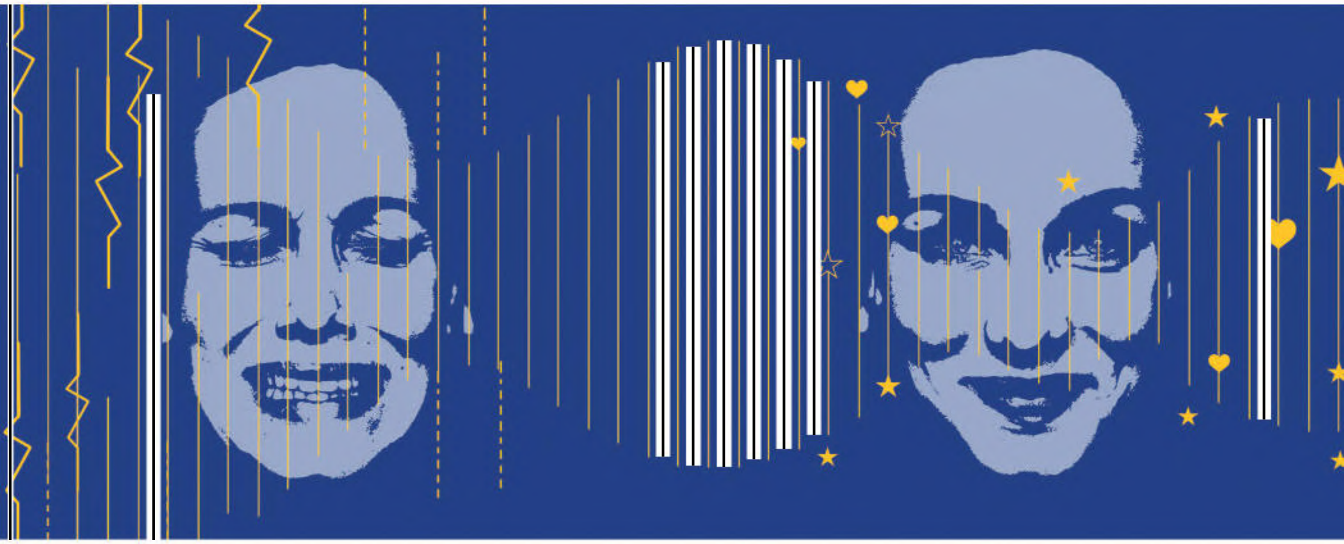
TINNITUS

ADVANCES IN PREVENTION, ASSESSMENT, AND MANAGEMENT

ANIRUDDHA K. DESHPANDE
JAMES W. HALL III



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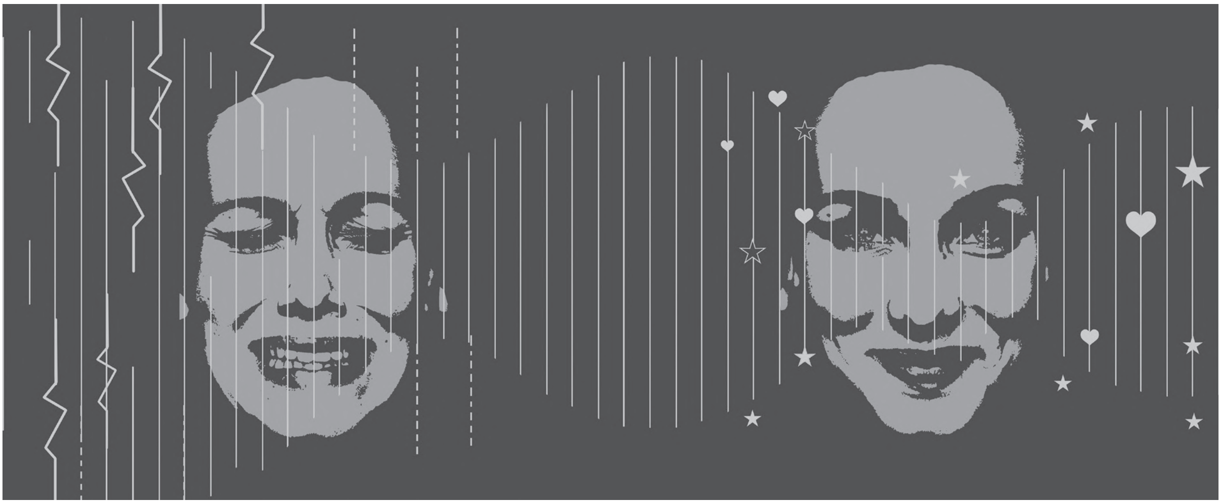

