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WIND NOISE: ITS EFFECT ON HUMAN AUDITION

by

William Roy Nelson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Communicative Disorders

Approved:

[redacted]

UTAH STATE UNIVERSITY
Logan, Utah

1972

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William Roy Nelson

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ABSTRACT

Wind Noise: Its Effect on Human Audition

by

William Roy Nelson

Utah State University, 1972

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Department: Communicative Disorders

An examination was made of the acoustic characteristics of wind turbulence generated noise in a car traveling at 70 mph over smoothly paved highway with the driver's window down. The overall noise level was found to be at 112 dB SPL with the predominance of energy in the low frequencies. The study was concerned with the effects of such noise on human audition in terms of temporary threshold shift.

Twenty normal hearing young adults were exposed to a tape recording of wind noise for 15 minutes. Post-exposure auditory thresholds at seven discreet frequencies were compared to pre-exposure auditory thresholds at the same seven frequencies. Threshold shift was taken as the difference between pre-exposure and post-exposure thresholds. Post-exposure thresholds were obtained immediately after exposure and at five, ten, and fifteen minutes after exposure.

The results of the study indicate no significant difference in the amount of threshold shift or the rate of recovery based on sex.

A significant difference was observed in the amount of threshold shift at different test frequencies. The rate of recovery at different test frequencies was also significantly different.

Decisions of significance were made at the .01 level of confidence. The statistical tool utilized was analysis of variance. (69 Pages)

CHAPTER I

INTRODUCTION

One of the most striking characteristics of human hearing is its adaptability. Man is able to hear the slight buzz of a mosquito in flight on the one hand, and is able to tolerate the din of a jet engine on the other. It is toward the latter aspect that the present investigation will be addressed. That is, the present study will involve an investigation regarding the effects of intense sound on the human auditory system. Man is able to ignore uninteresting or undesired sounds, even when the intensity is sufficient to cause damage to the auditory sensory structures in the cochlea. However, the capacity of the human to ignore intense sound does not diminish the deleterious influence it can have on hearing. In fact, permanent damage to the auditory system can be sustained without the person being aware of the process.

High intensity sound is a prominent component of our present day environment. Acoustic pollution is a growing problem in the world modern man is creating for himself. In our contemporary society, almost everything makes "noise" of some sort, and very often this noise is at an "excessive" intensity. The home is often filled with the obnoxious sound of vacuum cleaners, electric mixers, blenders, or perhaps a stereo playing "hard rock" music at an intensity just above the threshold of pain. At the same time, someone may be using a tablesaw or electric drill in the basement shop. Outside, the street crew may be using a jackhammer and the sound may be blended with blaring automobile horns and the scream of a train on an elevated railway. People at work are often exposed to such noise as that of a printing press, rivet gun, or a drop-forge. Even the woods today seem to be filled with such acoustic tidbits as chain saws, motorcycles, snowmobiles, and discharging firearms. Even when retiring to the relative quiet of a library, one is often exposed to 60 dB of hum from the air conditioner.

The enjoyment derived from the acoustic environment varies greatly from one individual to another and may range from annoying or offensive on the one hand to desirable, enjoyable, or pleasurable on the other, depending on the particular stimulus. It is probably true that few people appreciate the sound of a pneumatic drill, but contemporary teen-agers typically enjoy hard rock music at intensity levels sufficient to damage hearing.

Regardless of the aesthetic value of any particular sound, exposure of the human ear to excessive stimulation may result in a temporary or permanent loss of auditory sensitivity. This fact is almost common knowledge. Yet daily, millions of people voluntarily subject themselves to the acoustic pollution of modern life with little concern.

There is, however, a growing concern relative to the deleterious effects of noise on the part of the lay public as is indicated by increasing mention of noise and/or noise related hearing loss in non-professional magazines. Further evidence is found in the increasing activity of groups involved in hearing conservation programs, noise abatement programs, and legislation relative to acoustic pollution.

The scientific examination of high intensity noise and its affect on the human auditory mechanism is the natural result of such concern. Studies of the relationship between noise and hearing loss range from the anatomical and physiological examination of experimental animals subjected to noise, to behavioral and psychoacoustic studies of human responses to sound of all types.

Of particular relevance to the present study are those psychoacoustic experiments related to temporary threshold shift (TTS). Temporary threshold shift is one term used to designate an auditory phenomenon characterized by a transient diminution of auditory sensitivity resulting from over stimulation of the auditory sense organ. Under a variety of names, this phenomenon has been observed and studied for over one hundred years. Nevertheless, to date, the parameters involved in TTS remain elusive, complex, and incompletely understood. TTS is elusive because an adequate explanation is yet forthcoming, and complex because the list of factors influencing TTS is long and their relationships are not well understood. Chapter II contains background information and a review of literature designed to shed some light in this area. However, it is appropriate at this point to reiterate that any sound may result in a loss (temporary or permanent) of auditory sensitivity if it is sufficiently intense and the world is full of such sounds. The information regarding the effects of these most common sounds on hearing is somewhat limited. It is hoped that the present study will expand that body of information.

It was the intent of the present investigation to study the possible effects on human hearing of one of contemporary man's most common experiences; namely, riding in an automobile with the window down. Because of the many variables possible, the study, of necessity, must be delimited. It will, therefore, be restricted to an examination of wind noise generated in one car at one speed under certain conditions and how that noise affects hearing. In general terms, the study is concerned with: (1) the intensity and spectrum of noise generated by wind turbulence in a passenger sedan traveling at 70 miles per hour with the driver's window down and, (2) the effects of such noise on pure tone threshold sensitivity.

The wind noise was recorded and instrumentally analyzed. The recording was then used as stimulus material and presented to 20 experimental subjects with normal hearing. In general, the experimental procedure was as follows. Pure tone audiometric thresholds were obtained for each of 20 subjects who were then exposed to the recorded wind noise at the same intensity as measured during recording. After exposure for 15 minutes, thresholds were again measured and threshold shift was considered as the difference in dB between pre-exposure and post-exposure thresholds. Recovery time was also considered. A detailed description of the methods and procedures is found in Chapter III.

To enable the reader to understand the rationale underlying the procedures described in Chapter III, some background information is perhaps necessary. As mentioned earlier, this material is presented in Chapter II. Specifically, Chapter II contains a discussion of the physical properties of sound and the correlated psychological aspects. Sound measurement techniques are considered in some detail. Consideration is also given to important literature in areas related directly to the present study. Such areas as adaptation and fatigue, damage risk criteria and specific studies related to TTS are reviewed.

In summary, it has been observed that man lives in a world of noise and that noise can damage human hearing. Far too little is known about the effect of common everyday activities on hearing. It is hoped that the present study will increase that knowledge by answering the questions related to whether or not wind noise generated in a car traveling at a high speed with the window down causes a temporary hearing loss to the driver. Chapter II contains background material and a review of pertinent literature. The third chapter details the methods and procedures employed in the study and the fourth chapter is a presentation of results and discussion.

CHAPTER II

BACKGROUND INFORMATION AND REVIEW OF LITERATURE

Introduction

The material contained in this chapter is devoted to a presentation of background information dealing with the physical properties of sound, the psychological aspects of auditory perception, and a review of the pertinent literature related to the phenomenon called TTS. Peripheral data is discussed only in sufficient detail to provide an adequate informational background for understanding of the present study.

Physical Properties of Sound

A physicist might define sound as: "a form of energy consisting of an organized movement of molecules in a series of waves of pressure through a transmitting medium," (Davis and Silverman, 1964, p. 29). Such a definition suggests that sound consists of two basic parameters. One is the sequential movement of the molecules which can be counted during one second of time. The number of vibrations or oscillations in one second is referred to as frequency (f) and is measured in units called cycles per second (cps) or, more recently, Hertz (Hz). The second aspect of the definition involves pressure. Acoustic sound pressure is commonly measured in dynes per square centimeter. The measured sound pressure is referred to as amplitude (A).

The simplest of all sounds is a pure tone and can be fully described by the stipulation of the two parameters, frequency and intensity. Therefore, if a pure tone were described as .0004 dynes/cm^2 at 60 Hz it would mean that the molecules in the transmitting medium were oscillating, or vibrating back and forth at the rate of 60 times per second and with a pressure of .0004 dynes per square centimeter. This pure tone could be graphed as a simple sine wave as shown in Figure 1. The X axis represents time and the Y axis represents pressure.

It is important to note at this point that amplitude is seldom reported in terms of dynes per square centimeter. Amplitude is more commonly assigned a number representative of a ratio between the sound pressure being measured and a reference pressure. The ratio is converted to units on a logarithmic scale and the units are called decibels (dB). The reference pressure most commonly used is .0002 dynes per square centimeter and when this reference pressure is used, the dB values are listed as dB sound pressure level (SPL). The relationship can be represented as a mathematical formula in the following way: $N(dB) = \log_{10} \frac{P1}{P2}$ where: N = number of decibels, P1 = measured sound pressure in dynes per centimeter square, and P2 = value of the reference sound pressure in dynes per centimeter square. Such calculations yield the root mean square (RMS) amplitude of the sound. When using the term "decibel (dB)" it is proper to designate the reference pressure. In cases where .0002 dynes/cm^2 is the reference, amplitude is stated in terms of dB SPL. Throughout this study, sound pressures will be expressed with reference to .0002 dynes/cm^2 and, hence, in dB SPL.

