEPT FARM				
201	Assessors, controllers, and treasurers; local public administration	2	2	2	1
202	Bank officers and financial managers	1	2	1.5	12
203	Buyers and shippers, farm products	4	3	3.5	2
205	Buyers, wholesale and retail trade	1	2	1.5	3
210	Credit men	1	1	1	5
211	Funeral directors	2	1	1.5	5
212	Health administrators	2	2	2	7
213	Construction inspectors, public administration	4	4	4	0
215	Inspectors, except construction, public administration	2	3	2.5	5
216	Managers and superintendents, building	2	2	2	9
220	Office managers, n.e.c.	1	2	1.5	18
221	Officers, pilots, and pursers; ship	4	4	4	1
222	Officials and administrators; public administration, n.e.c.	1	2	1.5	23
223	Officials of lodges, societies, and union	2	2	2	8
224	Postmasters and mail superintendents	2	3	2.5	3
225	Purchasing agents and buyers, n.e.c.	1	2	1.5	11
226	Railroad conductors	6	4	5	1
230	Restaurant, cafeteria, and bar managers	4	3	3.5	31
231	Sales managers and department heads, retail trade	1	2	1.5	7
233	Sales managers, except retail trade	2	2	2	21
235	School administrators, college	1	1	1	3
240	School administrators, elementary and secondary	2	1	2.5	16
245	Managers and administrators, n.e.c.	2	2	2	287
	SALES WORKERS				
260	Advertising agents and salesmen	2	3	2.5	6
261	Auctioneers	2	3	2.5	2
262	Demonstrators	3	3	3	4

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
264	Hucksters and peddlers	3	3	3	8
265	Insurance agents, brokers and underwriters	1	2	1.5	15
266	Newsboys	2	3	2.5	1
270	Real estate agents and brokers	1	3	2	17
271	Stock and bond salesmen	1	2	1.5	6
280	Salesmen and sales clerks, n.e.c.	2	2	2	153
	CLERICAL AND KINDRED WORKERS				
301	Bank tellers	1	2	1.5	7
303	Billing Clerks	1	2	1.5	3
305	Bookkeepers	1	2	1.5	86
310	Cashiers	3	2	2.5	43
311	Clerical assistants, social welfare	1	2	1.5	2
312	Clerical supervisors, n.e.c.	3	2	2.5	7
313	Collectors, bill and account	1	2	1.5	0
314	Counter clerks, except food	2	2	2	10
315	Dispatchers and starters, vehicle	4	4	4	3
320	Enumerators and interviewers	2	2	2	2
321	Estimators and investigators, n.e.c.	1	2	1.5	11
323	Expediters and production controllers	4	3	3.5	5
325	File clerks	2	2	2	6
326	Insurance adjusters, examiners, and investigators	1	2	1.5	5
330	Library attendants and assistants	1	1	1	4
331	Mail carriers, post office	2	3	2.5	17
332	Mail handlers, except post office	3	4	3.5	9
333	Messengers and office boys	2	3	2.5	0
334	Meter readers, utilities	1	4	2.5	2
	Office machine operators				
341	Bookkeeping and billing machine operators	3	4	3.5	3
342	Calculating machine operators	3	4	3.5	1
343	Computer and peripheral equipment operators	3	4	3.5	8
344	Duplicating machine operators	3	4	3.5	1
345	Key punch operators	3	4	3.5	9
350	Tabulating machine operators	3	4	3.5	0
355	Office machine operators, n.e.c.	3	4	3.5	3
360	Payroll and timekeeping clerks	2	3	2.5	5
361	Postal clerks	2	3	2.5	18
362	Proofreaders	1	2	1.5	4
363	Real estate appraisers	1	2	1.5	1
364	Receptionists	1	1	1	19
	Secretaries				
370	Secretaries, legal	1	2	1.5	9
371	Secretaries, medical	1	2	1.5	5
372	Secretaries, n.e.c.	2	2	2	123
374	Shipping and receiving clerks	2	3	2.5	19
375	Statistical clerks	2	2	2	10
376	Stenographers	3	3	3	4

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
	Office machine operators (Cont.)				
381	Stock clerks and storekeepers	2	3	2.5	24
382	Teacher aides, exc. school monitors	2	2	2	12
383	Telegraph messengers	2	3	2.5	0
384	Telegraph operators	2	4	3	0
385	Telephone Operators	3	4	3.5	19
390	Ticket, station, and express agents	2	3	2.5	9
391	Typists	2	4	3	31
392	Weighers	2	3	2.5	0
394	Miscellaneous clerical workers	2	3	2.5	33
395	Not specified clerical workers	2	3	2.5	38
	CRAFTSMEN AND KINDRED WORKERS				
401	Automobile accessories installers	5	5	5	0
402	Bakers	2	4	3	5
403	Blacksmiths	5	6	5.5	1
404	Boilermakers	7	7	7	3
405	Bookbinders	3	4	3.5	2
410	Brickmasons and stonemasons	4	5	4.5	12
411	Brickmasons and stonemasons, apprentices	4	5	4.5	0
412	Bulldozer operators	7	6	6.5	3
413	Cabinetmakers	5	6	5.5	3
415	Carpenters	5	6	5.5	52
416	Carpenter apprentices	5	5	5	0
420	Carpet installers	4	4	4	2
421	Cement and concrete finishers	6	4	5	4
422	Compositors and typesetters	4	6	5	12
423	Printing trades apprentices, exc. pressmen	5	5	5	0
424	Cranemen, derrickmen, and hoistmen	5	5	5	8
425	Decorators and window dressers	3	3	3	2
426	Dental laboratory technicians	3	3	3	3
430	Electricians	3	4	3.5	25
431	Electrician apprentices	3	4	3.5	0
433	Electric power linemen and cablemen	2	4	3	6
434	Electrotypers and stereotypers	3	5	4	0
435	Engravers, exc. photoengravers	3	6	4.5	0
436	Excavating, grading, and road machine operators, exc. bulldozer	6	6	6	15
440	Floor layers, exc. tile setters	2	4	3	1
441	Foremen, n.e.c.	6	5	5.5	72
442	Forgemen and hammermen	6	6	6	0
443	Furniture and wood finishers	3	6	4.5	2
444	Furriers	2	5	3.5	0
445	Glaziers	2	5	3.5	0
446	Heat treaters, annealers, and temperers	4	6	5	3

