DROP FORGE IMPACT NOISE: TEMPORARY AND PERMANENT EFFECTS ON HEARING THRESHOLDS

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ABSTRACT

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By

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The purpose of this study was to obtain basic information concerning the nature of drop forge noise in the industrial setting and its effects upon the hearing thresholds of men exposed to such noise. Since a review of the literature revealed a dearth of information, a three phase study was completed to study the nature of the impact noise and its temporary and permanent effects on hearing thresholds.

The nature of drop forge impact noise was investigated in Phase I. At a Lansing drop forge, peak SPL, rise time, duration, octave band spectrum, number of impacts and repetition rate measurements were made on impacts produced by drop hammers. Also, continuous noise measurements from fans, furnaces and other forge noises were obtained including linear, dB A and octave band readings. For all parameters, several readings were made and the means and standard deviations were computed. Results revealed that peak levels from different hammers

hour recovery period. No accumulated TTS was found over a five day work period when ear protection was worn.

Phase III was designed to study the effects of drop forge noise on permanent threshold shifts. A retrospective study was completed of the audiometric records of 71 drop forge workers who were screened with strict criteria regarding work, ear protection, and hearing loss histories. Results indicated considerable variability in amount of hearing loss among drop forge workers. Typically, the greatest impairment occurred in the frequencies above 1000 Hz during the first 15 years of exposure, whereas the low frequencies showed continued reduction in thresholds throughout the work history. Effect of aging upon thresholds was substantially less than the loss resulting from noise exposure even for men who were near retirement (age 65). Differences in hearing thresholds were not marked between forge companies. Small differences were found related to job and ear protection, but these differences were partially related to years of exposure and age.

Three primary conclusions from this study are warranted. First, both impact and continuous (steady state) noise levels measured in a drop forge were found to be potentially hazardous to the workers' auditory systems according to current DRC. Secondly, permanent varied by stroke of hammer and position of employee, but were consistent for the same strokes on different series. Rise times and durations were longer than other types of impulsive noise (e.g., gunfire) and decreased in time from the first stroke of a series to the last. Number of impulses and repetition rates suggest that hammer shop workers receive excessive exposure to high level noise. Overall shop noise and steady state background noise were found to exceed the current Walsh-Healey damage-risk criteria (DRC) for continuous type noise.

In Phase II, the temporary effects on hearing thresholds of 20 drop forge workers (in the same forge as Phase I) were evaluated by manually administering pure-tone threshold tests four times over two consecutive days. In addition, nine employees were tested following a five day work period. Subjects were divided into two groups based on years of exposure and into subgroups according to the type of ear protection employed. Results revealed poorer resting thresholds at all frequencies tested for the older men with longer exposure to the noise. Temporary threshold shift (TTS) for both groups was mild except for one subject who used no ear protection. Small but inconclusive differences between groups were noted. TTS for both groups varied only slightly from one day to the next. Thresholds returned to rested (pre-exposure) levels after a 16 threshold shifts obtained from a large sample of hammer shop employees exhibited serious hearing impairment after ten to fifteen years of employment. Finally, both rested (non-noise exposed) thresholds and TTS measurements obtained from men with less than ten years of noise exposure suggest that utilization of appropriate ear protective devices substantially reduces the hazard to hearing. The primary implication is that if hearing conservation programs are initiated in drop forges, the risk to the employee's hearing can be significantly reduced.

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CHAPTER I

INTRODUCTION

The human auditory system can be damaged in many ways. Among the different causes of hearing impairment, noise has been recognized as a major contributor for many years (Bunch, 1937). While noise is present in many phases of our environment, the industrial setting generally has been considered particularly hazardous (Kryter, 1950). Recent legislation by the federal government regarding noise level control further emphasizes the industrial noise problem (Walsh-Healey, 1969). Within the industrial settings, the drop forge industry is one which has been shown to provide a hazardous environment which can result in hearing loss (Fox, 1953). It is this industrial setting with its impact noise with which the present study is concerned.

Impulse or impact noise, which for purposes of this study are considered synonomous, is a short burst of sound which reaches a maximum sound pressure level (SPL) and then drops in intensity within one or two seconds or less, i.e., gunshots, drop forges, etc.

Industrial impulse noise can be divided into three general types as described by Coles and Rice (1967). The first type consists of discrete impulses that are separated in time by two or more seconds, such as is found in pile driving and drop forging. The second type is the semicontinuous. In this case impulses occur at ten or more times per second and are found in riveting, fettling, and pneumatic caulking. The final type of industrial impulse noise is the repetitive discrete impulses which occur at a rate of one impact every two seconds or up to ten per second. This kind of noise is found in blanking and other types of hammering, such as drop forging.

In an effort to limit the hazard of exposure to the various types of industrial noise, guidelines have been developed specifying the physical characteristics of the noise and the length of time men can be exposed without incurring hearing loss. These guidelines are referred to as damage risk criteria (DRC). In order to develop risk criteria, data regarding the physical characteristics of the noise are needed including: SPL, duration of the impact and rate of occurrence. Studies relating the physical characteristics to temporary threshold shifts (TTS) resulting from exposure to the noise are also required. TTS is defined as a reduction in hearing threshold resulting from noise exposure provided that thresholds return to pre-exposure levels with time after cessation of the noise exposure. These TTS studies should be done both in the laboratory and in the actual industrial environment if possible. Finally, data regarding the permanent threshold shift (PTS) should be obtained. PTS is defined as the reduction in hearing threshold which remains after exposure to noise has occurred and any temporary shift has recovered. When considering DRC, one also must keep in mind that the use of ear protection devices, such as ear plugs or ear muffs, will reduce the effect of the noise upon both TTS and PTS.

DRC have been developed for continuous (steady state) and intermittent noise (Kryter, Ward, Miller, and Eldredge, 1966; AAOO, 1969; Walsh-Healey, 1969). For impulsive type noise, particularly high intensity sounds such as gunfire, enough data have been obtained for the development of DRC (Coles, Garinther, Hodge, and Rice, 1968) with modifications by the Committee on Hearing, Bioacoustics and Biomechanics (Ward, 1968) and suggestions by Coles and Rice (1970). Studies have also been completed showing the effects of ear protection on gunfire impulse noise (Coles and Rice, 1966; Forrest and Coles, 1970).

The use of current DRC for impulse noise, developed primarily for gunfire, has several disadvantages if applied to industrial types of impulse noise. First, the DRC have limiting criteria. The number of impulses is set at 1000 per exposure which is less than the average number of impulses per day to which the average drop forge worker is exposed. In addition, the number of exposures per year is limited to about 10 in the DRC while the industrial worker must be exposed daily. Second, in studies which have been conducted using simulated impact noise conditions, discrepancies have been found between their results and those predicted by the current DRC for impulses. Third, as Cohen, Kylin, and LaBenz (1966) have indicated, the typical industrial situation has a combination of both steady state and impulse noise. Information regarding the addition of steady state noise to the industrial setting with impact noise needs to be acquired if a damage risk criterion is to be applicable. Finally, and most importantly, the exact nature of the hazards from the various types of impact noise in industry are still basically unknown, particularly drop forge noise. The lack of sufficient evidence supporting the relationship of drop forge noise and hearing loss makes generalization to the current DRC questionable.

In order to aid in the establishment of a damage risk criterion for industrial impact noise, particularly drop forge noise, basic information is needed (Coles and Rice, 1967; Coles, *et al*., 1968; Noble, 1970). The present investigation was an attempt to gain some of this basic information regarding drop forge noise and its effects on hearing. Such data are needed for later development of more encompassing DRC. This study also sought to obtain some notion as to the effectiveness of ear protection in the drop forge industrial setting.

Purpose of the Study

This study sought basic information concerning the nature of drop forge noise and its effects upon the hearing thresholds of men exposed to such noise. The investigation was conducted with three purposes in mind:

1. To obtain basic information regarding the nature of impulse noise produced in the hammer shop of a local drop forge through appropriate measurements of the physical parameters. Questions delimiting the research for Phase I were as follows:
    a. What are the peak sound pressure levels resulting from drop hammers?
    b. What are the rise times and total duration of the impacts from drop forges?

   c. At what frequencies is the energy concentrated for impact noise in the drop forge?

   d. What are the intensity level and spectral make-up of the constant background noise present in the drop forge?

   e. What is the typical exposure for a hammer man in terms of number of impulses for work day, week, etc?

2. To compare hearing threshold measurements obtained using standard pure-tone audiometry at the start of a week's work with post exposure thresholds after eight hours work, after a sixteen-hour recovery period, after a second eight hour work period, and after five days' work. The following questions governed the research for Phase II.

   a. What are the changes in resting threshold as a function of years of exposure and type of ear protection?

   b. What differences exist in TTS following eight hours of exposure within age groups with different types of ear protection?

   c. Are differences in TTS obtained between age grouping when using similar types of ear protection devices?

   d. Are sixteen hours of recovery time sufficient for total recovery of any TTS resulting from one day's exposure to drop forge noise?
   e. Does TTS vary from one day's exposure to another?
   f. Is the TTS present on the fifth day greater than that obtained after one day's exposure?

3. To analyze the permanent hearing threshold data obtained from records of drop forge employees seen for hearing evaluations at a hearing and speech clinic. Questions of interest for Phase III were:
   a. Are there typical audiometric configurations of workers exposed to drop forge noise?
   b. Does the degree of loss reach a terminal level after many years of exposure to drop forge noise?
   c. Does the audiometric configuration or degree of loss differ for exposure to impact noise from different drop forge companies?
   d. Is the use of ear protection devices reflected in the degree of loss demonstrated by employees at different work positions?

Importance of the Study

While the fact that drop forge workers do have hearing losses has been documented by Fox (1953), the need exists for a more complete analysis of the nature of the loss as represented by the pure-tone audiogram.

Coles and Rice (1970) have stressed the need for data from the actual source of the hazard, the drop forge. TTS and PTS measures need to be obtained and related to physical parameters if appropriate DRC are to be established or current DRC expanded and modified.

The use of sound attenuating devices in noise has long been recognized as a major contribution to the protection of hearing. While studies have shown the benefit of ear protection to gunfire, the effectiveness of these devices in the industrial setting, particularly drop forges, is apparently unknown. This knowledge would be useful not only for scientific reasons but also for the benefit of the men employed in the industrial setting.

CHAPTER II

REVIEW OF LITERATURE

In this chapter four areas of impact noise are considered. First, problems associated with the measurement of impact noise are discussed. Second, TTS effects from impact noise are reviewed. Third, PTS effects from impact noise are discussed and, finally, the use of ear protection for this type of stimulus is considered.

Problems in Measurement of Impact Noise

The rapid onset and decay of an impact noise present particular problems in measurement not found with steady state noise. These problem areas include rise time, frequency response, operational characteristics of the measurement instruments and position of the instruments at the time of testing.

Rise Time

The rise time capability of a measurement system must exceed the rise time of the impact if an accurate measurement is to be obtained (Harbold, *et al*., 1965;

Coles, et al., 1968). This is particularly important for the microphone employed, but must also be considered for the entire system.

Frequency Response

The frequency response of a microphone or measurement system will strongly influence the results obtained. First, as Harbold, et al. (1965) indicated, the rise time is inversely proportional to the upper limit of the frequency response. Thus, rise time and frequency response are highly related. Coles, et al. (1968) recommend a response curve of from 100 Hz to 70 kHz. Second, the wider the response curve, the higher is the natural frequency of the system. The natural resonant frequency results in ringing or overshoot in the measurement of transients (Harbold, et al., 1965). These must be kept to a minimum.

Operational Characteristics

Even though the rise time and frequency response of the system has been considered, other problems may occur. For example, in the past, sound level meters could not be used because the ballistics of the needle on the VU meter in the fast response made was not rapid enough to accurately measure the peak level of most impact sounds. In addition, the impact meters used until recently necessitated the use of integration time constant and thus gave peaks lower than those measured with the oscilloscope. (Coles, *et al.*, 1968). The development of the new Bruel and Kjaer Type 2204 S sound impact meter has eliminated the above mentioned two problems.

Some attempts have been made to record impact noise for later analysis. However, the rise time response characteristics as well as signal-to-noise ratio and peak clipping problems have generally resulted in poor recordings (Harbold, *et al.*, 1965).

Coles, *et al.* (1968) further noted that problems with the equipment can develop if it is not durable enough to withstand acoustic damage from the pressures being measured. They also noted that unless the equipment is properly mounted, problems with vibrations and microphonics can occur.

Position of Microphone

Coles, *et al.* (1968) stressed the need for the microphone to be at an angle of 90° to the travel of the impact wave. They cited differences between microphones of 2 - 10 dB for peak measures when using 0° incidence. Better agreement was found between microphones at the 90° angle of incidence. If different angles were used to measure the same sound, additional problems would be present.

As can be seen, the problems of measuring impact noise are many. Using the newest instrumentation available commercially, as many of these problems as possible were eliminated in this investigation.

TTS Effects from Impact Noise

Unlike continuous steady state noise, impact noise presents a more complicated group of physical variables or parameters which must be considered regarding their relationship to TTS and PTS if appropriate DRCS are to be developed. Loeb, Fletcher, and Benson (1965) indicated that these variables include peak pressure, pulse duration, rise and decay time, number of impulses, spacing of impulses and repetition rate. The problems of attempting to study all these variables are many, considering the numerous types of impulse producing equipment in industry. Therefore, studies have been done primarily in the laboratory in order to control as many of the noise variables as possible. These methods include the following: gunfire (Kryter and Garinther, 1965; Fletcher and Loeb, 1965; Rice and Coles, 1965), discharging a capacitor across a speaker (Ward, Selters, and Glorig, 1961), opening and closing toy crickets (Ward, et al., 1961), electrical spark gap (Loeb, et al., 1965; Fletcher and Loeb, 1967), taped drop hammer noise (Chisman and Simons, 1961), taped mechanically driven hammers (Walker, 1970), slapping a board on a table (Cohen, Kylin and LaBenz, 1966), or using short bursts of noise (Spieth and Trittipoe, 1958). The latter four methods were used to attempt to relate laboratory noise to industrial noise. Most research, however, has been concerned with gunfire noise. While gunfire research is of interest, studies related to industrial type noise are of major concern in this review.

Temporary threshold shift studies have considered four main areas: growth as related to physical parameters, recovery, reliability and susceptibility.

Growth of TTS

Initial studies by Ward, et al. (1961) revealed that the growth of TTS with time follows a linear function. Their investigation, using the shift at 4000 Hz to impulses presented at 2.4 second intervals, supports the notion that growth of TTS is proportional to the number of impulses presented. Carter, Ball and Kryter (1962) and Carter and Kryter (1962) using impulses of one msec duration obtained similar findings of a possible linear function with time. Kryter and Garinther (1965) reported the linear function at least for the frequencies of 1000-3000 Hz while studying the effects of gunfire.

In 1965, Loeb, _et al_., using impulses of 800 microseconds duration and 156 dB peak intensity, reported that growth of TTS was greater than a linear function with time but less than logarithmic. Walker (1970) reported similar findings when employing levels of 124-127 dB and 20 msec impulses. Walker (1970) suggested, however, that the function depended on the total exposure time, the total number of impulses, and the rate at which the pulses were presented. While contradicting the findings of a linear function, the studies do indicate a growth of TTS which is somewhat different from that generally found for continuous noise. The differences obtained among impulse noise studies would appear to be related to other parameters as suggested by Walker (1970). These parameters affecting growth of TTS include temporal spacing and repetition rate, peak level, spectrum and duration.

Temporal spacing and repetition rates.--Murray and Reid (1946) reported that more TTS was produced by firing one shot at a time than when firing the same number of rounds rapidly. Smith and Goldstone (1961) supported that finding in another gunfire study. Ward, _et al_. (1961) reported that when laboratory produced impulses occurred at intervals of less than one second, less TTS was reported than when impulses were presented at one or more per second. Carter and Kryter (1962) found that one impulse per second produced the most severe TTS of the different intervals studied. Loeb, _et al_. (1965) further supports these results. Walker (1970) while noting the influence of the inter-pulse-interval on TTS also concluded that the rate was more important for the most suspectible subjects.

The cause of the lower TTS at the faster rates and shorter intervals has been attributed to the influence of the middle ear muscle acoustic reflex by all of the investigators. If impulses occur at a fast enough rate, the muscles in the middle ear do not have sufficient time to relax completely. Thus, some measure of protection is carried-over to the next impulse. Differences in individual relaxation rates have been hypothesized as a possible factor in suspectibility to impulse noise. (Ward, _et al_., 1961; Carter and Kryter, 1961).

Ward, _et al_. (1961) have also reported that with impulses widely spaced in time, less TTS occurs. In a study of this phenomenon Ward (1962) found that intervals of 1, 3, and 9 seconds were equivalent in the production of TTS. Intervals over 9 seconds resulted in less TTS, a finding Ward attributed to the effects of recovery. Kryter (1970b) suggested that after only five seconds the auditory system starts the recovery process.

Peak SPL.--With continuous noise, the more intense the noise the greater the amount of TTS. Ward, _et al_. (1961) indicated that the same process holds for impulse noise. However, data are somewhat unclear concerning the relationship with different types of impulse noise. For gunfire, Kryter (1970a, 1970b) reviewed a number of studies and made the necessary conversions to equate the results. He reported that for gunfire the relation of peak SPL to TTS could be shown as a straight line up to approximately 170 dB SPL. Above this point of 170 dB, rapid growth in TTS has been observed (Kryter and Garinther, 1965; Kryter, 1966).

When Kryter (1970b) attempted to equate the non-gunfire studies, such as the spark gap data by Fletcher and Loeb (1967), the loudspeaker data by Ward, _et al_. (1961) and Carter and Kryter (1962), and the mechanical clicker data by Ward, _et al_. (1961), he found that the amount of TTS was not systematically related to the peak pressure of the impulses. Thus, while a systematic relationship has been observed with gunfire noise between TTS and peak pressure, more data are needed on other types of impulses.

In one study, Carter and Kryter (1962) used impulses of one msec duration and reported a three decibel increase in TTS with each six decibel increase in peak pressure. Other studies reviewed have not substantiated this relationship, particularly for the industrial setting.

Spectral Effects.--One of the problems in the measurement of impact noise noted by the American Standards Subcommittee Z24-X-2 (1954) was spectral analysis. Measurement problems have hindered the study of the effects of spectrum on the TTS from impulse noise. There are now methods of measurement and computation which can be used. In addition, there is a method of estimating the spectral characteristics based on the rise time, duration, and peak SPL of the pulse (Kryter, 1970b). Because of the difficulty in measuring and establishing the spectrum of impulses, Coles, et al. (1968) and CHABA (Ward, 1968) do not include this measurement as part of their DRC.

Gunfire studies by Kryter and Garinther (1965), Plomp (1966), and others have generally shown the greatest TTS to occur above 3000 Hz. Little shift is noted in the lower frequencies. The spectral analysis of the four weapons employed by Kryter and Garinther (1965) indicated peak pressure to be about one octave below the area of greatest TTS. This finding suggests that the maximum shift resulting from impact noise is located in the same area as the maximum shift of an octave band continuous type noise (Ward, Glorig and Sklar, 1959).

When considering impulse noise other than gunfire, Ward, et al. (1961) reported a range from 3000 to 10,000 Hz as being most affected by impulse noise. The greatest shift was seen at 4000 Hz, but the frequency of maximum shift varied with the individual and in the same person over repeated exposures. Walker's (1970) data supported the 4000 to 6000 Hz range.

Since duration has an influence on the spectral composition, different durations of pulses should result in different areas of maximum TTS. Fletcher and Loeb (1967) employed pulse duration times of 36 microsec and 92 microsec. With the longer duration of 92 microsec more TTS was obtained in the lower frequencies. The authors, however, indicated that frequencies up to 18,000 Hz are affected for both durations. Loeb, et al. (1965) also using very short impulses, found a range of greatest TTS from 8000 to 12,000 Hz. Loeb and Fletcher (1968), on the other hand, found that frequency of maximum shift appeared independent of impulse duration. They observed that the maximum loss occurred from 11,000-16,000 Hz but that shifts had also occurred at 3000 and 4000 Hz.

While some question remains about the various parameter effects, the place of maximum threshold shift is from 3000 Hz to 6000 Hz for gunfire and from 3000 Hz to 18,000 Hz for other types of impulse noise.

Duration of Impulses.--Rice and Coles (1965) found that the duration of the impulse resulted in different degrees of hazard when firing on the open range and an enclosed range. The longer the duration, the more hazard from gunfire. In the development of the DRC for impulses (Coles, et al., 1968) and the modifications by CHABA (Ward, 1968), duration was quite important. Rice (1968) indicated that levels well above the 140 dB maximum permissible ceiling can be tolerated depending upon the duration of the impulse and total number of pulses (Kryter, Ward, Miller and Eldredge, 1966; Walsh-Healey, 1969).

Studies specifically designed to test the effect of pulse duration on TTS have strongly supported the detrimental effects of longer impulse duration. Fletcher and Loeb (1967) noted that 10-25 impulses at 92 microsec. had the same effect as 75-100 impulses at 36 microsec. duration. Loeb and Fletcher (1968) found further support indicating greater shift from longer impulse duration. These changes occurred with no modification of intensity. The effects of different durations on other types of impulse noise have not been determined. The only attempt to relate duration to industrial noise is through the current DRC for impulse noise.

Recovery of TTS from Impact Noise

In 1958, Ward, Glorig and Sklar reported that the process of the shifted threshold returning to pre-exposure levels followed a logarithm of time basis for continuous noise. Ward, et al. (1961), found that the pattern of recovery for this very different kind of noise followed the same function. This pattern was similar for TTS of 40 dB or less. When TTS exceeded this level, a change in the pattern of recovery occurred. Carter, et al. (1962) and Ward (1962) supported the logarithm of time recovery function for impulse noise.

A recent study by Fletcher (1969) found that the recovery of TTS took longer for the impulsive type noise than for continuous noise. Even after seven hours, recovery was not completed in the high frequencies, up to and including 14,000 Hz. While the results indicate longer recovery time was for the impulse noise, it must be noted that the impulsive noise produced a greater amount of TTS initially; therefore, recovery would be expected to take longer.

With this one exception, the bulk of the literature on recovery of TTS supports the logarithm of time recovery pattern.

Susceptibility to TTS

One of the major findings of the studies on impulsive noise has been the wide range of susceptibility to TTS. Murray and Reid (1946) reported large variability in TTS from gunfire as did Rice and Coles (1965). With laboratory types of impulse noise, findings have also indicated a large degree of variability (Ward, et al., 1961; Carter, et al., 1962; Carter and Kryter, 1962; Hecker and Kryter, 1964). For example, Carter and Kryter (1962) found a total TTS range of 55 dB for impulse noise but only a 20 dB range for continuous octave band noise. This large range of susceptibility to TTS impulse noise. This large range of susceptibility to TTS from impulse noise, coupled with the fact that the impulse TTS did not correlate with the continuous noise TTS, has lead most authorities to be extremely cautious in exposing subjects to high intensity noise. As a means of control and analysis for laboratory studies, Rice and Coles (1965) recommended dividing subjects into three groups according to their susceptibility to impulse noise.

Reliability of TTS

The question of the reliability of TTS from impulse noise, while being a part of most studies of repeated measure, has been specifically studied by

Hodge and McCommons (1966) and Hodge, McCommons and Blackmer (1966). Their findings indicate that individual TTS's are not reliable enough to generalize as to the effects of the noise. However, group mean TTS was found to be a reliable indicator for both normal hearing and hard-of-hearing subjects. These findings were demonstrated for a number of different impulse conditions. The source of the impulse noise was gunfire. TTS from industrial impact noise has not been considered in terms of reliability and would be difficult to do so as the nature of the stimulus and a man's exposure time varies considerably between exposures.

As is evident from the review of the TTS studies, most investigations have focused their attention upon the gunfire type of impulse noise or upon intensities and durations similar to that found with gunfire. Studies by Walker (1970) and Rol, Sporr, and van Dishoeck (1967) have considered repetitive discrete impulses and simulated pneumatic drill noise respectively. Walker (1970) reported that the TTS resulting from 127 dB peak impulses produced more TTS than would be predicted on the basis of the current DRC for impulses. Rol, et al. (1968) raised the question as to the influence of combined steady state noise and the impact noise of the pneumatic drill. This question had been considered by Cohen, et al.

(1966). Their findings indicated less TTS from combined steady state noise and impact noise than from impact noise alone. This occurred as long as the level of the steady state noise was below 110 dB. Their TTS results disagreed with that predicted by the DRC for impulse noise.

The only study found to date which reports some data on TTS from drop forge workers in the actual setting is the Z24-X-2 subcommittee report of the American Standards Association (1954). With 35 drop forge workers tested, results indicated sizable threshold shifts. There was, however, no differentiation of PTS and TTS in the data given. As is evident, few data exist concerning the TTS effects of impact noise as found in the drop forge.

PTS Effects from Impulse Noise

In studying the effects of permanent loss, specific information can only be obtained from studies in the field, where little or no control can be developed by the experimenter. Thus, the first problem in field studies is that the test environment situation must be used as it is found (Burns, 1969). The only practical method at present to estimate the degree of PTS over several years of exposure is to measure the hearing of persons who have been exposed to specific types and amounts of noise over a known period of time. Burns (1969) has indicated that the problem of presbycusis as well as other physical and biological factors can confound the results of this type of study. Thus for control of these factors, there is need for precise information as to the nature of the noise and the duration and pattern of exposure and the need for a complete background of a person's work in noise and his history with guns. Control of biological factors include the need to know the state of hearing before exposure, the present physical condition of the ear, and a general medical history. These problems and an inability to control the above factors make studying permanent hearing loss difficult to relate to the various types of industrial noise and to the different impulse noise parameters.

As with TTS studies, the majority of PTS studies have been accomplished with regard to the effects of gunfire, apparently as an outgrowth from military needs. Studies concerned with hearing loss resulting from gunfire are numerous and, while of interest, the area of priority in this review is industrial impact noise. Generally, the characteristics of hearing loss resulting from gunfire are as follows: 1) the hearing loss increases rapidly in the first few years; 2) there are large individual differences to susceptibility to PTS; 3) the maximal shift occurs at 4000 Hz or 6000 Hz; 4) the slope of the loss is very steep, with little or no loss below 2000 Hz; and 5) the left ear loss is somewhat greater than the right ear loss (Ward, Fleer and Glorig, 1961; Fletcher, 1963; Coles and Knight, 1965; Livesey, 1965; Plomp, 1967).

Other types of impulse noise-induced PTS have generally not been investigated thoroughly, other than to establish the fact that a hazard exists. Only one study was found to date in the literature which deals with the permanent effects from drop forge noise. Fox (1953) reported on 62 drop forge employees who had been seen for otologic and audiologic evaluations and who had claimed hearing loss resulting from drop forge noise. His results revealed that 1) the hearing loss found was proportional to exposure time; 2) workers in the fourth and fifth decade of life had equal loss when determined using a percentage basis; 3) employees with limited exposures showed mild to moderate deficits at 4000 Hz; 4) moderate to severe losses involved the speech range with greater losses in the higher frequencies; and 5) the hearing impairment involved both ears equally. Because losses were reported in a percentage, the relationship of the loss to the spectrum of the noise and the peak levels cannot be assessed. Another problem with this investigation is the lack of control regarding the previous noise history of the workers seen. For example, Fox indicated that eight of his subjects were between 60 and 70 years of age. One of these subjects had worked only seven years in the drop forge. The question that comes to mind is this: Prior to working in the forge did he work in a different noisy environment? There is need for more documented data in the area of drop forge noise.

Ear Protection in Impulse Noise

In high intensity impact or impulse noise where noise level reduction and equipment isolation cannot reduce the noise to acceptable levels, some form of protection for the ears is required. Protection means reduction in the amount of sound energy reaching the cochlea by some device (e.g. ear plug) or method of utilization of the natural protective mechanism of the ear.

As previously noted, the natural protective mechanism of the auditory system for intense acoustic stimuli is the acoustic reflex. In those studies considering spacing of impulses and repetition rate, less TTS occurred with the rates faster as opposed to rates slower than one per second. This finding was related to the residual effects of the acoustic reflex (Ward, et al., 1961; Loeb, et al., 1965; Walker, 1970). Cohen, et al. (1966) attributed the lower TTS obtained from combined steady state and impact noise to the improved sustaining power of the reflex. In these studies, the protection of the aural reflex was evident after the onset of the stimuli and the reflex were established. However, one of the limitations of the aural reflex is its latency period (Loeb, 1963). Impulsive sounds have a faster rise time than does the reflex; thus, the effects on the cochlea occur from single pulses before the reflex can provide its protection.

