

TINNITUS

ADVANCES IN PREVENTION, ASSESSMENT,
AND MANAGEMENT

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FOREWORD

My journey into the world of tinnitus started about 40 years ago. I was a freshman in the field of audiology at that time and I had developed an interest in tinnitus. It had been almost one decade since Jack Vernon, PhD, cofounded the American Tinnitus Association in the early 1970s, and fresh ideas on tinnitus management kept being introduced by scientists and clinicians. I always wondered how tinnitus could be so irritating to people who suffer from it until I developed it myself in 2005. Ironically, at the time when my tinnitus started, I was attending and presenting my research at the International Tinnitus Seminar in Pau, France. I was hearing the sound of a *jet engine* wanting to take off in my left ear! Now that I had tinnitus, I could perceive and feel the level of annoyance my patients were experiencing and dealing with this darn sound in their ears or head day and night. For years, I had been treating tinnitus patients, but suffering from it was another story. I thought to myself, if I can help my own patients with tinnitus then I can help myself too. Conveniently, I was able to habituate to my tinnitus in less than a year. Since then, my daily fascination with tinnitus has continued to grow and I have become further motivated to help those who suffer from it.

The current book titled *Tinnitus: Advances in Prevention, Assessment, and Management*, written and edited by Dr. Aniruddha K. Deshpande and Dr. James W. Hall III, is an excellent resource to understand, evaluate, and manage tinnitus. This book is compa-

rable to a bridge that connects two generations of tinnitus scientists. On one side, we have an author and a scientist of the caliber of Professor Hall, who is one of the pioneers in the field of audiology and tinnitus with many years of experience and knowledge. On the other side, we have Professor Deshpande, a young tinnitus expert and a devoted scientist who applies modern concepts and technologies for tinnitus management. The editors of this book have gathered an excellent team of tinnitus experts and scholars from around the globe and have placed their expertise into a marvelous collection of contemporary approaches to the management of tinnitus that is suitable for a wide spectrum of tinnitus enthusiasts and clinicians. Scientists and experts such as Aazh, Baguley, Beukes, DiSogra, Djalilian, Eggermont, Henry, Lobarinas, Manchaiah, Pryce, Searchfield, Spankovich, and Tyler are a few of the numerous experts who have contributed to this tinnitus masterpiece.

The book starts with a chapter on tinnitus due to noise exposure. This is an excellent opening for a book on tinnitus, as noise exposure is the most common reason for the generation of bothersome tinnitus. Professor Lobarinas and his colleagues authored this chapter, where they also introduce a series of theories for tinnitus generation such as the theory of aberrant cortical oscillation and thalamocortical dysrhythmia. The book continues with genetic aspects of tinnitus. Out of more than 20,000 genes that humans share, there must be some genetic contribution to tinnitus too. The chapter

on the genetics of tinnitus emphasizes an audiogenomics approach to define and identify genotype-phenotype relationships in tinnitus populations. Additionally, the epidemiology of tinnitus is explored and described by Professor Spankovich and colleagues, who discuss the data driven from the National Health and Nutrition Examination Survey (NHANES) data sets and review the prevalence and epidemiology of tinnitus within an array of ethnicities and geographical areas.

The world of medicine and related fields changed drastically when COVID-19 hit the world in late 2019. Accordingly, the role of social media and telehealth in tinnitus has also been addressed in this book. These advanced and technology-based interactive methods have been able to provide social, emotional, and experiential support to tinnitus patients. The use of technology and tinnitus apps with therapeutic sound stimuli, application of sound maps, counseling, mindfulness, and relaxation techniques in the management of tinnitus takes the readers to the future, where bioinformatics, biotechnology, and robotics will play an important role in the management of tinnitus and other health-related conditions. At least four chapters of this book address the use of app-based tinnitus assessment tools, concepts of soundscapes, telehealth, teleaudiology, internet-based management, and employment of apps in tinnitus rehabilitation. Home-based and self-directed strategies are just some ways to utilize technology for tinnitus, addressed in this book. The patient history chapter emphasizes that no two patients experience their tinnitus in the same way. It has been known that tinnitus is a remarkably diverse condition, and many underlying etiologies can result in the perception and generation of tinnitus. The interaction between the clinician and the patient is extremely important and the

rapport between them is critical in better assessment and management of this hard-to-treat yet manageable condition.

