INDUSTRIAL DEAFNESS

·SATALOFF·

INDUSTRIAL DEAFNESS

Hearing Testing and Noise Measurement

Joseph Sataloff, M.D., D.Sc. (Med.)

Assistant Professor of Otology, The Jefferson Medical College of Philadelphia; Visiting Professor of Audiology and Codirector of Industrial Deafness Course, Colby College; Consultant in Audiology, Veterans Administration; Audiologist to the Children's Hospital of Philadelphia; Editorial Board, AMA Archives of Otolaryngology

The Blakiston Division
McGraw-Hill Book Company, Inc.
New York Toronto London 1957

INDUSTRIAL DEAFNESS

Library of Congress Catalog Card Number: 56-10330

Contributors

CHARLES R. WILLIAMS, Ph.D.

Director, Industrial Hygiene Services, Loss Prevention Department, Liberty Mutual Insurance Company; Associate Professor of Applied Industrial Hygiene, Harvard University School of Public Health; member, American Standards Association Z24-X2 Committee and Committee on Noise, Associated Industries of New York

ROBERT ROOP, Ph.D.

Group engineer, Philco Corporation; chairman, American Standards Association Subcommittee Z24-X24 on Acoustic Testing; formerly senior physicist, Johns-Manville; formerly staff member, Acoustics Laboratory, Massachusetts Institute of Technology

ROBERT GOLDMAN, Ph.D.

Lecturer in Physics, Temple University; project engineer, Research Division, Philco Corporation; member, American Standards Association Subcommittee Z24-X23 on Fan Noise; author of papers on noise and acoustics

JOHN A. ZAPP, JR., Ph.D.

Director, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. du Pont de Nemours & Co., Inc.; consultant, Army Chemical Corps; member of several committees, National Research Council; author of chapter on Industrial Noise in *Modern Occupational Medicine,* by Fleming, D'Alonzo, and Zapp

Preface

The increase in industrial noise and a greater appreciation of deafness in general during recent years have focused attention upon industrial deafness, which is the loss in hearing that results from exposure to intense noise.

Emphasis on the medicolegal aspect of this condition has furthermore introduced a number of challenging problems that noisy industries must meet and resolve. Such industries need to consider:

1. How to achieve a better understanding of and a clearer perspective on all aspects of industrial deafness as it affects employees and management.
2. How to determine whether a noise problem exists, and if so, what steps are necessary to establish a practical and effective conservation-of-hearing program.
3. How to train industrial personnel to perform reliable and valid hearing tests.

Considerable material has been published in the medical and acoustical literature in reference to these problems, but there has been no one volume that could be said to cover all phases of industrial deafness or to serve as a guide in solving the many problems now facing industry.

This book attempts to fill these needs and concerns itself with all aspects of noise measurement and audiometric testing. It is intentionally fundamental and is directed not to the acoustical expert but to industrial executives, industrial physicians, hearing testers, otologists, nurses, industrial hygienists, and engineers. It is hoped that this book will make it possible for individuals with no previous experience in hearing testing or acoustics to acquire sufficient basic information and technique to perform measurements. Comparatively few bibliographic references are included because of the nature of the text, and the author and contributors have forsworn footnotes. At the end of the book, however, is included a bibliography of recommended articles published in the medical and acoustical literature.

Part I is intended to provide an over-all perspective of the various problems relating to noise and deafness. It covers the elementary physics of sound, how we hear, the causes of deafness, the medicolegal aspects of occupational deafness, and the basic problems involved in developing a conservation-of-hearing program. Certain complicated concepts, particularly in the chapter on The Physics of Sound, have been simplified. Efforts have been made to avoid equations and complex explanations as well as equivocal opinions throughout the book.

Part II is somewhat more technical and is intended for safety engineers, hygienists, and technicians concerned with noise measurements. It describes how to make noise measurements and how to use the necessary equipment. It also discusses damage-risk criteria relating noise and deafness, the principles of noise control, and the factors to be considered in making a room suitable for audiometric testing.