Fletcher and Riopelle (1960), in order to counter this problem, found that the aural reflex could be activated by a tone just prior to a gun shot. In this way protection could be obtained. This approach has been further documented by Fletcher (1965) and Chisman and Simon (1961). Fletcher and Loeb (1962b) reported that the use of the noise was a better eliciting stimulus than pure tones. Fletcher (1961), however, found that when comparing the protection of the aural reflex to that of ear plugs, more protection resulted from the ear plugs in the high frequency region. As more TTS occurs in the high frequencies, the use of devices such as ear plugs would appear to be the best method of protection.

A large variety of ear protecting devices have been employed for both impact and continuous noise. These devices include ear plugs, ear muffs and helmets. Of these methods, cotton plugs have generally been shown to be the least effective for continuous noise, whereas ear muffs have been most effective. How the devices protect the ear from impact noise has not been entirely determined.

Of the methods for evaluating the effectiveness of different ear protection, the threshold reduction method advanced by Fletcher and Loeb (1962) and stressed by Rice and Coles (1966) appears best for impact noise. In this approach, TTS is measured first with no protection and then with the protector of interest. The difference in shift is the effectiveness of the protector.

How effective the ear protectors have been against impulse noise compared to continuous noise has been studied by Cohen (1961) and Fletcher and Loeb (1962a). Cohen reported that a helmet was less effective against impulse noise than ear plugs. On the other hand, Fletcher and Loeb (1962a) found both plugs and helmet to be equal in effectiveness of protection. The use of cotton for both continuous and impulsive noise is generally considered ineffective.

Studies using ear protectors for impulse noises alone have generally been completed using gunfire as the noise source (Ogden, 1950; Forrest and Coles, 1970; Brasher, 1969; Plomp, 1967). The studies have found that the use of ear protection is sufficient to reduce TTS from gunfire to insignificant amounts. Thus, for gunfire the use of protection has been evaluated and found acceptable.

The fact that even if protectors are used, the amount of protection they can provide varies in efficiency according to the type used, the fit, and the way in which they are used (Coles, 1969). Some of the variance in efficiency has been noted in exposure to high intensity explosive sounds. For example, Flottorp and Quist-Hanssen (1960) found that for some types of ear plugs better attenuation was obtained in the lower frequencies for impact sounds. Coles and Rice (1966) have also noted the low pass filter plugs, designed to improve communications in noise, were not as efficient in long duration impulse sounds as they were for short impulse sounds.

No studies in the literature have been found which indicate the effectiveness of ear protection in industry, particularly drop forge industries. All of the studies have concerned themselves with gunfire effects.

While the need for protection is evident in industry where impact noise is prevalent, research is needed to determine whether the protection devices employed in that setting are adequate.

Summary

Numerous instrumentation problems have delayed until recently the study of the effects of impact noise upon the human auditory system. Some of these problems include: slow rise times; poor frequency responses; the inability of instruments to follow the wave front, to withstand the high intensities, or to accurately reproduce the stimulus; and poor directional placement of microphones.

The effects of impulse and impact noise are evident in both temporary and permanent changes in hearing. Unlike steady state noise, the influence of many parameters in TTS and PTS must be considered. Studies of impact and impulse noise have primarily been concerned with gunfire, although some controlled laboratory studies using high intensity impulses have been completed.

While TTS studies have considered the effects of some of the various parameters of impulse noise, few studies have investigated the parameters of the noise as it occurs in industry. In addition, no evidence was found in the literature regarding TTS resulting from daily exposure in the drop forge industry.

While evidence regarding permanent effects of gunfire noise is substantial, only one study was found regarding permanent hearing loss from drop forge noise exposure. Fox (1953), while showing that hearing loss did result from exposure to impact noise, did not sufficiently describe the hearing losses so that relationships to noise parameters and DRC could be made.

The use of ear protecting devices for impulse noise has been found to be generally adequate for gunfire exposure, but there are differences in the effectiveness of the various types of protectors. No studies have been found to date dealing with the use of ear protectors in the drop forge industry.

The over-riding question remains: What are the temporary and permanent effects of drop forge impact noise upon the hearing thresholds of employees working in the hammer shop?

CHAPTER III

EXPERIMENTAL PROCEDURES

To study drop forge noise and its effects upon men working in that type of environment, a three part investigation was performed. Phase I involved the measurement of the drop forge noise using current methods to ascertain peak levels, rise times, duration, repetition rates, and frequency spectrum. The continuous background noise in the forge was also measured. Phase II of the investigation involved the testing of selected employee's pure-tone hearing thresholds prior to their entering and upon leaving the work area after a day's shift. Resting thresholds and TTS measures were obtained several times during a five day work period for each employee. No attempt was made to control the noise, to hinder the employee during his regular duties, or to control his use of ear protection. Phase III of the investigation consisted of descriptive analyses of documented hearing loss cases seen at the Hearing and Speech Department of the Rehabilitation Medical Center. Those cases selected for review were drop forge personnel who had worked in the forge for a known period of time. The objective was to analyze resting or permanent thresholds on a relatively large sample of workers.

Phase I Noise Analysis

Instrumentation

In the drop forge two types of noise are present: impact noise from the drop hammers and continuous noise from furnaces and blowers. Measurement of the continuous noise was made using a precision sound level meter (Bruel and Kjaer, Type 2204 S) with a one-half inch condenser microphone (Bruel and Kjaer, Type 3134) and an octave band filter (Bruel and Kjaer, Type 1613). Calibration was completed using a pistonphone (Bruel and Kjaer, Type 4220) with its accompanying barometer.

Measurement of impact noise has been a problem in the past (Larsen, 1946). Problems related to fast transients, high peak levels, and measurement devices have been noted (Harbold, Tegt, and Standeven, 1965; Coles and Rice, 1967; Coles, et al., 1968; and Rice, 1968). In the selection of the instrumentation, an effort was made to assure proper rise times, frequency responses and intensity limits. The instrument for making peak level measurements and spectrum analyses included the following: one-half inch condenser microphone (Bruel and Kjaer, Type 3134), sound level meter

(Bruel and Kjaer, Type 2204 S) set for the peak/hold circuitry, and the octave band filter (Bruel and Kjaer, Type 1613). Corrections were made to the octave band measurements on the basis of the response curve of the microphone provided with the instrument. Rise times and total duration of the impacts were measured using a second one-half inch condenser microphone (Bruel and Kjaer, Type 3134) with a cathode follower (Bruel and Kjaer, Type 2615) coupled to a microphone power supply (Bruel and Kjaer, Type 2801) and to a single beam dual channel storage oscilloscope (Tektronic Model 564) (see Figure 1). The waveform of the impact was photographed using a Polariod camera coupled to the oscilloscope. The film employed was Polariod Type 107, 3000 speed. The overall frequency response of the measurement system was flat from 10 Hz through 40,000 Hz. The sound level meter and the condenser microphone and cathode follower were each mounted on a microphone stand (Bruel and Kjaer, Type UA 0049).

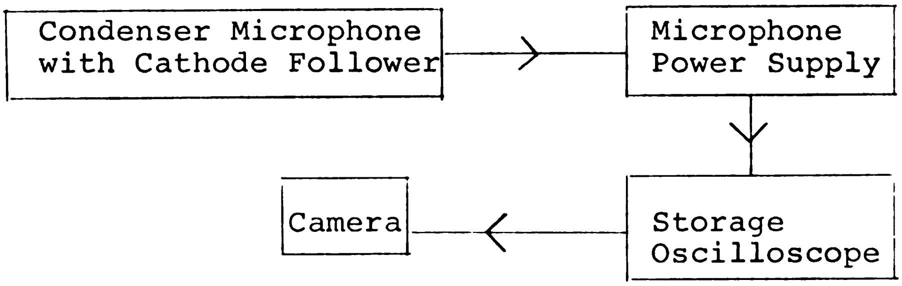

FIGURE 1.--Block diagram of instrumentation for determining rise times, total duration and pictures of wave form.

To obtain measures of repetition rates and an estimate of the number of impulses the men were exposed to daily, the noise was recorded using a dynamic microphone (Electro-Voice Model 635 A) coupled to a magnetic tape recorder (Ampex Model 601). Scotch Brand 201 magnetic tape was employed. The measurement of the rate and number of impacts was obtained by using the tape recorder in conjunction with a level recorder (Bruel and Kjael Type 2305). In this way, an accurate number of the impulses over a known period of time was calculated.

Procedure

In a local Lansing, Michigan,drop forge hammer shop, noise measurements were obtained during the normal working period for both the impact and the ambient noise. Impact peak linear measurements were obtained initially on two drop hammers during the normal morning break-time. A different hammer was tested each day for two successive days by having one hammer crew work while the rest of the hammers were shut down. In this way, impact measurements were made on a 3000 pound board hammer[1] and

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[1] A board hammer is a gravity fall hammer in which the ram is attached to a hard wood board. The ram is raised by motor driven rolls and by friction against the board.

a 2000 pound air hammer.[2] At the time of testing, bearing parts were being forged from one and three-quarters inch hot steel bars on the 3000 pound hammer, and metal elbows were being forged from one and five-sixteenths leaded steel bars on the 2000 pound hammer. The peak linear measurements were made at the hammerman's, the heaterman's, and the straightener's position (see Figure 2). For the 3000 pound board hammer, ten readings were made at the hammerman's position for the first and eighth strokes of the series required in forming the piece being made. Five readings were made at the straightener's and heaterman's positions for the same strokes. For the 2000 pound hammer, peak linear readings were made for the first, third and fifth strokes at the three positions. Additional readings were made on the eleventh stroke at both the hammerman's and straightener's positions. The 2000 pound hammer was forging two pieces from each bar of steel. Five strokes were required for the first half of the bar and six strokes for the second half of the bar. Thus eleven strokes were required to forge each bar. The sixth stroke on the last half of the bar was required as the steel cooled somewhat and was harder. Readings of

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[2] An air hammer is a gravity fall hammer in which the ram is attached to a metal rod and cylinder. The ram is raised by air pressure.

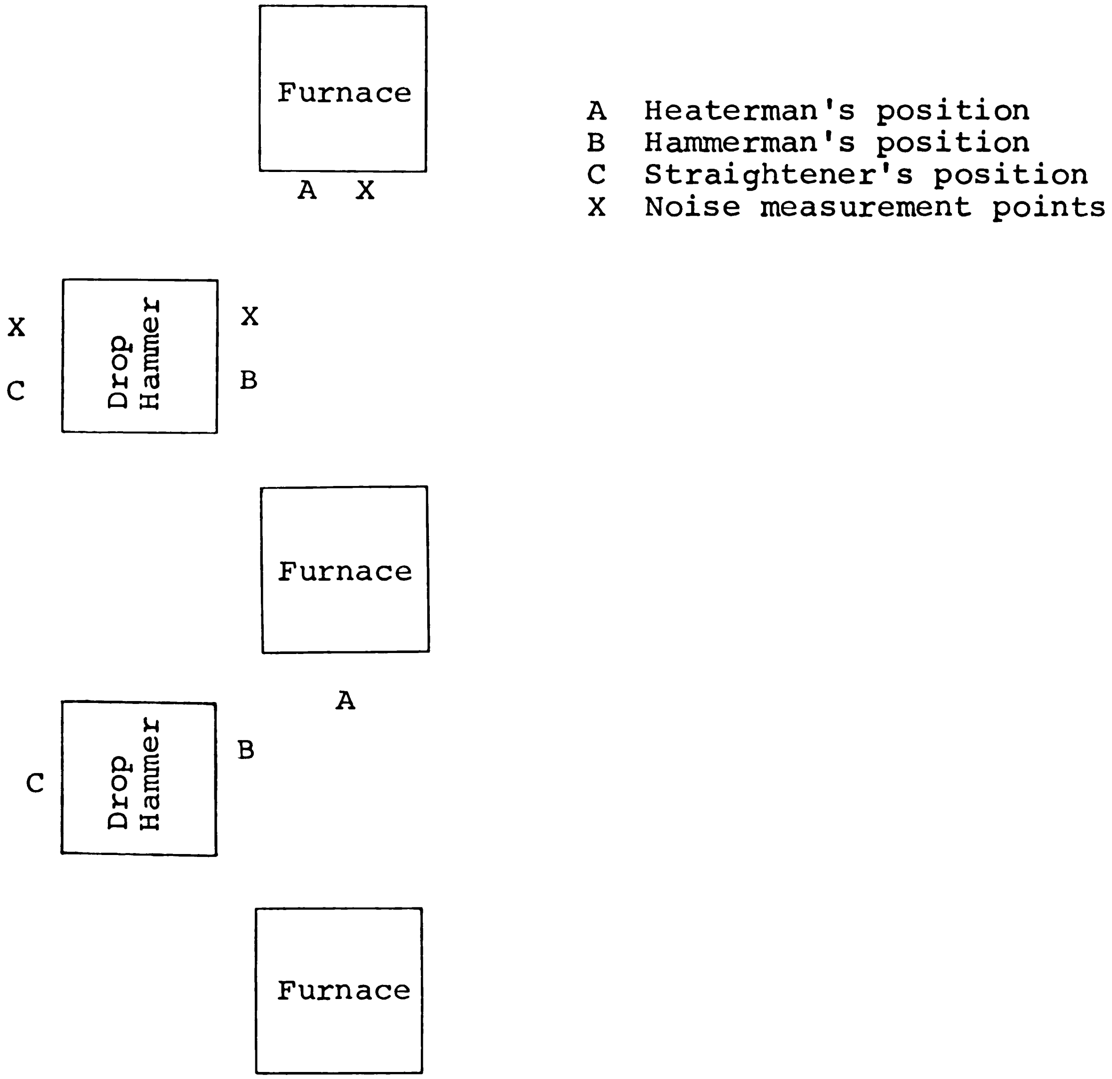

FIGURE 2.--Diagram of two adjacent drop hammers and furnaces with the positions of the operating crew shown. (Also noted are the points at which peak level measurements were taken for the three positions.)

the last stroke were made to determine if the peak intensity was different from the other strokes measured. Because it was found that the repetition rate for both the hammers tested was equal to or more than one stroke per second, ten peak linear readings and ten RMS A scale, slow response readings were made on a 3000 pound air hammer at the hammerman's position. The peak readings were made on the last stroke of a series of seven. The dB A readings were made by visually determining the average level for the series of seven strokes.

Octave band measurements of the impact noise were completed at only the hammerman's position for both the 2000 pound and 3000 pound hammer using the octave band filter coupled to the sound level meter. The peak level for each of the octave bands from 31.5 to 31,500 Hz was obtained using the peak hold circuit on the sound level meter. Two readings were made at each octave band. As the octave band characteristics for just one impact could not be obtained without additional specialized instrumentation, readings were made on the same stroke for a number of series. For the 3000 pound board hammer, readings were made on the eighth stroke, and for the 2000 pound air hammer readings were made on the third stroke. Corrections were made for the use of the protective grid on the microphone and the frequency responses.

The rise time and the total duration of the impacts were determined by photographing the waveform from the screen of the storage oscilloscope and calculating the time required for the waveform to occur. Rise time was defined as the time required from the onset of the impulse for the intensity to reach its peak positive amplitude. Total duration was defined as the total time required for the amplitude to return to the level of the background noise. The rise time and total duration were calculated for the last six strokes of the 2000 pound air hammer. The microphone was placed at a 90° angle of incidence during all testing of individual hammers.

During the measurement period, a recording of the impact noise in the shop near the hammer being measured was made for analysis of repetition rate and number of impacts during a specified period of time. The tape recorder was then coupled to the level recorder and a record was obtained of the number of impulses which occurred during a 15 minute period for the 2000 pound hammer singly and a 5 minute period for the hammer when the whole shop was operating. The repetition rate was then calculated and the number of impulses over a working day estimated.

In addition to the readings on individual hammers, overall RMS linear levels and A weighting scale levels were obtained when the whole hammer shop was operating. During each shift, eight drop hammers were in operation. Three readings were made at two locations on each of the two days of testing. Thus, readings were made at four locations in the hammershop.

The continuous background noise of the furnaces and blowers was measured during a work break. At this time, all hammers were shut down but the fans and furnaces continued to operate at a level similar to that of the normal work period. Sound pressure level measurements were made with the sound level meter and the octave band filter. Readings were made with the linear and the A scale weighting response at five different locations. Four different readings were obtained for each of the octave bands from 31.5 Hz through 31,500 Hz. The mean levels were then calculated.

In summary, the following impact noise measurements were made on two hammers: Peak levels, rise times, duration, repetition rate, and frequency spectrum. In addition, certain measurements were made while eight hammers were operating simultaneously and while no hammers were operating.

Phase II TTS Measurement

The second phase of this investigation concerned the effects of drcp forge impact noise upon the hearing thresholds of employees exposed on a daily basis.

Subjects

Based upon information obtained from a questionnaire (See Appendix A) given to all hammer shop employees of a drop forge, twenty subjects were selected from the sixty-two men responding. Selection was based on the following criteria:

1. An accurate account of the type and use of ear protection by the subject was known.
2. He was not exposed to other types of industrial noise or to gunfire either in the armed services or in civilian life on a habitual basis.
3. There was no unaccounted for periods in his work history to assure that working in the drop forge was his chief occupation.
4. There was no history of congential hearing loss or of loss prior to his working in the forge.

5. There was no history of conductive pathology.
6. There was no evidence of a unilateral hearing loss.

The 20 subjects selected were placed into two sub-groups according to age and number of years of exposure as follows:

1. Subjects between twenty and thirty years of age were placed in Group 1 and those between thirty-five and fifty years of age were put in Group 2.
2. Group 1 subjects had to have between one and ten years of exposure to drop forge noise; whereas, Group 2 subjects must have had between fifteen and twenty-five years of exposure.

The men with between one to ten years of exposure ranged in age from 21 years 9 months to 27 years 11 months, with a mean age of 24 years 11 months. The men with between 15 to 25 years of exposure ranged in age from 35 years 8 months to 50 years 6 months, with a mean age of 43 years 8 months. Each group was then further subdivided according to the type and use of ear protection. Group 1 was divided into three sub-groups: those who had used cotton or no protection (N=3); those who had always used plugs or muffs (N=2); and those who had shifted from cotton to plugs or muffs (N=5). Group 2 was divided into two sub-groups: those who had always used cotton (N=3) and those who had shifted from cotton to plugs or muffs (N=7). Of the older men who had shifted from cotton to another type of protection, all had used cotton between ten to twenty-three years. Their use of plugs or muffs ranged from two weeks to five years.

Description of the Work Area and Exposure Periods

All of the subjects selected were employed in the hot hammer shop of a local drop forge. The shop contained sixteen drop hammers and twenty-one furnaces. Only eight of the hammers were in operation during any one shift. The hammers ranged in size from 1600 pounds to 5000 pounds. The five largest hammers had two furnaces supplying them. The shop is composed of two large rooms connected to form a 90 degree angle. The older portion of the shop had two rows of hammers with a walkway between. The back of the hammers faced the outside wall. In the newer section of the hammershop, the hammers were located in one row with a wide corridor on the front side of the hammer. There was no acoustic treatment of the area for sound reduction.

Each hammer had a crew of three or four men: the hammerman, one or two heatermen, and the straightener. Other men in the shop were those transporting steel to and from the hammers. These latter men had the most variable exposure. It should be pointed-out that all new employees generally started at the position of transporting steel so that all men in the forge have had that type of exposure as well as working on the hammer crew. Of the men used as subjects in this phase of the study, ten were heatermen, seven were hammermen, and three were straighteners.

The noise to which these men were exposed is similar to that described in Phase I of this investigation. The employees were exposed to the forge noise for up to six and three-quarter hours a day. Time away from the work area included a fifteen minute break after two and one-half hours work and a thirty minute lunch break after an additional one and three-quarters hours of work. Exposure time following the long break was approximately two and one-half hours. Exposure to the intense impacts from one hammer varied daily depending on work conditions, mechanical failure or changes in the work schedule. As a consequence of these factors, exposure varied from one and a half hours up to six and three-quarter hours on different days while the study was in progress.

Instrumentation

A pure-tone portable audiometer (Beltone 12C) with THD-39 earphones equipped with MX 41/AR cushions and a bone conduction transducer (Radioear B-70A white dot) was employed to administer the pure-tone tests. The audiometer was calibrated in accordance with the International Standards Organization (ISO) 1964 standards. Linearity of the attenuator was accurate in two decibel steps. As a result, all testing was completed using 2 dB steps.

In order to assure proper calibration throughout the testing period, calibration was checked at regular intervals. No systematic changes were noted. The equipment employed for calibration included the following: a sound level meter (Bruel and Kjaer, Type 2204), an octave band filter (Bruel and Kjaer, Type 1613), an artifical ear (Bruel and Kjaer, Type 4151), and a condenser microphone (Bruel and Kjaer, Type 4144). Bone conduction calibration was completed with an artificial mastoid (Beltone Model M5B) and its associated amplifier coupled to a microphone amplifier (Bruel and Kjaer, Type 2603). The Hearing Aid Industry Conference (HAIC) Interim Standards for bone conduction were used for 0 dB hearing threshold level (Lybarger, 1966).

All pure-tone tests were administered in an acoustically treated trailer constructed for the Michigan Association for Better Hearing and Speech. The trailer was located adjacent to the employee's entrance of the forge so that subjects could come directly from work to be tested and return to complete their shift with a minimum loss of time. The ambient noise levels were measured in the trailer test room on five occasions. Readings were made using the A and C weighting scales of the sound level meter as well as octave bands. The levels noted in Table I were measured during the busiest time of the day to assure that the room could be used in the worst conditions that could occur. Instrumentation employed for measuring the ambient noise included the following: a condenser microphone (Bruel and Kjaer, Type 4145), a sound level meter (Bruel and Kjaer, Type 2204S), and an octave band filter (Bruel and Kjaer, Type 1613). In view of the highest readings (see Table I, reading 4), it was necessary to arrange with the forge company to close all doors in the vicinity of the trailer during the testing time. When all precautions were taken, the only frequency being tested which was affected by noise was 500 Hz and only those subjects with normal hearing at that frequency were affected. No correction was made to the thresholds at 500 Hz. However, the ambient noise problem at 500 Hz was considered in the interpretation of the results.

TABLE 1.--Ambient noise levels in dB in the testing room of the trailer as measured for the A weighting scale, C weighting scale, and octave bands.

Readings	Octave Band Center Frequency									A scale	C scale
	31.5	63	125	250	500	1000	2000	4000	8000		
1*	64.0	54.0	50.0	44.0	35.5	24.0	20.0	14.0	10.0	40.0	65.0
2	65.0	54.0	46.0	40.0	30.0	19.0	10.0	10.0	10.0	34.0	64.0
3	65.5	54.0	45.0	41.0	30.0	20.0	14.0	10.0	10.0	35.0	65.0
4*	68.0	54.0	51.0	48.0	41.0	30.0	23.0	14.0	10.0	43.0	68.0
5	66.0	54.0	48.0	42.0	30.0	19.0	10.0	10.0	10.0	38.0	65.0
Maximum levels in order to test 0 dB ISO-1964**			31.0	25.0	26.0	30.0	38.0	51.0	56.0		

* Readings were made when doors to shop area were open.

** Levels obtained by subtracting difference between ISO-1964 and ASA-1951 Standard from maximum levels described by Cox (1955).

Administration

All testing in this phase of the study was completed in a four week period. Five subjects were tested each week. Care was taken to assure that both day and night shifts as well as men from both age groups were tested each week. On the Friday preceding the week of testing, each subject was contacted and a second history form was completed (see Appendix B). In addition, he was provided a notice of the test time (see Appendix C).

When the subject reported for work on Monday of the week he was to be tested, he was given a brief otoscopic check to insure that ear canals were free from excessive cerumen, foreign bodies or physical abnormalities of the outer ear. When cleared by otoscopic examination, each subject was given the pre-exposure pure-tone test. This pre-exposure test took place between 6:15 AM and 7:00 AM for the day shift, and between 2:45 PM and 3:30 PM for the evening shift. Monday was selected to start the testing because of the need to have at least 48 hours away from the noise to assure accurate resting (non-noise exposed) threshold. Following the first test, each man was given a reminder notice for the other tests during the week (See Appendix C).

Post-exposure test number one was obtained just before the end of the subject's work shift. The schedule was arranged so that as each hammer crew completed its quota for the day, the subject came immediately to the testing trailer, was tested, and then returned to his position and completed the rest of his shift. The average time elapsing between the time the subject left his position and the time the test started was 5.9 minutes for all subjects on the Monday test.

Each subject returned the following day prior to starting work. At that time, post exposure test number two was given to determine if recovery of the initial (Monday) TTS had occurred. At the end of the work shift following the second day's exposure, the subject returned for testing. Average time elapsing between the stopping of work and testing averaged 6.6 minutes the second day. The time elapsing between work stoppage and testing was markedly influenced by two subjects who because of mechanical breakdowns stopped work twenty and thirty minutes before the experimenter was available for testing.

On Friday of the test week, nine subjects were seen for testing following their work shift to determine if any accumulated TTS could be determined over the week. Only nine subjects were tested as some subjects did not work the full week, other subjects were injured or became sick, or work stopped because of the extreme heat. Because of these problems, a total picture of TTS on Friday could not be obtained.

During the pre-exposure test, auditory thresholds were obtained at 500, 1000, 2000, 4000 and 8000 Hz for each ear. The test was completed twice in order to obtain some measure of reliability and to provide some subject training for subsequent tests. Results of the second test were used as the resting threshold for each ear. Bone-conduction thresholds were obtained without masking at 500 and 1000 Hz for each ear to determine if an air-bone gap was present. If an air-bone gap of greater than 8 dB was found, the subject was excluded from the study. One subject was found to have a unilateral conductive loss and was replaced by another subject. In the initial test, the subject's better ear was tested first. If no preference was noted, then the right ear was tested. Time required for the initial test was 12 to 15 minutes.

For all post-exposure threshold tests, pure-tone air-conduction thresholds were obtained on only the better ear. The better ear was selected on the basis of the average hearing level for the four octaves from 500-4000 Hz. When both ears were the same, one ear was arbitrarily selected. Twelve right ears and eight left ears were tested. The frequencies tested in the four post-exposure tests were the same as those initially measured. However, the order of the frequencies tested was rotated to minimize recovery time order effects on TTS measurements. The time required for the TTS measures was three minutes or about 30 seconds per frequency.

Administration of all pure-tone tests was completed manually by the experimenter. The earphones were placed on the subject by the tester to insure proper alignment with the ear canal. The testing method employed was the ascending method advocated by Carhart and Jerger (1959) but using 2 dB steps instead of 5 dB steps. Each subject was instructed as follows:

> This test is a brief evaluation of your hearing for tones. The object of the test is to find the point where you can just barely detect the tone. Some tones will be very high pitched and some low pitched. Regardless of the pitch of the tone, the important thing is that you indicate every time you hear it. You can signal that you hear the tone by raising your hand. Keep you hand raised as long as you hear the tone. When the tone is gone lower your hand. We will test your _____ ear first and then your _____ ear. Do you have any questions?

The same instructions were given before each of the post-exposure pure-tone tests. An outline of the testing procedure for the pre-exposure test and the post-exposure tests is provided in Appendix D.

Threshold level in this study was defined as the lowest intensity at which the sound was reported to have been heard by the subject at two successive presentations, or at two out of three presentations. All threshold results were recorded on a data form, as shown in Appendix E. TTS was calculated by subtracting the resting thresholds from the post-exposure thresholds at each frequency. The differences noted between tests indicated the amount of TTS which occurred despite the use of the various types of ear protection employed.

In summary, pure-tone thresholds were obtained on four occasions over a two day period for 19 drop forge workers and following five day's exposure for 9 of the subjects in order to evaluate temporary threshold shift from impact noise.

Phase III Retrospective Analysis

The third portion of this study involved a review of the audiological records of drop forge workers who had been referred for audiometric testing and if necessary, fitting of a hearing aid.

Selection of Cases

From a population of 167 drop forge workers referred for testing at the Rehabilitation Medical Center, Edward W. Sparrow Hospital, Lansing, Michigan, 71 cases were selected for retrospective analysis of their pure-tone hearing thresholds. All of the subjects were seen for testing between January 1961 and March 1971. Testing was done by staff audiologists.

Selection of the cases for review was based upon the following specific criteria:

1. Each subject was employed in the hammer shop of the forging companies[3] in the local area.
2. His chief occupation was that of working in the drop forge hammer shop.
3. He was not habitually exposed to other types of high intensity noise, either steady state or impact.
4. He did not have a congential hearing loss or a hearing loss which pre-existed to working in the drop forge.
5. There was no history of conductive pathology or unilateral hearing loss.
6. His use of ear protection was documented e.g., type and length of use.
7. The forging company at which the case was employed was known.
8. The position (specific job) of the individual subject was documented.

For some cases insufficient data were found in the audiological records. Therefore, the individual or the forge at which he worked was contacted and the missing

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[3] Subjects were drawn from four drop forges in the Lansing, Michigan area.

information obtained. Cases for which any of the above data could not be obtained were excluded from this study.