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CONTENTS

Foreword *ix*
Preface *xiii*
Acknowledgments *xv*
About the Artist *xvii*
Contributors *xix*
Reviewers *xxv*

Section I. Prevention of Hearing Loss and Tinnitus **1**

1 Mechanisms of Noise- and Music-Induced Tinnitus 3
Monica Trevino, Aastha Trehan, Celia D. Escabi, and Edward Lobarinas

2 Genetic Basis of Tinnitus 23
Ishan Sunilkumar Bhatt

3 Health Determinants and Modifiable Risk Factors of Tinnitus 41
Conner Jansen, Colleen Le Prell, and Christopher Spankovich

4 Toward Integration of Sound Maps in Tinnitus Research 71
Tae Hong Park

Section II. Assessment of Tinnitus **85**

5 The Importance of Patient History 87
Patricia C. Mancini and Richard Tyler

6 Audiological Assessment of Tinnitus 101
James W. Hall III

7 App-Based Tinnitus Assessment 133
Magdalena Sereda, Derek J. Hoare, and Aniruddha K. Deshpande

8 Objective Diagnosis of Tinnitus 147
Jos J. Eggermont

Section III. Management of Tinnitus 157

9 Self-Directed Tinnitus Therapy: A Review of At-Home Tinnitus Therapy Options 159
Grant D. Searchfield and Sun-Jae (Jay) Kim

10 The Role of Amplification in Tinnitus Management 179
Giriraj Singh Shekhawat, Laure Jacquemin, and Roland Schaette

11 Audiologist-Delivered Cognitive Behavioral Therapy for Tinnitus 193
Eldré W. Beukes and Vinaya Manchaiah

12 Application of Teleaudiology to the Clinical Management of Tinnitus 209
James A. Henry, Emily J. Thielman, and Leslie D. Grush

13 Cutting-Edge Approaches in Tinnitus Management 221
Sook Ling Leong and Sven Vanneste

14 Dietary Supplements, Essential Oils, and Cannabinoids for Tinnitus Relief 247
Robert M. DiSogra, Colleen A. O'Brien-Russo, and Aniruddha K. Deshpande

15 Complementary and Alternative Medicine and Tinnitus 261
Gemma Crundwell and David M. Baguley

16 Values-Led Care in Tinnitus 275
Helen Pryce

Section IV. Hyperacusis 287

17 Hyperacusis and Misophonia 289
Hashir Aazh

Section V. Recent Developments 311

18 The Role of Social Media in Tinnitus and Hyperacusis 313
Colleen A. O'Brien-Russo and Aniruddha K. Deshpande

19 Implications of the COVID-19 Pandemic for Tinnitus 325
Eldré W. Beukes and Vinaya Manchaiah

Section VI. Illustrative Clinical Scenarios **339**

20 Case Study 1: Asymmetrical Sensorineural Hearing Loss and Tinnitus 341
Aniruddha K. Deshpande and Lisa Mener

21 Case Study 2: Sudden Sensorineural Hearing Loss and Tinnitus 353
Aniruddha K. Deshpande and Diana Callesano

22 Case Study 3: Pulsatile Tinnitus 359
Adwight Risbud, Mehdi Abouzari, and Hamid R. Djalilian

23 Case Study 4: Managing Debilitating Tinnitus in a Patient With Complex Comorbidities 367
Tricia L. Scaglione, Lori Zitelli, and David P. Jedlicka

24 Case Study 5: Somatosensory Tinnitus 381
Maja Svrakic

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 comparable 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.