An interesting chapter on dietary supplements for tinnitus is presented by Dr. DiSogra and colleagues, and is followed by a chapter written by Professor Baguley and Gemma Crundwell, who describe complementary and alternative medicine for tinnitus and review relaxation strategies such as tai chi and qigong. The use of electrophysiological methods and identification of tinnitus *biomarkers* are some of the most fascinating dimensions in the science behind tinnitus. If we all believe that tinnitus is a brain phenomenon, then we can expect to find the neuroelectrical and neurochemical reasons responsible for its generation. Professor Eggermont describes potential biomarkers for tinnitus identification and understanding, with the use of electrophysiologic and neuroimaging techniques. Although we are still far away from such identifying abilities, brain neural network research on tinnitus is very promising. Just imagine that one day we may find a method that can identify where in the brain tinnitus is generated and universally employ that technique to assess and manage tinnitus.

Researchers Dr. Beukes and Professor Manchaiah discuss the concept of audiologist-delivered cognitive behavioral therapy (CBT) for tinnitus and the importance of this tinnitus management strategy as a part of routine audiological care for tinnitus patients. As most of us are aware, CBT is one of the most studied approaches in tinnitus management and utilizing this approach is considered one of the highly accepted evidence-based practices in the field of tinnitus management and its rehabilitation. The use of magnetic, electrical, and electromagnetic stimulations on tinnitus management are also introduced and discussed in this book. Application of electrical currents

in the management of tinnitus is not new. From the early days of the invention of electric pills, many scientists have attempted to use electrical stimuli for the suppression of tinnitus. Bimodal auditory and electrical/magnetic stimulations and neuromodulation procedures are well described in this book and sound very promising.

In addition to tinnitus, this book also addresses hyperacusis, which is a commonly associated condition. A chapter dedicated to hyperacusis written by Dr. Aazh highlights the underlying reasons for hyperacusis generation and emphasizes the impact of parental mental health on the handicap perceived by individuals affected by hyperacusis.

Finally, the book closes with a series of case studies. A variety of unusual and hard-to-manage tinnitus cases such as pulsatile tinnitus are discussed and presented by seasoned audiologists and otologists.

In 1986, Jack Vernon sent me a letter that I have kept for more than three decades. He wrote a sentence in that letter that was my driving force over the years. He said, “Keep up the good work!” This sentence had the most impact on my academic and professional life and I’d like to finish this foreword with the same sentence to the editors of this tinnitus masterpiece, their excellent chapter contributors, and particularly to the future tinnitus scientists: Keep up the good work!

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PREFACE

Imagine not being able to hear silence . . . ever. That means no quiet enjoyment or getting away from it all. That's a reality for 30 to 60 million Americans suffering from tinnitus.

Tinnitus is the phantom auditory sensation of sound such as ringing, hissing, or buzzing in the absence of external auditory stimuli. The term *tinnitus* is researched more than 110,000 times every month. However, the information obtained through internet searches is questionable at best and detrimental at worst. Our research (Deshpande et al., 2018, 2019) reveals that as much as 45% of tinnitus-related information available online can be classified as misinformation. Misinformation can easily spread across different platforms, either innocuously by unwitting carriers of inaccurate information, like people advising others to give up coffee to reduce tinnitus on Facebook groups, or more maliciously by those trying to profit off of the incurable nature of this disorder. Unfortunately, there are many forms of this purposeful marketing misinformation. One example is using online search engine optimization to promote a miracle pill that cures tinnitus.