Procedure

From each of the 71 cases selected from the populations of drop forge workers tested, the following data were obtained:

1. Name
2. Address
3. Age
4. Years of employment (or exposure)
5. Position held
6. Employing company
7. Type of protection used and how long
8. Pure-tone air-conduction thresholds.

The data obtained were placed on individual data sheets. Each subject was coded according to the forge at which he was employed. Recorded on the data sheet was a copy of the audiogram, including the pure-tone thresholds at 250, 500, 1000, 2000 and 4000 Hz for both ears. Data regarding thresholds at 6000 and 8000 Hz were found to be omitted from a considerable number of cases due to differences in testing procedures over the ten year testing period. Therefore, these two frequencies were excluded from the analysis. They are included, however, in the data tables in Appendix J. All pure-tone thresholds were converted to ISO-1964 standards to facilitate handling and interpretation of the data.

For each subject, the average loss for the four frequencies of 500, 1000, 2000 and 4000 Hz was calculated. In addition, the slope of the loss across the three octaves from 500 to 4000 Hz was determined for each subject by dividing the total decibel change by the number of octaves.

Once the data had been compiled, the data were grouped according to age, years of exposure, types of positions held, employing drop forge and the type of ear protection used. The mean loss and standard deviation for each frequency for the right and left ears combined were determined in order to ascertain if particular trends were evident for each of the variables noted.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter contains the basic data obtained for each of the three phases of the study and discussions of their significance with regard to the experimental questions posed. Each phase is considered separately followed by a discussion of the relationships between the different phases and relevant areas of interest.

Since the goal of the investigation was to study the nature and effects of drop forge noise upon the auditory system, elaborate statistical procedures were ruled out in favor of obtaining an overview of the problems involved and determining trends where evident. Results are presented primarily using means and standard deviations.

Phase I Noise Measurement Results

The raw data obtained during the noise survey at the drop forge are presented in Appendix F, Tables F1-F8. The measurements of interest regarding impact noise were: peak SPL, rise time and duration, spectral composition, and some indication of the typical exposure as revealed by repetition rate, the number of impulses per exposure period, and the overall noise levels in the drop forge. Continuous noise measurements of the ambient background noise involved linear and dB A readings as well as an octave band analyses.

Impact Peak SPL

The mean peak SPL and standard deviations obtained on Hammer I (3000 lb. board hammer) and Hammer II (2000 lb. air hammer) are presented in Tables 2 and 3. Several findings should be noted. First, the peak pressure levels vary with the position at which the employee stands in relation to the hammer. The hammerman and the straightener are exposed to the greatest intensity peaks. The mean peak levels ranged from 122.7 dB to 143.6 dB for both hammers measured. Second, the peak levels vary according to the stroke of the hammer. As is illustrated in Figure 3, the initial stroke of a series was always less intense than the strokes which followed. Tables 2 and 3 also show the variation of peak levels by stroke. This result is consistent with the nature of the forging operation as the initial stroke is made on a hot piece of metal of large diameter. A type of cushion occurs between the dies on the first stroke. As the metal becomes thinner and cools, the peak intensity increases accordingly, with the final stroke usually being the most intense. Third, while the intensity varies between

TABLE 2.--Peak pressure means and standard deviations* at the three positions for the first and eighth strokes on the 3000 lb. hammer.

Position	Strokes			
	1st		8th	
	Mean	SD	Mean	SD
Hammerman**	128.0	1.0	143.0	0.9
Heaterman	124.3	0.3	139.0	0.7
Straightener	125.5	1.9	143.6	0.9

*In dB re 0.0002 microbar

**Ten readings made at the Hammerman's position. Five readings made at each of the other positions.

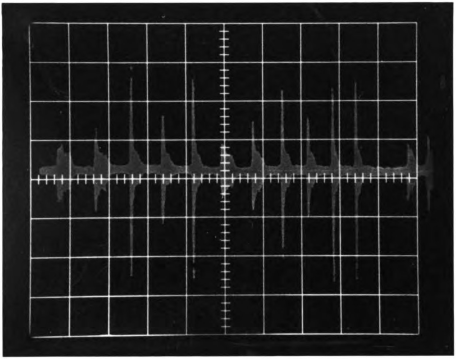
TABLE 3.--Peak pressure means and standard deviations* at the three positions for the 1st, 3rd, 5th, and 11th strokes on the 2000 lb. hammer.

Position	Strokes							
	1st		3rd		5th		11th	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hammerman**	128.4	0.8	140.6	1.2	139.4	0.9	141.1	0.6
Heaterman	122.7	0.8	135.4	0.5	134.0	0.9		
Straightener	126.1	0.7	143.4	1.2	141.8	0.8	143.6	1.3

*In dB re 0.0002 microbar

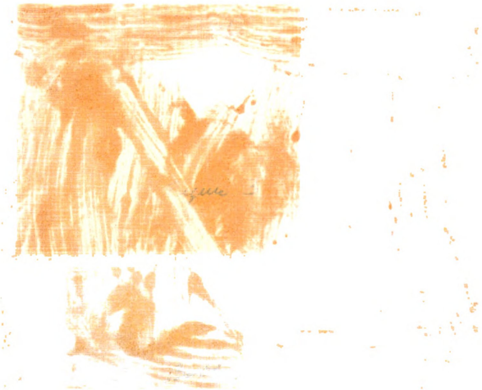
**Ten readings made at the Hammerman's position. Five readings made at each of the other positions.

strokes, the peak levels for a particular stroke in a different series on the same hammer were found to be extremely consistent as indicated by the small standard deviations for both Hammers I and II. Fourth, the peak levels for both Hammers I and II are comparable despite the difference in type of hammer, weight of the ram, and piece being forged.



Ordinate: .5 volts per division
Abscissa: 1.0 second per division

FIGURE 3.--Photograph of the eleven stroke series of the 2000 lb. hammer taken from the screen of a storage oscilloscope.



A third hammer, a 3000 pound air hammer was measured for peak levels on the last stroke of a series of seven for further comparison between hammers. The mean peak level obtained was 145.8 dB with a standard deviation of 1.3 dB. This higher peak level indicates some differences between hammers. This finding will be discussed in a later section of this chapter.

Since initial measurements on both hammers showed repetition rates of more than one stroke per second, dB A slow response readings were made on a third (3000 lb. air) hammer to compare with the peak readings. The mean dB A level was 113.2 dB for 10 series. Each reading was the average level for a series of seven strokes, determined visually from the VU meter of the sound level meter.

Impact Rise Time and Duration

Rise times and total durations were determined from photographs taken of individual impacts for the last six strokes of a series of eleven by the 2000 lb. hammer. Rise times as indicated in Table 4 are between 6 and 10 msec. The six strokes measured were those required to forge one piece of metal on the hammer. Three strokes were made in each of two dies. As evident from

TABLE 4.--Rise time and total duration in msec for each impact of a series of six strokes out of a total of eleven produced on the 2000 lb. hammer.*

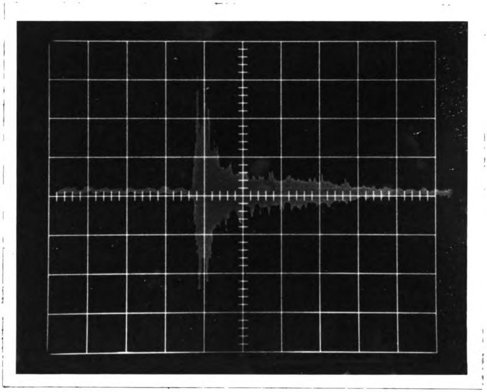
Stroke	Rise Time (msec)	Total Duration (msec)
6	10	355
7	7	272
8	6	270
9	10	230
10	9	225
11	6	207

*Strokes represented series required to form the last half of a metal bar.

Strokes 1-5 formed the first half of the bar.

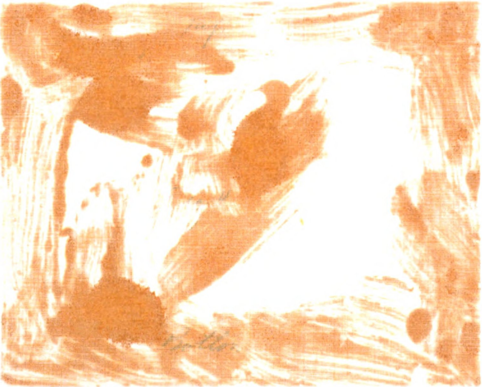
the rise times in Table 4, the first stroke in each of the two dies had a slightly greater rise time. As the metal became thinner the rise time decreased.

The duration of the impact was difficult to determine because an intense blast of air occurred immediately after the hammer blow. It was not possible to differentiate the duration of the impact from the air blast. However, since the employee was exposed to both the impact of the hammer and the air blast, a decision was made to compute the combined duration of those two noise sources. Hence, the total duration shown in Table 4 is for the impact of the hammer plus the air blast. The duration ranged from 355 msec on the first stroke measured in a series to 207 msec for the last stroke of the series. The duration became progressively shorter with each stroke of the series. A typical waveform of the last stroke of the series of six on Hammer II is shown in Figure 4.



Ordinate: 0.5 volts per division
Abscissa: 50.5 msec per division

FIGURE 4.--Photograph of the final (11th) stroke of the series on the 2000 lb. hammer taken from the screen of the storage oscilloscope.



Impact Octave Band Spectrum

Figure 5 presents the spectrum of the octave band measurements of the impacts from Hammers I and II. Readings were taken from the same stroke of two series of impacts for each octave band. The raw data are presented in Appendix F, Tables F4 and F5. Results indicated a peak intensity in the 2000 Hz octave band for both hammers. However, the levels were high over a broad frequency range. Levels were greater than 120 dB SPL from 125 Hz through 31,500 Hz. Below 125 Hz, the levels exceeded 110 dB SPL for Hammer I and 105 dB for Hammer II.

Impact Repetition Rate and Number of Impacts

The repetition rate was calculated in two ways. Initially the rate was approximated from Figure 3, which gave one series of impacts over a particular period of time. Using this method, it was determined that a rate of more than one stroke per second occurred. The second method entailed the use of a tape recorder coupled to a level recorder. The number of strokes occurring from Hammer II over a 10,000 second or 16 minute and 40 second period was determined. The mean number of strokes per minute was 53.7 or one stroke every 1.1 seconds. As the strokes occurred in series of eleven

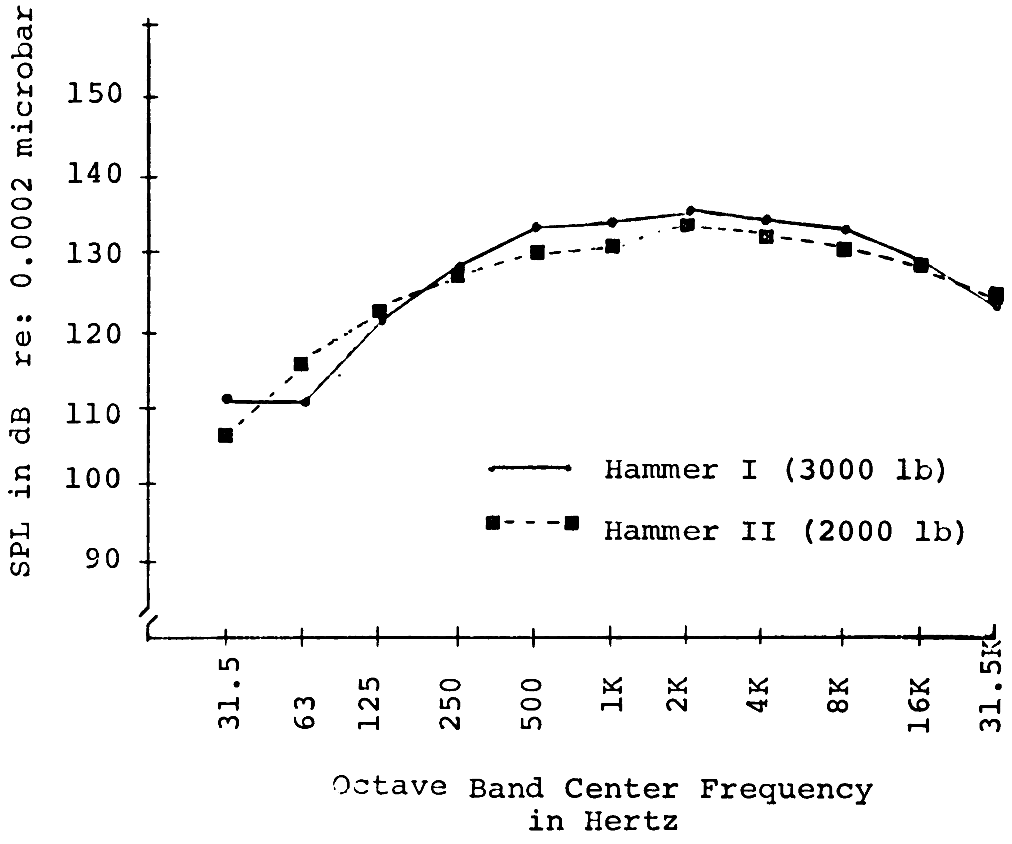


Figure 5. Octave band analysis of impact noise from two drop forge hammers (Stroke 8 on Hammer I and Stroke 3 on Hammer II).

strokes per piece of metal, 4.9 pieces were forged each minute. Between each series of strokes, a period of 2.35 seconds elapsed. When the time the hammer was not being operated is subtracted from the total time, the actual repetition rate of the hammer was 1.1 strokes per second. These findings apply only to Hammer II.

The total number of impacts to which an employee was exposed was determined by taking the average strokes per minute and calculating the number of strokes per hour, day, week and month. This of course, assumes that the employee operates that particular hammer and job constantly during the work period in question. When calculated, the number of impulses produced was 3222 per hour, 20,943 per day, 104,715 per week, and 418,860 per month.

When other hammers were operating, the number of impacts reaching the hammerman of Hammer II was 2.4 per second. This rate is an approximate since peaks on the level recorder writeout do not indicate if two hammers struck simultaneously. Assuming this rate of 2.4 strokes per second to be an average rate of 144 per minute, the hammerman would be exposed to 56,160 impacts per day or 280,800 impacts per week. The peak intensities from the other hammers at Hammer II's location were not determined.

Overall Shop Noise

The general level of the noise in the hammer shop when the hammers were running was obtained using both the linear response and the A weighting scale of the sound level meter. The means and standard deviations are shown in Table 5. Raw data are presented in Appendix F, Table F6. Results indicate that at four locations in the hammer shop, the levels are fairly constant for both the linear and dB A readings. The only reading not consistent with the others is location five. Here the readings were somewhat more intense because this location was close to two 3000 pound hammers and one 5000 pound hammer. The standard deviations obtained for the readings at each position indicate that when the hammers are in operation the levels are fairly constant.

TABLE 5.--Means and stardard deviations for linear and dB A scale measurements made of overall noise levels during hammer shop operation.

Locations*	Linear		dB A	
	Mean	SD	Mean	SD
1	106.0	1.0	101.7	0.6
2	103.7	1.5	99.3	0.6
3	105.7	0.6	100.7	0.6
4	105.7	0.6	98.3	0.6
5	110.3	0.6	105.3	0.6

*Three readings made at each location. The five locations were simply five typical work areas in the hammer shop.

Continuous Background Noise

The second type of noise found in the drop forge is the continuous noise of the furnaces and blowers which is present at all times during the work period. Figure 6 illustrates the levels obtained in each octave band as well as the linear and dB A scale measurements. The most intense components of the noise appear to be below 1000 Hz. Levels below 31.5 Hz could not be tested due to the limitations of the equipment. Actual levels obtained are presented in Appendix F, Table F7.

Phase I Noise Measurement Discussion

The questions asked at the start of this study regarding the nature of the drop forge noise were as follows:

1. What are the peak pressure levels from drop forge noise?
2. What are the rise times and total duration of the impacts from a drop hammer?
3. At what frequencies is the energy concentrated in drop forge impact noise?
4. What is the intensity and spectral makeup of the background noise in the forge?
5. What is the typical exposure for a hammerman in terms of number of impulses per exposure and their repetition rate?

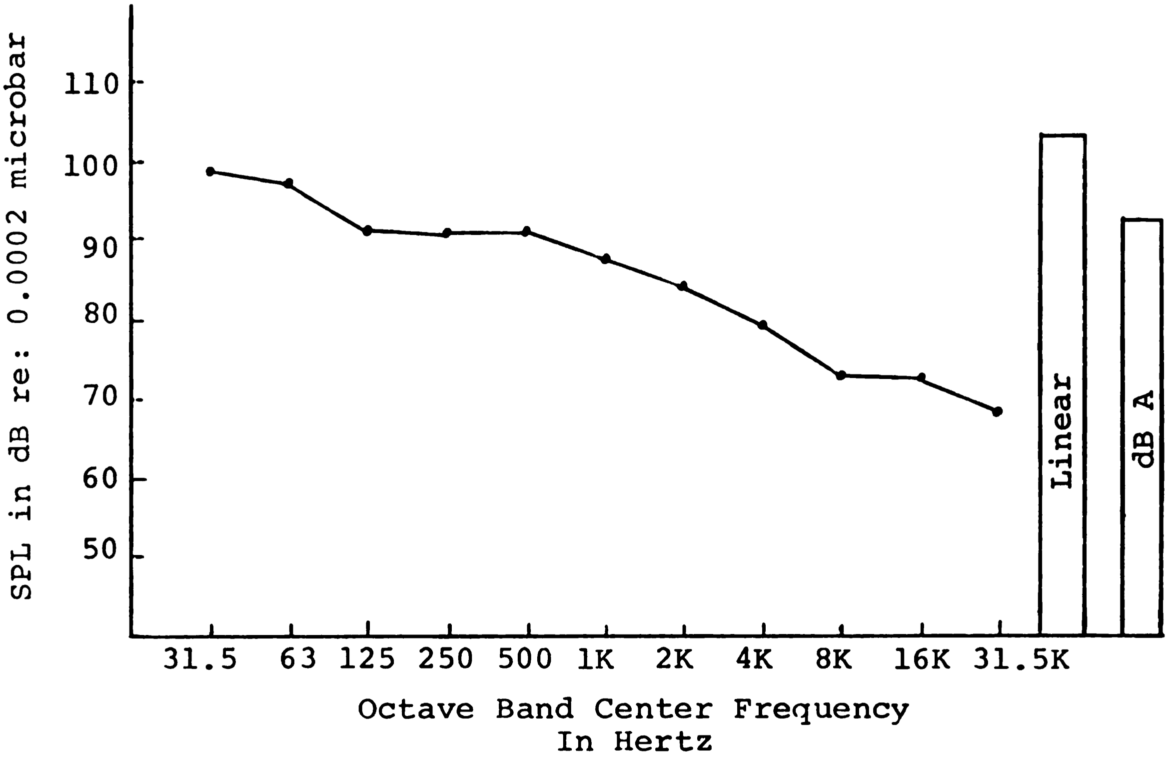


Figure 6. Octave band analysis of steady state furnace and blower noise from the hammer shop of a drop forge.

The results presented in the preceding section answer each of these questions. Restatement of the results here is unnecessary; however, several aspects of the noise must be discussed further.

Previous study of peak levels in drop forges by Bolt, et al. (1952) revealed average levels of 138 dB ±5 dB. Present findings indicate that peak levels on the 2000 and 3000 pound hammers generally are consistent with the earlier findings. However, not only did a third hammer reach higher mean levels, 145.8 dB as a maximum peak (see Appendix F8), but all hammers measured varied depending upon the stroke of the series being used to forge the piece of metal. Thus, there is considerable variability to be expected not only between hammers, but also, from a single hammer. Fox (1953) indicated that the variation in peak levels from one hammer to another is not strictly related to the size of the hammer. Factors such as the construction of the machine and its mode of operation contribute to the production of intensity peaks.

The remarkable small variation in peak levels for the same stroke of different series on the same hammer suggests a consistency which might be useful in the establishing of DRC. This is assuming that other factors such as the influence of other hammers and the background noise are also constant.

The rise times, as calculated for the impacts studied, ranged between 6 and 10 msec. These times are somewhat longer than the rise times of 2 msec reported by Bolt, et al. (1952). When comparing the hammer rise times to the near instantaneous rise times of gunfire, it is evident that this type of impact noise requires more time to reach maximum intensity. However, the fact that the rise time is more than 0.5 msec reduces the hazard (Coles and Rice, 1967). The same type of finding was made for the total duration of the impact noise. That is, drop forge noise requires a longer decay time than does gunfire. In the current study, the exact duration of the impact could not be established because a blast of air which followed the impact became a part of the envelope. As the impacts were made within an enclosure, reverberation also prolonged the impact intensity.

The octave band spectrum of two hammers is an unusual measure for impact noise, in that, the literature has generally disregarded this type of measurement. The primary reasons for not using octave band analysis or other spectral methods in the live situation have been the difficulty in measuring the variable noise levels and the inability of the instrumentation to capture the peak levels. More recent advances in instrumentation have permitted more complex spectral analysis. However, due to equipment limitations, the octave band approach was the only method at hand which could be employed in the live situation. The consistency of the peak levels for particular strokes from one series to the next suggested the method employed was feasible. Differences might exist, however, because of different pieces of metal being forged. The results indicated a broad band spectrum with its peak at the 2000 Hz octave band. On the basis of the rise times and durations, one would expect to find more energy in the lower frequencies. Why this did not occur is unknown at this time.

The background noise of the forge is continuous and was measured in the conventional way. The dB A level measured exceeds current DRC limits (Walsh-Healey, 1969). Thus, considering the noise from the blowers and furnaces alone, a level sufficient to cause hearing impairment exists. The noise of the hammers naturally adds to the total intensity in the shop area.

The question of what is a typical exposure for a hammerman is a difficult one to answer. The number of impulses he is exposed to will vary from one day to the next, depending on the type of metal product being forged, the number of hammers operating in the forge, and the number of times his hammer needs repair or reset for a new job. The numbers given in the results section were estimates based upon slightly over 15 minutes of actual work time on only one hammer doing one type of work.

Phase II Temporary Threshold Shift Results

The second phase of this study was divided into two parts: obtaining resting thresholds on two groups of drop forge employees and measuring TTS on the same groups. The raw data obtained are in Appendices G and H.

Resting Thresholds

The mean combined right and left ear resting thresholds for the 0-10 year group and the 15-25 year group are presented in Tables 6 and 7 respectively. These thresholds are graphically presented in Figure 7. The 0-10 year group had an average 3.6 years exposure to the noise while the 15-25 year group had an average of 20.2 years of exposure.

Results indicate that the younger group had a mild deficit at 4000 and 8000 Hz with essentially normal hearing in the lower frequencies. The older group showed a mild to moderate deficit with a 15 dB per octave slope from 500-4000 Hz. Since there were only 10 subjects in each group, insufficient data were available to compile a progressive audiogram showing resting thresholds at

TABLE 6.--Means and standard deviations of combined right and left ear resting thresholds* for the one to ten year exposure group according to type of protection employed.

Protection Type	Number of Subjects		Frequency in Hertz				
			500	1000	2000	4000	8000
Cotton or None	3	Mean	8.7	2.7	3.7	15.0	23.7
		SD	3.1	1.2	3.1	10.5	7.0
Cotton to Plugs or Muffs	5	Mean	15.0	14.0	10.4	19.2	14.0
		SD	11.1	12.3	8.7	16.5	9.8
Always Plugs or Muffs	2	Mean	4.5	2.5	6.5	4.5	20.5
		SD	6.4	3.5	9.2	2.1	12.0
All Ss	10	Mean	11.0	8.3	7.6	15.0	18.2
		SD	9.0	10.3	7.4	13.5	9.5

*In dB hearing level (re:ISO, 1964).

TABLE 7.--Means and standard deviations of combined right and left ear resting thresholds* for the 15 to 25 year exposure group.

Protection Used	Number of Subjects		Frequency in Hertz				
			500	1000	2000	4000	8000
None or Cotton	3	Mean	12.3	28.3	36.3	59.3	60.3
		SD	11.8	5.8	15.3	21.0	48.8
Switched to Plugs or Muffs	7	Mean	20.9	37.3	49.4	59.4	57.6
		SD	11.2	17.9	21.1	24.2	30.8
All Ss	10	Mean	18.3	34.6	45.5	59.4	58.4
		SD	11.5	15.5	19.7	22.1	34.1

*In dB hearing level (re: ISO, 1964).

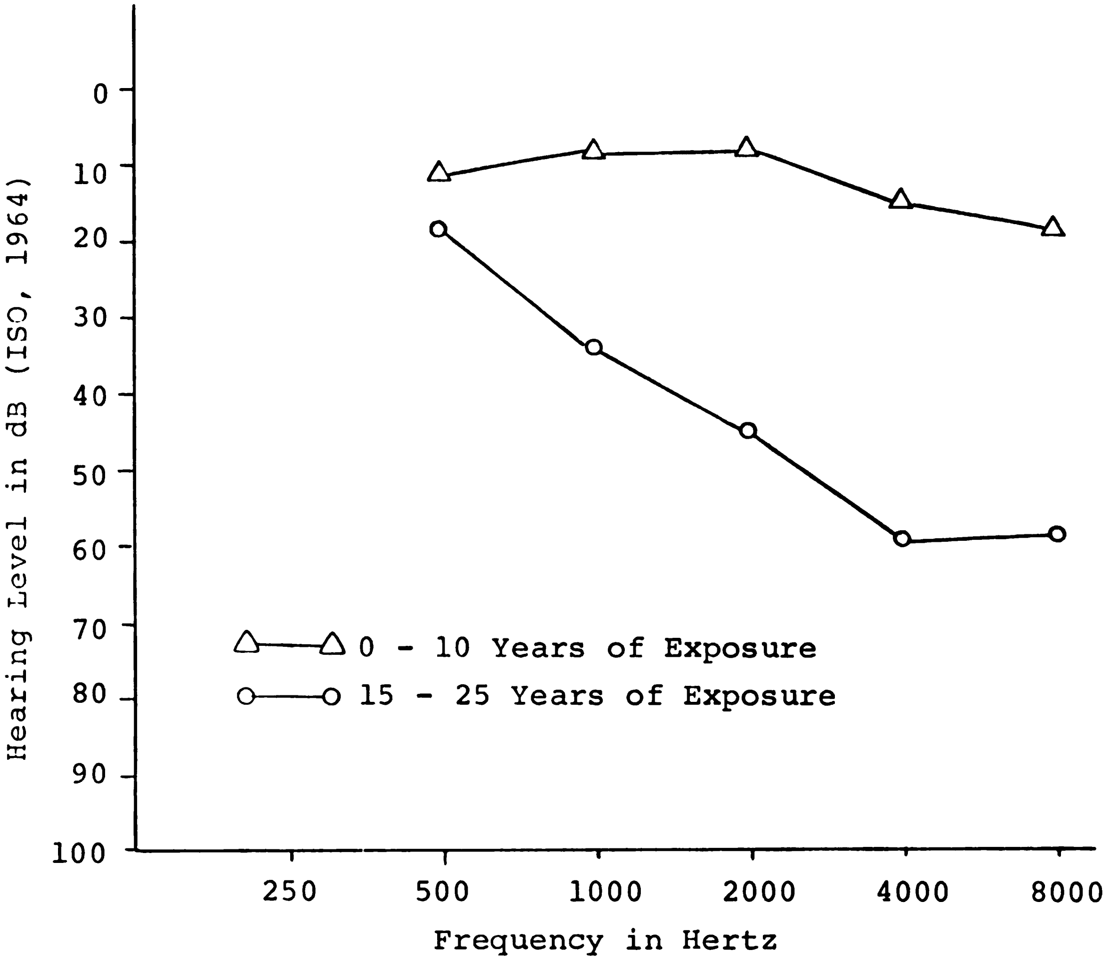


Figure 7. Mean Resting thresholds for the 0-10 and the 15-25 years of exposure groups. (N=10 subjects per group).

different years of exposure. (This, however, is shown in Part III.) A second finding is that the older group had larger standard deviations at all frequencies than the younger group. This result demonstrates that there is a large variation among the older men in degree of loss from essentially similar exposure to drop forge noise.

Resting Threshold and Protection Used

Tables 6 and 7 also contain the mean thresholds for the subjects in the younger and older exposure groups respectively, according to the type of protection used while working in the forge. As expected, the men with greater exposure demonstrated greater hearing loss than did the men in the group with less than 10 years exposure. As demonstrated in Figure 8, the 0-10 year exposure group showed some differences when compared by protection. The two subjects using muffs since beginning work showed no deficit at 4000 Hz with only a slight drop at 8000 Hz. The three subjects who had used no protection or cotton indicated a slight deficit at 4000 Hz and 8000 Hz as did the five men who had switched from cotton to plugs or muffs. The latter group also evidenced poorer thresholds at 500 and 1000 Hz than did the other two groups. All means for this group were within normal hearing limits (<25 dB ISO).