Part III is devoted to all aspects of hearing testing and is intended to serve as a guide and reference manual for industrial hearing testers. The directions for performing reliable and valid hearing tests are presented in a simple, step-by-step, practical manner so that they can be used for training personnel. The need for critical appraisal of testing techniques and extensive training under supervision is emphasized. This section also describes methods of record-keeping and the details to be considered in organizing a conservation-of-hearing program; it also discusses auditory fatigue, malingering, and presbycusis. The roles of the industrial physician and otologist are presented in detail, and the principles of audiogram interpretation are demonstrated.

In order to make the book as comprehensive as possible, the author has invited several specialists to provide certain chapters so that the reader may have the benefit of the most authoritative information available. For these contributions the author wishes to express his appreciation to Charles Williams, Robert Roop, Robert Goldman, and John Zapp. To William Heimback and William Gross of the Westinghouse Corporation for their suggestions on industrial relations and the responsibilities of the engineer, and to Dr. H. Menduke for his criticism of the material on presbycusis, the author extends his appreciation.

The author also expresses gratitude to a number of colleagues and friends whose sustained interest, criticisms, suggestions, and encouragement have made this book possible: particularly to Drs. Frederick T. Hill, George M. Coates, and Frederick T. Harbert, and to those who comprise the faculty for the special course in Industrial Audiology given at Colby College, where Dr. Hill is director of the course. The different perspectives, ideas, and methods in this book have been influenced to some degree by these men at Colby, among whom are Drs. Walter Rosenblith, Hallowell Davis, Aram Glorig, Wayne Rudmose, Charles Williams, Kenneth Stevens, John Zapp, Jerome Cox, Ira Hirsh, and Stewart Nash.

For the opportunity to conduct a conservation-of-hearing program in a large industry for the past seven years, and by so doing to obtain additional field experience, the author thanks Dr. C. D. Stull, industrial physician.

The author also wishes to express his sincerest appreciation to Dale Phalen for his invaluable editorial assistance; and for continued patience in deciphering his handwriting during countless hours of typing and retyping, he is most grateful to his secretary, Nisa Delli-Pizzi.

Joseph Sataloff

Contents

PART ONE *General Considerations*

PART TWO *Noise Measurement*

PART THREE *Hearing Testing*

PART ONE

General Considerations

CHAPTER 1 *The Physics of Sound*

In order for one to have a clear perspective of the problems related to industrial deafness, an understanding is necessary of the physical principles upon which noise measurement and hearing testing are based. The explanation of physical fundamentals that follows is especially designed for those persons in industry without thorough technical training who may be concerned with various aspects of industrial deafness and particularly with noise measurement and hearing testing. An attempt is made to provide information that will make it possible for them to understand and perform more competently audiometric testing and measurement of noise.

Sound Waves

First, we must understand what sound actually is and how it behaves. Sound is produced by the vibrations of very minute particles in the air around us, a vibration being any motion that repeats itself in regular time intervals. When we observe the regular swing of the pendulum of a clock, we see the pendulum's vibration and can measure its amplitude (the distance covered) and its period (the time it takes to make one complete vibration). It is impossible for us to see, however, the constant vibrations of the very minute particles known as *molecules* that are in the air. Sound waves consist of areas of compression and rarefaction of these vibrating particles in the air.

The constant back-and-forth movement of the molecules themselves is confined to a very small range. But when this ordinary movement is disrupted by a change in the atmospheric pressure due to a vibrating body, the molecules are pushed by the pressure into patterns of compression and rarefaction that can travel great distances before they lose their energy and become dissipated. Sound waves travel in a manner somewhat similar to the wave of pressure that can be seen traveling along the surface of a field of wheat or tall grass on a windy day. As the wind crosses the field, the stalks themselves move back and forth only a short distance, but their movement causes a pattern of compression and rarefaction, dependent upon the force of the wind to produce a pressure wave on the surface, that travels the entire width or length of the field.