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
450	Inspectors, scalers, and graders; log and lumber	3	5	4	1
452	Inspectors, n.e.c.	2	5	3.5	3
453	Jewelers and watchmakers	2	3	2.5	1
454	Job and die setters, metal	6	6	6	8
455	Locomotive engineers	6	5	5.5	1
456	Locomotive firemen	6	5	5.5	0
461	Machinists	6	6	6	15
462	Machinist apprentices	6	6	6	0
	Mechanics and repairmen				
470	Air conditioning, heating, and refrigeration	4	5	4.5	13
471	Aircraft	7	6	6.5	8
472	Automobile body repairmen	7	5	6	8
473	Automobile mechanics	6	5	5.5	30
474	Automobile mechanic apprentices	5	5	5	0
475	Data processing machine repairmen	4	4	4	1
480	Farm implement	6	4	5	4
481	Heavy equipment mechanics, incl. diesel	7	6	6.5	30
482	Household appliance and accessory installers and mechanics	4	4	4	4
483	Loom fixers	6	7	6.5	1
484	Office machine	4	4	4	0
485	Radio and television	3	4	3.5	4
486	Railroad and car shop	6	6	6	3
491	Mechanic, exc. auto, apprentices	6	5	5.5	0
492	Miscellaneous mechanics and repairmen	6	5	5.5	8
495	Not specified mechanics and repairmen	6	5	5.5	3
501	Millers; grain, flour, and feed	4	4	4	0
502	Millwrights	4	5	4.5	7
503	Molders, metal	4	6	5	2
504	Molder apprentices	4	6	5	0
505	Motion picture projectionists	3	4	3.5	2
506	Opticians, and lens grinders and polishers	3	5	4	3
510	Painters, construction and maintenance	4	4	4	17
511	Painter apprentices	3	4	3.5	1
512	Paperhangers	1	3	2	0
514	Pattern and model makers, exc. paper	3	5	4	1
515	Photoengravers and lithographers	3	5	4	4
516	Piano and organ tuners and repairmen	3	5	4	0
520	Plasterers	1	3	2	1
521	Plasterer apprentices	1	3	2	0
522	Plumbers and pipe fitters	2	5	2.5	20
523	Plumber and pipe fitter apprentices	2	4	3	0
525	Power station operators	5	5	5	2
530	Pressmen and plate printers, printing	5	6	5.5	9

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
530	Pressmen and plate printers, printing	5	6	5.5	9
531	Pressman apprentices	6	5	5.5	0
533	Rollers and finishers, metal	6	6	6	0
534	Roofers and slaters	6	5	5.5	7
535	Sheetmetal workers and tinsmiths	6	6	6	6
536	Sheetmetal apprentices	6	6	6	0
540	Shipfitters	6	6	6	1
542	Shoe repairmen	4	4	4	4
543	Sign painters and letterers	1	3	2	2
545	Stationary engineers	6	3	4.5	19
546	Stone cutters and stone carvers	4	6	5	0
550	Structural metal craftsmen	6	6	6	5
551	Tailors	1	3	2	4
552	Telephone installers and repairmen	2	4	3	7
554	Telephone linemen and splicers	2	4	3	1
560	Tile setters	2	4	3	1
561	Tool and die makers	6	6	6	12
562	Tool and die maker apprentices	6	6	6	0
563	Upholsterers	1	4	2.5	2
571	Specified craft apprentices, n.e.c.	5	4	4.5	0
572	Not specified apprentices	5	4	4.5	0
575	Craftsmen and kindred workers, n.e.c.	5	-	5	4
580	Former members of the Armed Forces	5	-	5	0

OPERATORS, EXCEPT TRANSPORT

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
601	Asbestos and insulation workers	3	4	3.5	73
602	Assemblers	5	5	5	45
603	Blasters and powdermen	3	7	5	0
604	Bottling and canning operatives	5	6	6.5	2
605	Chainmen, rodmen, and axmen; surveying	2	4	3	1
610	Checkers, examiners, and inspectors; manufacturing	5	5	5	40
611	Clothing ironers and pressers	3	3	3	14
612	Cutting operatives, n.e.c.	4	5	4.5	8
613	Dressmakers and seamstresses, except factory	4	5	4.5	6
614	Drillers, earth	6	7	6.5	1
615	Dry Wall Installers and lathers	4	5	4.5	0
620	Dyers	3	5	4	0
621	Filers, polishers, sanders, and buffers	5	6	5.5	1
622	Furnacemen, smeltermen, and pourers	6	7	6.5	4
623	Garage workers and gas station attendants	4	5	4.5	10
624	Graders and sorters, manufacturing	5	4	4.5	1
625	Produce graders and packers, except factory and farm	5	4	4.5	2
626	Heaters, metal	6	5	5.5	0