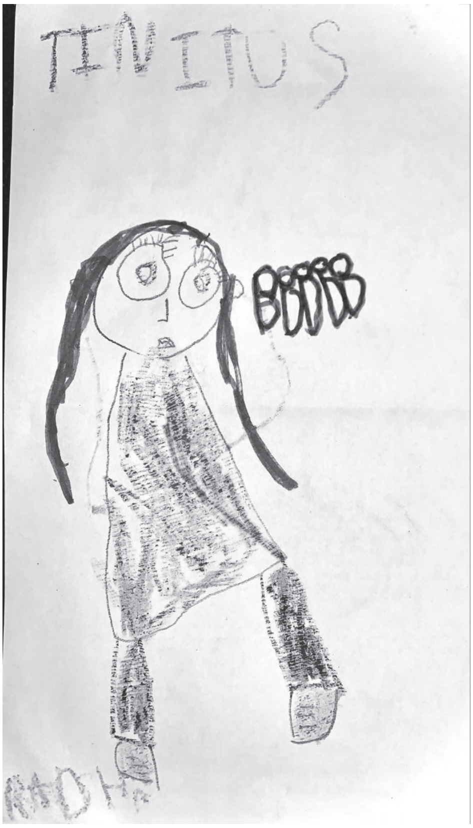
Individuals with tinnitus turning to the internet for help with their disorder may accept inaccurate information at face value. Presumably, most hearing healthcare providers either question or reject this misinformation. However, audiologists and other health professionals may struggle in directing patients 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 *B*s 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 shoutout 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 university 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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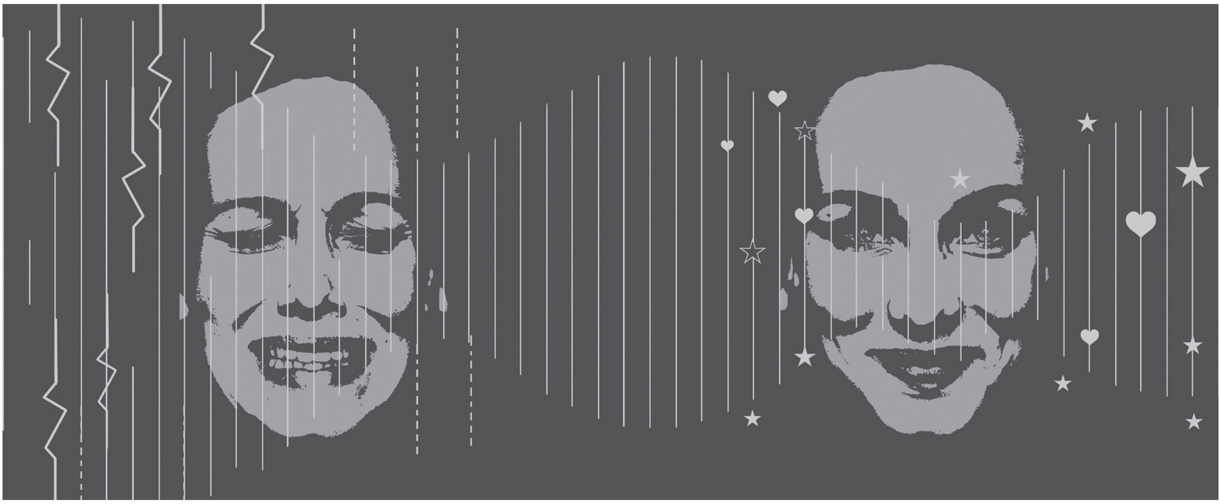
SECTION I