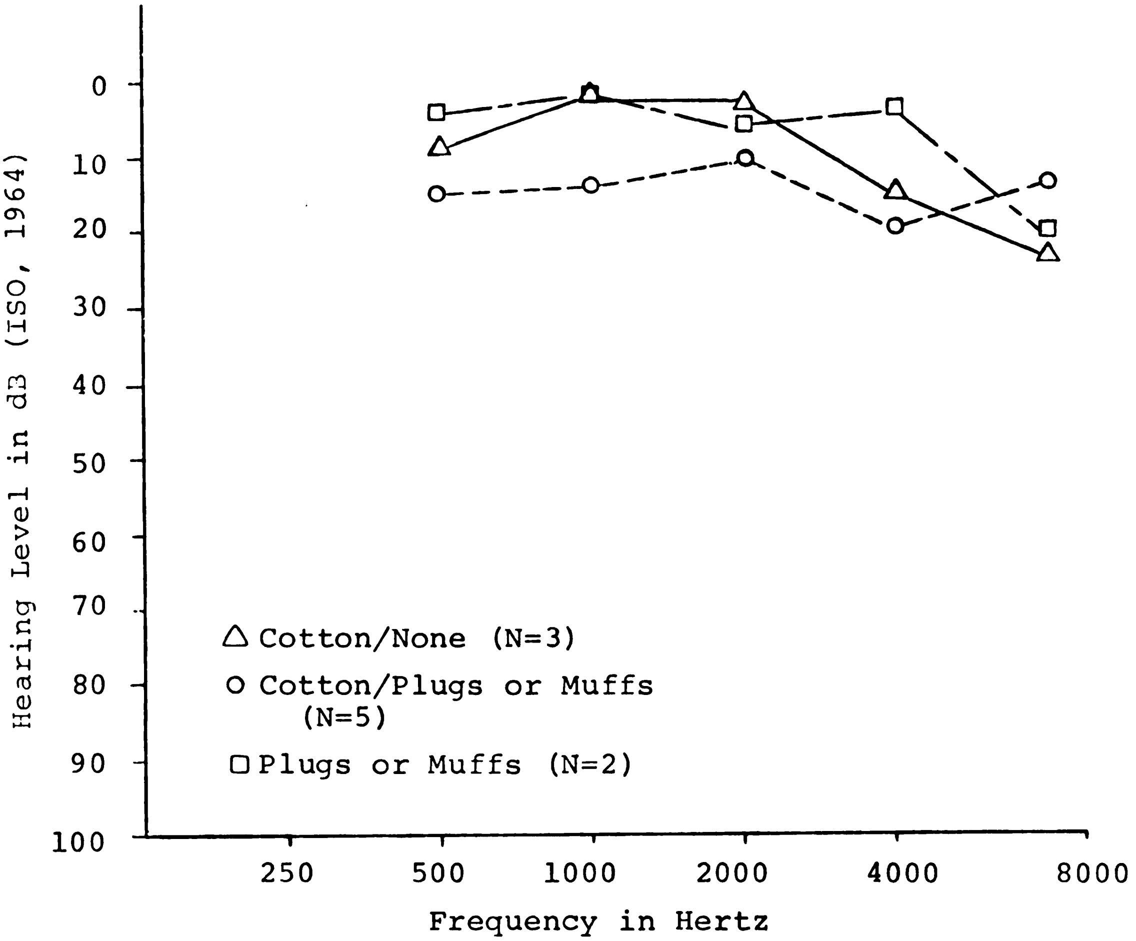


Figure 8. Mean resting thresholds according to type of protection employed by the 0 - 10 years of exposure group.

For the 15-25 years exposure group (see Figure 9) the three subjects who had employed cotton since they started working in the forge showed better thresholds up through 2000 Hz than did the group that switched from cotton to plugs or muffs. Only at 4000 and 8000 Hz were the thresholds similar. Thus for both groups, the men who switched from cotton to muffs or plugs showed the greatest loss. This finding was unexpected because cotton provides very little attenuation. Why this occurred will be discussed later.

Temporary Threshold Shift After One Day's Exposure

As shown in Table 8, small mean TTS values were obtained for both the 0-10 and 15-25 year exposure groups. The small TTS values found apparently are a result of the use of protection. The one subject in the group who did not use protection demonstrated a shift of 46 dB at 4000 Hz after one day's exposure. The older subjects demonstrated greater shift in the lower frequencies where generally their resting thresholds were better, while the younger men showed higher threshold shifts at 4000 Hz.

The mean shifts did not exceed 10 dB for either group at any frequency. However, there were a number of subjects that exceeded the acceptable levels of 10 dB below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at 3000 Hz and above according to the CHABA DRC (Kryter, *et al*.

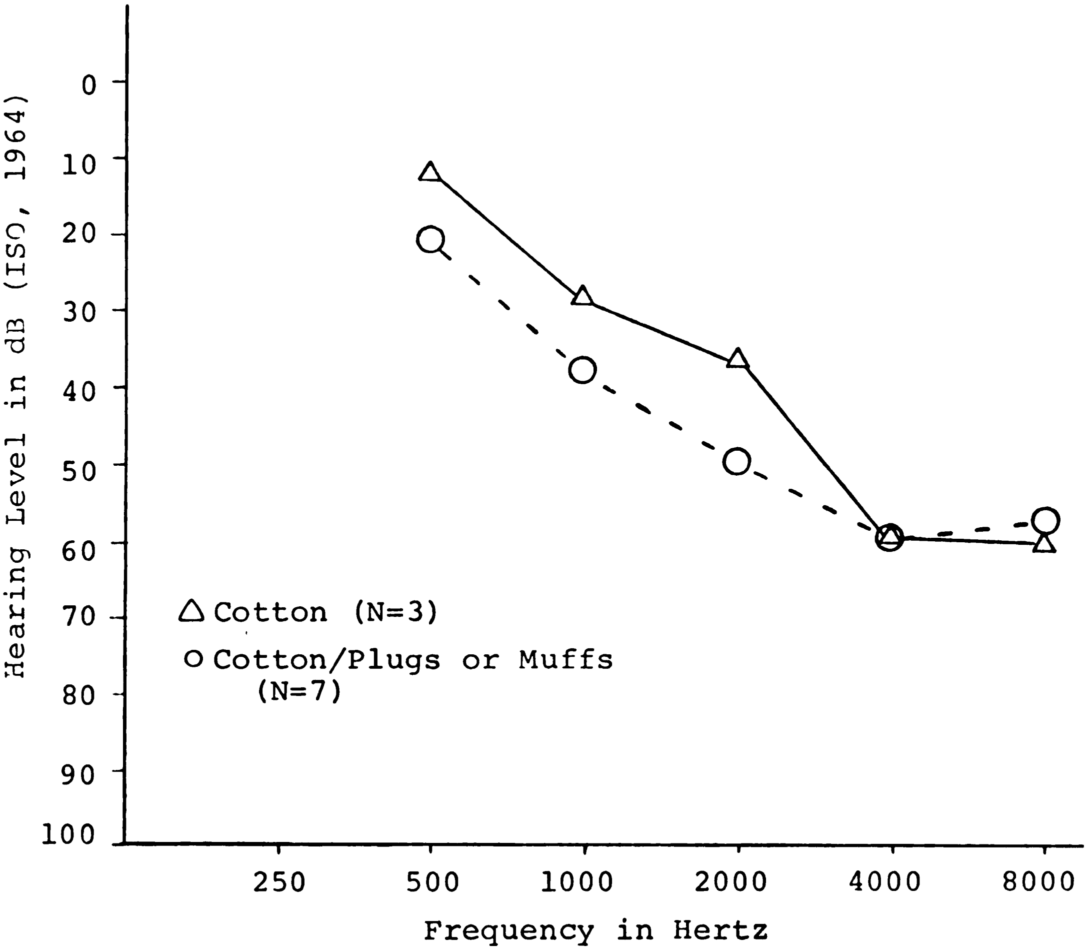


Figure 9. Mean resting thresholds for the 15 - 25 years of exposure group according to type of protection employed.

TABLE 8.--Mean TTS and standard deviations in dB following one day's exposure for each of the two exposure groups.

Exposure Groups		Frequenzy in Hertz				
		500	1000	2000	4000	8000
0 - 10 yrs.	Mean	4.9	3.1	5.3	7.0	4.0
	SD	4.1	2.8	5.6	14.6	9.4
15 - 25 yrs.	Mean	7.0	7.2	5.2	2.2	2.6
	SD	5.4	5.8	4.8	2.2	6.1

1966). In interpreting the shift at 500 Hz, however, one must recall the ambient noise levels in the test room exceeded recommended levels for testing 0 dB hearing level. In most cases, however, the men's thresholds were sufficiently elevated that testing as low as 0 dB was not required. Individual TTS patterns for the younger and older men are illustrated in Figure 10 and 11, respectively.

When considering the younger subjects by type of protection, the two subjects using cotton or no protection showed the greatest shift in the higher frequencies. When plugs were employed, the one younger man demonstrated small amounts of TTS primarily in the lower frequencies. The three subjects using muffs showed variable TTS at all frequencies. In no case did TTS exceed acceptable limits (CHABA working group #46) when muffs or plugs were employed.

Among the older subjects, the greatest TTS for the men that employed cotton for protection occurred in the lower frequencies. The majority of the men in the 15-25 year exposure group had switched to the use of plugs within the past 5 years. TTS obtained from those men revealed small shifts at each frequency, but the amount was variable from man to man.

TTS after Second Day's Exposure

The mean TTS following the second day's exposure is presented in Table 9 for each group. The mean shifts are fairly constant with those obtained after the first day's exposure. Only at 4000 and 8000 Hz for the 0-10 year exposure group was any real change noted. By comparing the shifts made by Subject 3 on Figure 10 for the two days, one can note why the change in mean threshold shifts occurred at 4000 and 8000 Hz. Again, the older group showed the greater shift for the lower frequencies while the younger group demonstrated a more consistent shift across frequency. No large change was noted for most subjects from one day to the next.

Recovery from One Day's TTS

Thresholds were obtained on both groups sixteen hours after the first day's exposure. Results shown in Table 10 indicate that thresholds had essentially returned to pre-exposure levels for both groups of subjects.

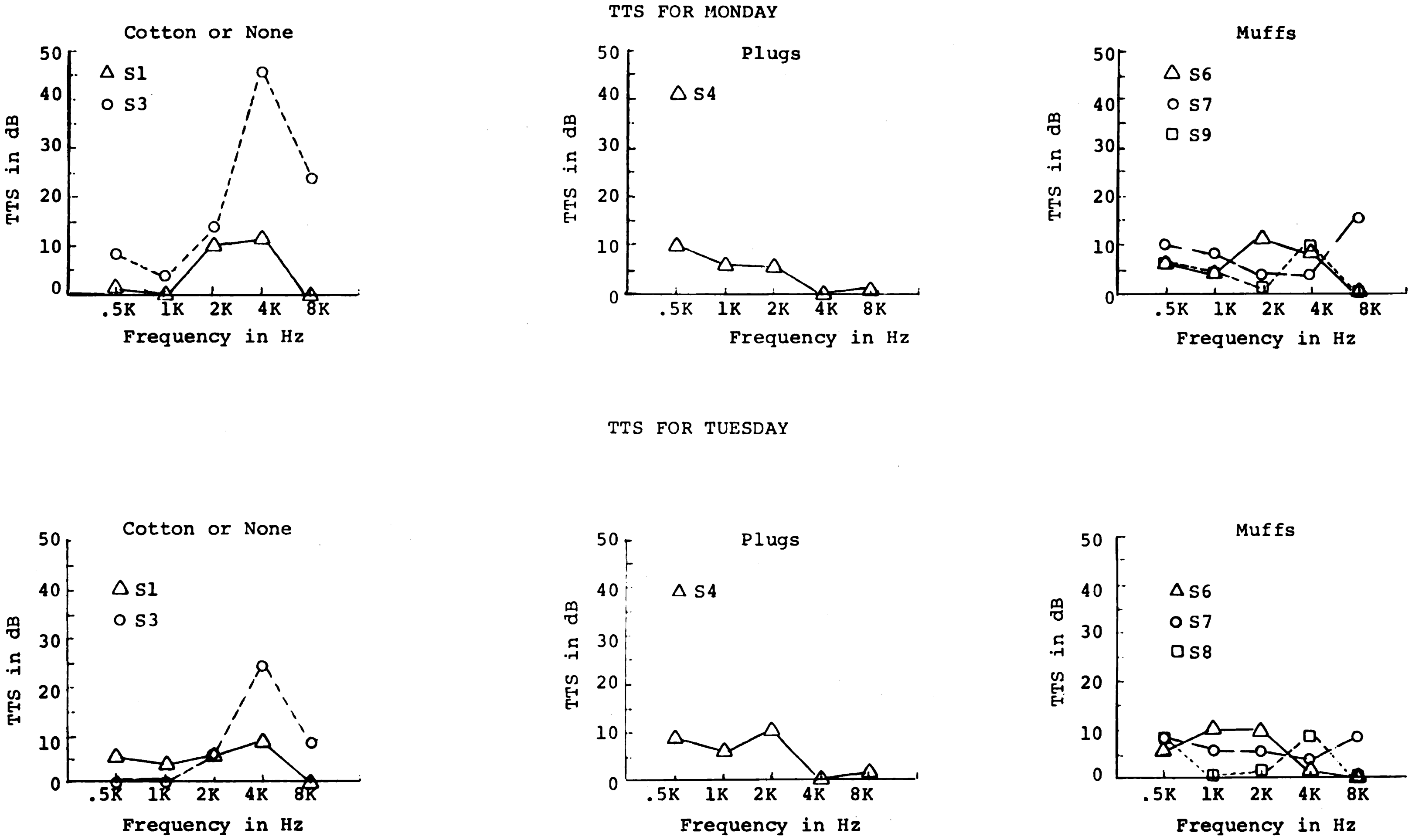


Figure 10. Monday and Tuesday TTS for subjects in 0-10 years exposure group who shifted more than 4 dB at any test frequency.

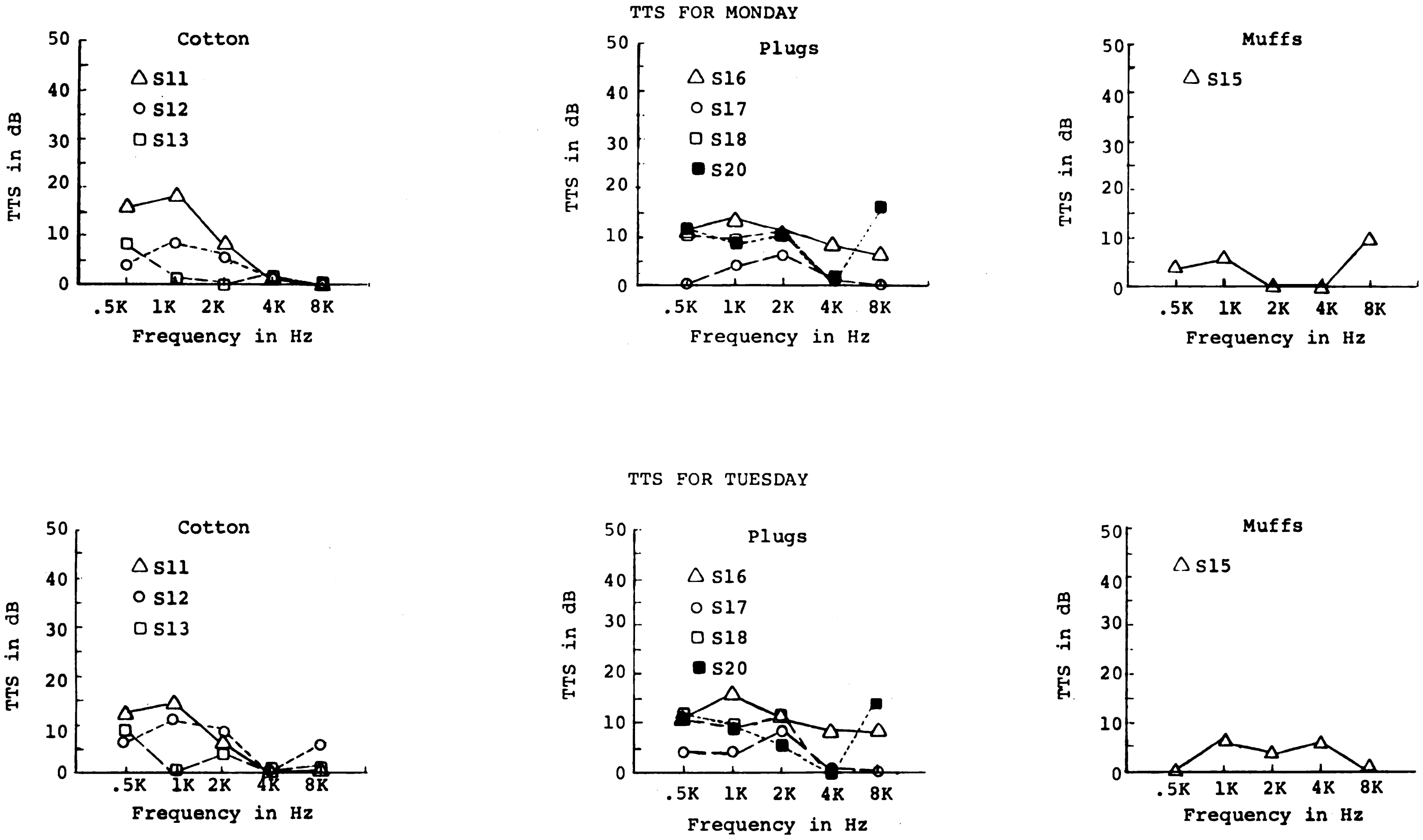


Figure 11. Monday and Tuesday TTS for subjects in 15-25 years of exposure group who shifted more than 4 dB at any test frequency.

TABLE 9.--Mean TTS and standard deviations in dB following the second day of exposure for each of the two exposure groups.

Exposure Groups		Frequency in Hertz				
		500	1000	2000	4000	8000
0 - 10 yrs.	Mean	4.0	2.9	4.4	4.6	0.4
	SD	4.2	3.9	4.2	8.2	4.7
15 - 25 yrs.	Mean	6.2	7.0	6.0	1.6	2.4
	SD	5.9	6.1	4.3	3.1	5.5

TTS after Five Days of Exposure

Only nine of the twenty subjects completed five consecutive work days during the week that they were being tested. Reasons for those not working five days included injury, illness, or work stoppage because of extreme heat. Also, a couple of subjects forgot to report for hearing testing despite reminders. Table 11 presents the TTS of each of the nine men for Monday, Tuesday, and Friday. As can be seen, TTS did not vary greatly from one day to the next except in rare instances. The important finding, however, is that TTS after five days of working in the forge was essentially the same as the TTS after one day of exposure. Thus, there appeared to be no accumulative effect during the work week.

TABLE 10.--Mean TTS and standard deviations in dB following 16 hours recovery time from initial exposure period.

Exposure Groups		Frequency in Hertz				
		500	1000	2000	4000	8000
0 - 10 yrs.	Mean	0.7	0.4	0.4	1.1	-1.1
	SD	2.8	1.9	1.7	1.8	1.1
15 - 25 yrs.	Mean	1.0	-0.2	-0.6	-1.0	0.2
	SD	2.2	2.4	1.0	1.1	2.4

Several of the subjects were tested prior to entering the shop on the last day of the week. While these results are not presented, the thresholds indicated that hearing levels at the start of the fifth work day were essentially the same as the resting thresholds taken at the start of the week. Subject 3, the one who shifted 46 dB after one day's exposure, also started the last day of the week with no accumulative TTS.

TABLE 11.--TTS in dB following exposure on Monday, Tuesday, and Friday for nine subjects working the full week.

Exposure Group	Ss	Date of Test	Frequency in Hertz				
			500	1000	2000	4000	8000
0 - 10 yrs	6	Monday	6.0	4.0	12.0	8.0	-2.0
		Tuesday	6.0	10.0	10.0	2.0	-2.0
		Friday	6.0	12.0	10.0	10.0	-2.0
	8	Monday	-2.0	0.0	0.0	0.0	2.0
		Tuesday	-2.0	-2.0	0.0	-2.0	0.0
		Friday	-4.0	-2.0	0.0	0.0	-2.0
	10	Monday	2.0	0.0	-2.0	0.0	-2.0
		Tuesday	0.0	0.0	-2.0	0.0	-4.0
		Friday	0.0	4.0	0.0	0.0	-4.0
15 - 25 yrs	11	Monday	16.0	18.0	8.0	2.0	0.0
		Tuesday	12.0	14.0	6.0	0.0	0.0
		Friday	18.0	10.0	4.0	0.0	-2.0
	14	Monday	2.0	2.0	0.0	0.0	0.0
		Tuesday	-2.0	2.0	-2.0	2.0	-2.0
		Friday	4.0	0.0	0.0	4.0	0.0
	15	Monday	4.0	6.0	0.0	0.0	10.0
		Tuesday	0.0	6.0	4.0	6.0	2.0
		Friday	8.0	8.0	2.0	0.0	8.0
	17	Monday	0.0	4.0	6.0	2.0	-2.0
		Tuesday	4.0	4.0	8.0	0.0	-2.0
		Friday	8.0	8.0	4.0	2.0	6.0
	18	Monday	10.0	8.0	10.0	2.0	----*
		Tuesday	12.0	8.0	12.0	-2.0	----*
		Friday	8.0	6.0	8.0	0.0	----*
	20	Monday	12.0	10.0	10.0	2.0	16.0
		Tuesday	12.0	10.0	6.0	0.0	14.0
		Friday	10.0	10.0	6.0	2.0	8.0

*Ss did not respond at this frequency for any pre or post exposure test.

Phase II Temporary Threshold Shift Discussion

The questions asked at the start of the investigation concerning TTS resulting from drop forge noise were as follows:

1. What are the changes in resting threshold as a function of years of exposure and type of ear protection?
2. What differences exist in TTS following eight hours of exposure within age groups with different types of ear protection?
3. What are the differences in TTS obtained between age groups when using similar types of ear protection devices?
4. Is sixteen hours of recovery time sufficient for total recovery of any TTS resulting from one day's exposure to drop forge noise?
5. Does TTS vary from one day's exposure to another?
6. Is TTS on the fifth day of exposure greater than that resulting from one day's exposure?

In considering the first question regarding resting threshold changes due to years of exposure, the mean thresholds for the 15-25 year exposure group were influenced greatly by the results of subject 4. This subject had 23 years of exposure to drop forge noise and as shown in Appendix G, Table G2, his hearing is exceptionally good. As a result, because of the small sample size, the means for the men that changed protection types as well as the older group as a whole showed less loss than was generally found over all. Variability was also demonstrated in the 0-10 years of exposure group individual thresholds although not to the degree that the older group varied. The younger men, having the benefit of protection early in their work history, show less loss and less variability. The older men generally had not employed protection other than cotton until after 15 years of exposure. This work period allowed individual differences in susceptibility to be demonstrated.

The resting thresholds according to work position of the men were not compared as the men were not equally divided by position between groups. Most of the hammermen were in the older group because that position is a seniority position, while the heatermen and straighteners were in the younger group of men.

In Figures 8 and 9, it was previously noted that the men in both groups who had switched from cotton to plugs or muffs demonstrated a slightly greater hearing loss than did the groups that used just cotton or had used only muffs or plugs. While, again, the sample size was too small to generalize, one might conjecture that these men switched to plugs or muffs when available because they were not satisfied with the protection provided by cotton. The approach of looking at resting thresholds as a way of determining effectiveness of protection is relatively new and has several limitations. These will be discussed later in this chapter. It is, however, one way of determining what long term effects ear protection has on threshold changes.

The second question regards TTS after 8 hours of exposure for men in the same exposure group with different types of protection. For the men in the 0-10 years exposure group, the subjects using cotton or no protection demonstrated the greatest shift. The TTS occurring when plugs and muffs were used was generally small, exceeding 15 dB at only one frequency for one subject (see Figure 10). Again, the N was too small to make an adequate statistical comparison. Nonetheless, the use of protection does appear to reduce TTS.

For the older men, the use of cotton for protection resulted in TTS occurring primarily in the lower frequencies. A contributing factor, however, is the fact that resting thresholds were poorer in the higher frequencies and thus less TTS occurred in those frequencies. When using plugs, wax impregnated or valve type, the older men showed mild TTS, 0-16 dB; but, both the low and the high frequencies were shifted.

The use of muffs for one of the older men also showed mild shifts in both the low and high frequencies. In general, the TTS resulting from one day's exposure is reduced but not eliminated through the use of ear protection devices, preferably plugs and muffs.

When comparing TTS between the two age groups, the only differences occurred in the cotton or no protection subgroups. The older men demonstrated TTS in the lower frequencies while the younger men showed the greatest shift in the higher frequencies. This appears to be related to the amount of hearing loss present before exposure.

The time needed for recovery from one day's exposure apparently was less than 16 hours for all subjects. Thus, the fourth question was answered affirmatively.

Variability from one day's exposure to another is shown graphically in Figures 10 and 11. Small variations did occur for most of the men, but the changes were small. Subject 3, however, demonstrated considerable change at 4000 Hz. The cause for the large difference in TTS for subject 3 is probably due to the marked difference in type and amount of exposure over the two day period. The first day he spent as a heaterman on a 3000 pound hammer for 6½ hours. The second day, because of equipment breakdowns, he was exposed to his particular hammer only 1¼ hours, plus the background noise from other hammers and fans and furnaces. The exposure varied for other men also, but not as dramatically. The exposure changes which occur from one day to the next must be considered in more detail if the relationship of hearing loss to impact noise is to be determined.

The results indicated little change in TTS from one day to five days exposure under actual working conditions. Even pre-exposure thresholds showed no effects of accumulation of TTS over the five day period. These findings suggest that when using ear protection, each man tends to start at his resting threshold each working day. What happens when no protection is employed is unknown at this time. However, because of the recent surge of interest in protection, availability of subjects for a study of that type would be limited.

Phase III Permanent Threshold Shift

This phase involved reviewing the audiologic findings of 71 drop forge employees seen for evaluation at the Rehabilitation Medical Center. Results based upon the pure-tone thresholds are presented according to: configuration of loss, age, years of exposure, employing forge, position worked, and type of protection worn. Raw data regarding personal data and hearing thresholds are presented in Appendix I and J respectively.

Configuration of Loss

For each subject selected, a four frequency average (500-4000 Hz) was calculated along with a two frequency average (250-500 Hz) and the slope of the loss for the octaves from 500-4000 Hz. After reviewing each case, arbitrary criteria were established for categorizing the configuration of the loss according to amount of slope. This was done to differentiate the steeply sloping losses from those with gradual or flat configurations. The criteria were as follows: a) a two frequency average equal to or less than 40 dB hearing level; b) a difference between the two frequency and four frequency average of greater than 20 dB; and c) a slope equal to or greater than 8.3 dB per octave. When all three of these criteria were met in one or both ears, the subject was placed in the steeply falling configuration category (See Figure 12). When one or more of the criteria were not met, the subject was placed into the gradual sloping category (See Figure 13). When applied to the cases selected for this study, 69% had hearing losses with steeply sloping configurations while 31% did not meet these criteria and hence demonstrated a flatter configuration while being exposed to similar amounts of drop forge impact noise. While the amount of slope of loss varied somewhat, these two patterns predominated.