As previously stated, pure tones represent the simplest form of sound; yet they are seldom found in man's environment. Most sounds are complex in that more than one pure tone is present and, consequently,

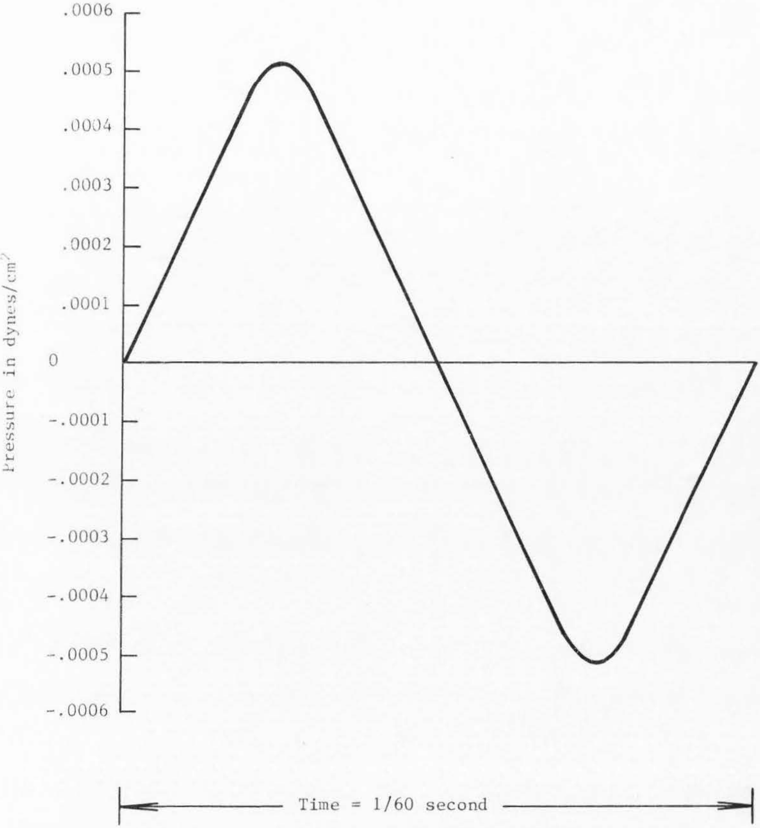

Figure 1. Graph of Pure Tone: f = 60 Hz, A (RMS) = .0004 dynes/cm^2.

information relative to the individual frequencies and their individual amplitudes is needed for an adequate description. The "spectrum" of a complex sound refers to the specification of the individual frequencies and intensities present in the sound. This information is referred to as "spectrum."

Since complex sounds consist of combinations of pure tones, a complex sound can be described in terms of the pure tones that combine to make up that sound. One means of graphically displaying information about a complex sound is in terms of a "line spectrum." A line spectrum indicates the frequency and intensity of each of the pure tones that combine to form the complex sound. An example of a line spectrum is found in Figure 2. Information regarding the frequency and intensity of the first five harmonics of a violin is contained in Figure 2. A graph similar to a line spectrum will be used in subsequent chapters to display information regarding the nature of the complex sound used in the present study.

Complex sounds are generally grouped into one of two classes; namely, periodic and aperiodic sounds. Complex sounds in the periodic class are characterized by a regularly repeating pattern or wave form and the components are all harmonically related. Such patterns are characteristic of sounds produced by musical instruments or by the human voice. The rate of pattern repetition is designated as the fundamental frequency and the integral multiple frequencies are termed harmonics.

By contrast, an aperiodic sound has no regularly repeating wave form and is characterized by random fluctuations in intensity and component frequencies. When the number of combining frequencies is large and no harmonic relationship exists, the product is termed noise. The wind noise used in the present study is an example of an aperiodic

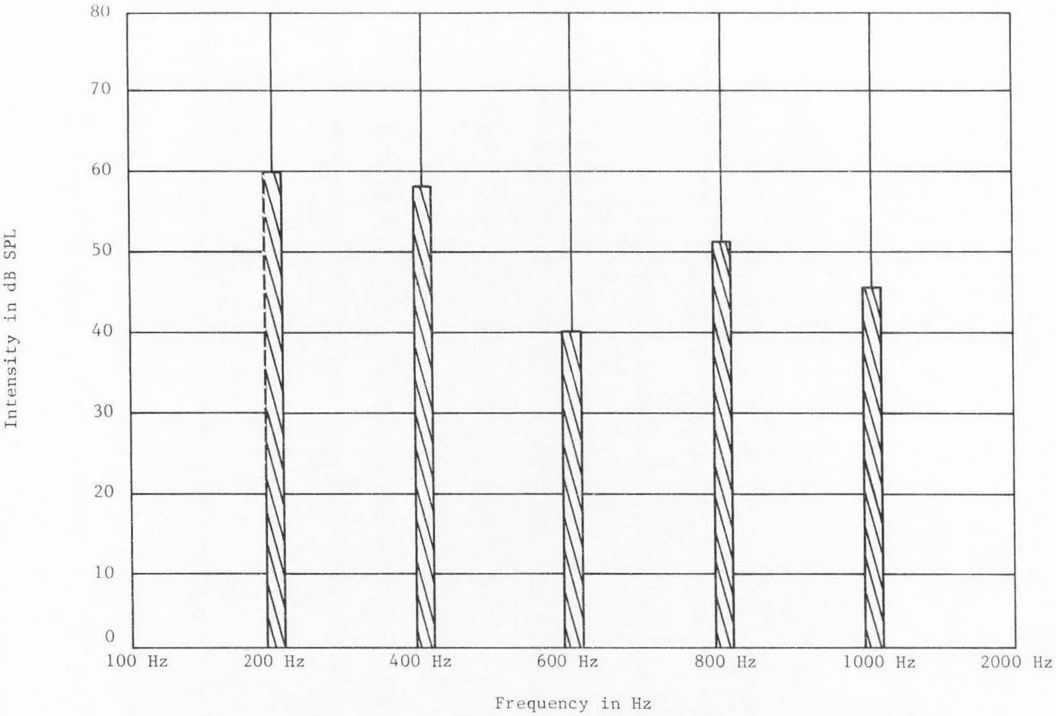

Figure 2. Line spectrum of a violin (first five harmonics).

complex sound. The acoustic characteristics of wind noise will be described and discussed in detail in Chapter III. The regularity in the wave form produced by the human voice is readily observable in Figure 3a, while no such pattern is apparent in the wave form of random noise represented in Figure 3b.

Many instruments have been developed to aid in the study of complex sound. Since a number of such instruments were employed in the present study, it seems appropriate to discuss each in some detail. The next section entitled, "Sound Measurement," contains a discussion of sound measurement techniques and the instruments used in such measurements.

Sound Measurement

Analysis of the acoustic environment is most frequently undertaken with an instrument referred to as a sound level meter. This electronic instrument generally consists of the following basic components. The first is a microphone which transduces the acoustic signal into an analogous electric signal with the same wave form. This signal is fed to an amplifier where the power is increased. The signal from the amplifier is of sufficient strength to register on a calibrated meter, where sound pressure level can be read in dB.

The sound level meter is capable of measuring the overall intensity of sound in the frequency range from 20 Hz to 15,000 Hz with an accuracy of ± 1 dB over a full scale range of 22 dB to 134 dB SPL (Brüel and Kjaer, 1965). Each frequency is given equal emphasis. This is called a "linear" reading.[1]

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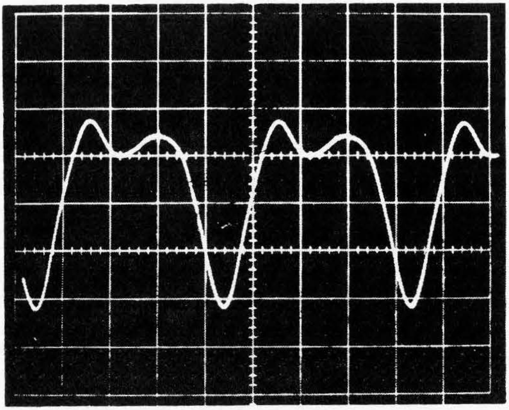
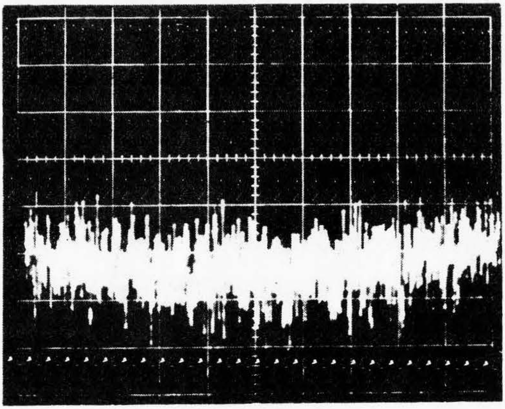
[1] No use will be made of the weighting networks (special circuitry



(a) Oscillogram of vowel sound produced by a human voice



(b) Oscillogram of random noise

Figure 3. Oscillographs of complex sound. (Burns, Noise and Man; 1968, p. 28)

An electronic band-pass filter network is frequently used in conjunction with the sound level meter and consists of a series of electronic filters which allow selective passage of certain octave[2] bands of sound. Any sound above or below the selected octave band is eliminated. Each octave is designated by its central frequency.

By international agreement the preferred octave bands for acoustic analysis are as found in Table 1.

Table 1. Band designation and band limits of preferred frequencies for acoustic measurements

Band Designation in Hz	Approximate Band Limits in Hz
16	11 - 22
31.5	22 - 45
63	45 - 90
125	90 - 180
250	180 - 355
500	355 - 710
1000	710 - 1400
2000	1400 - 2800
4000	2800 - 5600
8000	5600 - 11200
16000	11200 - 22400

Coupling of the sound level meter and the octave band filter set allows the measurement of sound in given finite octave bands. By measuring the intensity in each octave, a quantitative analysis can be made of

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used to modify the frequency response of the instrument) in measurements of sounds for this study.

[2] An octave is defined as a frequency band, "in which the lowest frequency is half that of the highest frequency." (Burns, 1968; p. 47)

frequency versus intensity and the spectral nature of the sound can be plotted.

The graphic level recorder (Brüel and Kjaer, Model 2305) was also utilized in the present study. The graphic level recorder provides a graphic illustration of the relative intensity of the input signal as a function of time. In the present instance, the graphic level recorder was employed to provide data relative to the constancy of intensity of the noise.

The use of such instrumentation yields specific information concerning the physical parameters of complex sounds. Specifically, the above instrumentation provides data relative to how frequency and intensity vary as a function of time. Each of the physical parameters of sound has a psychological counterpart. The psychological aspects of sound will be discussed in the following section.