Individuals with tinnitus turning to the internet for help with their disorder may accept inaccurate information at face value. Presumably, most hearing healthcare providers either question or reject this misinformation. However, audiologists and other

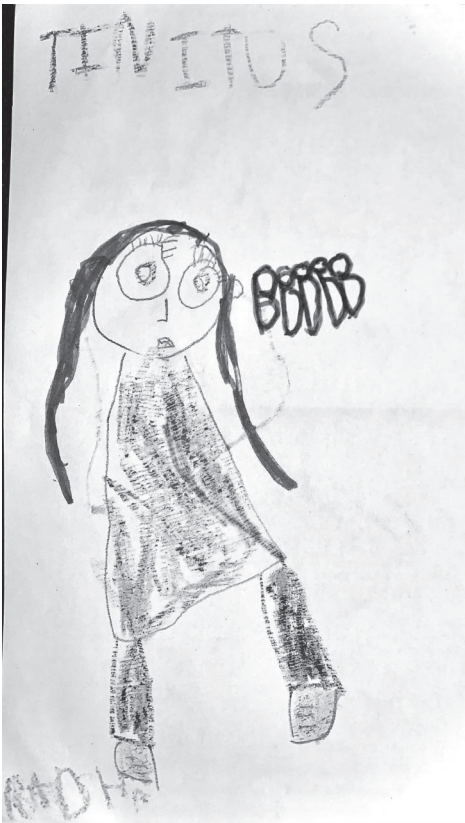
health professionals may struggle in directing patients to valid sources of accurate and up-to-date information on tinnitus. Accurate evidence-based information on advances in tinnitus research is available in peer-reviewed journal publications. Realistically, individuals with tinnitus, and at times audiologists, do not always have direct access to research findings or the time and inclination to process dense scientific jargon.

Our book aims to bridge this information divide with up-to-date, peer-reviewed, evidence-based information on tinnitus prevention, assessment, and management. The compilation of recent advances in tinnitus, presented in an organized and easy-to-read format, should resonate with busy practitioners, students, and researchers alike. Short chapters under each section contain practical information that can easily be applied in the assessment and management of bothersome tinnitus and disorders of sound sensitivity and tolerance, such as hyperacusis, that often accompany tinnitus.

We strongly believe that this book will serve as a one-stop shop for researchers and clinicians to bring themselves up to speed with recent advances in tinnitus prevention, assessment, and management. Additionally, since this book helps clarify and expand on several difficult concepts related to tinnitus and hyperacusis, it can be incorporated by instructors in the audiology curriculum to explain such concepts to students.

ACKNOWLEDGMENTS

When I first told my 5-year-old daughter, Radha, that I was working on a book on tinnitus, she asked me what tinnitus was. When I explained it to her, she nodded and left the room. I was not sure she really understood the concept. But she returned a few minutes later with this drawing.



She explained to me that the *Bs* next to the girl's ears represented bee-like buzzing sounds that she heard "all the time." The confused look on her face represented that

she was not happy with the constant presence of those sounds. After this thorough explanation, Radha was ready with a pop quiz for me!

Radha: Baba, do you know why she got tinnitus?

Me: No, why?

Radha: Do you see the yellow earphones in her ears? She listens to loud music all the time. And do you know what she should do about it?

Me: Stop listening to music?

Radha: No silly! She likes music; music is good for you. She should go to her audiologist (Radha knows that my wife and I are both audiologists) and just turn down the music, and the tinnitus will go away!

I was amazed by my daughter's in-depth analysis of tinnitus. In her own unique way, she touched upon the topics of prevention, assessment, and management of this complex disorder. Although it may seem naïve, we are all guilty of indulging in the wishful thinking that tinnitus would somehow just go away. After our conversation, I was able to see the book in a new light. It was not just an academic endeavor; it was the product of years of scientific investigations by thousands of researchers. I am proud to be a part of such an exercise. I would like to thank each and every one of those researchers who continue to contribute to our collective

knowledge base on tinnitus. I would like to thank the clinicians who pour their hearts and souls in managing tinnitus patients. I would like to thank the instructors who train students to become skilled clinicians. And I would like to acknowledge the sacrifices made by tinnitus patients and their family members. This book is for all of you!

This book started with just an idea in my head. Special thanks to Jay for believing in me and helping me take this idea from conception to publication. Thank you to all the contributors of the book for sharing your expertise with the readers. Thank you to Angie, Valerie, Christina, and the entire Plural team for your guidance throughout the publication process. A big shout-out to my wonderful colleagues at Hofstra University and the Long Island Doctor of

Audiology Consortium for your collegiality. Finally, this book would not have been possible without the sabbatical I received from Hofstra University. As a small token of my gratitude, the front cover of the book carries the official Hofstra colors of blue and gold—#HofstraPride!