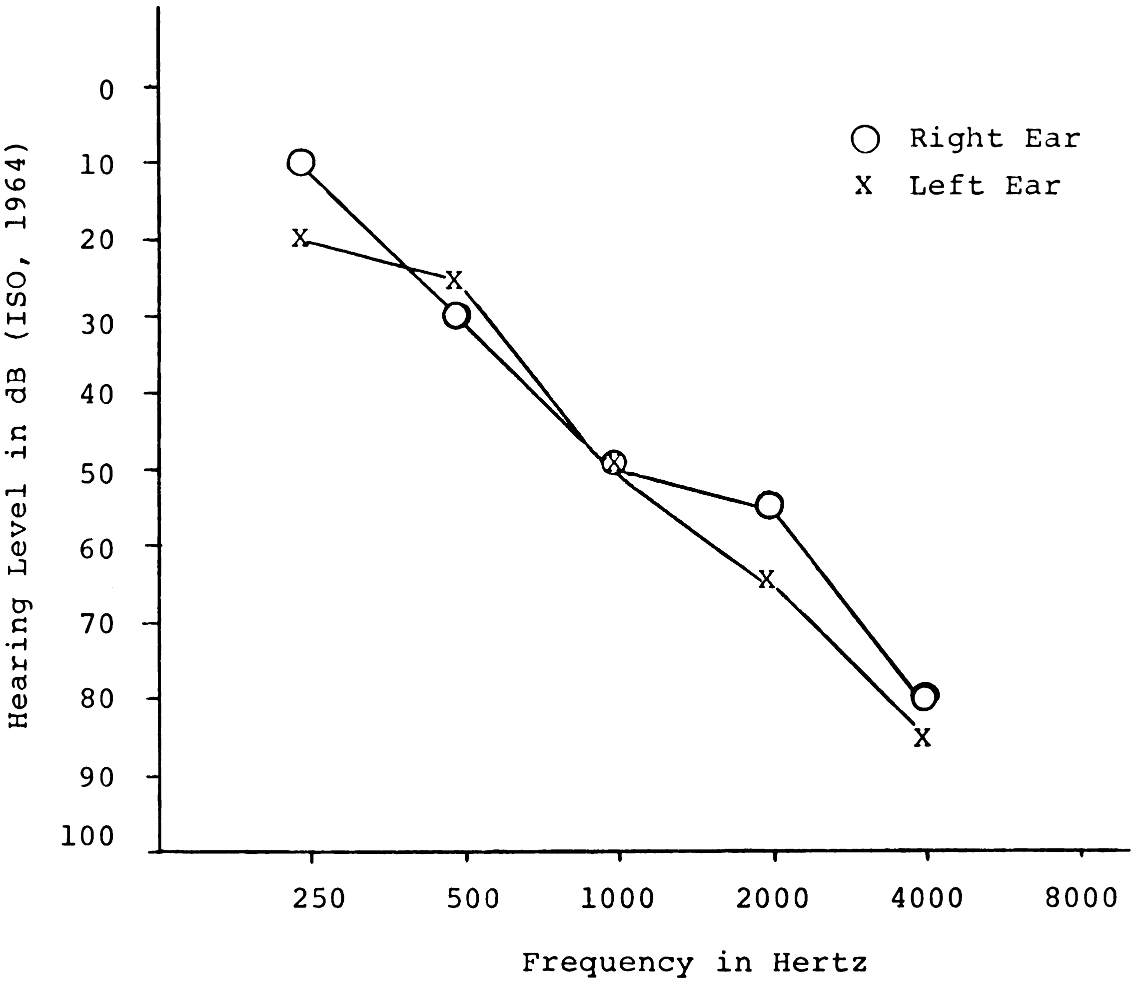


Figure 12. Typical steeply sloping audiomatric configuration of a subject (A13) with 24 years exposure.

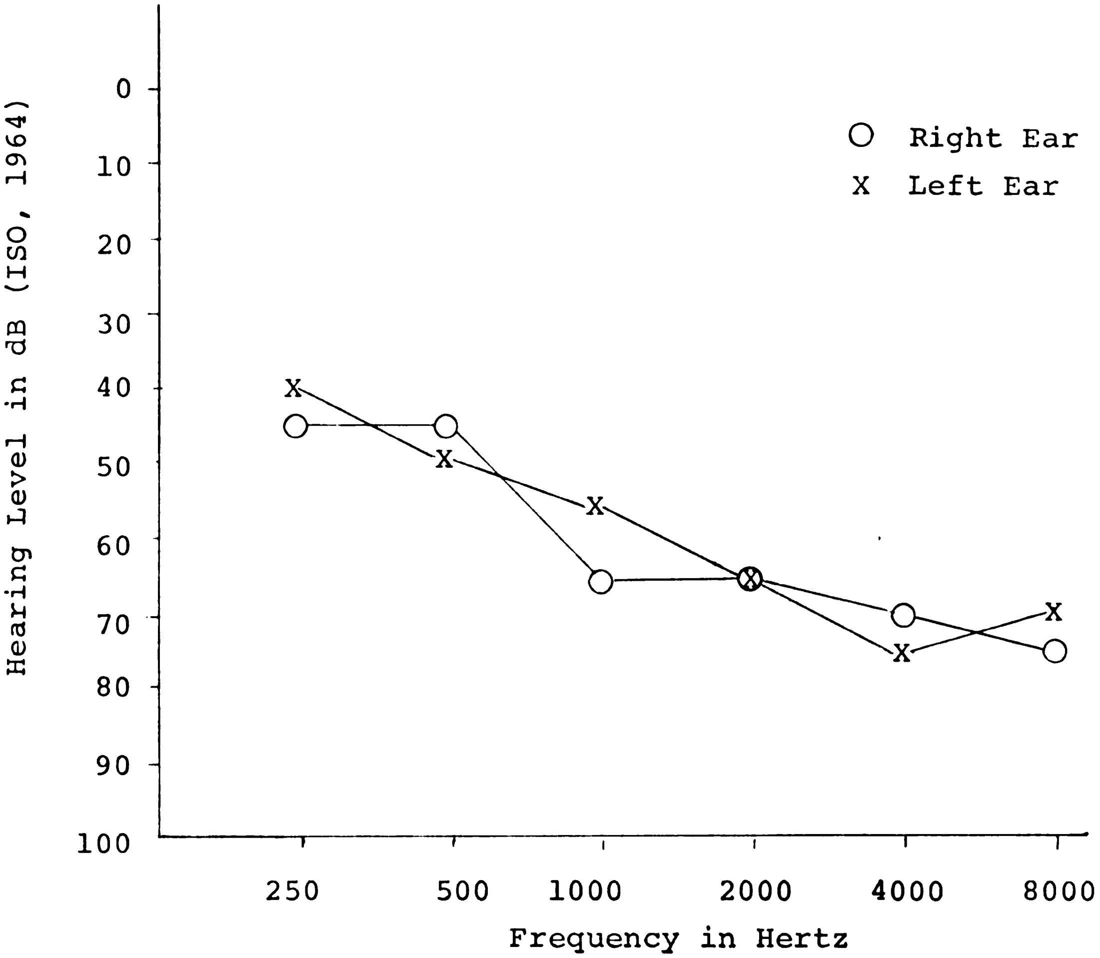


Figure 13. Typical gradual sloping audiomatric configuration of a subject (C13) with 16 years exposure.

Hearing Loss by Age

For purposes of analysis, the men were grouped according to age. The groups were patterned after Corso (1963) with cases falling between Corso's age classifications being placed in the closest category. Corso's data were selected as they provided a homogenous population with little or no noise exposure. The age distribution is presented in Table 12. As is evident, very few cases are in the age group from 26 to 32 years. The reason for this lack of cases was that very few younger men were referred to the hearing clinic from which the cases were selected.

Table 13 presents the mean thresholds and standard deviations for each of the age groups by frequency. In addition, the table presents the difference between the mean thresholds and the presbycusic factor according to Corso (1963). To explain, the difference between the actual threshold and predicted loss due to presbycusis is the amount by which the hearing loss was greater than the age factor alone. For example, the mean threshold at 4000 Hz for the 59-65 year age group was 74.4 dB. The presbycusic loss for that age group is 34.8 dB (See Appendix K). The difference between the two is 39.6 dB which represents the amount that the loss due to noise was greater than the age factor. The data for each age group are presented graphically in Figure 14.

TABLE 12.--Age distribution* for 71 drop forge workers seen for hearing evaluations.

Age Group in Years	No. of Cases
26 - 32	2
34 - 40	14
43 - 49	24
51 - 57	18
59 - 65	13

*Distribution according to Corso's (1963) groups.

TABLE 13.--Means and standard deviations for combined right and left ear thresholds by age groups along with difference between the thresholds obtained and the presbycusic factor.*

Age Groups		Frequency in Hertz				
		250	500	1000	2000	4000
26 - 32 (N=2)	Mean	20.0	33.8	47.5	63.8	76.2
	SD	7.1	7.8	7.1	1.8	8.8
	Diff.	19.6	31.6	46.9	62.7	68.7
34 - 40 (N=14)	Mean	20.2	32.1	49.8	57.8	70.9
	SD	10.3	15.3	8.8	9.5	15.3
	Diff.	22.5	31.8	46.9	55.5	61.7
43 - 49 (N=24)	Mean	24.7	32.4	51.4	64.9	72.9
	SD	13.6	15.3	11.6	11.1	14.5
	Diff.	20.5	29.5	44.8	53.5	60.4
51 - 57 (N=18)	Mean	29.4	40.1	51.7	64.2	74.0
	SD	9.7	8.4	14.7	15.7	16.2
	Diff.	27.9	35.4	45.2	53.2	51.7
59 - 65 (N=13)	Mean	33.8	43.8	55.2	68.1	74.4
	SD	19.2	17.3	15.0	8.7	10.1
	Diff.	26.3	36.3	45.6	49.9	39.6

*Presbycusic factor based on Corso's (1963).

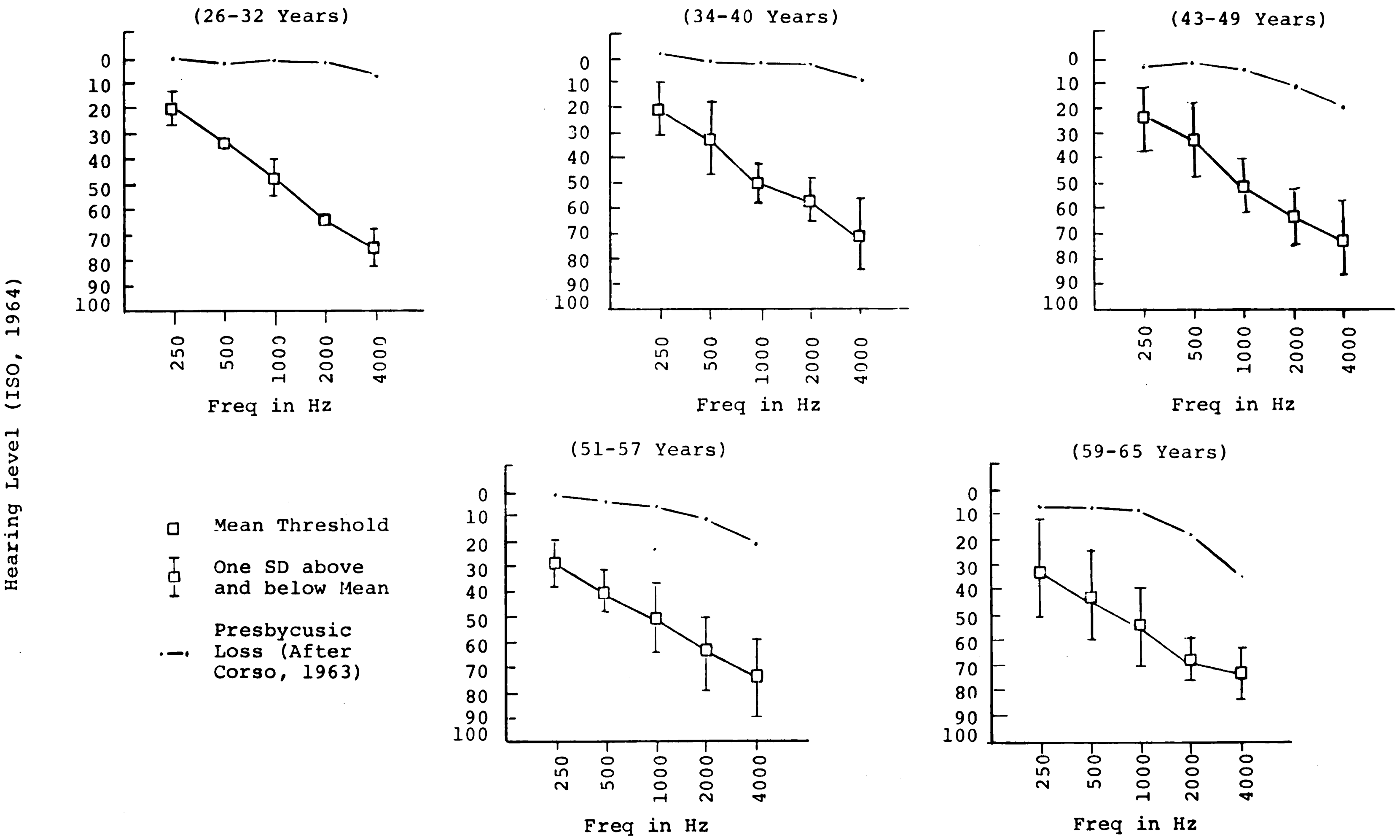


Figure 14. Mean combined right and left ear hearing thresholds and loss resulting from presbycusis for each age group.

While the N is small for the youngest age group, the configuration of the loss is similar for all five groups. The loss at 4000 Hz appears to be similar for all groups, suggesting it has reached a terminal level of change already by the youngest age group. The presbycusic effects according to Corso (1963) show the increasing loss due to age. However, over the five groups, the loss does not continue to get poorer at 4000 Hz, suggesting that the effect of presbycusis has not been added on the loss due to noise exposure. If presbycusis would be a significant factor for a group of workers, this can be observed (see Table 13) by the difference in actual thresholds and the presbycusic factor becoming smaller as a function of years of exposure. In other words the longer a man works in noise, the resulting hearing loss becomes less a loss from noise and more a loss from age. Table 13 shows that this was not the case. Instead, differences between actual thresholds and presbycusic factors remained large, allowing the conclusion that presbycusis was not an important factor. Further comment will be made regarding this effect in the general discussion section of this chapter.

A composite audiogram is presented in Figure 15 and illustrates the mean threshold changes resulting by age group. The major changes which can be seen are in the low frequencies. Both 250 and 500 Hz show changes

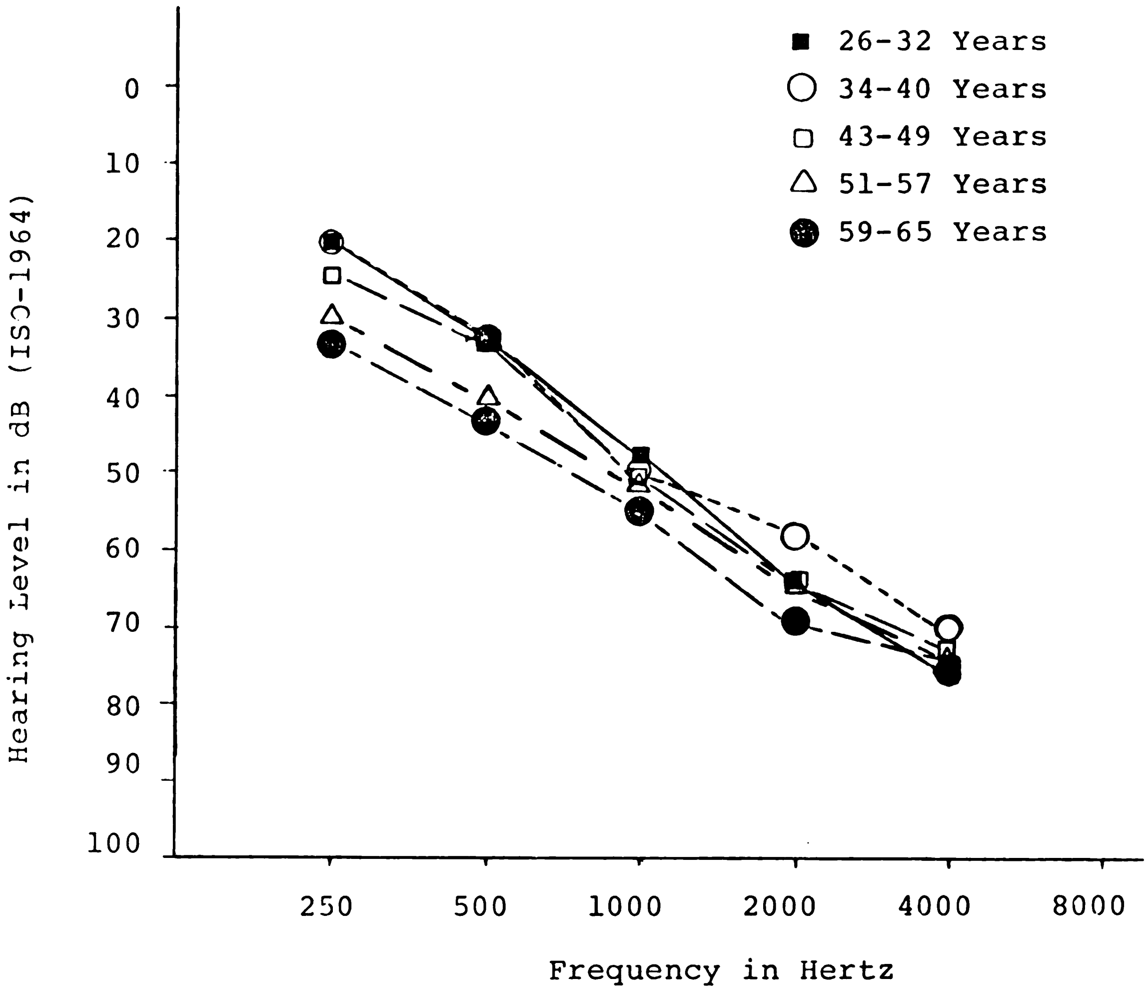


Figure 15. Mean hearing levels for combined ears for each age group.

from the youngest to the oldest age group greater than the loss from presbycusis alone. Frequencies from 1000-4000 Hz showed little change from the younger group to the older group. This implies that maximum hearing loss resulting from this type of noise exposure occurs within a few years (in the youngest age group). Further, the presbycusic factor never "catches up" with the noise - induced portion of the hearing loss, even among the older men.

Hearing Loss by Years of Exposure

The cases were subdivided into six groups according to years of exposure to drop forge noise. The results of this distribution are shown in Table 14. As can be seen from Table 14, most of the cases had been exposed between 15 and 35 years. Cases under 15 years of exposure were scarce in the records reviewed for this study. The reasons why more men between 1 and 15 years of exposure have not been seen for audiological evaluation can only be conjectured. This will be discussed later in this chapter. Table 15 presents the mean ages and years of exposure for each of the six exposure groups. As can be seen, the variation in years of exposure within each group is small. This is partly the result of having groups based on six year intervals.

TABLE 14.--Years of exposure distribution for 71 drop forge workers seen for hearing evaluations.

Years of Exposure	No. of Cases
8 - 14	4
15 - 21	25
22 - 28	24
29 - 35	11
36 - 42	6
43 - 49	1

TABLE 15.--Means and standard deviations for age and years of exposure of subgroup.

Years of Exposure	Age		Years of Exposure	
	Mean	SD	Mean	SD
8 - 14	35.0	6.4	11.2	2.2
15 - 21	42.1	4.0	18.6	1.8
22 - 28	51.5	6.3	24.3	1.5
29 - 35	54.8	3.0	31.5	2.3
36 - 42	60.5	2.7	40.9	1.1
43 - 49	65.0	---*	48.0	---*

*N=1 for 43-49 years of exposure group.

Table 16 presents the means for the combined ear thresholds by frequency. These results are graphically depicited in Figure 16 in a composite audiogram. The lower frequencies, up to and including 1000 Hz show a consistent pattern of increasing hearing loss as a function of number of years of exposure. The frequencies above 1000 Hz show a more variable pattern of loss by years of exposure suggesting that high frequency thresholds are essentially maximally affected by this type of noise after approximately eleven years of exposure (See tables 15 and 16).

Thus, analysis of the data by age groups or years of exposure demonstrates that the severity of the loss changes only slightly after 10 to 15 years exposure. The hearing loss after that time is primarily in the low frequencies resulting in a flattening of the configuration. Finally, it would appear that the major hearing loss resulting from drop forge impact noise has occurred prior to the time that presbycusis becomes an important factor. Further, hearing loss resulting from age alone (presbycusis) is vastly "over-shadowed" by the loss resulting from noise exposure (See Figure 14).

TABLE 16.--Means and standard deviations for combined right and left ear thresholds* by years of exposure.

Years of Exposure		Frequency in Hertz				
		250	500	1000	2000	4000
8 - 14	Mean	20.6	33.1	46.9	57.5	77.5
	SD	10.1	14.3	13.9	15.1	14.3
15 - 21	Mean	22.0	30.4	49.4	60.5	71.0
	SD	11.9	14.6	9.0	10.6	15.5
22 - 28	Mean	27.7	39.3	52.0	65.2	71.5
	SD	11.6	6.1	12.6	13.2	12.9
29 - 35	Mean	30.5	42.5	55.2	61.4	75.9
	SD	13.9	10.2	15.5	12.7	14.6
36 - 42	Mean	36.2	45.8	57.5	68.3	75.4
	SD	23.1	22.4	18.6	11.1	12.7
43 - 49	Mean	42.5	55.0	55.0	72.5	80.0
	SD	----	----	----	----	----

*In dB hearing level (re: ISO, 1964).

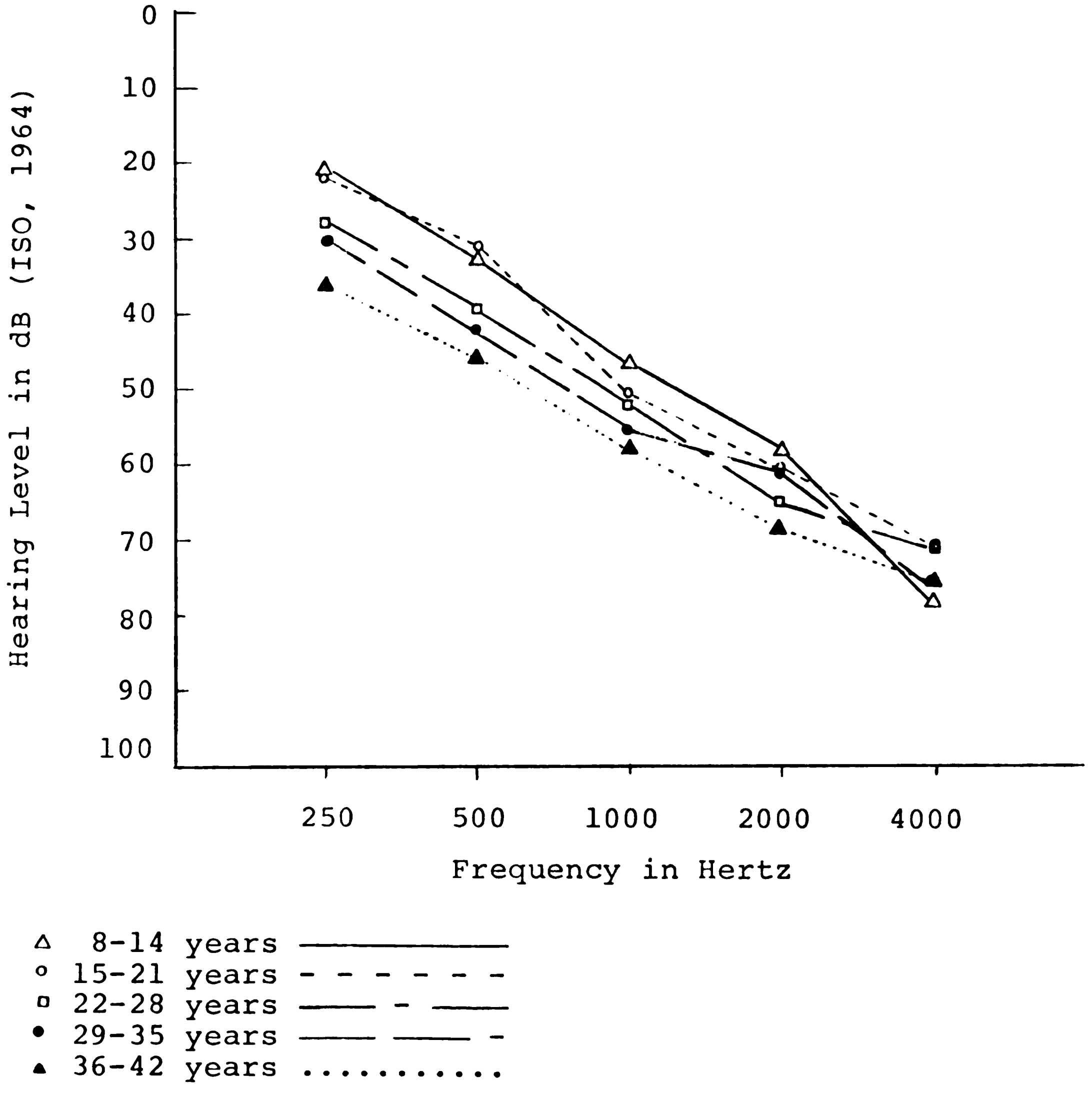


Figure 16. Composite audiogram of mean combined ear thresholds grouped by years of exposure.

Hearing Loss and Employing Drop Forge

To determine if differences existed between the four drop forges at which the men were employed, a comparison of hearing losses by company was completed. Table 17 presents a summary of the combined ear thresholds, the slope of loss and the number of employees for each position by forging company. The results indicate that the combined average loss (500-4000 Hz) for forges A, B, and C are very similar although the standard deviations are large. The fourth forge (D) shows a somewhat greater mean loss but the small number of cases from that company may account in part for the disparity. The mean slope of the loss for all of the companies is consistently greater than 10 dB per octave. Of the cases reviewed, 68% had slopes of 10 dB per octave or greater while 32% had slopes of less than 10 dB per octave. Slopes ranged from .8 dB per octave to 30 dB per octave.

The breakdown of personnel by forge indicates that 51 men were employed as hammermen, 14 as heatermen, and 6 were straighteners.

The distribution of hearing loss by drop forge is depicited in Figure 17, A, B, C, and D. The overall distribution is shown as Figure 18. The most evident result is the spread of loss for each forge. The variability of loss is markedly influenced by age and exposure time, but not in the progressive manner as one

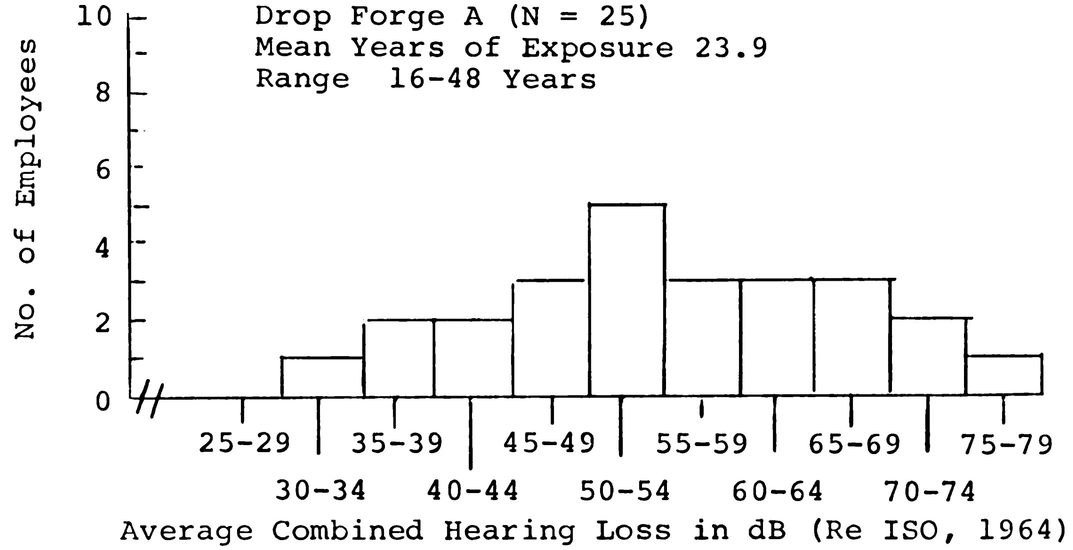


Figure 17A. Distribution of hearing loss in Drop Forge A.

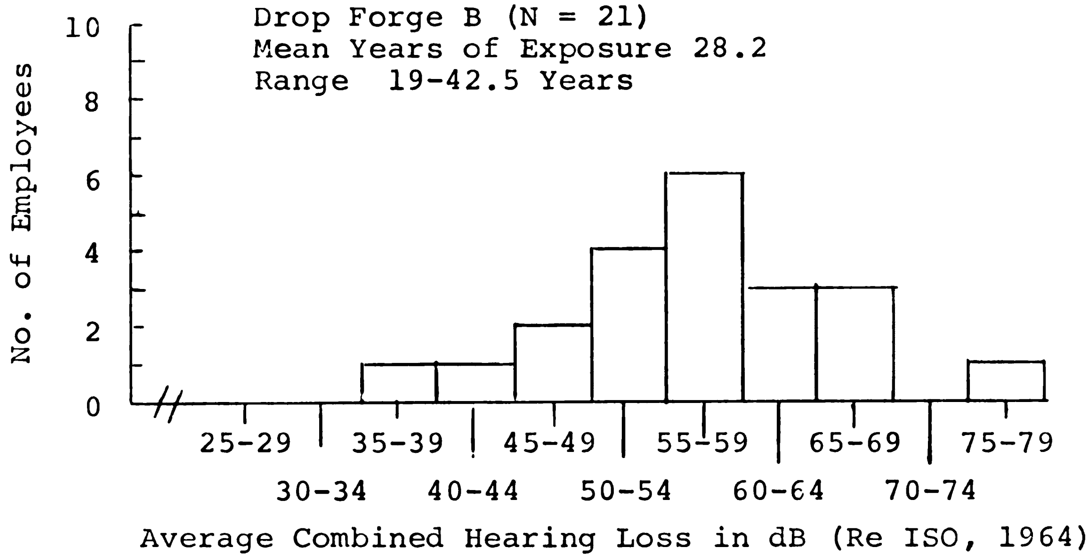


Figure 17B. Distribution of hearing loss in Drop Forge B.