Psychological Aspects of Sound

The psychological correlate of physical intensity is loudness. In general, loudness grows as physical intensity is increased, but the relationship is not linear and varies as a function of frequency. Perception of loudness by the individual depends on the relative state of the auditory mechanism. A person with a normal ear can respond to sounds as minute as 7 dB SPL in the most sensitive frequency range and yet tolerate sound at 140 dB SPL. In such a case, the second sound is 10,000,000 times more powerful than the first. In contrast, people with a particular type of damage to the auditory system may not perceive sound until the intensity reaches 80 dB SPL, but be unable to tolerate sound in excess of 115 dB SPL. Such a diminished dynamic range is often four in persons suffering from sensory hearing loss or, i.e., damage to the cochlea.

Pitch is the psychological correlate of frequency. In general, as frequency increases, pitch is perceived as being higher and conversely, pitch is typically lowered as frequency is decreased. However, as in the case of intensity and loudness, the relationship between pitch and frequency is not linear. Variations in intensity can also affect pitch perception in a minor way. A normal ear can perceive pitch for sounds as low in frequency as about 15 or 16 Hz. The upper pitch limit lies somewhere between 16,000 and 20,000 Hz for most normal human listeners.

Psychologically, spectral make up is perceived as quality. Differences in spectral composition enable man to discriminate one complex sound from another, even when the sounds have similar fundamental frequencies and are presented at essentially equivalent intensities.

With this background in the physical and psychological aspects of sound, it would seem appropriate to review the specific effects of high intensity sound on human hearing. This endeavor will be approached from a historical standpoint.

The Phenomenon of Temporary Threshold Shift

Pattie (1927, p. 39), upon reviewing literature back to 1871, reported efforts by some to examine a phenomenon he called "fatigue in audition." He described auditory fatigue as "a labile phenomenon" and summarized his findings in this manner, "The work done on fatigue in audition has been meager, with techniques not above criticism, and often with negative or uncertain results."

Almost ten years later, Ewing and Littler (1935, p. 286) summarized the information available in these words, "In general the conclusions of previous workers were of a somewhat inconsistent character."

After the passage of almost fifteen years, Wever (1949, p. 319) added his interpretation of the situation. "For a long time the problem of auditory fatigue has been vexed with uncertainty and controversy."

Hirsh (1952, p. 178) seemed merely to echo the previous writers when he wrote, "The experimental literature on auditory fatigue is discouragingly large. The size itself is not so discouraging as the disjointed and apparently unrelated nature of the parts. As a matter of fact, in auditory fatigue the unsolved problems greatly outnumber the established facts."

Ward (1963, p. 240) could almost have been referring to this last statement when expressed his fellings thus, "And, alas, the ensuing ten years have done little to dispel the controversy and vexation."

Historically, the study of TTS has been fraught with inconsistencies and contradictions, however, in more recent years there has been an emergence of some order.

The terms "fatigue in audition," "post-stimulatory fatigue," "auditory fatigue," and "temporary threshold shift" are all used to designate the same phenomenon; namely, a temporary diminution of auditory acuity resulting from over stimulation of the auditory sense organ.

The general method of assessing auditory fatigue is simple. Pre-stimulus pure tone thresholds for the ear to be exposed to sound are determined either by conventional audiometry or by automatic testing. After the pre-stimulus thresholds are established, the selected acoustic stimulus is presented to the test ear at a measured intensity for a given duration. Immediately after stimulation, pure tone thresholds are again assessed. The difference in dB between pre-test and post-test thresholds is considered to be the magnitude of TTS.

Recovery of the auditory mechanism after exposure may be observed by obtaining a continuous threshold trace on an automatic audiometer or by intermittent threshold testing using conventional audiometry. Recovery is considered as being complete when the post-stimulus thresholds are essentially the same as the pre-stimulus thresholds.

Certain parameters of the stimulus material have been observed to have major influence on the characteristics of auditory fatigue. Ewing and Littler (1935, p. 306) were among the earliest experimenters to demonstrate that auditory "fatigue is related to the duration, intensity and frequency of the stimulus."

Davis (1950) and his associates completed an extensive study of auditory fatigue during the first half of the 1940's. Severe post-stimulatory fatigue was produced as a consequence of exposing experimental subjects to pure tone stimuli. Stimuli ranging in intensity from 100 dB to 140 dB SPL were presented with durations ranging from one minute to over an hour. The results indicate the relationship between the acoustic properties (frequency and intensity) of the exposure stimulus and the degree of threshold shift. This relationship can be stated simply in the following manner; as stimulus intensity or duration of exposure increase, auditory fatigue increases. The loss of sensitivity is greater for tones of frequency equal to or higher than the frequency of the fatiguing tone and frequencies 2000 Hz and above are more susceptible to fatigue than frequencies below 2000 Hz.

Examination of post-stimulatory fatigue as related to stimulus intensity led Hood (1950, p. 12) to, "the notion of a critical intensity at which the ear begins to overload." He describes his procedures in this way:-

> "The ears of three normal subjects were fatigued in a series of tests at intensities of 50,60,70,80,90,100, and 110 dB above threshold for a duration of one minute and the time course of recovery from the fatigue produced was then studied..., fatigue being taken in each case as the rise in threshold in decibels found to be present ten seconds after the cessation of the fatiguing tone."

The results of Hood's (1950, p. 14) study show only slight fatigue and rapid recovery from stimulus intensities 90 dB and below. Fatigue resulting from stimulus intensities above 90 dB was severe and prolonged. He concluded that "between 90 dB and 100 dB there exists a critical fatiguing intensity below which fatigue is slight and above which it increases rapidly."

The effect of stimulus frequency on fatigue was evaluated by Rawdon-Smith (1936) who found the magnitude of fatigue to be greater among the receptor cells subserving high frequency sounds than among receptors of low frequency sounds.

The susceptibility of high frequency receptor cells to fatigue was clearly demonstrated by Hirsh and Ward (1952, p. 141). Using a variety of stimulus materials and a rather unique method of recording recovery, they undertook an extensive examination of fatigue as it relates to stimulus frequency. In their conclusions they state that, "different frequency regions of the auditory system recover at different rates." Examination of their data reveals an increase in recovery time as test frequency is increased. This point is demonstrated by one subject, who, following a three minute exposure to a 4000 Hz tone at 100 dB SPL, reached full recovery for a test tone of 2000 Hz in five minutes but required eight minutes for full recovery to an 8000 Hz test tone.

The influence on fatigue of increasing stimulus duration was examined in detail by Davis et al., (1950); Hood, (1950); and Hirsh and Bilger, (1955). Hirsh and Bilger used durations of 10,15, and 30 seconds and one, two, and four minutes for exposure to a 1000 Hz tone at intensities from 20 to 100 dB SL. The amount of shift and recovery time increased as the duration of exposure was increased. The average amount of threshold shift for a test tone of 1400 Hz varied from a shift of one dB after a 15 second exposure to over five dB of shift after a four minute exposure. These findings were in general agreement with the above mentioned studies on this subject.

More recently, interest has developed in the physiological phenomena produced by exposure of the human auditory mechanism to high intensity sound. De Mare (1951) differentiated between the temporary and permanent effects of high intensity sound on audition. He further differentiated between adaptation and fatigue and described them as two separate temporary effects. Zwislocki and Pirroda (1952) viewed adaptation as the functional state attained by the ear under sustained mild stimulation. After the initial "on-effect," adaptation results in a new, lower state of equilibrium for the system which does not change with continued exposure. Adaptation does not decrease the system's potential for future response. By contrast, fatigue in audition results from over stimulation and reduces the system's potential for future response. As has already been observed, fatigue increases with an increase of either intensity or duration.

Interest in the differences between adaptation and fatigue led Kopra (1954), and later Bragg (1958) to a more detailed examination of the subject. Kopra differentiates among five sequential entities involving adaptation and fatigue. The first, momentary adaptation, is the result of a very brief (a few seconds or less) exposure to sound. Momentary adaptation is characterized by stable recovery features which are independent of the stimulus intensity. Threshold shift in momentary adaptation is not cumulative. That is, the effects of repeated exposures to a given stimulus do not add together to result in a greater threshold shift. Therefore, once the new equilibrium is achieved, it remains constant. The amount of TTS is dependent upon the stimulus intensity and may be as great as 40 to 50 dB HL. Momentary shifts in auditory acuity have been studied by Harris (1950) and Jerger, Lightfoot and Carhart (1954). Luscher and Zwislocki (1947) conducted a study on momentary adaptation. They first measured subjects auditory thresholds for a 20 millisecond pip. The subjects were then exposed to a 40 millisecond pure tone burst of sound after which recovery was observed, recovery being perception of the 20 millisecond pip at the same intensity as before exposure. A graphic representation of such an experiment might[3] give results as found in Figure 4a. It can be seen from this graph that recovery is stable and repeated exposures do not add to the amount of TTS.

The second entity, namely, equilibrated adaptation, is characterized by the establishment of a threshold shift which grows slowly and reaches a maximum after approximately 3.5 minutes of exposure, regardless of stimulus intensity. Once maximum TTS is achieved, it does not grow with added exposure. Recovery from equilibrated adaptation is most rapid during the first ten seconds after exposure and is complete after one minute. A graphic representation of equilibrated adaptation might look similar to that shown in Figure 4b. Hood (1950), Thwing (1955), and Morgan (1968) referred to this phenomenon as "perstimulatory fatigue." For both momentary adaptation and equilibrated adaptation, individual differences from subject to subject are minimal.