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
630	Laundry and dry cleaning operatives, n.e.c.	4	4	4	8
631	Meat cutters and butchers, exc. manufacturing	3	4	3.5	9
633	Meat cutters and butchers, manufacturing	3	4	3.5	6
634	Meat wrappers, retail trade	2	4	3	1
635	Metal platers	6	5	5.5	1
636	Milliners	5	5	5	0
640	Mine operatives, n.e.c.	6	6	6	10
641	Mixing operatives	5	5	5	2
642	Oilers and greasers, exc. auto	6	5	5.5	1
643	Packers and wrappers, except meat and produce	4	4	4	16
644	Painters, manufactured ariticles	3	3	3	8
645	Photographic process workers	3	3	3	1
	Precision machine operatives				
650	Drill press operatives	6	5	5.5	4
651	Grinding machine operatives	7	6	6.5	8
652	Lathe and milling machine operatives	6	5	5.5	3
653	Precision machine operatives, n.e.c.	5	5	5	1
656	Punch and stamping press operatives	6	6	6	8
660	Riveters and fasteners	5	7	6	1
661	Sailors and deckhands	3	5	4	0
662	Sawyers	4	6	5	4
663	Sewers and stitchers	4	5	4.5	58
664	Shoemaking machine operatives	5	4	4.5	1
665	Solderers	3	5	4	3
666	Stationary firemen	3	4	3.5	4
	Textile operatives				
670	Carding, lapping, and combing operatives	6	5	5.5	2
671	Knitters, loopers, and toppers	6	6	6	0
672	Spinners, twisters, and winders	6	6	6	7
673	Weavers	4	7	5.5	4
674	Textile operatives, n.e.c.	5	6	5.5	9
680	Welders and flame-cutters	6	5	5	[illegible]
681	Winding operatives, n.e.c.	5	6	5.5	2
690	Machine operatives, miscellaneous specified	6	6	6	55
692	Machine operatives, not specified	5	5	5	18
694	Misscellaneous operatives	5	5	5	

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
710	Motormen; mine, factory, logging camp, etc.	6	6	6	0
711	Parking attendants	3	4	3.5	1
712	Railroad brakemen	6	5	5.5	0
713	Railroad switchmen	3	5	4	0
714	Taxicab drivers and chauffeurs	4	4	4	5
715	Truck drivers	6	5	5.5	85
	LABORERS, EXCEPT FARM				
740	Animal caretakers, exc. farm	2	3	2.5	0
750	Carpenters' helpers	5	4	4.5	4
751	Construction laborers, exc. carpenters' helpers	5	5	5	31
752	Fishermen and oystermen	2	4	3	2
753	Freight and material handlers	5	4	4.5	25
754	Garbage collectors	3	5	4	3
755	Gardeners and groundskeepers, exc. farm	2	4	3	22
760	Longshoremen and stevedores	3	6	4.5	0
761	Lumbermen, raftsmen, and woodchoppers	4	6	5	4
762	Stock handlers	4	5	4.5	11
763	Teamsters	5	5	5	0
764	Vehicle washers and equipment cleaners	5	5	5	3
770	Warehousemen, n.e.c.	3	3	3	6
780	Miscellaneous laborers	5	4	4.5	7
785	Not specified laborers	5	4	4.5	19
	FARMERS AND FARM MANAGERS				
801(W)	Farmers (owners and tenants)	6	4	5	55
802	Farm managers	6	4	5	5
	FARM LABORERS AND FARM FOREMEN				
821	Farm foremen	6	4	5	2
822	Farm laborers, wage workers	6	4	5	25
823	Farm laborers, unpaid family workers	6	4	5	9
824	Farm service laborers, self-employed	6	4	5	0
	SERVICE WORKERS, EXC. PRIVATE HOUSEHOLD				
	Cleaning service workers				
901	Chambermaids and maids, except private household	2	2	2	10

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
902	Cleaners and charwomen	1	3	2	34
903	Janitors and sextons	4	3	3.5	65
	Food service workers				
910	Bartenders	2	5	3.5	13
911	Busboys	1	4	2.5	0
912	Cooks, except private household	2	3	2.5	37
913	Dishwashers	4	4	4	8
914	Food counter and fountain workers	3	3	3	13
915	Waiters	2	3	2.5	28
916	Food service workers, n.e.c., except private household	3	3	3	21
	Health service workers				
921	Dental assistants	4	4	4	6
922	Health aides, exc. nursing	2	3	2.5	5
923	Health trainees	2	3	2.5	2
924	Lay midwives	1	2	1.5	0
925	Nursing aides, orderlies, and attendants	2	3	2.5	44
926	Practical nurses	2	3	2.5	22
	Personal service workers				
931	Airline stewardesses	5	4	4.5	0
932	Attendants, recreation and amusement	4	4	4	1
933	Attendants, personal service, n.e.c.	3	4	3.5	4
934	Baggage porters and bellhops	2	3	2.5	2
935	Barbers	3	4	3.5	8
940	Boarding and lodging house keepers	1	3	2	0
941	Bootblacks	2	2	2	0
942	Child care workers, exc. private household	2	2	2	13
943	Elevator operators	3	2	2.5	4
944	Hairdressers and cosmetologists	3	2	2.5	18
945	Personal service apprentices	2	2	2	0
950	Housekeepers, exc. private household	2	2	2	8
952	School monitors	2	2	2	3
953	Ushers, recreation and amusement	4	4	4	0
954	Welfare service aides	2	2	2	2
	Protective service workers				
960	Crossing guards and bridge tenders	2	4	3	1
961	Firemen, fire protection	3	4	3.5	8
962	Guards and watchmen	2	4	3	23
963	Marshals and constables	3	3	3	1
964	Policemen and detectives	3	5	4	21
965	Sheriffs and bailiffs	3	5	4	6