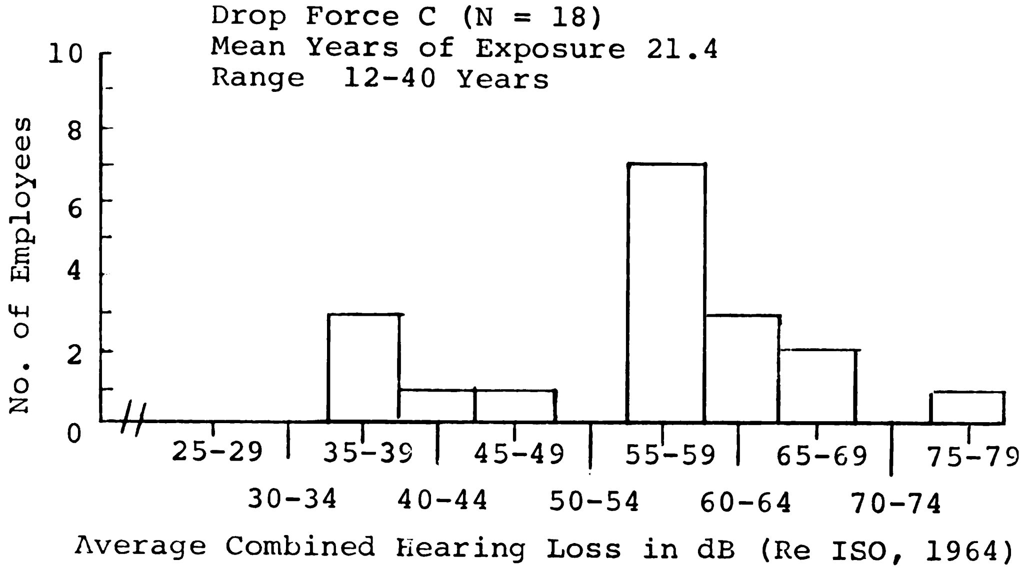


Figure 17C. Distribution of hearing loss in Drop Forge C.

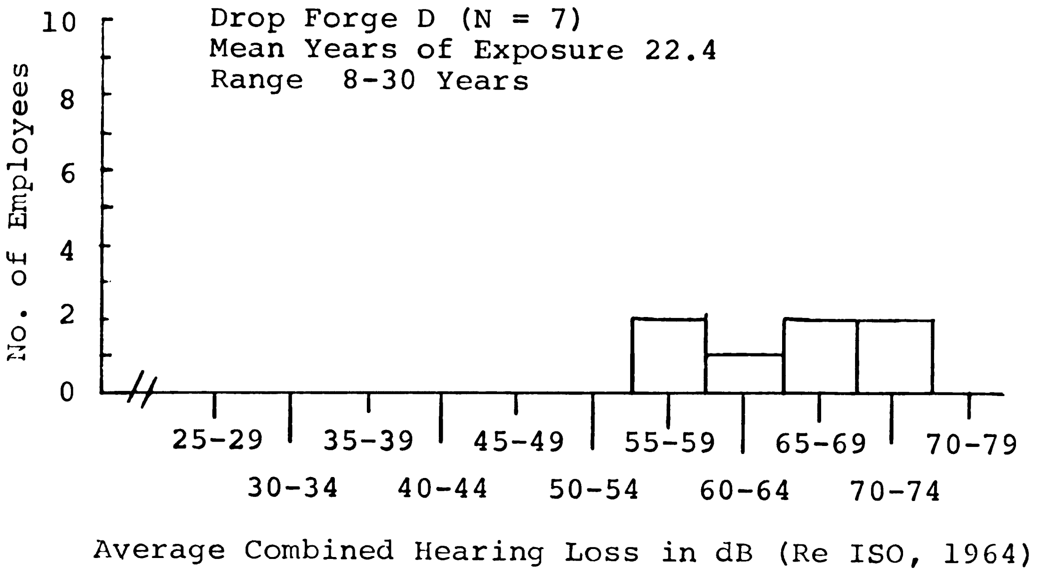


Figure 17D. Distribution of hearing loss in Drop Forge D.

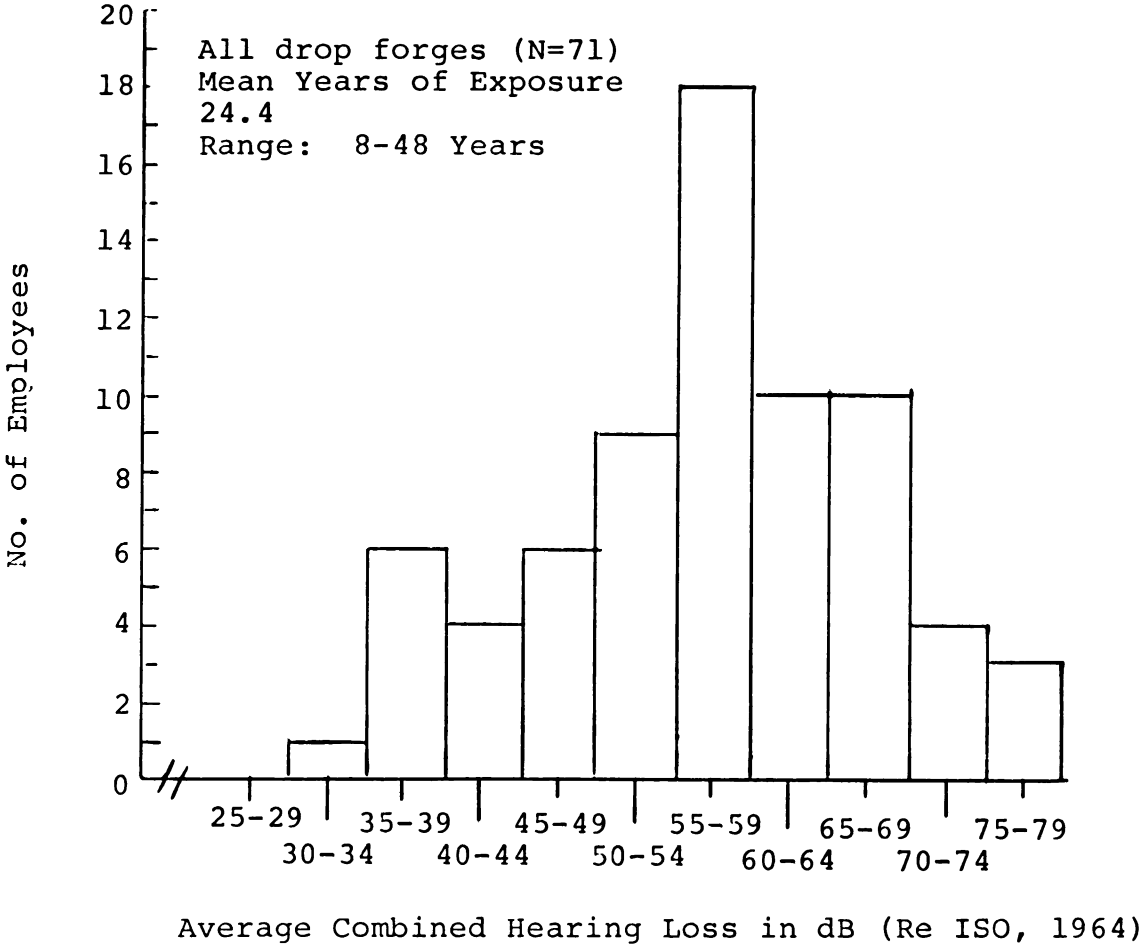


Figure 18. Distribution of hearing loss for all four forges.

TABLE 17.--Summary of combined ear thresholds, slope of loss, and number of employees for each position by drop forge company.

Drop Forge Company	Combined Ears				Position		
	PTA*		Slope				
	Mean	SD	Mean	SD	Hammerman	Heaterman	Str.
A	54.9	12.5	11.4	4.3	19	3	3
B	56.1	9.4	13.8	5.0	15	6	-
C	55.5	12.0	11.3	6.3	10	5	3
D	64.0	7.2	12.9	6.1	7	-	-

*Pure-tone average 500-4000 Hz (re: ISO, 1964).

would expect. Some of the cases with better hearing are among the older men who have had considerable exposure. The consistency of the means for the three forges with the larger N indicates that the losses generally are comparable between forges. The fourth forge which shows the greater mean loss also had the smallest N and, therefore, is not directly comparable.

Hearing Loss by Position

Regarding hearing loss by position, data were organized to consider the age, years of exposure, average loss for the right and left ears separately and combined, and average losses at each frequency. Table 18 summarizes the data concerning age, years of exposure and average for the ears separately and combined. Results indicate that while the number of cases reviewed by position were not equal, the mean age for employees working different positions were comparable. There did exist, however, an approximate 4 years difference in years of exposure.

When considered by position, the combined ear hearing loss averaged 58.7 dB for the hammermen and 51.9 and 45.9 dB for the heatermen and straighteners respectively. Apparently the position worked does influence the degree of loss; however, this finding is also influenced by the difference in years of exposure between hammermen and the other two positions. Viewing the ears separately, the mean average losses were within three dB for each position as were the standard deviations. These findings suggest that the losses for each ear are essentially the same.

Table 19 presents the mean combined thresholds for each frequency according to the position worked. Figure 19 compares the three positions. The results indicate that the hammermen have the greatest loss while the heatermen have a parallel but somewhat lesser hearing loss. The straighteners, on the other hand, demonstrate less loss in the higher frequencies than either of the other positions. It must be noted, however, that the difference in number of cases and in years of exposure may account for part of the disparity between positions. Also, since the hammermen have usually

TABLE 18.--Age, years of exposure, average* hearing thresholds and standard deviations for the right ear, left ear, and combined ears as a function of the employee's position.

Position	Age Mean	Years of Exposure Mean	Right ear Mean	Left ear Mean	Combined ears Mean
Hammerman	48.5	25.5	60.0	57.4	58.7
(N=51)	(9.0)**	(8.7)	(11.5)	(11.7)	(10.8)
Heaterman	47.2	21.6	52.0	51.6	51.9
(N=14)	(6.6)	(4.9)	(9.5)	(10.5)	(9.7)
Straightener	47.2	21.7	44.4	47.4	45.9
(N=6)	(5.4)	(5.0)	(9.0)	(9.3)	(8.7)

---

*Average of thresholds 500 - 4000 Hz in dB (re: ISO, 1964).

**Standard deviation.

TABLE 19.--Mean hearing thresholds* and standard deviations for the right and left ears combined as a function of position in forge.

Frequency in Hertz	Position					
	Hammerman		Heaterman		Straightener	
	Mean	SD	Mean	SD	Mean	SD
250	27.8	14.5	22.7	10.1	25.8	11.9
500	38.7	14.9	30.4	14.5	33.3	11.5
1000	54.1	12.4	48.6	10.5	40.0	10.4
2000	65.7	12.2	60.9	9.6	51.7	12.7
4000	75.9	13.9	67.7	11.0	58.8	7.7

*Average of thresholds at 500-4000 Hz in dB (re: ISO, 1964).

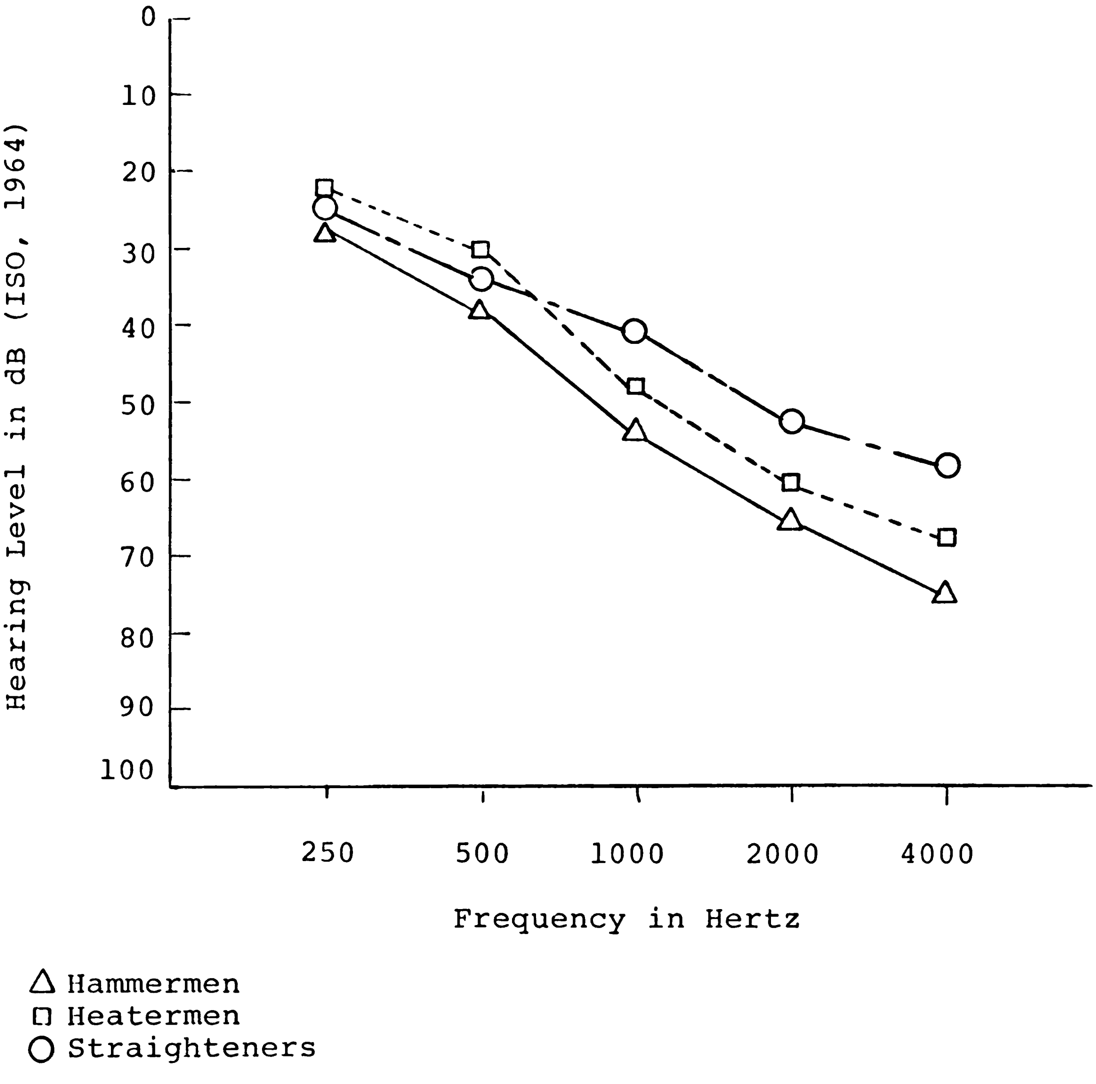


Figure 19. Composite audiogram showing mean combined thresholds by working position.

worked at all three positions in the past, their loss is a combination of exposure at all three positions. In general, hammermen show the greatest loss of the men in the forge.

Position by Years of Exposure

The mean thresholds for the combined ears for hammermen calculated by years of exposure are presented in Table 20, and graphically presented in a composite audiogram on Figure 20. The results continue to show the progressive loss in the lower frequencies and to a lesser extent in the high frequency region. The number of cases for each year of exposure group is not equal, a fact which limits any general interpretation. A trend, however, is present. The continuing finding of large standard deviations supports the wide range of individual susceptibility to impact noise.

Table 21 presents the same type of data seen in Table 20, but for heatermen. Because of the small number of cases reviewed, only three years of exposure groups are included. However, as seen in Figure 21 (A and B) the trend is for progressive loss at 250 and 500 Hz with smaller reductions or no change in hearing threshold for the higher frequencies. For purposes of comparison, the data were calculated both for average loss for the better ear and for combined ears. Figure

TABLE 20.--Mean thresholds* and standard deviations for the right and left ears combined for hammermen by years of exposure.

Years of Exposure	Frequency in Hertz				
	250	500	1000	2000	4000
8 - 14 N=3	24.2 (8.8)**	39.2 (9.5)	52.5 (10.0)	65.0 (2.5)	82.5 (12.5)
15 - 21 N=16	22.0 (12.6)	33.0 (14.3)	51.4 (7.0)	60.6 (10.8)	73.0 (16.5)
22 - 28 N=16	28.8 (14.0)	38.6 (14.3)	55.0 (12.7)	69.1 (12.8)	76.6 (12.0)
29 - 35 N=9	30.6 (15.6)	42.2 (11.2)	55.3 (17.2)	66.7 (15.6)	77.5 (15.7)
36 - 42 N=6	36.2 (23.1)	45.8 (22.4)	57.5 (18.6)	68.3 (11.1)	75.4 (12.7)
43 - 49 N=1	42.5	55.0	55.0	72.5	80.0

*Hearing thresholds in dB (re: ISO, 1964).

**Standard deviation.

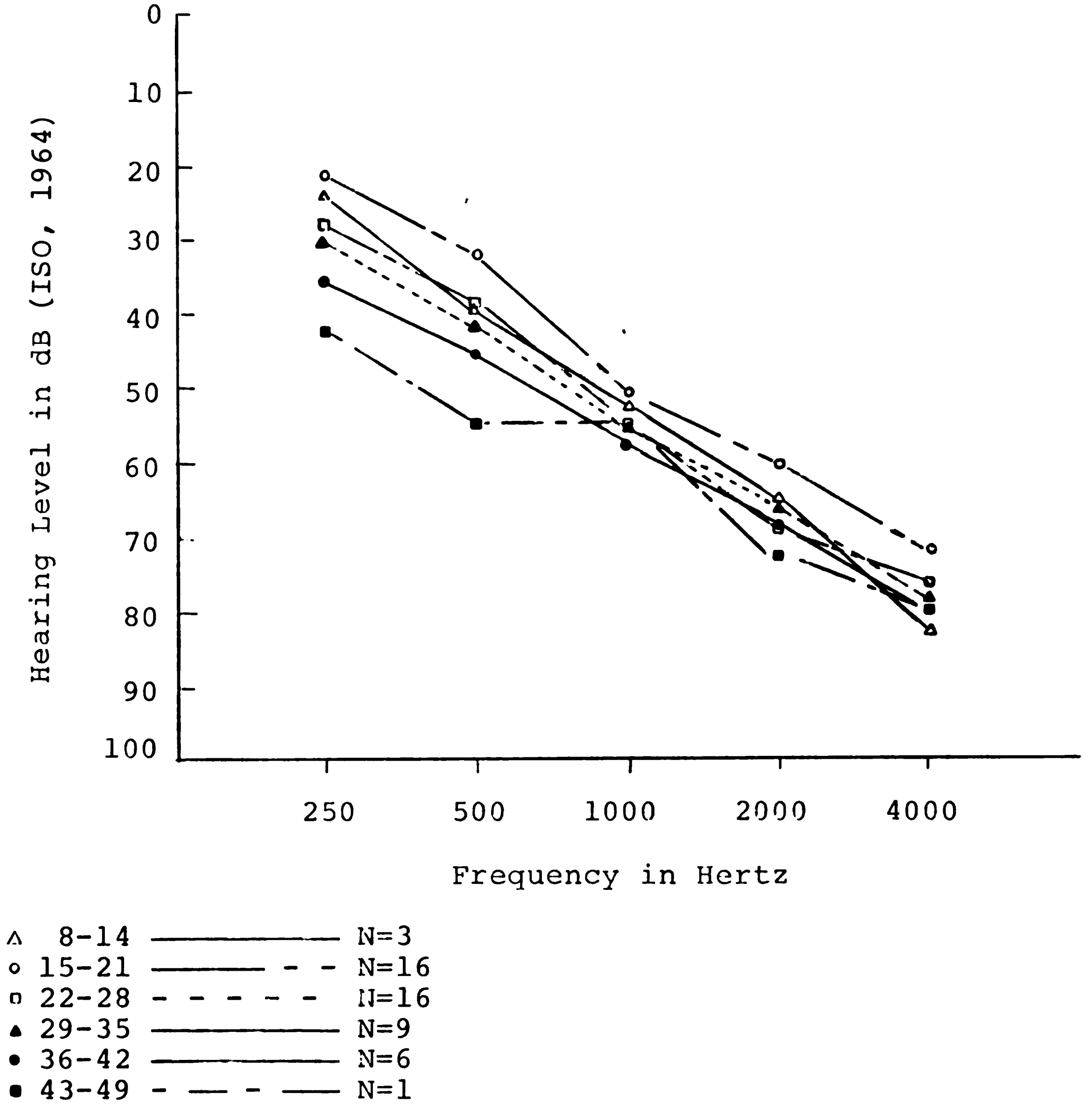


Figure 20. Composite audiogram of mean combined ear thresholds for hammermen by years of exposure.

TABLE 21.--Mean thresholds* and standard deviations for the right and left ears combined for heatermen by years of exposure.

Years of Exposure	Frequency in Hertz				
	250	500	1000	2000	4000
8 - 14 N=0					
15 - 21 N=9	21.9 (11.3)**	25.8 (15.6)	45.8 (11.3)	60.3 (10.6)	67.5 (13.7)
22 - 28 N=3	20.0 (9.0)	35.0 (9.0)	50.0 (8.7)	61.7 (11.8)	67.5 (4.3)
29 - 35 N=2	30.0 (0.0)	43.8 (5.3)	55.0 (7.1)	62.5 (3.5)	68.8 (5.3)
36 - 42 N=0					
43 - 49 N=0					

*Hearing thresholds (re: ISO, 1964).

**Standard deviation.

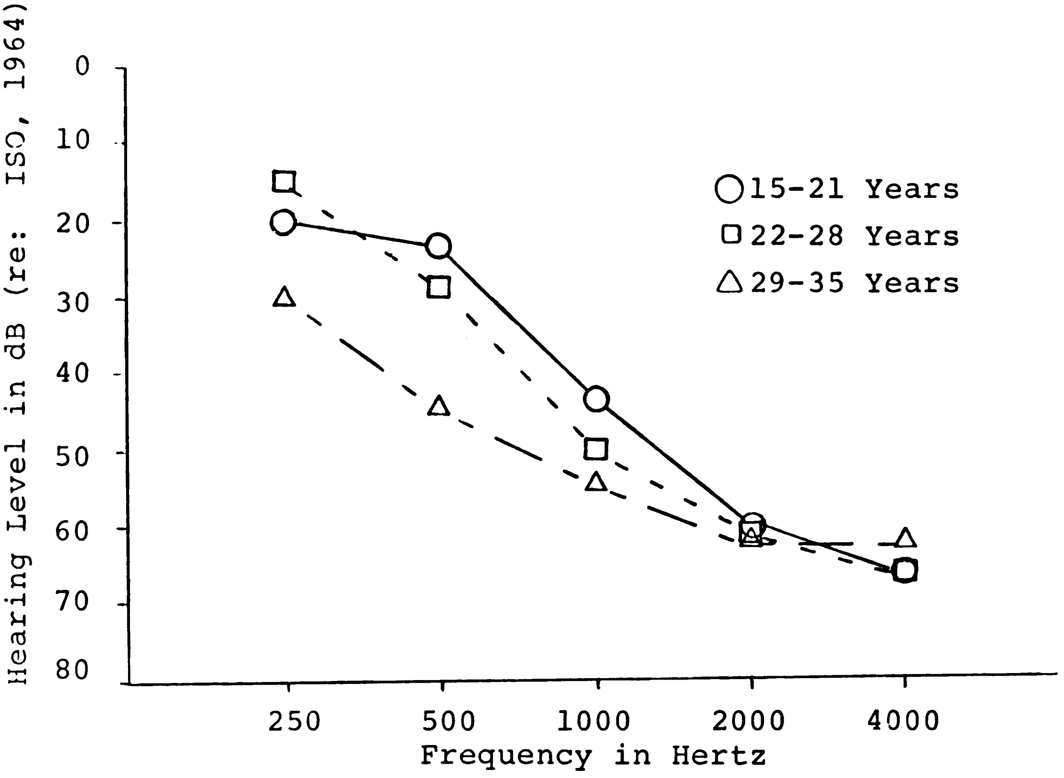


Figure 21A. Composite audiogram of mean better ear thresholds for heatermen by years of exposure.

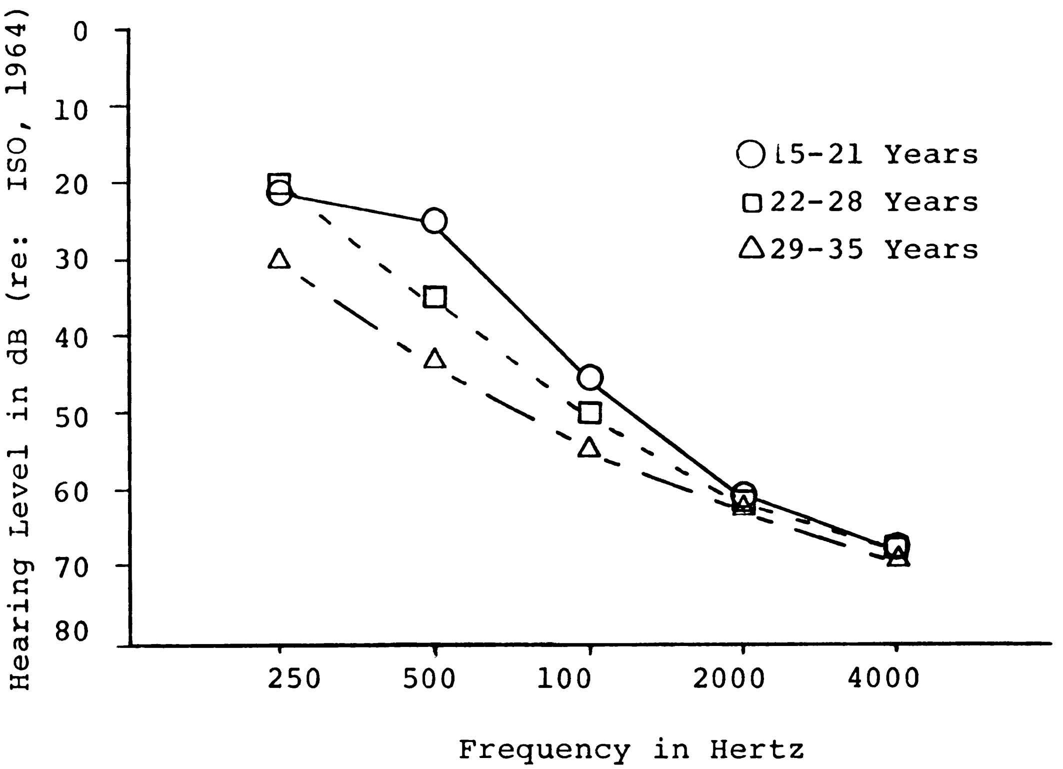


Figure 21B. Composite audiogram of mean combined ear thresholds for heatermen by years of exposure.

21 (A and B) depicts the two composite audiograms. As is evident, the patterns were the same with only small differences found in the dB levels.

The data regarding straighteners were limited (N=6) so that comparison by years of exposure could not be done.

Effects of Protection by Position

The hearing thresholds for combined ears for hammermen using cotton for protection and those not using protection are presented in Table 22 and illustrated in Figure 22. Results indicate an apparent protective effect resulting from cotton protection in the lower frequencies. However, there is a 4.6 years' difference in age between the two groups and 6 years' difference in years of exposure. These factors may partly account for the differences seen.

The combined thresholds for heatermen using cotton for protection or no protection are presented in Table 23. Results depicted in Figure 23 suggest a definite difference between the two groups with the protected group having the better hearing. While a two year difference in exposure to impact noise is present between the group protected with cotton and the unprotected group, results suggest cotton does help even if the difference is small. Further study is needed, however, as the number of heatermen is small (N=14).

TABLE 22.--Mean hearing thresholds* and standard deviations for hammermen as a function of protection.

Protection Type	Age	Years of Exposure	Frequency in Hertz				
			250	500	1000	2000	4000
None	50.9	28.2	31.7	42.9	57.3	66.7	75.6
N=25	(9.0)**	(9.1)	(17.0)	(16.2)	(12.2)	(10.8)	(11.4)
Cotton	46.3	22.9	24.1	34.6	51.0	64.8	76.2
N=26	(8.6)	(7.6)	(12.2)	(12.4)	(11.9)	(13.7)	(16.2)

*Hearing thresholds (re: ISO, 1964).