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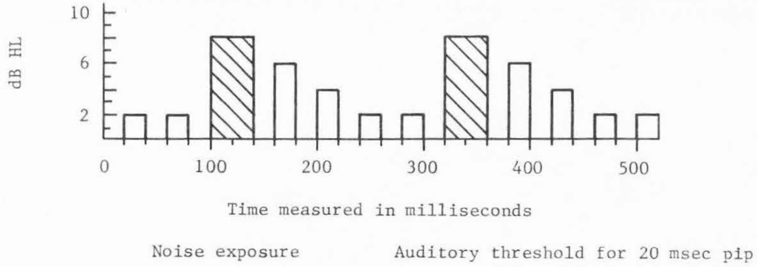
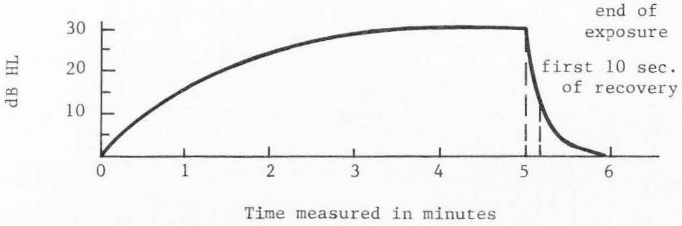
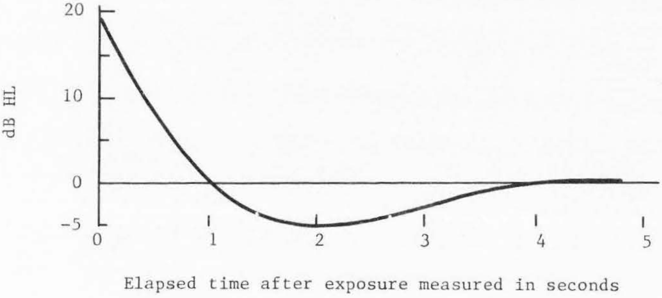
[3] Graphs contained in Figure 4 are only hypothetical and intended merely to illustrate possible results.



(a) Graphic representation of momentary adaptation



(b) Graphic representation of equilibrated adaptation



(c) Graphic representation of momentary fatigue

Figure 4. Graphic representation (hypothetical data) of first three sequential entities involving adaptation and fatigue.

Momentary fatigue, the third entity, is characterized by complete recovery within one second after termination of exposure. In fact, the recovery process frequently terminates in a short period of hypersensitivity, wherein, the subject is able to perceive a test tone at lower intensities than before exposure. A graphic representation of momentary fatigue might appear as in Figure 4c. As can be seen, recovery is complete within one second after cessation of the stimulus and terminates in a brief period of hypersensitivity. This entity was observed by Luscher and Zwislocki (1949), Bentzen (1953), and Tonndorf and Braggan (1953).

Kopra referred to the fourth entity as cumulative short-duration auditory fatigue. This phenomenon is the result of exposure over a short period of time to repeated sounds, each capable of producing momentary fatigue. This phenomenon is characterized by the absence of observable recovery during the first second after cessation of stimulation, and by the appearance of cumulative effects. Cumulation is an additive effect, wherein repeated exposure result in a greater TTS than is obtained by individual exposures. Lightfoot and Jerger (1954) demonstrated wide variability from subject to subject regarding the cumulative effects. Kopra suggests that cumulation marks the transition from equilibrated adaptation to prolonged fatigue, which is the last of the phenomena to be discussed by Kopra.

Prolonged fatigue, has been found to be dependent on both the intensity and duration of the stimulus exposure. Prolonged fatigue is the result of an exposure whose duration is measured in minutes, with fatigue persisting for at least a fraction of a minute. Intersubject variation is significant. Prolonged auditory fatigue is a prime concern to the present study and will receive extensive consideration later in the chapter.

To the five entities discussed by Kopra, Bragg (1958), added reversible hearing loss due to noise exposure and permanent hearing loss induced by noise. Delineation between prolonged auditory fatigue and reversible hearing loss due to noise exposure is primarily semantic. Both are characterized by prolonged threshold shifts after extended exposure to high intensity sound. In both cases recovery is slow. The difference lies in the fact that prolonged auditory fatigue is the result of systematic laboratory experimentation, while reversible hearing loss due to noise exposure is the result of nonsystematic exposure to environmental noise. Some rationale for such a distinction may lie in the fact that danger of permanent damage is minimal in controlled experimentation, yet unpredictable under conditions of military or industrial noise.

Permanent hearing loss induced by noise is acquired when the threshold shift caused by exposure to high intensity sound becomes irreversible. In such cases the auditory sense organ is damaged beyond its potential for self repair. The two entities included by Bragg have been studied by Carhart (1957), Theilgaard (1951), Glorig (1961, 1963 a,b) Webster (1954), Siirala and Lahikainen (1957) and many others.

Interest in the area of auditory adaptation and fatigue has grown primarily out of the apparent relationship they bear to permanent hearing loss induced by noise. The basic premise is that a greater propensity for temporary threshold shift is predictive of greater susceptibility to noise induced hearing loss. Utilizing this assumption, experts have sought a test to predict noise susceptibility and to outline general limits for safe exposure to high intensity sound. A detailed examination of hearing conservation, damage risk criteria, and predictive tests of noise susceptibility is beyond the scope of the present study. Greater detail is presented by Kryter (1950), Christiansen (1956), Rosenblith and Stevens (1953), Jerger and Carhart (1956), Kylin (1960), Glorig, Ward, Nixon (1961) and Smedley (1964). Suffice it to say in this review that a final answer is yet forthcoming.

As mentioned earlier, the present study is primarily concerned with the specific phenomenon of prolonged auditory fatigue. Being one of the first entities of temporary threshold shift identified from a historical standpoint, and one of the easiest to observe and measure, prolonged fatigue has been the object of extensive examination. Yet, the results of research efforts appear to be somewhat disjointed and unclear. Confusion is likely due to the complexity and multiplicity of factors affecting TTS.

Ward (1963, p. 258) has observed that, "the production of temporary threshold shift is dependent on many factors. As far as the parameters of fatiguing stimulus is concerned, practically everything one can measure is relevant." The interaction between the factors greatly complicates the problem.

In addition to the stimulus itself, it appears that almost anything can affect TTS. A few cases in point might serve to emphasize the complexity of the problem. Cook (1952), presents clinical evidence that table salt used in excess may increase TTS. Tonndorf et al., (1955), has presented some evidence to suggest that oxygen deprivation may increase TTS.

In discussing factors that exert a subtle influence on TTS, Ward (1963), refers to the work of Willemse and also Ruedi who suggest that deficiency in vitamin A is a contributor to noise susceptibility. He also cites the work by Morita which indicates that noise exposure results in greater TTS when the subject is vibrated during exposure. One is left with the impression from these examples that almost anything might influence TTS.

The fact remains that the primary factors influencing prolonged fatigue are spectral properties of the stimulus and duration of exposure. The prime variable relative to amount of threshold shift seems to be individual differences. Susceptibility differences from subject to subject have been observed by Wilson (1943, 1944), Wheeler (1949, 1950), Reger (1951), Hirsh and Ward (1952), Jerger (1955) and Jerger and Carhart (1955) and others.

Summary of Literature Review

The contents of this chapter to this point have dealt with the physical properties of sound which are frequency, intensity and complexity. Also discussed were the psychological aspects of sound (loudness, pitch, and quality) and their relationship to the physical properties just mentioned. Attention was then turned to the literature on TTS pertinent to the present study. The general methods of assessing TTS and recovery were outlined.

Specific attention was given to individual articles that would serve in providing background information to the reader. The relationship between certain parameters of the stimulus material (acoustic spectrum, duration of exposure, and intensity of presentation) and amount and persistence of the resulting threshold shift was discussed in some detail. Differential responses of the receptor cells mediating different frequencies were discussed.

The affects of high intensity sound on audition were discussed in terms of duration of exposures. A continuum was observed that extended from momentary adaptation to permanent hearing loss induced by noise. The characteristics of each entity were described. The variability from one person to another in his response to noise exposure was emphasized. With this background it seems appropriate to introduce the present investigation in more detail.

The Present Investigation

As stated previously, the present study is concerned with the acoustic characteristics of noise generated by wind turbulence in an automobile traveling at 70 mph. It is further concerned with the influence such noise might have on the auditory threshold of the driver of such a car in terms of TTS and how much one individual varies from another in his reaction to such stimulation. The hypotheses used as a basis for the study are as follows:

1. H_0: There is no differential susceptibility to TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together.

2. H_0: There is no differential susceptibility to TTS resulting from exposure to wind noise in a car at any given test frequency based on sex.

3. H_0: There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together.

4. H_0: There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car at any given test frequency based on sex.

5. H_0: There is no difference from one test frequency to another

in the amount of threshold shift resulting from exposure to wind noise in a car.

6. H_0: There is no significant recovery from TTS resulting from exposure to wind noise in a car during the first 15 minutes after exposure.

7. H_0: There is no significant difference in the rate of recovery from TTS resulting from exposure to wind noise in a car as a function of test frequency.

In order to test these hypotheses it was necessary to employ methods and procedures that would yield information about the acoustic characteristics of wind turbulence generated noise in a car and how that noise affects human audition in terms of TTS. The next chapter details the apparatus and procedures utilized in obtaining that information. The experimental subjects are also described.

CHAPTER III

SUBJECTS, APPARATUS AND PROCEDURES

Introduction

The present investigation is concerned with noise generated by wind turbulence in an automobile. More specifically, the present study is designed to examine the effect such noise might have on the driver in terms of TTS.

The basic approach utilized was to select subjects with normal auditory thresholds and to measure changes in threshold sensitivity subsequent to exposure to the noise as explained above. After pre-exposure threshold assessment, each subject was exposed to a tape recording of wind noise in a car. Immediately following exposure, auditory thresholds were again obtained and threshold shift at each frequency was defined as the difference between pre-exposure and post-exposure thresholds.

Chapter III details the procedures and instrumentation used in preparing and calibrating the stimulus material. The experimental environment, test sequence, and subjects are also described. In addition, a brief discussion of the acoustic characteristics of the stimulus material is presented in the present chapter.

Subjects

The test subjects for this study consisted of normal hearing young adults. All subjects were enrolled as students at Utah State University. The age ranged from 18 to 28 years of age with a mean age of 22 years and a standard deviation of 2.7 years. There were 10 male and 10 female subjects in the total of 20 participants. The following criteria were involved in assuring that each experimental subject had normal hearing. During an oral interview, each subject reported a negative history with respect to auditory disease or disorder. All subjects had "normal" auditory sensitivity in the left ear. For purposes of the present investigation, normal sensitivity was operationally defined as pure tone thresholds better than 15 dB HL (re the ANSI 1969 norm) at frequencies of 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. Thresholds were measured in an audiometric test booth (Industrial Acoustic Corporation, Model 1603A). The instrument used in all pure tone testing for this study was a calibrated pure tone audiometer (Beltone, Model 15-C) terminated in earphones (Telephonics, Model TDH-39).