I would always tease my wife, Shruti, that if I ever worked on a book, I would acknowledge her contribution as follows: Dedicated to my wife, without whose support this book would have been completed in half the time! But after testing out that hypothesis, I am happy to report that her support and encouragement did, in fact, help me complete the book in half the time. To Shruti, Radha, Cymba, Aai, and Baba—thank you for your love from here and from beyond.

—AKD

First, I wish to acknowledge Pawel Jastreboff for providing me approximately 25 years ago with practical evidence-based information about bothersome tinnitus along with a logical and clinically feasible approach to tinnitus assessment and management. Secondly, I'll acknowledge my gratitude to audiology colleague and friend David Baguley for inspiring me to develop and direct tinnitus and hyperacusis centers, first at Vanderbilt University Medical Center and later at the University of Florida Health Science Center. Third, I happily recognize the thousands of audiologists who have enrolled in my uni-

versity courses or attended my lectures and workshops on tinnitus and/or hyperacusis, and who have then implemented desperately needed clinical services to patients desperately needing them. Fourth, I thank my co-editor Aniruddha Deshpande for proposing the book, for his close attention to myriad details from its inception to publication, and for including me on the project. Finally, I extend my sincere appreciation to the many contributors to the book, chapter authors whose main motivation was to advance the clinical science underpinning effective tinnitus management.

—JWH3

ABOUT THE ARTIST



Smruti Balvalli is a visiting faculty at RV College of Architecture, a practicing landscape architect, and self-taught illustrator from Bengaluru, India. She graduated as an architect from the Academy of Architecture, Mumbai and completed her Master's degree in Landscape Architecture from CEPT University, Ahmedabad, India in 2013. With a keen focus on deliberating upon open spaces—both urban and natural, her academic interests are oriented toward visual communication and documentation, landscape urbanism, and ecological restoration. When invited to collaborate for the book cover, she instantly connected with the idea

of transitioning from “Pain to Hope.” The creative process involved deliberations on a minimal yet stark graphical language. The cover was highly inspired by abstracting and curating the editors' vision of representing the true nature of the book—to provide hope to millions suffering from tinnitus based on recent evidence-based advances in tinnitus prevention, assessment, and management. The cover represents a philosophical journey from an unmanaged chronic condition to a state of peace with a hope for a better quality of life.

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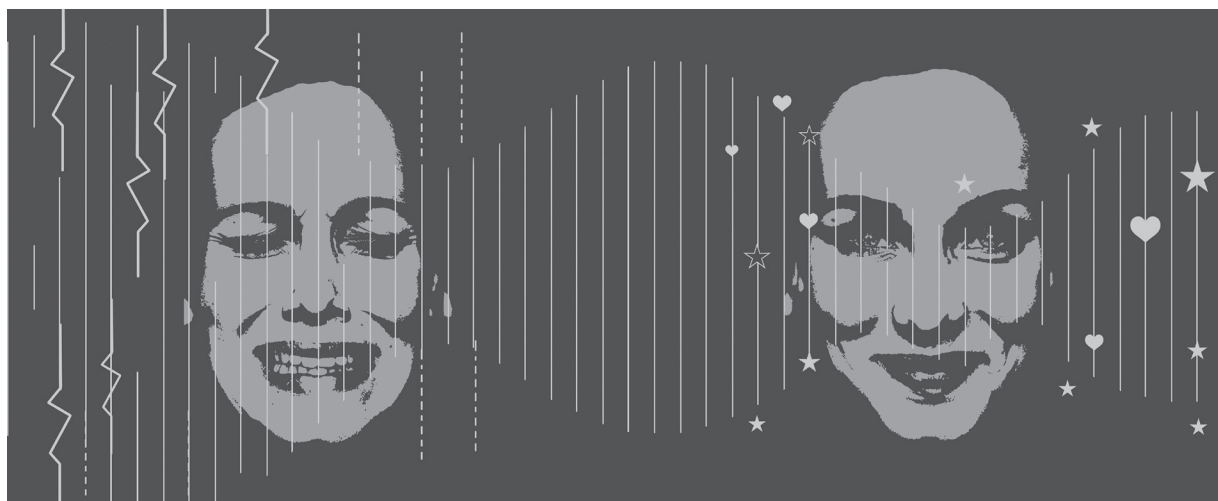
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SECTION I