**Standard deviations.

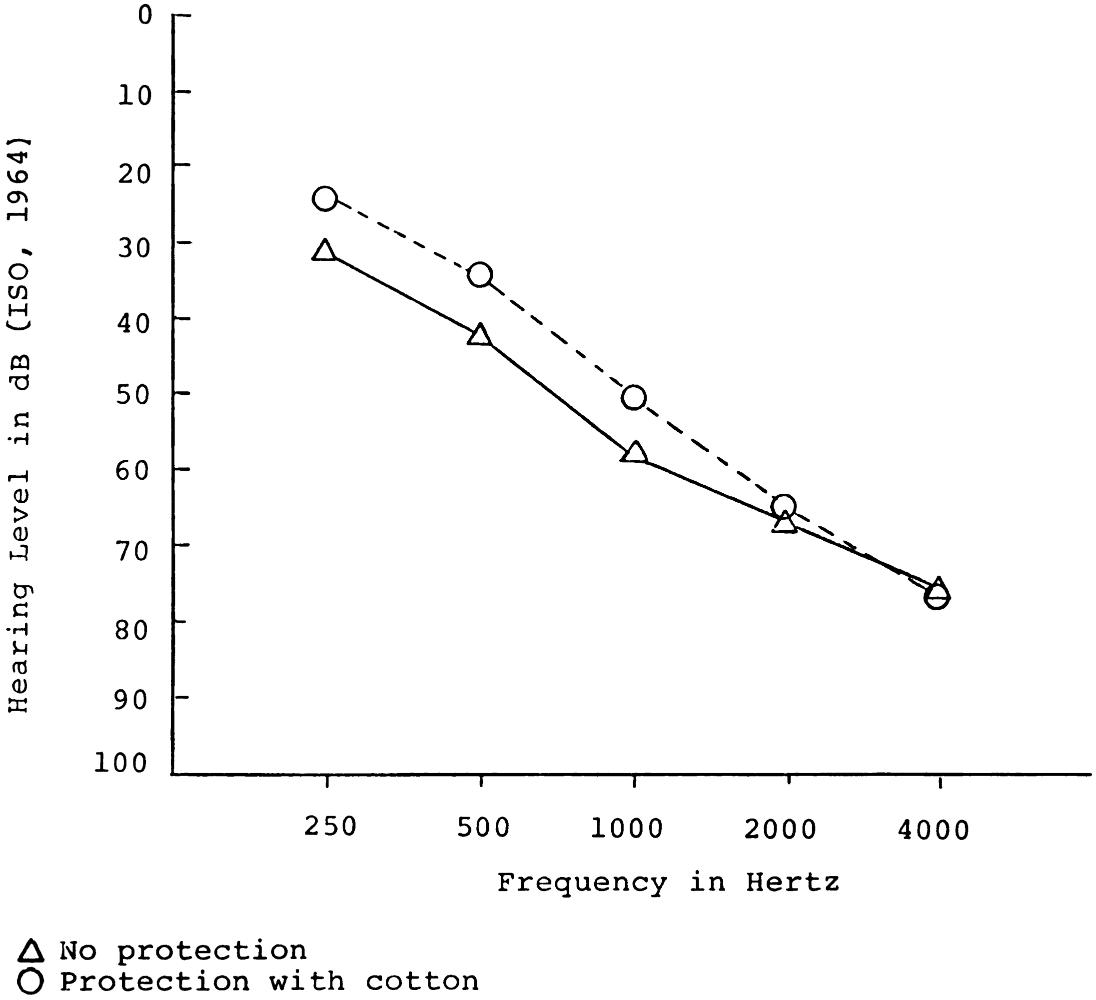


Figure 22. Composite audiogram of mean combined ear thresholds for hammerman by type of ear protection.

TABLE 23.--Mean hearing thresholds* and standard deviations for heatermen as a function of protection.

Protection Type	Age	Years of Exposure	Frequency in Hertz				
			250	500	1000	2000	4000
None N=8	47.2	22.5	26.2 (10.4)	36.9 (12.8)	52.8 (9.8)	64.1 (8.5)	71.6 (8.3)
Cotton N=6	47.2	20.3	17.9 (8.0)	21.7 (12.6)	42.9 (9.1)	56.7 (10.1)	62.5 (12.8)

[*] In dB (re: ISO, 1964).

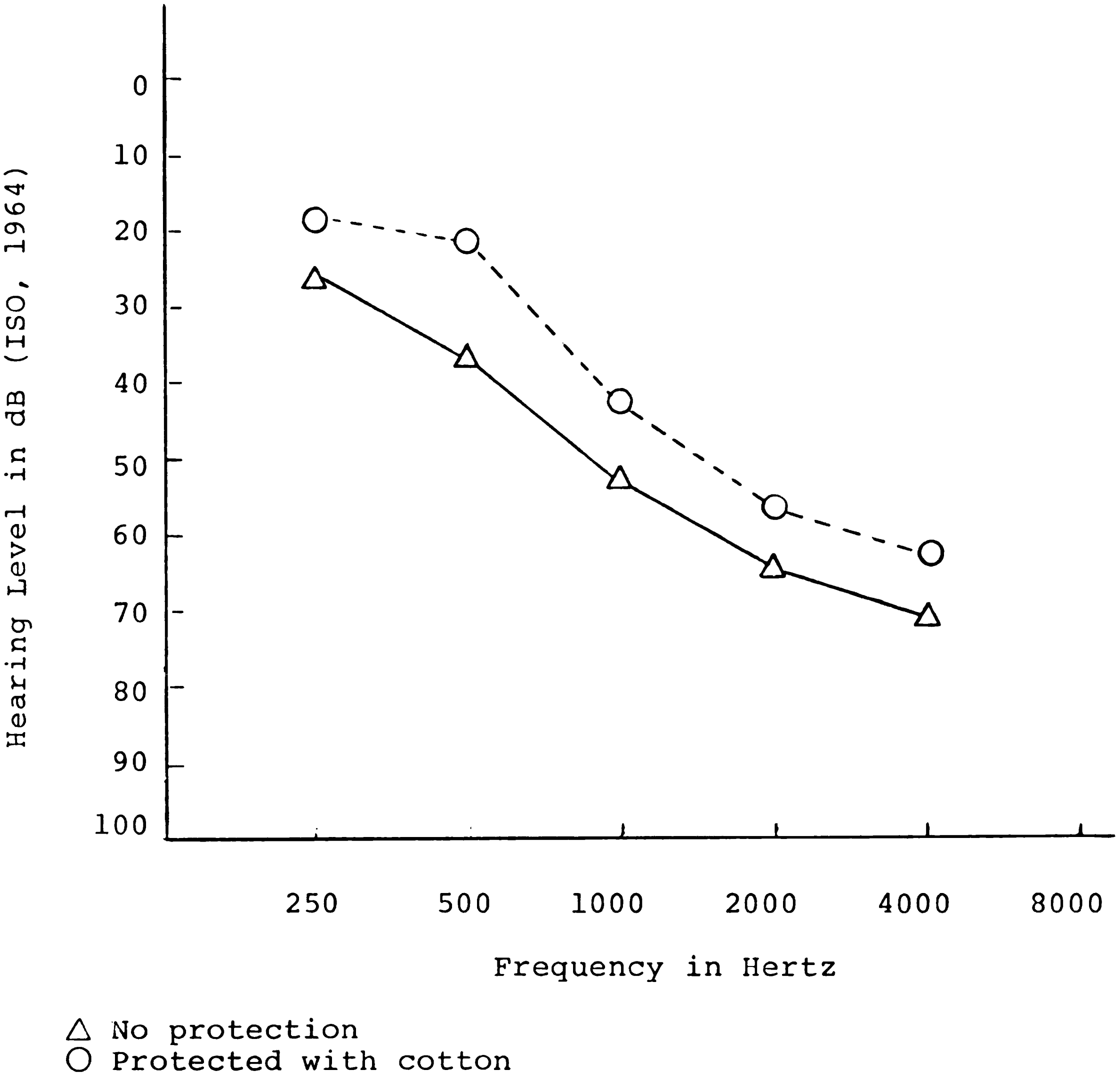


Figure 23. Composite audiogram of combined ear thresholds for heatermen by type of ear protection.

Because of the small number of straighteners reviewed, no comparison of protected versus unprotected thresholds was completed.

Phase III
Permanent Threshold Shift Discussion

In reviewing the cases, the lack of men seen with between one and fifteen years of exposure leaves a definite gap in the data presented. One might argue that the cases selected represent a restricted sample of the men working in the forge and thus not a true indication of the extent of hearing loss. It is true that in this study only the older men are really considered, but this limitation was imposed by the cases referred for testing. The younger men were not referred unless they demonstrated considerable hearing impairment. Nonetheless, the results reported do represent the effects of the impact noise in the drop forge for a fairly large sample, and thus add to the body of information needed to develop protective criteria.

A second factor which must be considered is that most of the men reviewed were working in a forge at the time of their hearing evaluation. Thus, the thresholds might more accurately be called resting thresholds. In addition, in this sample not all men had at least sixteen hours rest from the noise prior to being seen for audiological testing. However, it is the policy of the center doing the auditory testing to try to avoid testing any employee of a drop forge immediately following work. Therefore, most but not all of the thresholds analyzed in Phase III were "rested".

The questions asked at the start of the investigation concerning the permanent effects of drop forge impact noise were as follows:

1. Are there typical audiometric configurations of workers exposed to drop forge noise?
2. Does the degree of loss reach a terminal level after many years of exposure to drop forge noise?
3. Does the audiometric configuration or degree of loss differ for various drop forge companies?
4. Is the use of ear protection devices reflected in the degree of loss obtained on the different exposure groups of men studied?

An additional question was asked after the data were compiled: What differences in hearing result from working in different positions near drop forge hammers?

In answer to the question regarding audiometric configurations, the most frequently found configuration was a steeply sloping loss starting at 250 or 500 Hz. The slope of the loss did change with age and years of exposure. The lower frequencies progressively became poorer while the higher frequencies changed only slightly. The frequency of 1000 Hz seemed to be a fulcrum below which changes took place after several years of exposure. The low frequency changes, however, did not alter considerably the general configuration of the losses. There were also a number of men whose audiometric configurations were essentially flat even after a few years of exposure.

The second question regarding the degree of loss over time is a more difficult one to answer. First, the variability as the degree of loss was great. Some younger men had severe deficits while some older men displayed mild to moderate losses. This variability was also found in a previous drop forge study (Fox, 1953). The general statement can be made that, as in previous noise studies, no case was found in which total hearing loss in the speech range resulted from exposure to drop forge noise.

The degree of loss and its change over the years worked can be related to both age and years of exposure. In considering the effects of age on the cases studied, major deficits in hearing were found prior to fifteen years of exposure to drop forge noise. Losses following in latter years showed some evidence of more change in the lower frequencies than the presbycusic effects (Corso, 1963) would suggest. The higher frequencies appeared to have reached the terminal level by the time the men had worked 10 to 15 years. The results suggest that the major part of the loss occurred for most of the men before the effect of aging is generally considered a factor. Subtracting the presbycusic factor from their thresholds particularly in the high frequencies in the older age groups would suggest that their hearing loss due to noise is reduced as they get older. If presbycusis effects were additive, then one might expect to see considerably poorer thresholds in the higher frequencies for the older age groups; however, this did not occur. Therefore, the data were not corrected for presbycusis before considering other factors. (See general discussion for further consideration of this problem.)

The interesting finding regarding the increasing loss in the low frequencies after 15 years of exposure suggests that the impact noise continues to affect the auditory system. Why the loss in the low frequencies continues can only be conjectured. But, it is possible that the constantly fluctuating noise levels and changing of positions near the hammer might account for the continuing low frequency loss.

The degree and slope of the loss occurring in different drop forge companies were found to be quite consistent for three of the four forges studied. The fourth forge was not adequately represented to compare with the other companies. The consistency of the mean average loss and slopes between forges suggests that while different companies have different equipment, the resulting hearing loss from drop forge noise exposure is quite similar. Thus, results can be generalized to some extent for drop forges from different areas. Further study is required to verify this finding.

The method used to evaluate effects of protection in this study had not generally been employed in the field. By considering differences in resting thresholds between men protected and unprotected, assuming they started out with normal hearing, one might gain some insight into what long term effects the protection provided. In the present study, small differences were noted suggesting cotton did provide some protection. However, difference in age and years of exposure could have accounted for the dissimilarities noted.

In the current study, the hammermen evidenced greater mean threshold losses than did the heatermen or straighteners. This might be expected in light of the closer position to the hammer. However, the results are confounded in that most hammermen have been exposed to the noise at both the heaterman's and straightener's positions. The hammerman's job is obtained through seniority, and then only if he wants to work that position. The study does suggest that the hammerman's position is the more hazardous as the majority of the cases reviewed were working as hammermen or had worked as hammermen at the time they were evaluated.

General Discussion

The nature of drop forge noise and its relationship to current damage risk criteria for impulse noise needs further elaboration. Coles, *et al*. (1968) recognized the differences between industrial noise and gunfire. These differences included lower peak levels for drop forge noise, longer rise times and durations, and greater repetition rates and reverberation. The current DRC are, therefore, specifically for gunfire alone. Damage risk criteria based strictly on peak level and duration as well as a limited exposure period obviously cannot be applied to the industrial setting appropriately.

The three approaches used in developing DRC for industrial noise have included: attempting to relate industrial noise to the gunfire criterion, using the single figure limit for impacts or, as suggested by Coles *et al*. (1968), employing conventional steady state measures and DRC. The latter approach was suggested because the repetition rate and reverberation tend to make the noise relatively continuous.

None of the above mentioned approaches appear to be satisfactory for impact noise industrial applications at this time. Because of the numerous differences between gunfire and drop forge noise, current criteria are inadequate. The single level limit has been shown by Cohen, et al. (1965) and Walker (1970) to be inappropriate as TTS was obtained from impact noise with lower levels than the maximum set. The last approach, that of using conventional criteria, was not found to be adequate for fettling noise which has a repetition rate of greater than 20 impacts per second (Martin, et al., 1970). If not appropriate for fettling noise which is more continuous than drop forge noise, then dB A would hardly describe accurately the damage risk from drop forge hammer noise. The additional problem of both steady state and impact noise combined adds a further confounding factor to establishing impact noise protective guidelines. Thus, further research is needed to resolve this question of DRC for drop forge noise.

The second phase of the study, originally designed to consider TTS resulting from drop forge noise, had to be modified because the majority of the employees used ear protection devices. No subjects were asked to go without protection. Therefore, the TTS measured reflected the effects of noise as attenuated by the ear protectors. The confounding effects of the ear protection and the variable exposure for each man limited the findings of this study as to the relationship between the impact noise and TTS. The results do indicate, however, that in every day working conditions, TTS resulting from the drop forge noise is mild if ear protection is used. The fact that some TTS is present even with ear plugs or muffs suggests that 20-35 dB additional shift might have resulted if protection had not been employed. This is illustrated by subject 3 (see Figure 10) who demonstrated a 46 dB shift at 4000 Hz while going unprotected.

An important clinical implication regarding TTS should be noted. All subjects' TTS had recovered to resting threshold levels within a 16 hour period. Since many of these individuals receive hearing evaluations and hearing aid evaluations at audiological centers, the assumption can be made that test results reflect resting thresholds if 16 hours have elapsed since the person was exposed to noise. With impact noise, this assumption should only be made with employees using ear protection, as unprotected TTS studies have not been completed.

In relating the noise measured to the PTS for a group of men from different forges, one must assume that the noise measured is representative of the noise in all shops. While the hearing losses were found to be similar in three of the four forges reviewed, one cannot assume that the noise measured in one forge at the present time has remained constant during the past 50 years or so. The long-term effects of the noise, however, are demonstrated by the PTS data. The steeply sloping high frequency loss is consistent with other types of impact noise. Also, the impact noise exposure appears to continue to reduce the hearing acuity in the low frequency region up to the age of 65. In those cases in which thresholds at 6000 and 8000 Hz were obtained, the noise tends to affect those frequencies equally or more than 4000 Hz.

An important finding regarding permanent effects of the noise is that the results of Phase II clearly demonstrated that with the exception of the low frequency region, the terminal hearing loss from impact noise was already reached by the time men had spent 10-15 years in the hammer shop. In fact, it is possible that this terminal loss for some men might even occur earlier, but supporting evidence is not yet available for the younger men.

The relationship between TTS from one day's exposure and PTS from habitual exposure cannot be evaluated in this study as unprotected TTS measures were not made and the two phases were completed on two different groups of subjects. The relationship between TTS and PTS for steady state noise is uncertain, although many researchers feel a given TTS occurring often enough will result in a similar PTS. Impact noise has a different effect on the auditory system in terms of TTS growth rate and has more variability. The daily variation in exposure to drop forge noise might possibly increase the rate of PTS development. Coles, et al. (1968) suggested that possibly the levels arriving at normal incidence to the ear from other sources might actually be more hazardous and cause a more rapid onset of PTS. Their comments were made regarding gunfire noise but would appear to be applicable to drop forge noise also. Progression of hearing loss due to impact noise during the first few years of exposure could not be studied because cases with 0-15 years of exposure were not available for study. The reason for only a few younger men being referred for hearing evaluations is unknown. However, it is speculated that these men might demonstrate less difficulty hearing while at work and, therefore, not be referred for audiological evaluation.

The findings of the TTS study suggest that the use of protection devices results in shifts which for the majority of cases do not exceed the CHABA (Kryter, 1966) limits. The method of study is limited, however, since the unprotected TTS could not be obtained on each man as a comparative measure. Comparison of hearing loss on men using different protective devices in the PTS study is a different approach to the consideration of protection. Several assumptions must be met, however, if this approach is to be used. One must assume that each group of men start with equal hearing levels, that the age and years of exposure of the groups are comparable, and that the nature of the noise was the same for all groups. These assumptions were not entirely met in the current study. Thus, conclusions concerning protection based on PTS data are also limited.

The influence of age upon hearing thresholds has been considered by many researchers (Hinchcliffe, 1959; Glorig and Davis, 1961; Glorig and Nixon, 1962; Corso, 1963; Spoor, 1967; Wagemann, 1967). All show decreasing hearing resulting from the aging process.

In considering noise exposure, the effects of age have been generally considered additive with no interaction (ASA, 1954; Glorig and Davis, 1961). As a result, compensation usually is based upon an allowance for the hearing loss expected with advanced age.

In the current study, by using age groups based on Corso's divisions (Corso, 1963) it was found that younger subjects, 26-32 years of age, had losses comparable to the older group of men, particularly in the higher frequencies. If presbycusis effects were additive, then one might expect the loss at 4000 Hz to increase as the men became older. The effect of 34 dB at 4000 Hz[1] attributed to age was not apparent in the threshold difference from the youngest to the oldest group. The difference at 4000 Hz between these two groups was small. This suggests that the effects of presbycusis are "overshadowed" by the effects of the noise exposure.

One might conjecture that there is an interaction effect of noise exposure and age, and that the damage caused to the cochlea by the noise prior to the onset of presbycusis affects the same anatomical and physiological structures as does age. The result is that the damage expected from age alone has already been done by the noise and only minimal changes are evident from aging.

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[1] Presbycusic factor (34 dB at 4000 Hz) for men aged 59-65 according to Corso (1963).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

A review of the literature concerning industrial noise revealed a dearth of research concerning the effects of drop forge impact noise upon the human auditory system. The few studies reported to date have employed laboratory produced impact noise to investigate temporary effects on hearing thresholds. Unfortunately, these studies cannot be directly applied to actual industrial noise in terms of predicting potential auditory hazard because of the complex way numerous variables (e.g. type, amount, duration of exposure, etc.) exist in the field; but, these factors are controlled in the laboratory. Thus, in order to determine the nature of actual drop forge noise and its temporary and permanent effects on hearing thresholds, a three phase study was completed.

Phase I entailed measurement of drop forge noise and associated background noise in a local Lansing, Michigan, drop forge. Noise parameters measured included the following: peak SPL, rise time, duration, octave band analyses, total number of impacts and repetitions rates. Continuous noise measurement included linear and dB A readings as well as octave band analyses. For all parameters measured, several readings were made and the means and standard deviations were reported.

In Phase II, twenty employees of a drop forge company were given both resting threshold and TTS tests over a five day work period. Subjects were divided equally into two groups, 0-10 years of exposure and 15-25 years of exposure, and further subdivided according to the type of ear protection each man used. Manual conventional pure-tone tests were administered at the start of a week's work, three times following work shifts and once after 16 hours of recovery time. Mean resting thresholds were compared for the two groups and for the subgroups. TTS measurements after one day, two days and five days of exposure were compared on an individual basis.

Phase III was designed to study impact noise effects on PTS. A retrospective study was completed of the audiometric records of 71 drop forge workers. Each case met strict criteria regarding work, ear protection, and hearing loss histories. Results based upon pure-tone threshold configurations were analyzed according to age, years of exposure, employing forging company, position worked, and type of protection used. Because the hearing loss for each ear was essentially the same, combined right and left ear thresholds were computed for each case. Four frequency averages (500-4000 Hz) and slope of the loss per octave were also determined. Central tendency statistics were employed.

The major results from this three part investigation were as follows:

1. Impact peak levels vary greatly from one hammer to another and also for a given hammer. Levels ranged from 120 dB to 145 dB.

2. Steady state noise levels within the drop forge hammer shop are highly variable but remain higher than 90 dB A during a work shift.

3. Daily exposure to impact plus continuous noise is variable for each man depending upon his position near the hammer, the relationship to other hammers and daily changes in work procedures.

4. Differences between drop forge and gunfire impact noise relative to rise times, durations, peaks, and repetition rates reduce the applicability of current impact DRC which are based upon gunfire noise parameters.

5. As evidenced by the PTS and unprotected TTS results, the noise present in the drop forge is definitely hazardous to the human auditory system.

6. When using appropriate ear protection:
    - (a) daily TTS found for the majority of employees is reduced to within acceptable limits according to current DRC.
    - (b) no residual TTS is present at the start of the next work day.
    - (c) accumulative TTS over a five day work week was found to be negligible.

7. Hearing loss from impact noise for both temporary and permanent threshold shifts shows a high degree of variability in terms of amount of loss.

8. The typical audiometric configuration, resulting from drop forge noise found in 69% of the cases, was a bilaterally symmetrical steeply sloping hearing loss. A gradual slope or flat configuration was exhibited by the remaining 31% of the drop forge workers.

9. The primary loss of hearing resulting from drop forge noise occurs during the first 10 to 15 years of exposure. However, additional loss due to exposure to noise continues to affect the low frequencies until the employee retires at about age 65.

10. The effects of presbycusis contribute only a minor part to the hearing loss of drop forge workers; however, presbycusis and drop forge noise appear to have an interacting effect upon PTS instead of an additive one.

Conclusions

Three primary conclusions from this study are warranted. First, both impact and continuous (steady state) noise levels measured in a drop forge were found to be potentially hazardous to the workers' auditory systems according to current DRC. Secondly, permanent threshold shifts obtained from a large sample of hammer shop employees exhibited serious hearing impairment after ten to fifteen years of employment. Finally, both rested (non-noise exposed) thresholds and TTS measurements obtained from men with less than ten years of noise exposure suggest that utilization of appropriate ear protective devices substantially reduces the hazard to hearing. The primary implication is that if hearing conservation programs are initiated in drop forges, the risk to the employee's hearing can be significantly reduced.

Recommendations for Further Research

In view of the findings of the present investigation, the following recommendations for additional research are made:

1. It is suggested that a comparison study of both steady state and impact noise in different drop forges be made. This would permit generalization as

to the average noise levels from one forge to another, and permit conclusions regarding the relationship between noise levels and PTS.

2. A study designed to compare different methods of measurement and their relationship to hearing loss is particularly needed if criteria for industrial impact noise are to be developed. One such measure is the use of statistical distribution analyses such as employed by Dieroff (1966).

3. A follow-up study of the men tested in the TTS phase of the current investigation would provide needed data regarding hearing changes when using ear protection. These types of data are needed for the younger men.

4. Since the noise levels are constantly fluctuating but remain at hazardous levels, a study of the adaptation rate of the middle ear muscles to this type of stimulus might provide important information regarding the natural protection of the middle ear mechanism.

5. A study designed to compare TTS and different repetition rates of hammers on the job, or in the laboratory, is needed. These data are needed to supplement the findings of Ward (1962) regarding the growth of TTS.

6. A study designed to measure the incidence of hearing loss in the drop forge is needed to determine if all men are affected by the noise. This might be done during the initial testing for a hearing conservation program.

7. An investigation is needed to supplement the current data regarding the PTS of men working in the drop forge for 1 to 15 years. Obtaining threshold and other data on a large sample of these men would help answer the question regarding how rapid the hearing loss occurs from impact noise. However, it is in this group of younger men that ear protection has been introduced early in their work histories. Hence, it would be difficult to obtain PTS data that are comparable to that of the older men, namely, long-term unprotected pure-tone thresholds.

Studies such as those mentioned above are needed in order to establish and conduct hearing conservation programs. When this is accomplished, the profound hearing losses that are presently an occupational hazard in drop forge hammer shops will hopefully be eliminated.

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APPENDICES

APPENDIX A

EMPLOYEE SCREENING QUESTIONNAIRE

EMPLOYEE SCREENING QUESTIONNAIRE

PLEASE ANSWER ALL QUESTIONS AS COMPLETELY AS POSSIBLE:

Name:_______________________________________ Age:__________

Number of years working in the drop forge:_________________

Types of positions you have held in the forge:
(from first to present position)

1.____________________ No. of Yrs._____
2.____________________ No. of Yrs._____
3.____________________ No. of Yrs._____
4.____________________ No. of Yrs._____

Types of ear protection (Check the type you have used and the length of time):

None:_________________ Time used:______
Cotton:_______________ Time used:______
Ear Plugs:____________ Time used:______
(Brand name if known)
Ear Muffs:____________ Time used:______
(Brand name if known)
Other:________________ Time used:______
(Please specify)

Use of Protection: Always:_______________
Sometimes:____________
Rarely:_______________

Have you worked in other noisy jobs? (Armed Services, other factories, etc.)____

If so, what kind of noise:_________________________________

How long did you work there:______________________________

Did you use ear protection:________________________________

If so, what kind of protection:___________________________

Do you do much shooting:___________________________________

If so, do you use protection:_____________________________

If asked, would you be willing to spend about 5 minutes to have your hearing tested before and after your work shift?

____

Thank you.

APPENDIX B

SUBJECT DATA FORM

SUBJECT DATA FORM

No.____

Identification:

Name:______________________________

Birthdate:________________________ Age:______________

Present Position:________________ Time on Job:_____

Noise History:

Years in the Drop Forge:________

Previous Positions in Forge:

_____________________________ Time on Job:_____

_____________________________ _____

_____________________________ _____

Gunfire History:____

Other Noisy occupations:______________________________

Ear Protection:

Presently using: (Type)_________ Length of time_____

Consistency: Always:______Sometimes:_____Rarely____

Previous Use of Protection:

Types_________________ Time:____________

_________________ ____________

_________________ ____________

Medical History:

History of H/L prior to working in the Forge:

Yes:____________ No:______________

History of H/L in the family:_________Who:__________

History of Ear Pain:____________________

Drainage:____________________

Injury:_____________________

Surgery:____________________

Tinnitus:____________________________ Vertigo___________________

Following exposure periods:

	Monday	Tuesday	Friday
1. Time hammer stopped:	_________	2._______	3.______
Time of Test:	_________	_______	______

APPENDIX C

NOTICES GIVEN TO SUBJECTS FOR PRE-EXPOSURE TESTS AND POST-EXPOSURE TESTS

NOTICE GIVEN TO SUBJECTS FOR PRE-EXPOSURE TESTS

____

You are being asked to participate in a study here in the forge in order to help determine the effects of hammer noise on the employee's hearing. As noted in the announcements on the bulletin board, your participation involves having your hearing tested several times during one week's work period.

The first of these tests is scheduled for next Monday________________. This test is done prior to your starting work and therefore, it will be necessary for you to come to the forge a few minutes earlier than you would regularly. The test to be given at that time will require approximately 10-12 minutes.

Please report to the hearing test trailer, which will be located on the drive outside the employee's entrance, before you are scheduled to begin your shift.

Information regarding the other tests will be given following the first test on Monday. These other tests will take only 2-3 minutes each to complete.

YOUR TEST TIME ON MONDAY________________IS________________.

Please try to be prompt as we do not want to affect the start of your shift in any way.