The mean audiogram for the left ear of the 20 test subjects is displayed in Figure 5. Only the left ear of each subject was used in the present study. Rationale for the selection of the left ear is based on the fact that the left ear is the one most exposed to wind noise when one is driving a car with the driver's window down.

Stimulus Material

Practical considerations made necessary the use of recorded stimulus material in lieu of actual wind noise. Precedence has been set by earlier investigators (Pearson et. al., 1968; Pearson, 1969) for the

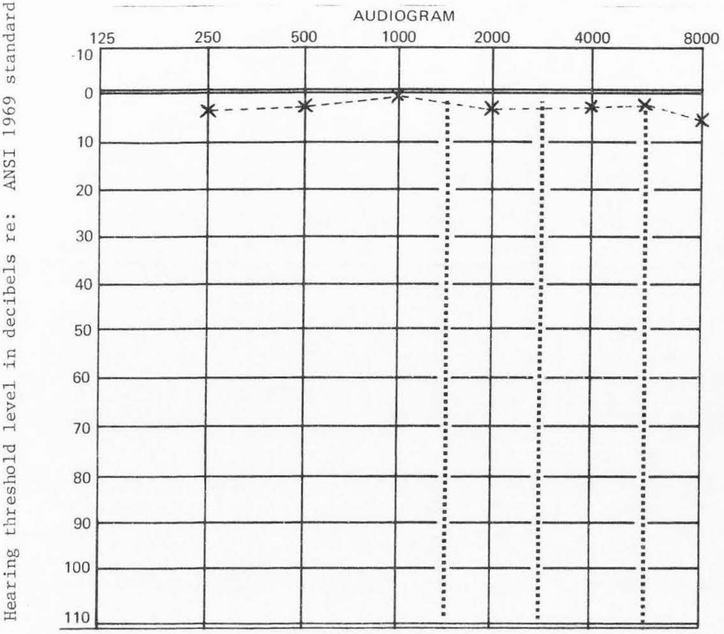


Figure 5. Mean threshold configuration for experimental subjects. The solid line indicates the mean audiogram for the left ear of the 20 subjects used in the present investigation.

use of recorded material in studies of noise exposure.

The stimulus material used in the present study consisted of a single 40 minute magnetic tape recording of wind noise generated by the wind turbulence in an automobile traveling at 70 mph over a relatively smooth, paved, four lane, divided highway with the driver's window all the way down and all other windows closed. The car used was a 1968 passenger sedan (Dodge, Superbee) with a standard transmission, a 383 cubic inch V-8 engine, and steel belted tires. This car was employed as the experimental vehicle because of its availability and because the wind noise generated in it was about average for the cars[4] measured prior to beginning the present study.

The recording was made on a magnetic recording tape (Sony, Type PR 150). The equipment used in preparing the stimulus material was a tape recorder (Sony, Model TC 630) and a condenser microphone (Sony, Model ECM 22). Since the tape recorder required an alternating current of 117 volts, it was necessary to use a DC to AC inverter (ATR, Type 12u) to convert 12 volt DC power from the car battery to 110 volt AC power which was compatible with the tape recorder.

The inverter was located under the hood of the car and rested on a brace to the engine block. The two cables were attached to the appropriate terminals of the battery. The inverter power control was set on "GH" which is the third of four settings labled Min, ED, GH, Max. The power control varies the output of the inverter and was set on GH because it provided optimum power to the recorder. The power cord of the tape recorder, which was plugged into the inverter outlet, ran under

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[4] During preparation for the present study, some pilot work was undertaken including preliminary assessments of sound pressure levels in different cars. The measured intensities ranged from 109 - 121 dB SPL. The cars tested ranged from imported compacts to large domestic automobiles.

the hood and through the wing window gasket on the passenger side. The tape recorder was located on the right front seat and was placed on two inch by two inch boards to elevate and level the recorder. Elevation was necessary to clear the cooling fan located at the bottom of the recorder. A block diagram of the power supply and equipment arrangement used in recording stimulus material is found in Figure 6. The microphone was plugged into the recorder and placed just behind the ear of the driver in an effort to obtain optimal simulation of the noise heard by the driver. The recorder was set to record at seven and one-half inches per second for maximum fidelity in recording. The record level control of the recorder was adjusted to yeild an average reading on the VU meter of between -2 and 0 dB to avoid distortion of the recorded wind noise.

Calibration of Stimulus Material

To provide a reliable and stable method of setting the intensity level for presentation of the stimulus material, a 1000 Hz calibration tone was recorded at the beginning of the stimulus tape at the same level as the average peaks of the recorded wind noise. Thus, for purposes of the present investigation, the intensity of the noise is defined as the intensity of a 1000 Hz tone that peaks to the same point on the VU meter.

The calibration tone was generated by a wide range oscillator (Hewlett-Packard, Model 200 CD). The pure tone calibration signal was checked for frequency accuracy on a universal counter-timer (Computer Measurements Company, Model 605A). A frequency count was also obtained directly from the tape recording of the 1000 Hz tone and was found

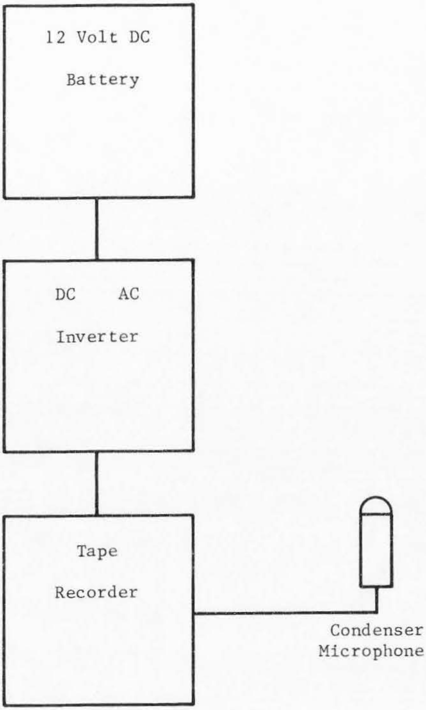

Figure 6. Illustration of equipment arrangement used in recording stimulus material.

to be accurate.

The intensity of the calibration tone was set in the following manner: the signal was fed from the oscillator through the tape recorder and to a graphic level recorder (Brüel and Kjaer, Type 2205). The intensity of the calibration tone was set by visual inspection to approximate the average peak intensity of the recorded wind noise. A diagrammatic illustration of the equipment arrangement is found in Figure 7. A graphic level recording of the relationship between the 1000 Hz calibration tone and the wind noise is displayed in Figure 8.

Wind Noise Analysis

The acoustic analysis of the recorded wind noise was approached in three ways. First, the overall sound pressure level (SPL) of the wind generated noise was measured with a sound level meter (Brüel and Kjaer, Type 2203) set to the linear scale and to the slow response. The measurements were obtained in the car during the recording session to determine the actual wind noise level during the recording. The overall SPL was found to be approximately 112 dB with some peaks between 115 and 118 dB. Secondly, in conjunction with the linear reading, an octave band analysis of noise was made by coupling an octave band filter set (Brüel and Kjaer, Type 1613) to the sound level meter. As shown in Figure 9, the predominance of acoustic energy is in the lower frequencies, but noise is present throughout the audible frequency spectrum. These same analyses were made of the recorded wind noise presented through the equipment and will be described later under the section entitled, Test Procedures and Sequence. The results of these analyses were essentially identical to those found in Figure 9.

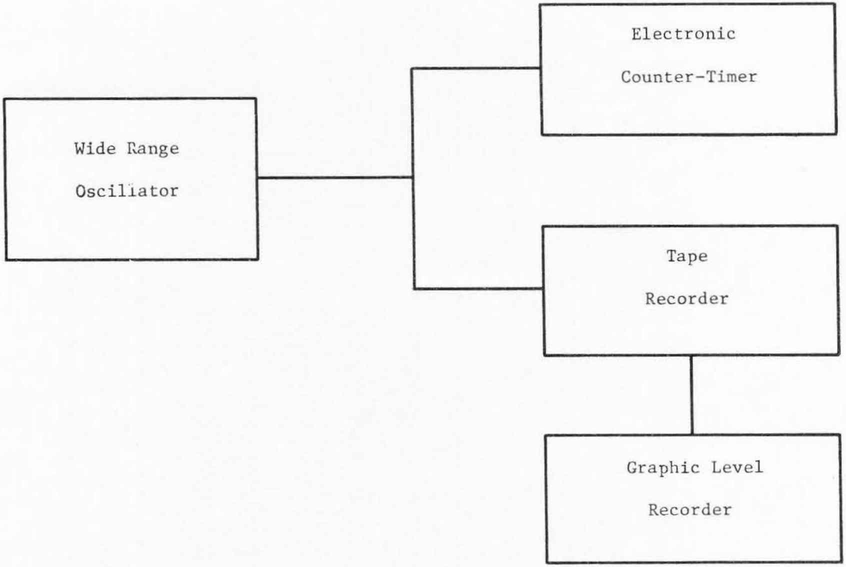

Figure 7. Diagrammatic illustration of equipment used in recording of calibration tone.