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 understanding 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 absence of any damage to OHCs, contradicting the discordant dysfunction theory. However, despite support for peripheral generation of tinnitus, Kujawa and Liberman's hypothesis recognizes that the sustained perception of tinnitus is encoded and maintained by the central auditory nervous system. The hypothesis of a central auditory system (CAS) role in tinnitus maintenance is supported by landmark studies in the 1980s showing that tinnitus persisted in approximately half of patients undergoing surgical cranial nerve (CN) VIII transection (House & Brackmann, 1981; Silverstein et al., 1986). The results of these studies confirmed that tinnitus could persist without cochlear input and was likely maintained by higher cortical structures. Among individuals with age-related hearing loss and NIHL, most do not experience chronic tinnitus, yet most individuals with tinnitus also have hearing loss. Thus, hearing loss may play a critical role in triggering the onset of tinnitus, whereas chronic tinnitus appears to be the result of abnormal cortical activity in most cases. Given this possibility, several brain imaging studies of tinnitus have been performed using positron emission tomography (PET), magnetic resonance imaging (MRI), and functional magnetic resonance imaging (fMRI). These studies suggest that the loss of cochlear input can lead to abnormal activity in the central auditory pathway of many patients who report tinnitus (Lockwood et al., 1998; Melcher et al., 2000). Because hearing loss produces a loss of peripheral input, it has been hypothesized that tinnitus resembles phantom limb pain, due to the fact that it arises from the loss of inhibition normally provided by the feedback loop from the periphery (Lockwood et al., 1999; Moller, 1997; Muhlnickel et al., 1998). As a result, most current research on noise- or music-induced tinnitus is focused on investigating tinnitus as a central phenomenon triggered by a peripheral hearing loss (Crummer & Hassan, 2004; Thabit et al., 2015).

Tinnitus as a Central Nervous System Phenomenon

Current theories of tinnitus postulate that noise- or music-induced tinnitus is the result of increased or abnormal brain activity in response to reduced auditory input due to hearing loss (Adjamian et al., 2009). However, tinnitus can also develop from nonauditory injuries such as trauma to the head, neck, or spinal cord. Other medical conditions such as hypertension, diabetes, TMJ problems, and migraines have also been correlated with tinnitus (Kreuzer et al., 2012). In some cases of idiopathic tinnitus, no overt medical origin or hearing loss can be identified (Crummer & Hassan, 2004). Nevertheless, because most people who report tinnitus also have hearing loss, the role of NIHL on the development of tinnitus remains a high-priority research area (Oosterloo et al., 2021; Roberts & Salvi, 2019; Sindhusake et al., 2003). Despite multiple advances in electrophysiological and imaging techniques, studies have not yet clearly identified a common central mechanism of tinnitus. However, several studies have shown differences in the patterns of activity between participants with and without tinnitus (Chen et al., 2014; Hu et al., 2021). It is important to note that the loudness perception of tinnitus does not always predict the severity of tinnitus and there is no clear evidence of differences in brain activity patterns between people experiencing bothersome and nonbothersome tinnitus.

Among study participants who report tinnitus, some of the brainstem and brain regions that have shown increased tinnitus-associated activity include the DCN, inferior colliculus (IC), primary auditory cortex (A1), and secondary auditory cortex (A2) (Araneda et al., 2018; Bauer et al., 2013; Seydell-Greenwald et al., 2012). Additionally, limbic system structures outside the CAS, such as the amygdala and thalamus, have also shown enhanced activity in individuals with chronic tinnitus (Chen et al., 2012; Leaver et al., 2016; Lockwood et al., 1998). It is believed that when these limbic structures fail to suppress the perception of tinnitus, tinnitus is instead maintained as a chronic signal (Rauschecker et al., 2010). The differential activity across brain structures could explain why some patients with tinnitus experience more distress than others, and that there may be identifiable and independent neural correlates for tinnitus distress and tinnitus perception (Seydell-Greenwald et al., 2012).