		Rater 1	Rater 2	Final Level Given	Number in Analytic Sample
	PRIVATE HOUSEHOLD WORKERS				
980	Child care workers, private household	2	2	2	12
981	Cooks, private household	2	2	2	4
982	Housekeepers, private household	2	2	2	13
983	Laundresses, private household	3	3	3	1
984	Maids and servants, private household	2	2	2	44
	ALLOCATION CATEGORIES				
196	Professional, technical, and kindred workers--allocated	3	4	3.5	0
246	Managers and administrators, except farm--allocated	2	4	3	0
296	Sales workers--allocated	2	3	2.5	0
396	Clerical and kindred workers--allocated	2	3	2.5	0
586	Craftsmen and kindred workers--allocated	4	5	4.5	0
696	Operatives, except transport--allocated	5	4	4.5	0
726	Transport equipment operatives--allocated	6	5	5.5	0
796	Laborers, except farm--allocated	6	4	5	0
806	Farmers and farm managers--allocated	6	3	4.5	0
846	Farm laborers and farm foremen--allocated	6	4	5	0
976	Service workers, exc. private household--allocated	3	3	3	0
986	Private household workers--allocated	3	2	2.5	0

Table II.4: Distribution of Analytic Sample by Occupational Noise Exposure, Age and Sex

Age at Examination and Sex	≤70dB	71-75dB	76-80dB	81-85dB	86-90dB	90-95dB	≥96dB	All Exposures
Both Sexes 25-74 years	87	1231	817	550	585	514	58	3842
25-34 years	24	341	255	122	127	152	13	1034
35-44 years	19	261	175	132	126	105	13	831
45-54 years	22	341	205	152	185	153	20	1078
55-64 years	13	223	138	102	120	93	10	699
65-74 years	9	65	44	42	27	11	2	200
Male 25-74 years	46	636	355	420	406	465	55	2383
25-34 years	12	166	109	92	93	140	13	625
35-44 years	12	127	66	95	82	93	12	487
45-54 years	9	178	84	117	129	132	18	667
55-64 years	5	126	66	79	81	89	10	456
65-74 years	8	39	30	37	21	11	2	148
Female 25-74 years	41	595	462	130	179	49	3	1459
25-34 years	12	175	146	30	34	12	0	409
35-44 years	7	134	109	37	44	12	1	344
45-54 years	13	163	121	35	56	21	2	411
55-64 years	8	97	72	23	39	4	0	243
65-74 years	1	26	14	5	6	0	0	52

BIBLIOGRAPHY

Bibliography

Abey-Wickrama, I., A'Brook, M.F., Gattoni, F.E., Herridge, C.F. (1970): "Mental Hospital Admissions and Aircraft Noise," Lancet 1 (644), 467-468.

AAOO (1959); American Academy of Ophthalomology and Otolaryngology, Committee on Conservation of Hearing, "Guide for the Evaluation of Hearing Impairment," Trans. Am. Acad. Ophthalmol. Otolaryngol. 63, 236-238.

AHA (1951) American Heart Association, Committee to Revise Standardization of High Blood Pressure Readings, Recommendations for Human Blood Pressure Determinations by Sphygmomanometers, New York.

Ahrlin, U. and Ohrstrom, E. (1978): "Medical Effects of Environmental Noise on Humans," Journal of Sound and Vibration 59(1), Academic Press Inc., London, 79-87.

AMA (1979): American Academy of Ophthalomology and Otolaryngology, Committee on Hearing and Equilibrium and the American Council of Otolaryngology Committee on the Medical Aspects of Noise, "Guide for the Evaluation of Hearing Handicaps," J. American Medical Assn., 241(19), 2055-2059.

American National Standards Institute (ANSI): ANSI Reports: S1 4-1971, S3 6-1969 (R 1973), International Electrotechnical Commission (IEC) 123, IEC 177. American National Standards Institute, New York.

American National Standards Institute-Sectional Committee on Acoustics, Vibration and Mechanical Shock (1954): The Relations of Hearing Loss to Noise Exposure, American National Standards Institute, New York.

Anticaglia, J.R. (1970): "Introduction: Noise in our Overpolluted Environment." In: Physiological Effects of Noise, Bruce L. Welch and Annemarie Welch. Plenum Publishing, New York 1-3.

Baughn, W. L. (1966): "Noise Control-Percent of Population Protected," International Audiology 5 (September), 331-338.