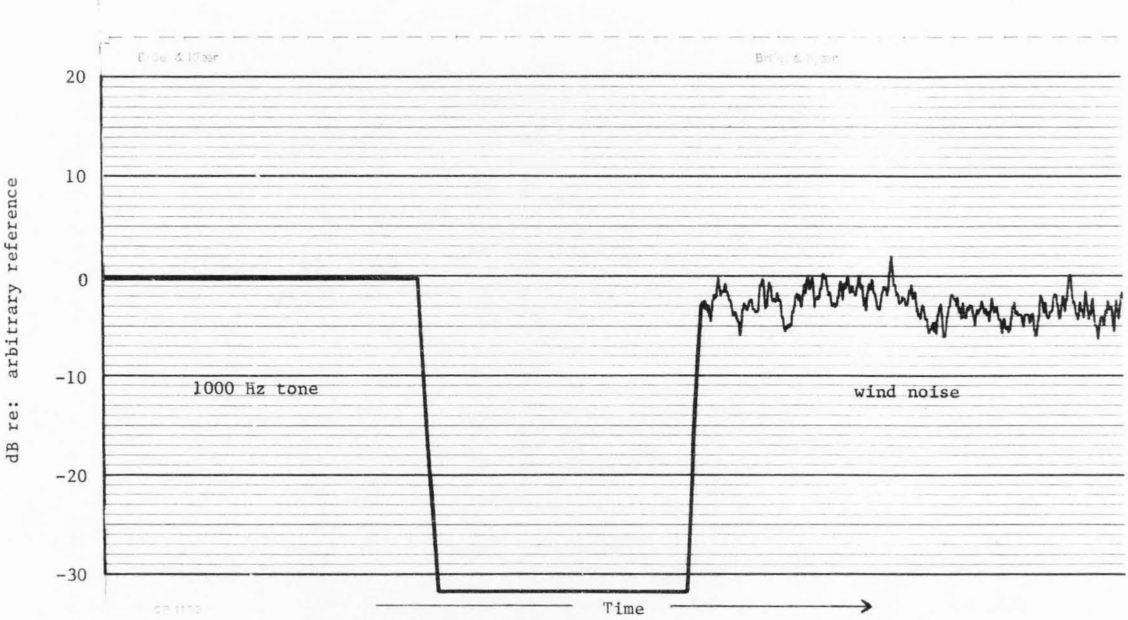

Figure 8. Graphic level recording of calibration tone and wind noise made directly from stimulus tape.

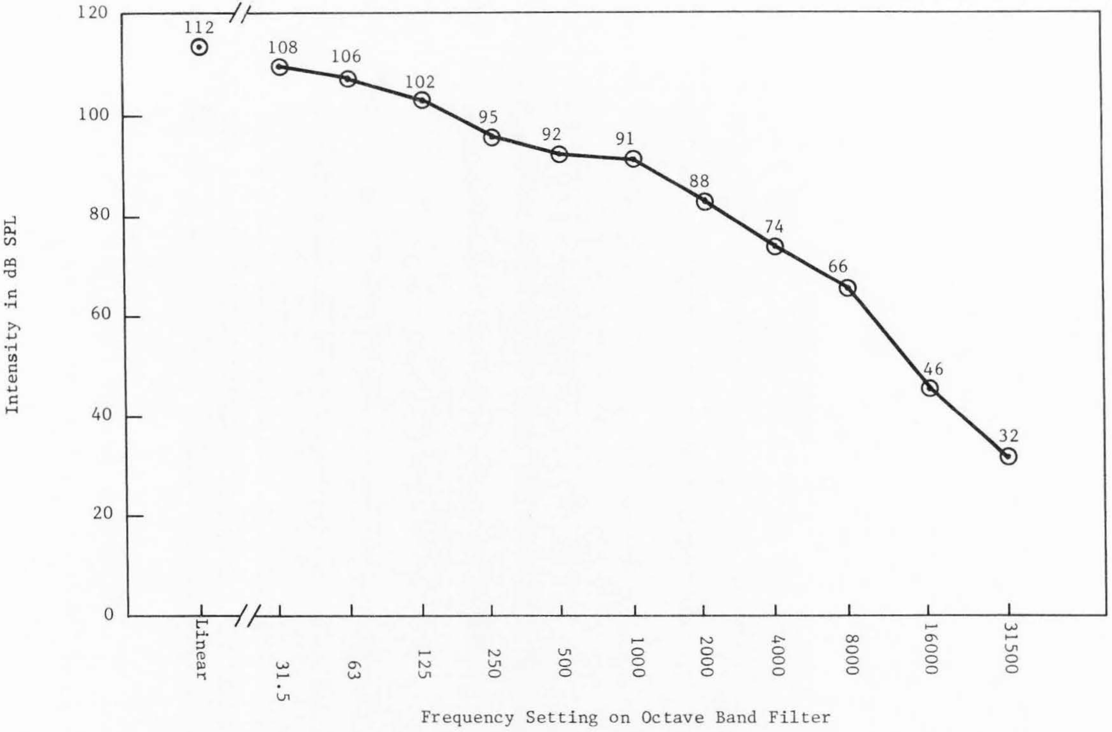

Figure 9. Linear reading and octave band analysis of wind noise as measured during recording session.

The third instrument employed in the analysis of the stimulus noise was the graphic level recorder. Specifically, the graphic level recorder was used to obtain information related to the homogeneity of the noise intensity. As can been seen from Figure 6, moment-to-moment fluctuations in the noise level vary by not more than about 10 dB.

The results of these analyses indicate that the wind turbulence generated noise in an automobile traveling at high speed with the window down is at about 112 dB SPL with the majority of the energy in the lower frequencies.

Test Procedures and Sequence

Prior to experimental testing, a brief oral interview was held with each subject. At this time, vital statistics were taken and a brief statement of the auditory history was obtained. Any candidate reporting prior auditory disease or disorder was not included in the study.

After the interview, pure tone audiometric thresholds at frequencies of 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz were obtained for each subject using the calibrated pure tone audiometer identified previously. The technique used in obtaining thresholds was to present the tone at an intensity well above the subjects threshold, then to reduce the intensity in 10 dB steps until the subject failed to respond. The intensity was then raised in two dB steps until a response was obtained. The intensity was then reduced 10 dB and increased in two dB steps until a response was obtained. In essence this is the technique outlined by Carhart and Jerger (1959). These two steps were alternated until the subjects threshold was established.

Some consideration was given to utilizing automatic audiometry in place of conventional techniques. However, conventional audiometry was concluded to be more efficient and was selected for use in the present study.

All preliminary testing and experimental stimulation was conducted in an acoustical test suite.

After pure tone thresholds were obtained, the tape recorded wind noise was presented by means of the tape recorder through a calibrated speech audiometer (Grason-Stadler, Model 162) terminated in earphones (Telephonics, Model TDH-39). This presentation was at an intensity equal to that of the actual wind noise during recording and was measured directly from the earphones with the sound level meter and the electronic filter set mentioned earlier. A standard 6 cc coupler was employed to couple the earphone to the microphone of the sound level meter. The results of this analysis are essentially the same as those found in Figure 9.

Exposure to the recorded wind noise was continuous for 15 minutes as mentioned previously, the noise was presented only to the left ear.

Immediately upon cessation of noise stimulation, pure tone thresholds were again obtained for frequencies of 4000, 6000, 8000, and 2000, 1000, 500, and 250 Hz respectively. This order was selected because greatest TTS commonly occures in the higher frequencies and because TTS is a fleeting phenomenon. It was felt that the maximum information could be obtained utilizing this sequence, since recovery begins immediately upon discontinuation of the stimulus sound and recovery is continuous from that point. Threshold shift is operationally defined for purposes of the present investigation as the difference between pre-test and post-test pure tone thresholds.

In addition to the initial threshold shift as measured immediately after exposure, measurements during recovery were obtained. Pure tone thresholds at the seven indicated frequencies were obtained immediately after exposure and at five minute intervals for 15 minutes after cessation of the noise stimulation. This procedure involved use of the same pure tone audiometer as mentioned previously.

Summary

The present investigation is concerned with the acoustic characteristics of the noise generated by wind turbulence in a car traveling at 70 mph. It is specifically concerned with how the human auditory mechanism responds to exposure to that noise.

Detailed in Chapter III are the criteria for selection of the 20 subjects used in the experiment. The chapter also contains all pertinent information regarding the preparation and calibration of the tape recorded wind noise used as stimulus material. Specifically, the stimulus material consisted of a continuous tape recording of wind noise in a car traveling at a speed of 70 mph. The equipment employed in the recording session was a high fidelity tape recorder and condenser microphone. A calibration tone was recorded at the beginning of the tape to aid in setting the intensity level appropriately prior to the exposure period of the experimental session.

Instrumental analyses were made of the wind noise and tape recorded wind noise in an effort to determine the acoustic characteristics of the noise. These analyses included overall sound pressure reading, octave band analysis, and graphic level recordings. From the results, it was observed that wind noise is high in intensity with a predominance of energy in the low frequencies but with acoustic energy in all audible frequencies.

The test procedures were also described and exposure time was specified.

The results obtained through application of the above methods and procedures with the described subjects is contained in the following chapter.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of the present study is to investigate noise generated by wind turbulence in a car traveling 70 mph and to determine the effect such noise has on the driver in terms of TTS.

The previous chapter details the methods, apparatus and procedures employed in preparing and analyzing a tape recording of such noise. The tape recording was used as stimulus material and was presented to the twenty subjects described in Chapter III. Details of the experimental environment, test sequence and instrumentation were presented in the previous chapter.

The acoustic characteristics of the wind noise in question were determined by instrumental analysis. The predominance of acoustic energy was found to be in the lower frequencies with a maximum around 31.5 Hz, but noise was present in all octave bands measured.

Chapter IV details the results obtained as a consequence of implementing the experimental procedures with the subjects mentioned earlier. A discussion of the results is also presented in an effort to answer the question that prompted the present study, i.e., "Does exposure to wind noise in a car result in a temporary threshold shift in hearing and of what magnitude?"

It will be remembered from Chapter II that the experimental null hypotheses to be tested are as follows:

1. H_0: There is no differential susceptibility to TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together.

2. H_0: There is no differential susceptibility to TTS resulting from exposure to wind noise in a car at any given test frequency based on sex.

3. H_0: There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together.

4. H_0: There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car at any given test frequency based on sex.

5. H_0: There is no difference from one test frequency to another in the amount of threshold shift resulting from exposure to wind noise in a car.

6. H_0: There is no significant recovery from TTS resulting from exposure to wind noise in a car during the first 15 minutes after exposure.