Collectively, the results of imaging and physiological studies have led to some of the most prevalent central models of tinnitus, which are discussed in more detail later in the chapter. These include the physiological model, thalamocortical dysrhythmia, the central gain model, and central disinhibition.

Tinnitus as a Psychological Phenomenon

Among individuals who experience chronic tinnitus, a small subset experiences bothersome tinnitus and an even smaller subgroup is debilitated by their tinnitus (Henry et al., 2015). It is not yet clear why some (but not all) individuals are bothered by chronic tinnitus. Individuals with bothersome tinnitus experience an emotional reaction to their tinnitus that can perpetuate annoyance, anxiety, and stress (Canlon et al., 2013; Salazar et al., 2019). These patients may also experience comorbid anxiety and depression that can exacerbate the patient's reaction to their tinnitus (Bhatt et al., 2017; Durai & Searchfield, 2016; Stobik et al., 2005). As a result, many therapies are aimed at reducing the reaction to tinnitus rather than reducing the tinnitus signal itself (McFerran et al., 2019). For example, the Progressive Tinnitus Management (PTM) program developed by the National Center for Rehabilitative Auditory Research (NCRAR) incorporates the psychological impact of tinnitus in an education-based intervention program (Henry et al., 2005; Henry et al., 2017; Myers et al., 2014). PTM has been shown to reduce tinnitus-related stress through coping skills in veterans with NIHL (Edmonds et al., 2017). Research on effective clinical management strategies must consider the multiple factors that contribute to tinnitus disability and how these factors interact in patients who are most bothered by tinnitus.

Recent Advances

Discordant Dysfunction Theory of Tinnitus

As stated previously, tinnitus is strongly correlated with NIHL. Among individuals with a history of noise exposure, the strongest correlate of tinnitus is the presence of elevated audiometric thresholds at 4 kHz (Rabinowitz et al., 2006). Hearing loss and subsequent threshold elevations occur largely due to OHC loss in the inner ear (Hamernik et al., 1989). Although OHCs transmit minimal acoustic information to the CAS, OHCs generate nonlinear cochlear amplification (Nin et al., 2012) and have afferent projections to the DCN. The role of these OHC afferents is not well understood but may play an inhibitory role in IHC input to the CAS. The discordant dysfunction theory, presented earlier in the chapter, postulates that loss of OHC inhibitory input results in IHC overactivity that is perceived as tinnitus by the CAS. This theory could explain why many patients experience tinnitus at or near the frequency of the highest degree of hearing loss. Additionally, this theory is also consistent with animal model data showing elevated spontaneous firing rates for neurons within the DCN following a noise exposure that was associated with behavioral evidence of tinnitus (Brozoski & Bauer, 2005). However, lesioning the DCN 3 months after exposure did not minimize the behavioral evidence of tinnitus, suggesting that the DCN may initiate tinnitus, but that persistent tinnitus is likely maintained by higher cortical structures. Consistent with these findings, a subsequent study lesioned the DCN in animals prior to noise exposure and successfully prevented behavioral evidence of tinnitus (Brozoski et al., 2012), supporting the hypothesis that the DCN may trigger the onset of tinnitus. More recently, high-frequency neural stimulation of the DCN was found to suppress tinnitus in an animal model of noise-induced tinnitus, suggesting a critical role of this structure in the early onset of tinnitus (van Zwieten et al., 2019). Bimodal stimulation of the DCN via transcranial electrical stimulation of the neck has also been found to suppress evidence of tinnitus in both animals and humans (Marks et al., 2018; Shore et al., 2016). These basic science studies strongly suggest that the peripheral auditory system and lower levels of the CAS are critical to the initiation of tinnitus (Baizer et al., 2015).