NOTICE GIVEN SUBJECTS FOR POST-EXPOSURE TESTS

As previously indicated, this study involves having your hearing tested several times during this week. The DAYS and TIMES of these other tests are as follows:

TEST 2: Monday (today) please return for a short test IMMEDIATELY FOLLOWING THE STOPPING OF YOUR HAMMER FOR THE DAY. This test takes only 2-3 minutes and you can return to finish the shift after the test is completed. (PLEASE NOTE THE TIME THAT THE HAMMER STOPS AND YOU LEAVE THE SHOP).

TEST 3: Tuesday morning please stop for a short test prior to starting work. Times scheduled are 6:30 AM or 3:00 PM for Heatermen and 6:45 AM and 3:15 PM for other men depending on which shift you are working.

TEST 4: Tuesday at end of shift: Same time as the test after Monday's work shift. Come immediately after your hammer stops for the day. Then return to complete shift. (PLEASE NOTE THE TIME THE HAMMER STOPS AND YOU LEAVE THE SHOP).

TEST 5: Friday at end of shift: Same time as Monday and Tuesday after the day's run is completed. (PLEASE NOTE THE TIME THAT THE HAMMER STOPS AND YOU LEAVE THE SHOP FOR THE TEST).

APPENDIX D

PRE- AND POST-EXPOSURE TESTING PROCEDURES

PRE-EXPOSURE TESTING PROCEDURE

1. Check both ears with the otoscope for impacted wax or other evident abnormality. Do not test subject if problem is present.

2. Check questionnaire for any incompleted questions. Complete quickly or note absence of data and time will be taken during one of the following tests to complete the form.

3. Give the following testing instructions:

   THIS TEST IS A BRIEF EVALUATION OF YOUR HEARING FOR TONES. THE OBJECT OF THE TEST IS TO FIND THE POINT WHERE YOU CAN JUST BARELY DETECT THE TONE. SOME TONES WILL BE VERY HIGH PITCHED AND SOME LOW PITCHED. REGARDLESS OF THE PITCH OF THE TONE, THE IMPORTANT THING IS THAT YOU INDICATE EVERY TIME YOU HEAR IT. YOU CAN SIGNAL THAT YOU HEAR THE TONE BY RAISING YOUR HAND. KEEP YOUR HAND RAISED AS LONG AS YOU HEAR THE TONE. WHEN THE TONE IS GONE, LOWER YOUR HAND. WE WILL TEST FIRST YOUR _____ EAR AND THEN YOUR _____ EAR. DO YOU HAVE ANY QUESTIONS?

4. Test the better ear first, if one is better. If not, test the right ear first.

5. When testing, use the Carhart and Jerger ascending technique. However, when ascending <u>use 2 dB steps</u> instead of 5 dB steps.
   a. Present the tone at a level above threshold.
   b. When response is obtained decrease tone in 10 dB steps.
   c. Ascend in 2 dB steps until response is obtained.
   d. Decrease in 4 dB steps until no response and then ascend in 2 dB steps until response is obtained.
   e. Threshold is the lowest point at which 2 consecutive responses are obtained or 2 out of 3 responses are obtained.

6. Test the Frequencies in the following order: 1000, 2000, 4000, 8000, repeat 1000, and then 500 Hz. Record the thresholds on the form provided, using the second 1000 Hz threshold, in the section TEST 1. Test both ears.

7. Repeat the test in both ears at the same frequencies (once only at each frequency). Cover the TEST 1 results so that they do not influence TEST 2. Record TEST 2 results in appropriate place on the form.

8. Test bone conduction at 500 and 1000 Hz bilaterally. If air-bone gap of greater than 8 dB is present, subject is not usable in study.

9. Give the subject the reminder slip for the other test times. REMIND HIM VERBALLY HE IS TO RETURN FOLLOWING THE SHUTING DOWN OF HIS HAMMER FOR THE DAY. (ASSUMING THAT IT IS THE END OF THE RUN). HE MUST NOTE THE TIME THAT THE HAMMER STOPS FOR THE DAY. Arrangements for his leaving the shop for a few minutes have been cleared with personnel office.

PROCEDURES FOR POST-EXPOSURE TESTS

1. Record the time that the hammer stopped according to the employee.

2. Record the time that the test starts.

3. (On Friday only, ASK EMPLOYEE IF HE WORKED ALL FIVE DAYS IN THE WEEK). If not, indicate so and do not test subject.

4. Do air-conduction test on the one ear indicated on the form. Test at the same frequencies as tested previously but in the order indicated on the form.

5. Record results on the data sheet in the space provided for the test being done.

6. Advise employee to return to the trailer prior to starting his shift the following day (following Monday's test) or

   Advise employee to return immediately after the stopping of his hammer (following Tuesday Morning's test) or

   Advise employee to return immediately after the stopping of his hammer on Friday (following Tuesday Afternoon's test).

APPENDIX E

THRESHOLD RECORDING DATA SHEET

THRESHOLD RECORDING DATA SHEET

PRE-EXPOSURE TEST

Frequency	Right Ear			Left Ear		
	Test 1	Test 2	Average	Test 1	Test 2	Average
8000						
4000						
2000						
1000		BC			BC	
500						

4 Frequency Total

POST-EXPOSURE TESTS

______ Ear

Post-Exposure Test	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Thresholds Monday Afternoon					
Thresholds Tuesday Morning					
Thresholds Tuesday Afternoon					
Thresholds Friday Afternoon					
RESTING THRESHOLDS (Monday Pre-Test)					
TTS Monday PM					
TTS Tuesday AM					
TTS Tuesday PM					
TTS Friday PM					

APPENDIX F

NOISE ANALYSIS RAW DATA

TABLE F1.--Impact peak pressure measurements* made at the hammerman's position on Hammer I** and Hammer II.†

No of Reading	Hammer I		Hammer II			
	1st Stroke	8th Stroke	1st Stroke	3rd Stroke	5th Stroke	11th Stroke
1	130.0	143.0	128.0	140.1	138.2	141.0
2	128.0	143.5	128.5	139.7	138.0	141.4
3	127.0	144.3	127.0	141.0	140.0	140.0
4	127.8	142.5	127.5	140.5	139.0	141.6
5	127.2	144.0	128.5	138.0	141.2	141.4
6	127.0	142.5	128.5	141.2	139.6	
7	128.5	143.1	128.3	139.5	139.6	
8	129.0	141.0	129.2	142.0	139.8	
9	128.1	143.0	128.3	141.5	139.0	
10	127.5	142.9	130.0	141.7	139.7	

* In dB re:0.0002 microbar

** 3000 lb board hammer

† 2000 lb air hammer

TABLE F2.--Impact peak pressure measurements* made at the heaterman's position on Hammer I and Hammer II.

Number of Reading	Hammer I Strokes		Hammer II Strokes		
	1st	8th	1st	3rd	5th
1	124.0	139.0	122.0	135.4	134.5
2	124.3	139.0	122.5	135.2	133.4
3	124.7	139.5	123.9	135.0	133.3
4	124.0	138.2	122.9	136.2	135.4
5	123.9	140.0	122.0	135.0	133.3

*In dB re:0.0002 microbar

TABLE F3.--Impact peak pressure measurements* made at the straightener's position on Hammer I and Hammer II.

Number of Reading	Hammer I Strokes		Hammer II Strokes			
	1st	8th	1st	3rd	5th	11th
1	128.0	144.5	126.5	144.5	142.8	141.5
2	123.0	143.0	125.9	142.0	142.3	144.5
3	125.3	144.6	126.4	142.5	141.5	143.3
4	124.8	142.5	126.7	143.0	141.0	144.0
5	126.5	143.4	125.0	144.8	141.2	144.9

*In dB re:0.0002 microbar

TABLE F4.--Impact octave band measurements made on the 8th stroke of Hammer I.*

Reading Number	Octave Band Center Frequency in Hz										
	31.5	63.0	125	250	500	1000	2000	4000	8000	16000	31500
1	111.2	111.5	124.0	128.4	133.8	134.4	135.3	133.9	134.1	129.1	123.0
2	112.5	112.0	120.4	128.0	132.4	134.5	135.7	134.8	132.1	130.1	124.0

*Hammerman's position.

TABLE F5.--Impact octave band measurements made on the 3rd stroke of Hammer II.*

Reading Number	Octave Band Center Frequency in Hz										
	31.5	63.0	125	250	500	1000	2000	4000	8000	16000	31500
1	108.4	116.8	123.7	127.3	129.6	131.3	130.7	133.5	130.8	129.1	123.5
2	106.3	115.0	122.2	127.5	130.6	130.9	135.3	131.5	132.5	128.7	124.7

*Hammerman's position.

TABLE F6.--Linear and dB A scale noise measurements* at five locations in the hammer shop of the drop forge.

Location	No. of Reading	Linear (Slow)	dB A (Slow)
A	1	105.0	101.0
	2	106.0	102.0
	3	107.0	102.0
B	1	104.0	100.0
	2	105.0	99.0
	3	102.0	99.0
C	1	105.0	100.0
	2	106.0	101.0
	3	106.0	101.0
D	1	105.0	98.0
	2	106.0	98.0
	3	106.0	99.0
E	1	110.0	106.0
	2	111.0	105.0
	3	110.0	105.0

*In dB re:0.0002 microbar

TABLE F7.--Continuous background noise measurement* (in dB re 0.0002 microbar).

Location	Octave Band Center Frequency in Hz												
	Linear	dB A	31.5	63	125	250	500	1000	2000	4000	8000	16000	31500
1	104.0	91.5	101.0	100.0	90.0	90.0	89.3	86.3	83.5	79.0	76.3	75.0	75.5
2	104.5	94.0	99.5	97.0	93.5	91.0	91.4	88.9	87.3	80.0	74.0	69.5	69.4
3	103.5	90.5	98.0	97.5	91.0	89.0	90.0	86.4	81.5	75.6	70.8	75.6	61.5
4	102.0	94.6	96.0	93.0	90.0	93.9	94.5	90.1	84.9	82.0	73.5	73.5	66.5
5	102.3	94.0	--	--	--	--	--	--	--	--	--	--	--
Mean	103.3	92.9	98.6	96.9	91.1	91.0	91.3	87.9	84.3	79.2	73.6	73.4	68.2
SD	1.01	4.15	2.14	2.90	1.65	2.11	2.30	1.88	2.44	2.68	2.26	2.74	5.84

*Measurements taken with no hammers running.

TABLE F8.--Peak SPL and dB A measures* on Hammer III.

Reading Number	Linear Peak SPL	dB A
1	146.0	112.0
2	146.5	113.0
3	146.0	114.0
4	145.5	114.0
5	144.5	112.0
6	143.0	113.0
7	146.0	114.0
8	145.5	113.0
9	147.5	113.5
10	147.1	114.0
Mean	145.8	113.2
SD	1.3	0.8

*Peak Measurement made on the seventh or last stroke of the series. dB A is visually determined average of all strokes in the series.

APPENDIX G

PHASE II: SUBJECT AND THRESHOLD DATA

TABLE G1.--Subject data and resting threshold* data for the right and left ears for the 0-10 years exposure group.

Subject Number	Age	Years Exposure	Posit.	Protect.	Frequency in Hz (Right Ear)					Frequency in Hz (Left Ear)				
					500	1000	2000	4000	8000	500	1000	2000	4000	8000
1	21.75	2.5	Heater	Cotton	6.0	2.0	0.0	8.0	14.0	6.0	2.0	6.0	24.0	32.0
2	24.92	5.0	Heater	Cotton	14.0	2.0	0.0	24.0	20.0	2.0	2.0	2.0	26.0	14.0
3	26.75	3.0	Heater	None	10.0	2.0	10.0	4.0	32.0	14.0	6.0	4.0	4.0	30.0
4	25.83	2.5	Heater	Cot-1 Plugs-1.5	6.0	4.0	10.0	0.0	12.0	4.0	4.0	6.0	8.0	8.0
5	24.42	3.0	Heater	Muffs-2 Plugs-1	10.0	6.0	2.0	38.0	8.0	10.0	10.0	8.0	56.0	4.0
6	23.0	2.0	Str.	Muff-1.5 Plug-.5	34.0	26.0	16.0	22.0	28.0	34.0	20.0	14.0	12.0	34.0
7	27.92	6.0	Str.	Muff-2 Plugs-1 Cot-2	12.0	26.0	12.0	12.0	10.0	12.0	36.0	34.0	24.0	12.0
8	26.92	8.0	Hammer	Plugs-.5 Muffs-1 Cot-6.5	14.0	4.0	0.0	8.0	16.0	14.0	4.0	2.0	12.0	8.0
9	20.75	2.0	Str.	Muffs	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	6.0	18.0
10	26.67	1.5	Str.	Muffs	8.0	6.0	12.0	0.0	22.0	10.0	4.0	14.0	12.0	36.0

*Air-conduction only re: ISO-1964.

TABLE G2.--Subject data and resting threshold* data for right and left ears for the 15-25 year exposure group.

Subject Number	Age	Years Exposure	Posit.	Protect.	Frequency in Hz (Right Ear)					Frequency in Hz (Left Ear)				
					500	1000	2000	4000	8000	500	1000	2000	4000	8000
11	43.25	22.0	Heater	Cotton	4.0	38.0	58.0	72.0	88.0	6.0	32.0	50.0	88.0	90.0**
12	40.50	20.0	Hammer	Cotton	6.0	38.0	34.0	30.0	6.0	6.0	12.0	22.0	46.0	2.0
13	50.50	17.0	Heater	Cotton	20.0	22.0	18.0	48.0	86.0	32.0	28.0	36.0	72.0	90.0**
14	43.50	23.0	Hammer	#W. Plug Cot.-23	6.0	2.0	6.0	26.0	6.0	8.0	0.0	4.0	10.0	4.0
15	39.17	16.0	Hammer	Muffs-2 Cot.-14	26.0	46.0	54.0	52.0	54.0	18.0	52.0	64.0	58.0	60.0
16	35.67	16.0	Hammer	W. Plugs Cot.-16	12.0	6.0	48.0	48.0	44.0	20.0	30.0	60.0	54.0	46.0
17	47.17	24.0	Heater	#V. Plug 5 Cot.-18	44.0	54.0	60.0	72.0	82.0	32.0	56.0	64.0	68.0	80.0
18	47.0	24.0	Hammer	V. Plug 4 Cot.-20	10.0	44.0	50.0	80.0	90.0**	10.0	40.0	44.0	94.0	90.0**
19	49.83	25.0	Hammer	V. Plug-3 Cot. 22	38.0	62.0	74.0	96.0	90.0**	20.0	32.0	66.0	74.0	82.0
20	40.0	15.0	Heater	V. Plug 5 Cot. 12	24.0	44.0	48.0	48.0	24.0	26.0	44.0	50.0	54.0	54.0

*Air-conduction only, re: ISO-1964

**Threshold given as maximum testing level although Ss gave no response to stimulus.

#V Plug refers to valve type plugs. W plug refers to cotton wax plug.

APPENDIX H

PHASE II: TTS DATA

TABLE H1.--Temporary Threshold Shifts for each of the 19 subjects* tested on Monday PM, Tuesday AM, and Tuesday PM.

Subject	Frequency in Hz Monday PM					Tuesday AM					Tuesday PM				
	500	1000	2000	4000	8000	500	1000	2000	4000	8000	500	1000	2000	4000	8000
1	2.0	0.0	10.0	12.0	0.0	4.0	4.0	0.0	0.0	-2.0	6.0	4.0	6.0	8.0	-2.0
2	2.0	2.0	2.0	2.0	-2.0	0.0	0.0	2.0	2.0	0.0	4.0	2.0	2.0	0.0	-4.0
3	8.0	4.0	14.0	46.0	24.0	6.0	2.0	2.0	4.0	-2.0	-2.0	0.0	6.0	24.0	8.0
4	10.0	6.0	6.0	0.0	2.0	-2.0	0.0	-2.0	0.0	-2.0	8.0	6.0	10.0	-2.0	2.0
6	6.0	4.0	12.0	8.0	-2.0	0.0	-2.0	2.0	0.0	0.0	6.0	10.0	10.0	2.0	-2.0
7	10.0	8.0	4.0	4.0	16.0	-2.0	2.0	2.0	0.0	0.0	8.0	6.0	6.0	4.0	8.0
8	-2.0	0.0	0.0	0.0	2.0	-2.0	-2.0	0.0	0.0	0.0	-2.0	-2.0	0.0	-2.0	0.0
9	6.0	4.0	2.0	10.0	-2.0	2.0	0.0	0.0	4.0	-2.0	8.0	0.0	2.0	8.0	-2.0
10	2.0	0.0	-2.0	0.0	-2.0	0.0	0.0	-2.0	0.0	-2.0	0.0	0.0	-2.0	0.0	-4.0
11	16.0	18.0	8.0	2.0	0.0	0.0	-2.0	0.0	0.0	-2.0	12.0	14.0	6.0	0.0	0.0
12	4.0	8.0	6.0	2.0	0.0	2.0	0.0	0.0	-2.0	0.0	6.0	12.0	8.0	0.0	6.0
13	8.0	2.0	0.0	2.0	-2.0	2.0	-2.0	0.0	-2.0	0.0	8.0	0.0	4.0	0.0	2.0
14	2.0	2.0	0.0	0.0	0.0	4.0	2.0	-2.0	0.0	0.0	-2.0	2.0	-2.0	2.0	-2.0
15	4.0	6.0	0.0	0.0	10.0	-2.0	-2.0	-2.0	0.0	-2.0	0.0	6.0	4.0	6.0	2.0
16	12.0	14.0	12.0	8.0	6.0	2.0	0.0	-2.0	0.0	-2.0	12.0	16.0	12.0	8.0	8.0
17	0.0	4.0	6.0	2.0	-2.0	4.0	4.0	0.0	-2.0	2.0	4.0	4.0	8.0	0.0	-2.0
18	10.0	8.0	10.0	2.0	NR**	0.0	0.0	0.0	-2.0	NR**	12.0	8.0	12.0	-2.0	NR**
19	2.0	0.0	0.0	2.0	-2.0	-2.0	-4.0	0.0	0.0	0.0	-2.0	-2.0	2.0	-2.0	-4.0
20	12.0	10.0	10.0	2.0	16.0	0.0	2.0	0.0	-2.0	6.0	12.0	10.0	6.0	0.0	14.0

*Subject 5 was injured during the final week of testing and TTS data could not be obtained for him.

**Ss18 gave no response to stimulus at 8000 Hz on all tests. As no change occurred no TTS was found.

APPENDIX I

PHASE III: PERMANENT THRESHOLD SHIFT

SUBJECT DATA

TABLE Il.--Subject data for employees from Forge A.

Subject Number	Age	Years of Exposure	Position	Protection
A 1	36	18	Hammerman	None
A 2	42	23	"	"
A 3	55	25	"	"
A 4	52	29	"	"
A 5	65	48	"	"
A 6	51	25	"	None 20/Cotton 5
A23	60	23	"	None 10/ Cotton 13
A 7	38	16	"	Cotton
A 8	38	16	"	"
A 9	36	17	"	"
A10	48	18	"	"
A11	40	20	"	"
A12	52	23	"	"
A13	43	24	"	"
A14	41	24	"	"
A15	46	26	"	"
A16	54	30	"	"
A17	56	35	"	"
A24	63	24	"	"
A18	51	22	Straightener	"
A19	53	24	"	"
A20	43	26	"	"
A21	46	19	Heaterman	Cotton 17/ Plugs 2
A22	49	20	"	Cotton 18/ Plugs 2
A25	63	23	"	Cotton

TABLE I2.--Subject data for employees from Forge B.

Subject Number	Age	Years of Exposure	Position	Protection
B 1	37	19	Hammerman	None
B 2	46	27	"	"
B 3	54	31	"	"
B 4	59	31	"	"
B 5	65	42.5	"	"
B 6	46	27	"	None 25/ Plugs 2
B 7	58	40	"	None 38/ Plugs 2
B 8	61	41	"	None 39/ Plugs 2
B21	40	20	"	None 19.5/Plugs .5
B 9	46	20	"	Cotton
B10	56	27	"	"
B11	50	32	"	"
B12	55	35	"	"
B13	59	42	"	Damp Cotton
B14	43	21	Hammer 15 Heater 6	Cotton 19/ Plugs 2
B15	43	20	Heater	None
B16	47	23	"	"
B17	59	34	"	"
B18	44	20	"	Cotton
B19	39	20	"	"
B20	42	20	"	"

TABLE I3.--Subject data for employees from Forge C.

Subject Number	Age	Years of Exposure	Position	Protection
C 1	41	13	Hammerman	None
C 2	41	18	"	"
C 3	45	23	"	None 10/ Cotton 13
C 4	45	24	"	None 19/ Cotton 5
C 5	58	40	"	None
C 6	62	40	"	"
C 7	30	12	"	Cotton
C 8	40	20	"	Cotton
C 9	42	20	"	Cotton 16/ Plugs 4
C18	51	15	"	Cotton
C10	45	24	Straightener	None 23/ Plugs 1
C11	51	22	"	Cotton 15/ None 7
C12	40	12	"	Cotton 11/ Plugs 1
C13	42	16	Heaterman	None
C14	39	16	"	"
C15	46	16	"	"
C16	48	25	"	"
C17	54	30	"	"

TABLE I4.--Subject data for employees from Forge D.

Subject Number	Age	Years of Exposure	Position	Protection
D1	54	24	Hammerman	Cotton
D2	50	26	"	"
D3	29	8	"	Cotton 7/ Muffs 1
D4	44	21	"	Cotton 20/ Muffs 1
D5	52	29	"	Cotton 28/ Muffs 1
D6	43	19	"	None
D7	58	30	Hammerman 18 Heaterman 12	None 20/ Cotton 10

APPENDIX J

PHASE III: PERMANENT THRESHOLD DATA

TABLE J1.--Resting Threshold Data* for employees from Forge A.

Subject	Frequency in Hz (Right Ear)							Frequency in Hz (Left Ear)						
	250	500	1000	2000	4000	6000	8000	250	500	1000	2000	4000	6000	8000
A 1	15	25	55	55	65	--	25	15	25	50	60	65	--	70
A 2	55	70	80	85	95	--	90	50	55	75	75	90	--	85
A 3	30	55	65	95	100	NR	--	35	40	55	85	85	NR	--
A 4	45	50	55	65	90	80	--	45	50	60	70	70	85	--
A 5	45	60	60	75	85	NR	--	40	50	50	70	75	85	--
A 6	25	30	45	45	60	--	75	5	15	15	50	65	--	80
A23	20	40	65	65	65	70	45	20	40	60	70	60	60	50
A 7	25	60	70	80	85	95	--	20	35	55	60	65	70	--
A 8	55	65	55	55	65	--	75	50	50	35	35	45	--	50
A 9	20	40	55	50	55	80	--	20	40	45	50	55	55	--
A10	5	15	45	65	60	70	--	5	10	50	65	70	NR	--
A11	15	25	55	55	60	70	45	5	15	45	60	60	75	50
A12	30	40	55	75	80	NR	--	35	50	70	95	90	NR	--
A13	10	30	50	65	80	90	--	20	25	50	65	85	85	--
A14	25	45	55	70	95	100	--	20	40	55	75	70	75	--
A15	25	45	65	95	85	NR	--	25	40	55	85	100	NR	--
A16	35	40	60	75	85	NR	--	20	45	60	80	100	NR	--
A17	20	25	15	15	55	75	--	20	25	10	60	55	75	--
A24	35	30	25	70	75	85	--	35	25	35	70	75	NR	--
A18	20	30	35	45	55	75	--	25	35	25	45	60	70	--
A19	40	45	60	65	65	80	--	30	40	55	70	70	75	--
A20	35	45	40	55	60	80	--	45	50	50	60	65	70	--
A21	10	5	40	45	50	--	25	5	5	45	50	45	--	75
A22	25	10	30	55	50	--	25	30	25	20	45	55	--	65
A25	15	35	45	55	60	75	--	20	30	50	60	65	80	--

*In dB Hearing Level (Re: ISO, 1964)

TABLE J2.--Resting Threshold Data for employees from Forge B.

Subject	Frequency in Hz (Right Ear)							Frequency in Hz (Left Ear)						
	250	500	1000	2000	4000	6000	8000	250	500	1000	2000	4000	6000	8000
B 1	15	45	55	55	75	--	45	15	35	45	60	75	--	45
B 2	60	60	70	70	75	--	75	50	45	50	40	75	--	80
B 3	20	40	60	80	100	--	65	20	30	50	60	80	--	65
B 4	15	40	60	65	80	--	NR	15	30	60	75	85	--	NR
B 5	50	50	65	65	80	--	NR	65	60	60	65	95	--	90
B 6	10	5	50	55	70	--	55	10	0	25	55	65	--	55
B 7	5	15	40	50	55	--	65	15	5	15	60	55	--	65
B 8	40	50	60	70	85	--	60	60	60	50	75	85	--	75
B21	35	40	50	55	60	--	60	25	40	55	60	65	--	NR
B 9	15	35	55	70	90	NR	NR	15	15	25	60	80	85	75
B10	30	35	60	60	60	--	NR	30	35	75	90	100	--	NR
B11	35	60	70	95	105	--	NR	30	35	75	90	100	--	NR
B12	35	45	55	55	60	--	85	30	30	50	60	55	--	60
B13	5	30	55	65	65	--	75	5	25	50	55	65	--	75
B14	30	30	55	50	85	90	90	20	30	55	50	95	90	90
B15	25	45	65	75	90	--	75	15	40	60	70	75	--	75
B16	10	15	50	55	70	65	45	15	40	45	50	70	75	65
B17	30	40	50	60	70	--	65	30	40	50	60	75	--	70
B18	25	35	50	65	60	--	40	25	35	45	70	55	--	35
B19	15	15	50	55	75	NR	NR	5	5	40	40	85	NR	NR
B20	20	30	50	70	75	--	55	20	30	50	70	75	--	65

TABLE J3.--Resting Threshold Data for employees from Forge C.

Subject	Frequency in Hz (Right Ear)							Frequency in Hz (Left Ear)						
	250	500	1000	2000	4000	6000	8000	250	500	1000	2000	4000	6000	8000
C 1	35	60	70	70	95	NR	--	30	40	55	65	95	NR	--
C 2	20	45	60	70	60	--	50	20	35	55	50	65	--	50
C 3	25	35	60	65	60	--	55	15	35	65	60	65	--	75
C 4	15	35	60	80	75	NR	--	20	30	60	70	65	90	--
C 5	35	55	60	65	75	85	--	45	60	65	85	85	NR	--
C 6	55	75	90	90	75	--	NR	55	65	80	80	85	--	85
C 7	25	40	55	65	70	90	--	25	30	50	65	70	80	--
C 8	10	15	55	75	105	--	NR	10	10	40	75	105	--	NR
C 9	10	15	40	40	50	--	35	10	10	35	45	50	--	NR
C18	30	40	55	55	75	--	NR	35	45	55	60	75	--	NR
C10	15	30	40	60	50	85	--	15	25	40	65	65	90	--
C11	35	40	30	30	40	55	--	30	30	45	55	50	45	--
C12	10	15	30	35	65	--	40	10	15	30	35	60	--	30
C13	45	45	65	65	70	--	75	40	50	55	65	75	--	70
C14	15	15	45	55	60	70	--	10	5	30	50	55	65	--
C15	35	35	40	70	90	--	NR	30	35	45	70	75	--	NR
C16	20	35	55	75	70	85	--	40	55	70	75	70	85	--
C17	30	50	60	65	55	80	--	30	45	60	65	75	95	--

TABLE J4.--Resting Threshold Data for employees from Forge D.

Subject	Frequency in Hz (Right Ear)							Frequency in Hz (Left Ear)						
	250	500	1000	2000	4000	6000	8000	250	500	1000	2000	4000	6000	8000
D 1	30	45	50	60	65	--	85	25	45	55	60	65	--	75
D 2	45	45	50	70	95	--	90	60	65	70	75	90	--	85
D 3	10	35	45	60	90	--	NR	20	30	40	65	75	--	NR
D 4	30	35	60	55	95	--	NR	30	25	60	90	105	--	NR
D 5	10	40	55	65	85	--	65	15	40	55	60	80	--	80
D 6	45	55	65	75	80	90	--	35	50	55	80	95	90	--
D 7	65	65	60	75	80	--	75	60	65	75	80	80	--	90

APPENDIX K

HEARING LOSS ATTRIBUTED TO PRESBYCUSIS

TABLE K1.--Hearing loss in dB attributed to presbycusis by age and frequency.*

Frequency (Hz)	Age Group (in years)				
	26-32	34-40	43-49	51-57	59-65
250	0.4	-2.3	4.2	1.5	7.5
500	2.2	1.0	2.9	4.7	7.5
1000	0.6	1.9	6.6	6.5	9.6
2000	1.1	2.3	11.4	11.0	18.2
4000	7.5	9.7	20.6	21.3	34.8
8000	6.0	9.2	12.5	19.0	27.7

*After Corso (1963).