This analogy should not be taken too literally, however. Sound waves should not be thought of as rising and dipping like ocean waves. Rather they travel outward in almost straight lines from the surface of a vibrating body. Their mode of travel is more analogous to what occurs on a billiard table when several billiard balls are lined up next to each other and the ball on one end is hit. The force from the first ball is carried along from one billiard ball to the next until the last one rolls away from the line. The wave has traveled from one ball to another along the surface of the table in a horizontal plane, and not by rising and falling like an ocean wave.

Any moving body can produce sound waves, and we are constantly surrounded by sound in everyday life. These moving bodies cause the areas of compression and rarefaction of the particles in the air. Actually these areas are alterations in normal atmospheric pressures, the compression causing an increase and the rarefaction a decrease in the pressure. A tuning fork is an excellent example of the means by which sound waves are produced by the rapid alteration of pressure in the air. The diagram in Fig. 1 1 is a graphic description of the production of sound waves. When the prongs of the tuning fork are set in vibration, they move back and forth. As they move outward, they strike the air molecules next to the prong and set them into vibration. The first row of air molecules then hits the next row, and so on and on. When the prongs of the fork reach their farthest point of outward movement, they start to come back to their original position. When they do so, they leave behind them areas of rarefaction rather than compression of air molecules. The molecules also follow the back-and-forth movement of the prongs. Because of the elasticity of the fork and the momentum that the prongs and molecules have gathered, they cannot stop at their precise starting point, but override this point so that they actually move on both sides of the original starting point. The prongs and air molecules move back and forth only a small distance, but the areas of compression and rarefaction continue to move onward and outward and to form sound waves. Air-borne sound is, therefore, a rapid alteration in normal atmospheric pressure.

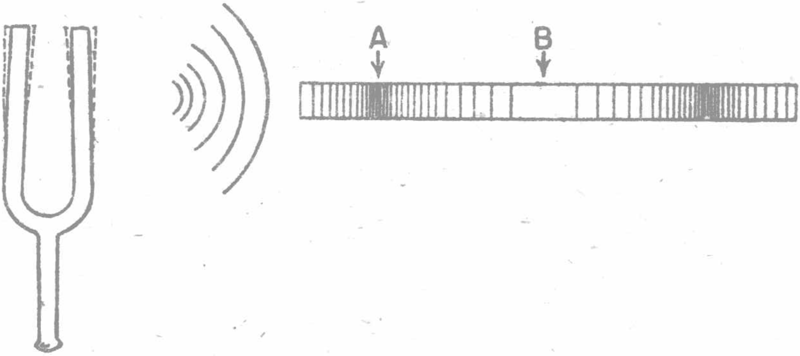

FIG. 1-1. Diagrammatic description of sound waves produced by a vibrating tuning fork. Compression is occurring at *A* and rarefaction at *B*.

Frequency Characteristics of the Human Ear

The human ear does not hear all these alterations in air pressure. It hears only those that vibrate within a certain frequency range and are strong enough to excite the ear. For example, the alterations must occur at least about sixteen times per second or they will not reach the lower sensitivity level of the ear. This is the reason, for instance, that no sensation of sound is produced (even though sound waves are present) when a siren is turned slowly. When the siren is moved rapidly, however, the sound waves reach a frequency that can be heard, and the pitch sounds higher the more rapidly the siren is turned.

At the other extreme, the alterations in pressure cannot be heard if they occur more than about 16,000 or 20,000 times per second, since they will then exceed the highest frequency to which the ear is sensitive. Above this frequency range, sound waves are said to be *ultrasonic* and are not audible even to the young ear with acute hearing.

Sometimes if the vibrations occur less than sixteen times per second and are rather intense, the ear seems to feel them rather than actually to hear them. The sensations of feeling and hearing seem to merge at these low frequencies. Anyone who has heard and felt the powerful vibrations of an organ, or even a bass drum, is well aware of this phenomenon.

Furthermore, the magnitude of the pressure alterations must be great enough to excite the ear. The human ear is so sensitive to small rapid changes in atmospheric pressure that it can almost—but not quite—detect the constant movement of molecules in the air around it. If the ear were more sensitive, we should constantly be hearing the noise of molecular motion.