Synaptopathic Noise-Induced Tinnitus

Emerging studies have suggested that peripheral initiation of tinnitus may occur even earlier than the DCN, at the level of IHC synapses in the cochlea. Synaptopathy is a loss or dysfunction of synapses between IHCs and the afferent auditory nerve fibers. This type of cochlear damage has been observed as a function of age in both animals and humans, and as a function of noise exposures that do not produce permanent threshold shifts (PTS) across multiple animal models (Kujawa & Liberman, 2009, 2015; Parthasarathy & Kujawa, 2018). This form of subclinical inner ear damage has been hypothesized to underlie a host of suprathreshold auditory perceptual problems that are independent of changes in hearing sensitivity (Hickox & Liberman, 2014; Lobarinas et al., 2017; Valero et al., 2017). Among these suspected deficiencies are difficulty hearing in noise, abnormal loudness sensitivity, and tinnitus. Proponents of this hypothesis suggest that tinnitus may result from IHC deafferentation and that the degree of synaptic damage increases the likelihood of individuals developing tinnitus even when their hearing thresholds are within normal clinical limits (Liberman & Kujawa, 2017). This hypothesis contradicts the discordant dysfunction theory in that loss of IHCs would not be predicted to be a catalyst for tinnitus. Although synaptopathy may be a possible mechanism of tinnitus for those patients without overt hearing loss or other underlying medical conditions, this accounts for only a small fraction of the total tinnitus population. Nevertheless, synaptopathy is likely a part of all NIHL and the degree of synaptic loss could be correlated with the presence of tinnitus (Hickox & Liberman, 2014). One of the hallmarks of synaptopathy in animal models is a reduction in the auditory brainstem response's (ABR) wave-I amplitude. This reduction is correlated with a loss of IHC synapses and a reduction in afferent cochlear output.

In humans, studies have found reduced ABR wave-I amplitudes in adults with a history of noise exposure and tinnitus despite normal audiograms (Schaette & McAlpine, 2011). This finding has been described as a potential clinical correlate of synaptopathy based on data observed in animal models (Hickox & Liberman, 2014). However, a subsequent study in humans found no evidence of synaptopathy (i.e., normal ABR wave-I amplitudes) in adults with tinnitus and normal hearing (Guest et al., 2017). In summary, although noise exposure is strongly associated with synaptopathy, it remains unclear whether synaptopathy alone is a peripheral generator of tinnitus.

Aberrant Cortical Oscillations and Thalamocortical Dysrhythmia

Maladaptive plasticity or abnormal reorganization of neural structures in response to cochlear hearing loss has been suggested as a potential underlying mechanism for tinnitus (Shore et al., 2016; Wu et al., 2016). Hearing loss has been associated with hyperactivity of subcortical and cortical areas (Wu et al., 2016). Among these changes are elevated neuronal signal bursting, elevations in spontaneous neuronal firing rates, and enhanced neural synchrony (Pilati et al., 2012). Research suggests that changes in neuronal synchrony may be essential in maintaining tinnitus (Shore et al., 2016). Thus, hearing loss alone is not sufficient for tinnitus, but the lack of cochlear stimulation could result in maladaptive plasticity in some individuals with hearing loss.

Abnormal neuronal synchrony in cortical and subcortical structures may create changes in oscillatory brain activity in the thalamus (Caspary & Llano, 2017). The thalamus is a sensory integration center and the last relay structure within the central auditory pathways before the auditory cortex (AC). The auditory thalamus (medial geniculate body) is an obligatory auditory brain relay that gates the percept of sound as it projects it to the AC and limbic structures. The connections from the auditory thalamus to both the AC and the limbic system have made it a target for tinnitus studies (Brinkmann et al., 2021; Caspary & Llano, 2017). The main hypothesis behind thalamocortical dysrhythmia (TCD) is that tinnitus is initiated by decreased auditory input (e.g., as a result of NIHL). The loss of auditory input reduces thalamic firing rates, which in turn reduces lateral inhibition. As a result, the areas surrounding the thalamus become hyperactive and spontaneously fire at gamma band rates. This hyperactivity ultimately transmits to the AC and may be perceived as tinnitus.