7. H_0: There is no significant difference in the rate of recovery from TTS resulting from exposure to wind noise in a car as a function of test frequency.

The section to follow will deal with the results of the current investigation in terms of these hypotheses.

As suggested in Chapter II, certain parameters of the stimulus material can affect TTS. These parameters include the spectral shape of the noise, duration of exposure, and intensity of presentation. Each of these parameters were carefully controlled during the present study.

Therefore, each subject was exposed to essentially the same stimulation in terms of acoustic spectrum, duration of exposure, and exposure intensity.

Results Related to Sex

In addition to the exposure parameters, other factors seem to have an effect on TTS. It has been suggested by Kylin (1960) that the sexes are differentially susceptible to noise exposure in that females experience less TTS than males when both are exposed to the same stimulus. Ward and his associates (1959), on the other hand, report no such difference. Statistical examination of the data obtained in the present study was undertaken to determine the significance of any observed differences. The problem of individual differences in susceptibility to noise exposure, as mentioned in Chapter II, is a fact that must be kept in mind when dealing with TTS and when drawing conclusions about possible relationships between the different factors that may influence TTS. The danger in setting a criterion for significance that is too lenient, is that one might accept as significant, a difference that is the result of individual susceptibility to noise exposure, rather than a difference that is the result of some factor that has direct influence on TTS. In statistics this is termed a Type II error (Fryer, 1966). The problem of individual differences in susceptibility to TTS prompted a decision to accept as significant, only those differences that reached the .01 level of confidence. The statistical technique employed in the present study was the analysis of variance. Table 2 contains the results of that analysis.

Table 2. Results of analysis of variance

Source of variation	Degrees of freedom	Mean square values	f score	Criterion for significance at .01 level (Snedecor, 1956)
Sex	1	.0875	.0012	8.28
Frequency	6	360.2071	6.5429	2.99
Sex X Freq.	6	158.4500	2.8781	2.99
Time	3	146.4827	43.5670	3.83
Sex X Time	3	1.3208	.3928	3.83
Freq. X Time	18	8.9730	2.6688	2.04
Sex X Freq. X Time	18	2.5778	.7669	2.04

With the data contained in Table 2 it is possible to give direct consideration to each of the experimental null hypotheses.

The first results to be discussed deal with differences related to sex. The first hypothesis related to sex states that, "There is no differential susceptibility to TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together." Examination of variability between the sexes from Table 2 reveals a mean square value of .0875 which results in an "f" score of .0012. A significant difference between the sexes would have been indicated at the 1% level of confidence only for an "f" score of 8.28 or greater. The null hypothesis, therefore, failed to be rejected and it was concluded that the two sexes were essentially identical in their susceptibility to TTS induced by exposure to the experimental stimulus when all test frequencies were considered together.

The second hypothesis related to sex states that, "There is no differential susceptibility to TTS resulting from exposure to wind noise in a car at any given test frequency based on sex.

Examination of variability between the sexes at each test frequency from Table 2 yields an "f" score 2.88. An "f" score equal to or greater than 2.99 was necessary for significance at the 1% level of confidence. Therefore, the null hypothesis, could not be rejected, and it was concluded that the amount of TTS sustained at each test frequency of 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz was essentially the same for both sexes.

The third hypothesis related to sex states that, "There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together." Examination of variability between the sexes in the amount of threshold shift at each post-exposure time when threshold shift was measured, as found in Table 2, results in an "f" score of .39. An "f" score required for significance at the .01 confidence level must equal or exceed 3.83. The null hypothesis, therefore, could not be rejected and it was concluded that males and females recover from TTS induced by exposure to wind noise in a car at essentially the same rate. In this instance, recovery was averaged for all test frequencies.

The last hypothesis related to sex states that, "There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car at any given test frequency based on sex." Analysis of the variability between the sexes at each post-exposure time for each test frequency presented in Table 2 resulted in an "f" score of .77. Significance at the 1% level required an "f" score of 2.04. Based on this result, the null hypothesis could not be rejected and it was concluded that the sexes experience approximately the same rate of recovery at each test frequency.

Results Related to Parameter of Stimulus Material

The remaining results from Table 2 deal directly with the relationship between the stimulus material and the induced threshold shift. It will be remembered from the literature review that Hirsh and Ward (1952) observed that the receptor cells mediating different frequencies respond differentially to over-stimulation. Analysis was undertaken, therefore, to determine significance of differences in responses to wind noise in a car by the receptor cells mediating different frequencies.

The first hypothesis to be tested states that, "There is no difference from one test frequency to another in the amount of threshold shift resulting from exposure to wind noise in a car." The "f" score for variability between frequencies found in Table 2 is 6.54, while significance at the .01 level of confidence requires an "f" score of 2.99. The null hypothesis was rejected in favor of the alternnate hypothesis which states that, "There is a difference from one test frequency to another in the amount of threshold shift resulting from exposure to wind noise in a car." It was concluded that a difference in TTS exists as a function of frequency; 8000 Hz being most effected with one subject experiencing a shift of 25 dB.

The next hypothesis states that, "There is no significant recovery from TTS resulting from exposure to wind noise in a car during the first 15 minutes after exposure." The average threshold shift for all test frequencies at each post- exposure time is found in Table 3.

Table 3. Mean threshold shift at each post-exposure time averaged for all test frequencies

Elapsed Time			
Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
2.13	0.88	0.28	-0.25

The information in Table 3 suggests that the most rapid recovery takes place during the first five minutes after exposure, with average recovery over all frequencies to within one dB of pre-exposure thresholds, while full recovery is rather slow after five minutes and may not be complete after 15 minutes. The "f" score dealing with significance of recovery is labled "time" in Table 2 and that score is 43.57. Significance at the .01 level is reached at 3.86. The null hypothesis was rejected on this basis and the alternative hypothesis of "a difference" was accepted. It was concluded that recovery from TTS induced by exposure to wind noise in a car is significant during the first 15 minutes after exposure with the predominance of recovery occurring during the first five minutes.

The last hypothesis to be tested states that, "There is no significant difference in the rate of recovery from TTS resulting from exposure to wind noise in a car as a function of test frequency." The average threshold shift at each post-exposure time for each test frequency is presented in Table 4.

Table 4. Mean threshold shifts[5] in dB at each of four post-exposure times for each of seven test frequencies

	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Test Frequency	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
250 Hz	-2.45	-3.70	-3.40	-4.25
500 Hz	1.00	0.15	-0.65	-1.05
1000 Hz	3.35	1.30	-0.05	-0.40
2000 Hz	4.50	1.75	0.65	0.05
4000 Hz	1.80	1.15	0.40	-0.40
6000 Hz	3.75	2.40	2.70	1.55
8000 Hz	2.95	3.10	2.30	2.75

As can be seen from Table 4, the amount and direction of threshold shift varies as a function of test frequency. Post-exposure thresholds were better than pre-exposure thresholds in the lower frequencies, while the mid and upper frequencies show some loss of sensitivity. Recovery seems to be rapid in the mid frequencies and slower in the upper frequencies, for instance at 500 Hz, recovery was generally complete within five minutes, while recovery was not generally complete after 15 minutes at 8000 Hz.

The "f" score from Table 2 related to recovery at each test frequency is 2.67. Significance of differences at the .01 level is attained for any score of 2.04 or greater. The differences in recovery rate of different test frequencies were, therefore, considered to be significant and, on this basis, the null hypothesis was rejected. It was

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[5] Minus numbers indicate post-exposure auditory thresholds were more sensitive than pre-exposure thresholds (hypersensitivity).

concluded that the rates of recovery from TTS induced by exposure to wind noise in a car differ significantly as a function of test frequency. Recovery appeared to be most rapid at 500 Hz as mentioned earlier.

The magnitude of individual differences relative to TTS induced by exposure to wind noise in a car can be observed in the tabulation of raw data found in the Appendix. Greatest variability appeared to be at 8000 Hz where threshold shift ranged from 0 - 25 dB.

Discussion

The factors having major influence on TTS are acoustic spectrum, duration of exposure, and intensity of presentation. As suggested in Chapter II, individual differences appear to be a prime variable relative to the amount of TTS observable in any given study. Though no significant differences exist between the sexes, wide variability is observed from one subject to another, as can be seen in the individual threshold shifts presented in the raw data in the Appendix. This individual variability can be observed within or between test frequencies, by time, and at any post-exposure time within any frequency. The actual amount of TTS is noticeably small, and would seem to negate the importance of wind noise as a significant source of fatiguing sound in our environment. The greatest shift in any subject was 25 dB at 8000 Hz. However, it is true that the duration of exposure was rather brief and that longer exposure would likely have resulted in increased threshold shift. This was, in fact, the case in at least one instance observed during preliminary work on procedures for the main study. One subject in the pilot investigation sustained a 24 dB threshold shift at 6000 Hz as measured immediately after a 30 minute exposure. Recovery was rather slow and was not complete even after 20 minutes had elapsed. During the pilot work, a number of subjects were exposed to the stimulus material for 30 minutes. Over half the subjects slipped the left earphone away from the ear when they thought they were unobserved. As will be remembered, only the left ear was stimulated. During the pilot study, each subject was interviewed and observed after the test sequence. All subjects were visibly agitated, and some appeared angry. Most subjects stated that the noise was too loud and the exposure was too long (30 minutes). Most subjects said they would "never do that again for anyone." It was primarily on the basis of these responses that exposure was limited to 15 minutes. The possibility does arise that extended travel by car with the windows down may contribute to short tempers and argumentative social postures by the driver and passengers.