Baughn, W. L. (1973): Relationship Between Daily Noise Exposure and Hearing Loss Based on the Evaluation of 6,835 Industrial Noise Exposure Cases, Aerospace Medical Research Laboratory, AMRL-TR-73-53, (June), Wright-Patterson Air Force Base, Ohio.

Berger, E.H., Royster, L.H., and Thomas, W.G. (1977): "Hearing Levels of Nonindustrial Noise Exposed Subjects," J. of Occupational Medicine 19(10), 664-670.

BBN Bolt, Beranek and Newman, Inc. (1974): Impact of Noise Control at the Workplace, Report No. 2671 submitted to Dept. of Labor.

Botsford, J.H. (1967): "Simple Method for Identifying Acceptable Noise Exposures," Journal of the Acoustical Society of America 42, 810-819.

Bunch, C.C. and Raiford, T.S. (1931): "Race and Sex Variations in Auditory Acruity," Arch. Otolaryngol. 13, 423-434.

Bureau of the Census (1980): Statistical Abstract of the United States: 1980 (101st edition) Washington, D.C.

Bureau of the Census (1971): Classified Index of Industries and Occupations, 1970 Census of Populations, Department of Commerce, Washington, D.C.

Burns, W. and Robinson, D.W. (1970): Hearing and Noise in Industry, Her Majesty's Stationery Office, London.

Carlestamn, G., Karlsson, C., and Levi, L. (1973): "Stress and Disease in Response to Exposure to Noise--A Review," In: Proceedings of the International Congress on Noise as a Public Health Problem, edited by W.D. Ward, EPA Report 550/9-73-008, 479-486.

Carlin, M.F. and McCroskey, R.L. (1980): "Is Eye Color a Predictor of Noise Induced Hearing Loss?", Ear and Hearing 1(4), 191-196.

Carter, N.L. (1980): "Eye Color and Susceptibility to Noise Induced Permanent Threshold Shift", Audiology 19, 86-93.

Cohen, A. (1979): "Extra-auditory Effects of Acoustic Stimulation" In: Handbook of Physiology - Reactions to Environmental Agents, Chapter 3, 31-44.

Cohen, A. (1976): "The Influence of a Company Hearing Conservation Program on Extra-Auditory Problems in Workers," Journal of Safety Research, December 8(4), 146-162.

Cohen, A. (1973): "Industrial Noise and Medical, Absence, and Accident Record Data on Exposed Workers," In: Proceedings of the International Congress on Noise as a Public Health Problem, edited by W.D. Ward, EPA Report 5501 9-73-008, 441-453.

Cohen, A., Anticaglia, J.R., and Carpenter, P.L. (1972): "Temporary Threshold Shift in Hearing from Exposure to Different Noise Spectra at Equal dBA Level," Journal of the Acoustical Society of America 51, 503-507.

Cohen, A., Anticaglia, J.R., and Jones, H.H. (1970): "Sociocusis-Hearing Loss From Non-Occupational Noise Exposure," Journal of Sound and Vibration 4, 12.

Cohen, S., Glass, D.C., and Phillips, S. (1979): "Environment and Health," In: Handbook of Medical Sociology, edited by H.E. Freeman, et al., Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 134-149.

Committee on Medical Rating of Physical Impairment of the American Medical Association (1961): "Guides to the Evaluation of Permanent Impairment-Ear, Nose, Throat and Related Structures," Journal of the American Medical Association 177 (July), 489-498.

Corso, J.F. (1963): "Age and Sex Differences in Pure-tone Threshold," Arch. Otolaryn. 77(4), 55-73.

Davis, H.A. and Silverman, S.R. eds. (1970): Hearing and Deafness, 3rd edition, Holt, Rinehart and Winston, Inc., New York, New York.

Dear, T.A. and Karrh, B.W. (1979): "An Effective Hearing Conservation Program--Federal Regulation of Practical Achievement," Journal of Sound and Vibration 13 (September).

Eldred, K. McK. (1975): "Demographics of Noise Pollution with Respect to Potential Hearing Loss" In: Effects of Noise on Hearing, edited by D. Henderson, et al., Raven Press, New York, 21-40.

Elkins, E. (1971): Development of the Speech Reception Test, Vital and Health Statistics, Series 2, Data Evaluation and Methods Research, No. 71, Department of Health, Education and Welfare, Washington, D.C.

EPA (1978): Environmental Protection Agency, Noise: A Health Problem, U.S. Government Printing Office, Washington, D.C.

EPA (1974): Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety, Washington, D.C.

EPA (1973a): Environmental Protection Agency, "Report on Aircraft/Airport Noise, Report of the Administrator of the Environmental Protection Agency to the Committee of Public Works, U.S. Senate."

EPA (1973b): Environmental Protection Agency, Proceedings of the International Congress on Noise as a Public Health Problem, edited by W.D. Ward, EPA Report 550/9-73-008.

EPA (1981): Environmental Protection Agency, "Detailed Research Plan: Cardiovascular Effects of Noise," EPA Report 550/9-81-104.

Fiedler, F.E. and Fielder, J. (1975): "Port Noise Complaints: Verbal and Behavioral Reactions to Airport-Related Noise," Journal of Applied Psychology 60(4), 498-506.

Freeman, H.E., Levine, S., and Reeder, L.G., eds. (1979): Handbook of Medical Sociology, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Galloway, W.J., Eldred, K. McK., and Simpson, M.A. (1974): Population Distribution of the United States as a Function of Outdoor Noise Level, EPA Report No. 550/9-74-009.