PREVENTION OF HEARING LOSS AND TINNITUS



1 MECHANISMS OF NOISE- AND MUSIC-INDUCED TINNITUS

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Introduction

Tinnitus, a phantom auditory sensation, is experienced by millions of individuals worldwide. In a subset of these individuals, this phantom sensation can have a negative impact on quality of life and may even become disabling (Kochkin, 2005). Because the underlying mechanisms of tinnitus are not yet well understood, tinnitus is often described as a symptom that is correlated with various pathologies and diseases, including hearing loss. Tinnitus is strongly associated with acquired hearing loss, including noise-induced hearing loss. A history of occupational or recreational noise exposure, including exposure to loud music, is often reported among patients with tinnitus (Nondahl et al., 2002; Shargorodsky et al., 2010). Because of the strong correlation between hearing loss and tinnitus, this chapter aims to provide an overview of the established and emerging hypotheses underlying the effects of noise and music exposure on the development of tinnitus.

Noise-Induced Tinnitus

Noise-induced hearing loss (NIHL) is the second-most common form of hearing loss (Han et al., 2009). This type of acquired hearing loss is associated with exposure to hazardous levels of occupational or recreational noise that can occur over the course of an individual's lifetime. Hearing loss and transient tinnitus are commonly associated with acute and chronic noise overexposure. Among individuals with NIHL, a subset also develops chronic tinnitus (i.e., tinnitus lasting longer than 3 months) (Mrena et al., 2002; Nageris et al., 2010). Although most individuals with NIHL do not report tinnitus, the majority of individuals with tinnitus have some level of comorbid hearing loss (Martines et al., 2010; Mazurek et al., 2010; Savastano, 2008). Consequently, individuals that are exposed to high levels of acute or repeated noise are at risk of developing not only NIHL, but also chronic tinnitus.

The severity of NIHL generally depends on three external factors: (a) the duration of the noise, (b) the intensity of the noise,

and (c) the energy content of the noise. The duration and intensity of noise exposure is directly proportional to the severity of the resulting NIHL. Noise energy content can also impact the severity of NIHL. For example, noise energy can be defined as continuous noise, impulse noise, or impact noise. The primary difference between these types of noise is the kurtosis, or highest short-duration peak intensity of a given noise. Impulse and impact noise types are more kurtotic than continuous noise, meaning they have short, high-intensity bursts of energy. These factors play a role in the degree and configuration of NIHL, and in turn influence the probability of developing noise-induced tinnitus. For example, due to the prevalence of both acute and chronic occupational noise exposures in the military, active-duty military personnel and veterans report disproportionately higher rates of NIHL and bothersome tinnitus when compared to the general population (Yong & Wang, 2015). Nearly half of soldiers exposed to blasts report developing chronic tinnitus (Cave et al., 2007; Helfer et al., 2011). Similarly, prolonged unprotected or underprotected exposures to high levels of industrial or recreational noise are associated with an increased likelihood of developing noise-induced tinnitus (Loughran et al., 2020). In the workplace, Occupational Safety and Health Administration (OSHA) regulations aim to mitigate the effects of noise exposures and thus aid in reducing the probability of developing noise-induced tinnitus (OSHA, 1983). In contrast, there are very few regulations in place for exposure to recreational noise. Similar to occupational noise exposures, repeated exposures to high levels of recreational noise such as firearms, fireworks, motorcycles, racing vehicles, or music can lead to both hearing loss and noise-induced tinnitus (Loughran et al., 2020).

Noise-induced tinnitus is generally categorized as a subjective tinnitus, meaning the tinnitus is only heard by the person experiencing it. In contrast, objective tinnitus is defined as sounds that can be heard by the individual as well as by the examining clinician. Objective tinnitus can be the result of eustachian tube dysfunction, temporomandibular joint (TMJ) problems, or somatosounds (Han et al., 2009). Other types of tinnitus can include primary, secondary, vascular, or pulsatile tinnitus (Esmaili & Renton, 2018). This chapter focuses on subjective tinnitus associated with NIHL given its higher prevalence.