Characteristics of Sound Waves

The medium through which the sound waves travel is also important. For example, sound travels at one speed in air but more rapidly in water. Furthermore, if the medium is not uniform the sound waves will travel at different speeds. Solids also transmit sound, as is demonstrated by placing an ear to the iron rail of a train track. The vibrations of an oncoming train will be heard on the rail long before its approach can be heard through air-borne sound. Sound waves will not be transmitted through a vacuum, as can be demonstrated by the classical experiment of placing a ringing alarm clock inside a jar and exhausting the air through an outlet. The ringing will not be heard when the air is exhausted, but will be immediately heard when the air is replaced. This emphasizes the importance of the medium through which the sound waves travel.

The bones of the head also conduct sounds, but ordinarily the ear is much more sensitive to sounds that are air-borne. Under certain abnormal conditions, such as conductive deafness, a patient may hear better by bone conduction than by air conduction. Such an individual can hear the vibrations of a tuning fork much better when it is held directly touching the skull than when it is held next to the ear but without touching the head.

Sound waves travel at the rate of about 1,100 fps (feet per second) in uniform air. They go in straight lines in all directions from the source, decreasing in intensity inversely to the square of the distance from their source. This means that if the distance from the source of a sound is decreased from 4 ft to 2 ft, the sound will be four times as loud, not twice as loud. A practical application of the inverse square law is that it applies only where there are no walls or ceiling present. It does not apply in a room where sound waves encounter obstruction or reflection; and this is one of the reasons why ordinary voice tests commonly performed by increasing the distance from the subject are rarely accurate or reliable.

When sound travels through air and encounters an obstruction such as a wall, the sound waves can bend around the obstacle, almost as water passes around a rock in a stream. Wind can distort sound waves in many ways, as is commonly demonstrated by the variability that occurs when one tries to hear sounds that are coming with the wind or against the wind, and also whether the wind is blowing faster, near the ground, or higher above it.

A simple type of sound wave is called a *pure tone* and is pictured in Fig. 1-2. This is actually a graphic description of one complete vibration, with the area of compression represented by the top curve, and the area of rarefaction by the bottom curve. A pure tone has two important characteristics: (1) *frequency*, which is the number of times per second that a complete vibration occurs, and (2) *intensity*, which is a measure of the maximum distance an air particle will move from its normal position during its vibration. When we represent a pure tone graphically, its intensity is indicated by the height of the wave from the base line.

A tuning fork of a specified frequency, for instance, is so constructed that it vibrates the required number of times per second to produce the tone of that frequency. Regardless of how hard or how gently the tuning fork is struck, its prongs will always vibrate back and forth the same number of times each second. If it is struck hard, it will not vibrate faster but it will vibrate more intensely: that is, its prongs will cover a greater distance or amplitude from their starting place, and thus increase the intensity.

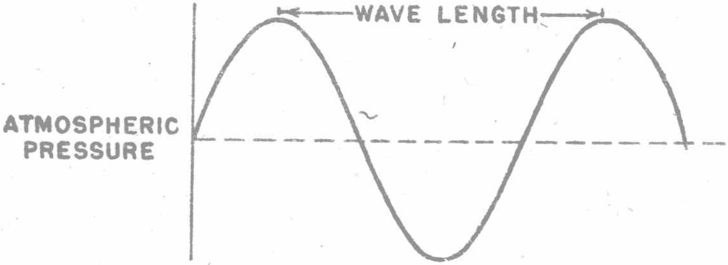

FIG. 1-2. Diagram of a pure tone (sine wave).

The *pitch* that the ear hears from a vibrating tuning fork is intimately related to its frequency. The *loudness* of the tone is similarly intimately related to its intensity or amplitude. In general, the greater the frequency, the higher the pitch, and the greater the intensity, the louder the sound. We say these terms are intimately related rather than exactly alike, because the relationship is somewhat more complicated than the reader may be led to believe; a fuller explanation, however, would serve no purpose here.