The TCD model has expanded to include the hypothesis that synchronized hyperactivity changes occurring in the AC may extend to more global workspace involving additional cortical structures (the global workspace model) (De Ridder, Vanneste, et al., 2015). This model extends to earlier iterations of the TCD model that suggested tinnitus was primarily attributed to a bottom-up reduction in auditory stimulation due to hearing loss (Llinas et al., 1999). Newer imaging technologies have made it possible to explore more parameters of the TCD model. For example, a recent preliminary study that utilized ultrahigh field fMRI found that patients with tinnitus had reduced thalamocortical and corticocortical connectivity when compared to patients without tinnitus, supporting the hypothesis that disruption of the auditory pathway can result in reduced inhibition throughout the cortex (Berlot et al., 2020). As imaging techniques progress, subsequent studies will be able to better define the perceptual and emotional components of tinnitus that are mediated by cortical structures.

Central Gain Theory of Tinnitus

Noise exposure that leads to NIHL has been shown to produce both cochlear damage and decreased neural input to the CAS. Several animal studies have shown that after NIHL, the CAS responds with compensatory central gain (Auerbach et al., 2014). This central compensation can be seen as early as the IC along the auditory pathway (Sheppard et al., 2017; Wang et al., 2002), and is present in sound-evoked AC responses at suprathreshold sound levels (Popelar et al., 1987; Sun et al., 2008; Syka et al., 1994). In animal models of tinnitus that used high doses of sodium salicylate—a drug shown to reliably induce tinnitus in humans and animals—enhanced gain in the IC and AC was correlated with the presence of tinnitus as measured by the gap startle reflex (Sun et al., 2009). Another study found that both the IC and AC demonstrated enhanced gain in response to high- but not low-intensity sounds in a salicylate animal model (Auerbach et al., 2019). The AC response was slightly stronger than the IC response, suggesting that gain enhancement escalates as it progresses through the auditory pathway. Similarly, exposure to loud noise has been shown to drive central compensatory gain. In animal studies, hazardous noise exposures that reduced ABR wave-I amplitudes showed hyperactivity to loud sounds and enhanced ABR wave II-IV peaks, which correlated with central auditory structures (Schrode et al., 2018). Even relatively low-level (65 dB SPL) noise exposure has been shown to enhance the response of the IC at the frequency within the noise exposure band, though the effects do not appear to be long lasting (Sheppard et al., 2018). As mentioned previously, NIHL typically manifests as damage to the region of the cochlea that corresponds to the energy content of the noise. Importantly, after exposure to hazardous noise, several animal studies have shown that the greatest degree of enhanced central gain is correlated with the frequency of the greatest auditory threshold elevation (Niu et al., 2013; Sheppard et al., 2018; Wang et al., 2002). Likewise, individuals exposed to loud noise or loud music often report tinnitus in the frequency region that had the highest degree of noise exposure (Axelsson & Prasher, 2000). Given that tonotopic organization is maintained throughout the CAS, it is likely that the regions of more damage at the level of the cochlea correspondingly alter function upstream. This hypothesis provides an explanation for a potential mechanism of tinnitus generation; however, it does not fully explain how tinnitus can become distressing in some individuals, but not others.