Gamble, J.F., Spirtas, R., and Easter, P. (1976): "Applications of a Job Classification System in Occupational Epidemiology," Am. J. Public Health 66, 768-772.

Ginnold, R.E. (1979): Occupational Hearing Loss: Workers Compensation Under State and Federal Programs, EPA Report No. 550/9-79-101.

Glorig, A. and Baughn, W.L. (1973): "Basis for Percent Risk Table," in Proceedings of International Congress on Noise as a Public Health Problem, edited by W.D. Ward, EPA Report 550/9-73-008.

Glorig, A., and Nixon, J. (1962): "Hearing Losses as a Function of Age," Laryngoscope 72: 1596-1610.

Graeven, D.B. (1974): "The Effects of Airplane Noise on Health; an Examination of Three Hypotheses," Journal of Health and Social Behavior 15(4), 336-343.

Graff, Von Ch., Bockmuhl, F. and Tietze, V. (1968): "Noise Exposure and Essential Arterial Hypertension in Humans," In: Larmbelastung, Akutischer Reiz und Neurovegetative Storungen, edited by S. Nitschoff and G. Kriwizkgia, Leipzig.

Heggie, S.A. (1978): "The OSHA Noise Standard and How to Live With It," Journal of Sound and Vibration 12 (June), 20.

Henderson, D., Hamernik, R.P., Dosanjh, D.S. and Mills, J.H., eds. (1976): Effects of Noise on Hearing, Raven Press, New York.

Herridge, C.F. (1974): "Aircraft Noise and Mental Health," Journal of Psychosomatic Research 18 (August), 239-243.

Herridge, C.F. and Low-Beer, L. (1973): "Observations of the Effects of Aircraft Noise Near Heathrow Airport on Mental Health," In: Proceedings of the International Congress on Noise as a Public Health Problem, edited by W.D. Ward, EPA Report 550/9-75-008, 559-610.

Hoar, S.K., Morrison, A.S., Cole, P., and Silverman, D.T. (1980): "An Occupation and Exposure Linkage System for the Study of Occupational Carciogenesis," J. of Occ. Med. 22(11), 722-725.

Holt, M.M. (1979): "SURREGR: Standard Errors of Regression Coefficients from Sample Survey Data," Research Triangle Institute, North Carolina.

Hood, J.D., Poole, J.P., and Freedman, L. (1976): "The Influence of Eye Color upon Temporary Threshold Shift," Audiology 15, 449-464.

Intersociety Guidelines for Noise Exposure (1967): American Industrial Hygiene Association Journal 28, 418.

ISO (1980): International Standards Organization, Acoustics--Assessment of Occupational Noise Exposure with Respect to Hearing Impairment. First Draft Proposal of ISO/DB 1999/1.

Jones, A. and Church, F.W. (1960): "A Criterion for Evaluation of Noise Exposures," American Industrial Hygiene Association Journal 21 (December), 481-485.

Kachny, G.G. (1977): "Blood Pressure in Weavers under Conditions of Industrial Noise," Vrachebnoe Delo 4, 107-109.

Kannel, W.B., Wolf, P., and Dawber, T.R., (1978): "Hypertension and Cardiac Impairments Increase Stroke Risk," Geriatrics 33(9), 71-83.

Karplus, H. and Bonvallet, G. (1953): "A Noise Survey of Manufacturing Industries," Industrial Hygiene Quarterly (December 1959), 236-263.

Karsai, L.K., Bergman, M. and Choo, Y.B. (1972): "Hearing in Ethnically Different Longshoremen," Arch. Otolaryngol. 96, 499-504.

Kendall, M. an. Stuart, A. (1963): The Advanced Theory of Statistics, Volume I, Griffin and Co., London.

Kish. L. (1964): Survey Sampling, John Wiley and Sons, New York.

Knipschild. P. (1977): "Medical Effects of Aircraft Noise: Community Cardiovascular Survey," Int. Arch. Occup. Environ. Health 40, 185-190.

Kryter, K.D. (1975): "Hearing Impairment and Damage Risk from Noise Exposure," testimony presented in support of OSHA Noise Standard.

Kryter, K.D. (1973): "Impairment to Hearing from Exposure to Noise," J. Acoustical Society of America 53, 1211-1234.

Kryter, K.D. (1970): Effects of Noise on Man, Academic Press, New York.

Kryter, K.D. (1963): "Exposure to Steady-State Noise and Impairment of Hearing," Journal of the Acoustical Society of America 35 (October), 1515-1525.

Kryter, K.D., Ward, W.D., Miller, J.D., and Eldredge, Donald H. (1966) "Hazardous Exposure to Intermittent and Steady-State Noise," Journal of the Acoustical Society of America 39 (March), 451-464.

Lader, M.H. (1971): "Responses to Repetitive Stimulation," In: Society, Stress and Diseases: The Psychological Environment and Psychosomatic Diseases, edited by L. Levi, Oxford university Press, London, 425-429.

Lawrence, M. (1964): "Current Concepts of the Mechanism of Occupational Hearing Loss," American Industrial Hygiene Association Journal 25 (May-June), 269-273.

Lawrence, M., Gonzalez, G., and Hawkins, J.E. Jr. (1967): "Some Physiological Factors in Noise-Induced Hearing Loss," American Industrial Hygiene Association Journal 28 (September-October), 425-430.