The differential susceptibility as a function of frequency is significant. The mean threshold shift immediately after exposure is greatest at 2000 Hz with a value of 4.5 dB. It appears that the receptor cells mediating 2000 Hz are most affected by the stimulus noise immediately after exposure, though recovery is slower at 6000 and 8000 Hz. The effect is opposite to the effect on the receptor cells mediating 250 Hz. The results at 250 Hz suggest a hypersensitivity following exposure. The mean threshold shift measured at this frequency immediately after exposure was -2.45 dB. Hypersensitivity has been observed in conjunction with noise exposure as explained in Chapter II. However, hypersensitivity is usually limited to the first two minutes after exposure. The current results indicate hypersensitivity persisting far beyond that extent. A full investigation into this phenomenon is beyond the scope of this research. However, two possibilities are suggested. One postulation is that the apparent hypersensitivity is an artifact resulting from a learning process wherein the subjects improve in their ability to detect faint sound as a consequence of experience in listening. Another possibility is that there may have been a temporary physiological change due to stimulation. Perhaps circulation to the cochlea was increased. No definite answer is currently available and further investigation is indicated. Some attempt was made to determine if a learning process was in operation. The results were inconclusive at the time of this writing.

Recovery rate was significantly different for different frequencies. Thresholds at frequencies of 6000 and 8000 Hz still had not evidenced full recovery 15 minutes after exposure, while the mean threshold shift values for the two lower frequencies indicate full recovery or hypersensitivity at five minutes after cessation of exposure. These results also suggest differential susceptibility of receptor cells mediating different frequencies.

Exposure to high intensity wind noise in a car can be avoided by keeping all windows closed while traveling at high speeds. During warm weather this may necessitate the use of air conditioning in the car.

Summary

The current study is concerned with the acoustic characteristics of the noise generated by wind turbulence in a car traveling at 70 mph. It is specifically concerned with how the human auditory mechanism responds to exposure to such noise. Chapter III describes the methods and procedure employed in obtaining information on this subject. The present chapter deals with the results obtained during the present investigation. The hypotheses to be tested and the conclusions reached were as follows:

1. H_0: There is no differential susceptibility to TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together. This hypothesis failed to be rejected.

2. H_0: There is no differential susceptibility to TTS resulting from exposure to wind noise in a car at any given test frequency based on sex. This hypothesis failed to be rejected.

3. H_0: There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car based on sex when all test frequencies are considered together. This hypothesis failed to be rejected.

4. H_0: There is no difference in the rate of recovery from TTS resulting from exposure to wind noise in a car at any given test frequency based on sex. This hypothesis failed to be rejected.

5. H_0: There is no difference from one test frequency to another in the amount of threshold shift resulting from exposure to wind noise in a car. This hypothesis was rejected in favor of the alternate hypothesis.

6. H_0: There is no significant recovery from TTS resulting from exposure to wind noise in a car during the first 15 minutes after exposure. This hypothesis was rejected in favor of the alternate hypothesis.

7. H_0: There is no significant difference in the rate of recovery from TTS resulting from exposure to wind noise in a car as a function of test frequency. This hypothesis was rejected in favor of the alternate hypothesis.

The decisions for acceptance or rejection were made on the basis of a .01 confidence criterion. The statistical tool employed was the analysis of variance.

A discussion of the results is also contained in the chapter. It was observed that the amount of TTS was small in most instances, but this was attributed to the brevity of exposure. Hypersensitivity in the lower frequencies was observed after exposure to wind noise. The cause of this hypersensitivity is unknown. The differences in recovery rate were also discussed. Recovery appeared to be most rapid at 500 Hz and slowest at 8000 Hz.

CHAPTER V

SUMMARY

It has been observed that exposure of the human auditory mechanism to high intensity sound can damage hearing. Far too little is known about the effects of common everyday activities on audition. It is the intent of the present study to increase that knowledge by answering questions related to whether or not wind turbulence noise generated in a car traveling at 70 mph with the driver's window down causes a temporary hearing loss to the driver.

Preliminary work involved sound pressure measurement of the wind noise in a number of cars ranging from imported compact cars to large domestic cars. The noise at 70 mph in all cars with the driver's window down exceeded 109 dB SPL. The experimental car was selected because of its availability and because it was about average in wind noise intensity for the cars tested.

A carefully prepared magnetic tape recording was then made of the wind noise. Concurrent with the recording, a sound level reading and an octave band analysis was made of the wind noise generated in the experimental car traveling at 70 mph with the driver's window down. Analysis of the noise revealed it to be predominantly low frequency in nature with an overall intensity averaging about 112 dB SPL.

Twenty normal hearing young adults were then selected as subjects for the experiment. After a brief interview, pure tone audiometric thresholds were obtained for each subject at seven discrete frequencies.

Following initial pure tone threshold testing, each subject was exposed to 15 minutes of tape recorded wind noise in the left ear. Following the exposure, pure tone threshold were again measured immediately after exposure, and at five, ten, and fifteen minutes after exposure. Threshold shift was defined as the difference between pre-test and post-test pure tone thresholds.

The results obtained as a consequence of implementing the experimental procedures with the test subjects were discussed relative to the experimental hypotheses. It was found that there was no significant difference in the results of the experiment that could be attributed to sex. There was however, a significant difference in the amount of TTS relative to pure tone test frequency. The higher frequencies evidenced the greatest threshold shift, while a possibility of hypersensitivity was observed in the low frequencies. No definite explanation for the hypersensitivity is currently available. Significant recovery was observed during the first 15 minutes after exposure with greatest recovery occurring during the first five minutes. Recovery at the different test frequencies varied significantly.

In conclusion, it should be stated that the basic methods and procedures utilized in the present study are satisfactory for noise studies, with a few minor alterations. Unilateral stimulation of the subject seemed to be distracting and annoying to most subjects. It is recommended, therefore, that in future studies, stimulation be presented to both ears.

In future studies, the use of automatic audiometry should be given consideration as a tool for assessing thresholds, especially if TTS at one or two test frequencies is the main concern.

Prospective future research might concern itself with the hypersensitivity observed in the lower frequencies during the present study.

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APPENDIX

Table 5. Raw data collected during experimental test session

Test frequency - 250 Hz				
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	0	-3	-1	-5
02	0	-5	-3	-3
03	0	0	0	0
04	-2	-2	-2	-2
05	-2	-5	-5	-5
06	0	-4	-2	-2
07	-2	0	-2	0
08	0	0	0	0
09	-5	-5	-7	-7
10	-2	-2	-2	-2
Male				
01	-5	-3	-5	-5
02	5	3	3	-2
03	-2	-2	-4	-4
04	-5	-8	-5	-8
05	-5	-4	3	-7
06	-3	-3	-6	-6
07	-10	-10	-10	-10
08	-6	-8	-8	-8
09	-3	-8	-5	-5
10	-2	-5	-7	-4

Table 5. Continued

Test Frequency - 500 Hz				
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	0	5	2	4
02	6	1	1	0
03	0	0	0	0
04	0	0	0	0
05	5	2	-1	-3
06	-2	0	-2	-2
07	3	2	2	0
08	0	0	0	0
09	0	0	0	0
10	2	2	-1	-3
Male				
01	-3	-3	-3	-3
02	3	1	0	0
03	1	-2	-2	-2
04	-3	-5	-5	-5
05	7	0	3	0
06	0	0	0	0
07	0	0	0	0
08	-2	0	-2	0
09	0	-2	-5	-7
10	3	2	0	0

Table 5. Continued

	Test Frequency - 1000 Hz			
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	0	-2	-2	-2
02	12	10	5	5
03	10	3	3	0
04	5	0	0	0
05	0	-2	-4	-5
06	2	2	-1	-1
07	3	2	0	0
08	5	0	0	0
09	1	0	-2	-4
10	0	0	0	0
Male				
01	-2	-2	-2	-2
02	5	5	4	0
03	5	2	0	0
04	0	0	0	0
05	8	2	3	2
06	11	7	3	0
07	5	2	-5	2
08	-3	0	-3	-3
09	0	0	0	0
10	0	-3	0	0

Table 5. Continued

Test Frequency - 2000 Hz				
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	5	2	0	0
02	13	5	0	0
03	10	3	2	0
04	5	2	0	0
05	0	0	0	0
06	-1	-1	-3	-1
07	13	8	7	0
08	0	0	0	0
09	2	0	0	0
10	2	0	0	0
Male				
01	7	3	3	2
02	2	2	3	2
03	0	0	0	0
04	0	0	0	0
05	7	3	2	2
06	11	5	2	0
07	4	1	0	-1
08	4	2	-1	-1
09	6	0	-2	-2
10	0	0	0	0

Table 5. Continued

	Test Frequency - 4000 Hz			
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	0	-2	-2	-2
02	7	7	5	2
03	0	0	0	0
04	-3	-3	-3	-3
05	0	0	0	0
06	8	5	2	3
07	3	1	0	-2
08	0	0	0	0
09	5	5	3	-2
10	0	0	0	0
Male				
01	0	2	5	0
02	8	7	7	5
03	0	0	0	0
04	-7	-7	-8	-7
05	-2	-2	-2	0
06	5	3	3	-2
07	0	0	-5	-5
08	0	0	0	0
09	5	5	3	3
10	7	2	0	2

Table 5. Continued

	Test Frequency - 6000 Hz			
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	0	5	5	1
02	2	0	0	0
03	0	0	0	0
04	-5	-5	-2	-7
05	0	0	0	0
06	-3	-8	0	0
07	11	6	5	5
08	0	-6	-8	-8
09	0	0	0	0
10	-1	-1	-1	-1
Male				
01	3	3	3	3
02	7	4	5	2
03	8	8	8	3
04	17	15	15	15
05	-5	-5	-5	-3
06	5	-2	-2	-7
07	7	8	8	8
08	19	19	15	12
09	5	0	0	0
10	5	7	8	8

Table 5. Continued

	Test Frequency - 8000 Hz			
	Elapsed Time			
	Immediate	+5 Minutes	+10 Minutes	+15 Minutes
Subjects	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB	Threshold shift in dB
Female				
01	0	1	0	0
02	15	17	10	12
03	0	0	0	0
04	23	25	15	20
05	5	0	2	0
06	0	0	0	0
07	3	2	2	2
08	-2	-2	-2	-2
09	0	0	0	0
10	2	0	0	0
Male				
01	2	2	2	2
02	5	10	8	8
03	0	0	0	0
04	-2	-2	-5	-2
05	-8	-8	-8	-8
06	4	0	0	0
07	2	7	7	10
08	5	7	7	7
09	5	3	5	3
10	0	0	3	3

VITA

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