Music-Induced Tinnitus

Like other forms of recreational noise exposures, exposure to loud music can also play a role in the emergence of chronic tinnitus among both performers and listeners. Because music is characterized by variable intensity, frequency, tonal quality, and rhythm, it is challenging to study its impact on hearing in a uniform research setting. Further, exposure to loud music can vary significantly across individuals in total listening time, relative to occupational noise exposure that might occur on a regular basis throughout an employee's workday. Moreover, prolonged exposure to high levels of noise is typically undesirable or uncomfortable to the listener, whereas individuals may enjoy prolonged periods of exposure to loud music. Finally, unlike occupational noise, there is little regulation regarding exposure to loud music.

Several studies have attempted to isolate the long-term impact of music on hearing by evaluating professional musicians from different music genres, including pop, rock, jazz, and classical music (Eaton, 2002; Halevi-Katz et al., 2015; Hoydal et al.,

2017). Among the different music genres, studies have shown that the prevalence of hearing loss was higher in pop/rock musicians than in classical musicians (Di Stadio et al., 2018). The higher prevalence of hearing loss is believed to be the result of exposure to higher intensity levels during practice and performances (>95 dB HL) and due to the widespread use of amplifiers (e.g., for electric guitars) among pop/rock musicians relative to classical musicians. Due to the higher likelihood of NIHL in pop/rock musicians, it would be reasonable to expect higher prevalence rates of tinnitus; however, regardless of genre, approximately 25% of all musicians report experiencing chronic tinnitus (Di Stadio et al., 2018).

Due to the aforementioned variability inherent in music exposure and methodological differences across studies, more research is needed to determine the risk factors of music-induced tinnitus. This information can be used to better educate the public that, like noise, exposures to high levels of music could contribute to the development of tinnitus. Ultimately, whether the sound exposure is from noise or music, the resulting hearing loss and tinnitus can be equally debilitating.

Background

Tinnitus as a Cochlear Phenomenon

Historically, tinnitus has been thought to arise primarily from dysfunction of the peripheral auditory system (Kaltenbach, 2009). Indeed, treatments for the “bewitched” ears of patients with tinnitus date back over two centuries (Stephens, 1984). These treatments included sound therapies, oils, or topical drugs applied to the ear (Stephens, 1984). Thus, despite limited understand-

ing of the auditory system and tinnitus, even early therapies recognized that the ear played a significant role in the development of tinnitus.

Continued support for the presence of a peripheral generator for tinnitus persists due to the strong correlation between tinnitus and cochlear damage (Jastreboff, 1990). Some theories attribute the presence of tinnitus to the dysfunction of sensory cells in the inner ear. For example, research suggests that spontaneous otoacoustic emissions (SOAEs) that are generated by cochlear outer hair cells (OHCs) could produce the sensation of tinnitus (Penner, 1990). However, SOAEs are unlikely to explain the presence of tinnitus among individuals with NIHL because these individuals typically present with damage or loss of OHCs and consequently have reduced otoacoustic emissions (Keppler et al., 2017; Santaolalla Montoya et al., 2007). An alternate theory suggests that damage or loss of OHCs leads to a reduction in afferent inhibitory input to inner hair cell (IHC)-driven activity in the dorsal cochlear nucleus (DCN). The loss of inhibition is thought to result in higher spontaneous firing rates at the level of the DCN that is then interpreted as sound by higher regions of the auditory system. This imbalance between excitation and inhibition at the level of the DCN, known as the discordant dysfunction theory, suggests that loss of OHCs, but not inner hair cells (IHCs), can trigger the perception of tinnitus (Baguley, 2002; Jastreboff & Hazell, 1993). This theory differs from current thinking on peripheral generators of tinnitus that suggest that damage to IHCs is the catalyst for tinnitus. Over the last decade, work by Kujawa and Liberman (2009) suggests that noise-induced damage to afferent synaptic terminals in IHCs can lead to suprathreshold hearing deficits and the development of tinnitus. These deficits can occur in the