McGuire, J.L. (1981): "The Effects and Dynamics of Worker Exposure to Industrial Noise," Unpublished Doctoral Dissertation, University of Michigan, Ann Arbor, Michigan.

Miller, J.D. (1971): Effects of Noise on the Quality of Human Life, Central Institute for the Deaf, St. Louis.

Mills, J.H., Gengel, R.W., Watson, C.S., and Miller, J.D. (1970): "Temporary Changes in the Auditory System Due to Exposure to Noise for One or Two Days." Journal of the Acoustical Society of America 48, 524-530.

MIT (1976): Center for Policy Alternatives, Massachusetts Institute of Technology. Some Considerations in Choosing an Occupational Noise Exposure Regulation, EPA Report No. 550/9-76-007.

Mosskov, J.I. and Ettema, J.H., (1977): "Extra Auditory Effects in Short-Term Exposure to Aircraft and Traffic Noise," International Archives of Occupational and Environmental Health, 165-173.

Mosskov, J.I. and Ettema, J.H. "Extra-Auditory Effects in Short-Term Exposure to Abuse from a Textile Factory," International Archives of Occupational and Environmental Health, 174-176.

Mosskov, J.I. and Ettema, J.H. "Extra-Auditory Effects in Long-Term Exposure to Aircraft and Traffic Noise," International Archives of Occupational and Environmental Health, 177-184.

NCHS (1981): National Center for Health Statistics, "Prevalence of Selected Impairments: United States 1977," Vital and Health Statistics, Series 10, Number 134, PHS Pub. No. 81-1562.

NCHS (1980a): National Center for Health Statistics, "Basic Data on Hearing Levels of Adults 25-74 Years, United States, 1971-1975," Vital and Health Statistics, Series 11, No. 215, PHS Pub. No. 80-1663.

NCHS (1980b): National Center for Health Statistics, Health: United States--1980, Report No. PHS 81-1232.

NCHS (1975a): National Center for Health Statistics, "Prevalence of Selected Impairments: United States 1971," Vital and Health Statistics, Series 10, Number 99, PHS Pub. No. (HRA) 75-1526.

NCHS (1975b): National Center for Health Statistics, "Persons with Impaired Hearing: United States 1971," Vital and Health Statistics, Series 10, Number 101, PHS Pub. No. (HRA) 76-1528.

NCHS (1973): National Center for Health Statistics, "Plan and Operation of the Health and Nutrition Examination Survey, 1971-73," Vital and Health Statistics, Series 1-Nos. 10a and 10b, DHEW Pub. No. (HSM) 73-1310.

NCHS (1972a): National Center for Health Statistics, "Examination Staff Procedures Manual for Health and Nutrition Examination Survey, 1971-1973," Instruction Manual, Data Collection, part 15a.

NCHS (1972b): Eighth Revision--International Classification of Diseases, Department of Health, Education and Welfare, Public Health Service, Washington, D.C.

NCHS (1968a): National Center for Health Statistics, "Hearing Levels of Adults by Education, Income and Occupation: United States 1960-1962," Vital and Health Statistics, Series 11, Number 31.

NCHS (1968b): National Center for Health Statistics, "Hearing Status and Ear Examination Findings Among Adults: United States 1960-1962," Vital and Health Statistics, Series 11, Number 32.

NCHS (1967a): National Center for Health Statistics, "Characteristics of Persons with Impaired Hearing: United States July 1962-June 1963," Vital and Health Statistics, Series 10, Number 35.

NCHS (1967b): National Center for Health Statistics "Hearing Levels of Adults by Race, Region and Area of Residence: United States 1960-1962," Vital and Health Statistics, Series 11, Number 26.

NCHS (1965): National Center for Health Statistics, "Hearing Levels of Adults by Age and Sex, United States, 1960-1962," Vital and Health Statistics, Series 11, No. 11, PHS Pub. No. 79-1063.

NIH (1977): National Institute of Health, Human Health and the Environment--Some Research Needs, Report of the Second Task Force for Research Planning in Environmental Health Science, DHEW Pub. No. (NIH) 77-1277.

NIOSH (1975): National Institute for Occupational Safety and Health, Survey of Hearing Conservation Programs in Industry, Cincinnati, Ohio.

NIOSH (1972): Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, Criteria for a Recommended Standard: Occupational Exposure to Noise, HSM 73-1001.

Newby, H.A. (1964): Audiology (2nd edition) Appleton-Century-Crofts, New York.

New York Academy of Sciences, (1968): Noise Effects on Health, Productivity, and Well-Being, Series II, Volume 30. New York Academy of Sciences, New York.

Ohrstrom, E. and Bjorkman, M. (1978): "Medical Symptoms in Noisy Industries," Journal of Sound and Vibration, Academic Press Inc., London, 115-118.

Olishifski, J.B. and Hartford, E.R. (1975): Industrial Noise and Hearing Conservation. National Safety Council, Chicago.

OSHA (1975): Department of Labor, Occupational Safety and Health Administration, Draft Environmental Impact Statement: Proposed Regulation, Noise.

OSHA (1981): Department of Labor, Occupational Safety and Health Administration, "Occupational Noise Exposure; Hearing Conservation Amendment", Federal Register, 46(11), 4078-4179.

Parvizpoor, D. (1976): "Noise Exposure and Prevalence of High Blood Pressure Among Weavers in Iran," Journal of Occupational Medicine 18(11), 730-731.

Passchier-Vermeer, W. (1973): "Noise Induced Hearing Loss from Exposure to Intermittent and Varying Noise," In: Proc. Int. Compress on Noise as a Public Health Problem, EPA Pub. No. 550/9-73-008, 169-200.

Passchier-Vermeer, W. (1968): Hearing Loss Due to Exposure to Steady-State Broadband Noise, Institute for Public Health Engineering, Report No. 235, The Netherlands.

Peterson, E.A., Augenstein, J.S., Tanis, D.C. and Augenstein, D.G. (1981): "Noise Raises Blood Pressure Without Impairing Auditory Sensitivity," Science 211, 1450-1452.

Reltinger, M. (1977): Acoustic Design and Noise Control, Vol. 2 Chemical Publishing Company, New York.

Roberts, J. (1979): "Hearing Levels of Adults 25-74 Years of Age in the General Population by Sex and Race: United States, 1971-1975 and 1960-1962", paper presented at the 97th Meeting of the Acoustical Society of America at the Massachusetts Institute of Technology, Cambridge, Mass.

Robinson, D.W. (1976): "Characteristics of Occupational Noise-Induced Hearing Loss" In: Effects of Noise on Hearing, edited by Donald Henderson, et al, Raven Press, New York, 383-406.

Robinson, D.W. ed. (1970): Occupational Hearing Loss, Academic Press, New York.

Robinson, D.W. (1968): The Relationship Between Hearing Loss and Noise Exposure. National Physical Laboratory, Aero Report Ae 32, Report 38, England.

Royster, L.H., Royster, J.D., and Thomas, W.G. (1980): "Representative Hearing Levels by Race and Sex in North Carolina Industry," J. Acoust. Soc. Am. 68(2), 551-566.

Royster, L.H., Lilley, D.T., and Thomas, W.G. (1980): "Recommended Criteria for Evaluating the Effectiveness of Hearing Conservation Programs," Am. Ind. Hyg. Assoc. J. 41, 40-48.

Royster, L.H., Driscoll, D.P., Thomas, W.G. and Royster, J.D. (1980): "Age Effect Hearing Levels for a Black Nonindustrial Noise Exposed Population (NINEP)," Am. Ind. Hyg. Assoc. J. 41, 113-119.

Royster, L.H. and Thomas, W.G. (1979): "Age Effect Hearing Levels for a White Nonindustrial Noise Exposed Population (NINEP) and Their Use in Evaluating Industrial Hearing Conservation Programs," Am. Ind. Hyg. Assoc. J. 40, 504-511.

Royster, L.H., Thomas, W.G., Royster, J.D., and Lilley, D.T. (1978): "Potential Hearing Compensation in Cost by Race and Sex," Journal of Occupational Medicine, 20(12), 901-806.

Rylander, R. (1978): "Workshop Conclusions," Journal of Sound and Vibration 59(1), Academic Press Inc., London, 139-142.

SAS (1979): Statistical Analysis System User's Guide, 1979 Edition, SAS Institute, North Carolina.

Schein, J. and Delk, M. (1974): The Deaf Population of the United States, National Association of the Deaf, Silver Spring, Maryland.

Schopenhauer, A. (1886): The World as Will and Idea, Vol. II, Translated by R.B. Haldane and J. Kemp, Ticknor & Co., Boston.

Searle, S.R. (1971): Linear Models, John Wiley and Sons, New York.

Shah, B.V. (1976): "STDERR: Standard Errors Program for Sample Survey Data," Research Triangle Institute, North Carolina.

Shatalov, N.N., Ostapkovich, V.E. and Ponomarev, N.I., (1969): "Hearing and Arterial Pressure in Persons Affected by Intense Production Noise," Gigiena Truda.

Suter, A. (1978): The Ability of Mildly Hearing-Impaired Individuals to Discriminate Speech in Noise. Joint EPA/AMRL Report No. EPA 550/9-78-100.

Tarnopolsky, A. (1978): "Effects of Aircraft Noise on Mental Health," Journal of Sound and Vibration 59(1), Academic Press Inc., London, 89-97.

Taylor, S.M., Young, P.J., Birnie, S.E., and Hall, F.L. (1980): Health Effects of Noise: A Review of Existing Evidence, McMaster University (Canada)--Motor Vehicle Manufacturer's Association (United States), Contract Number MU 8018-C1101.

Taylor, W. (1972): "The Weavers of Dundee," Trans. Soc. Occup. Med 22, 37-43.

Von Gierke, H.E. (1975): Noise--How Much is Too Much, Report of the Biodynamics and Bionics Division, AFSC, Wright-Patterson, Air Force Base, Ohio.

Ward, W.D. (1975): "A Critical Review of the 'Levels' Document," Prepared for the Motor Vehicle Manufacturers Association of the United States.

Welch, B.L. (1979): Extra-Auditory Health Effects of Industrial Noise: Survey of Foreign Literature Aerospace Medical Research Laboratory, AMRL-TR-79-41, Wright-Patterson Air Force Base, Ohio.

Welch, B.L. and Welch, A.S. eds. (1970): Physiological Effects of Noise, Plenum Press, New York.

Yerg, R.A., Sataloff, J., Glorig, A., and Menduke, H. (1978): "Inter-Industry Noise Study," Journal of Occupational Medicine 20 351-358.