Tinnitus and the Limbic System

The involvement and importance of the limbic system as a major component of tinnitus and tinnitus distress associated with hearing loss was modeled and later summarized by Hazell and Jastreboff (Hazell & Jastreboff, 1990; Jastreboff & Hazell, 1993). The potential role of the limbic system in mitigating the emotional response to tinnitus has led to studies and potential therapeutic interventions that specifically target neural mechanisms believed to underlie distress. Over the last decade, several attempts have been made to use stimulation of the vagus nerve to reduce tinnitus and tinnitus distress (Borland et al., 2019; De Ridder, Kilgard, et al., 2015; De Ridder et al., 2014; R. Tyler et al., 2017). Patients in whom tinnitus evokes a strong emotional response often demonstrate evidence of enhanced sympathetic nervous system activity (i.e., fight or flight response). Hence, stimulation of the parasympathetic system (rest and digest) could hold promise for both understanding the emotional reaction to tinnitus as well as the maintenance of chronic tinnitus. Research studies focusing on the vagus and trigeminal nerves have used multiple methods to stimulate this "rest and digest" response, including via acupuncture (Tu et al., 2019), subcutaneous implantation directly on the vagus nerve (De Ridder et al., 2014), and somatosensory neck and/or tongue stimulation (D'Arcy et al., 2017; Marks et al., 2018). Often, these methods pair nerve stimulation with auditory stimuli such as tones (De Ridder et al., 2014). Additional details regarding the involvement of the limbic system in tinnitus as well as therapeutic developments are addressed in Chapter 13.

Clinical Implications

The aforementioned proposed mechanisms of noise-induced tinnitus and tinnitus distress can provide guidance toward approaches for tinnitus management, while the introduction of new management options leads to increased research focusing on the mechanisms of tinnitus. This feedback loop between theoretical models and management approaches has significantly advanced our knowledge of tinnitus over the course of three decades. In the following sections, we will introduce proposed prevention and management strategies that target the underlying mechanisms of noise and music induced tinnitus. Subsequent chapters will uncover additional clinical management options to alleviate tinnitus.

Noise and Music Induced Tinnitus Prevention

As mentioned earlier in this chapter, noise- and music-induced tinnitus is often a symptom of underlying hearing loss (Han et al., 2009). Therefore, noise- and music-induced tinnitus prevention strategies focus on reducing or mitigating hearing loss as a result of noise and music overexposure. Hearing loss that results from hazardous occupational noise exposure is one of the leading causes of work-related illness (Masterson et al., 2015). For this reason, there are federal OSHA guidelines in place to limit occupational noise levels and to provide hearing protection for workers who experience hazardous noise levels (OSHA, 1983). This objective is achieved by carefully monitoring areas of high-level noise exposure and routinely performing audiological assessment on workers to evaluate their hearing status. In areas where noise levels exceed safe limits, hearing protective devices such as earplugs or headphones must be provided to workers (OSHA, 1983). Hearing protection is a common and recommended method of reducing NIHL. Hazardous noise levels not only exist in occupational environments, but in recreational listening environments as well. For example, noise levels at music and sports venues can reach hazardous levels (Chepesiuk, 2005). Unlike occupational noise exposure settings, recreational noise settings are seldom equipped with rules or guidelines for the benefit of the general public, and hearing protection is rarely required or provided. Given that music is enjoyable for recreational listeners, many forgo hearing protection (Bogoch et al., 2005; Gilles et al., 2013). Likewise, professional musicians have been shown to abstain from using hearing protection (Pouryaghoub et al., 2017), though not all may be aware of the benefits of wearing hearing protection or where to obtain it (Dinakaran et al., 2018). Musicians and concertgoers alike can benefit from hearing protection. Personal listening devices (PLDs) can also reach intensity levels that may damage the ear when used for long periods of time (Chepesiuk, 2005). In response to this risk, the European Union began limiting all PLDs to default to a maximum level of 85 dB in 2013, although the limit could be overridden and elevated by users. Similar attempts could be modeled elsewhere to reduce overexposure from these devices.

Ultimately, whether the source of the noise exposure is occupational or recreational, reducing overall noise levels where possible or wearing hearing protective devices lowers the risk of NIHL and subsequently the risk of noise- and music-induced tinnitus (Alnuman & Ghnimat, 2019).

Noise- and Music-Induced Tinnitus Management

Strategies to manage existing noise- and music-induced tinnitus primarily focus on the underlying hearing loss. One approach to tinnitus relief is by using therapeutic sound from an external source. Overall, the efficacy of sound therapy requires more investigation (see Cochrane review by Sereda et al., 2018); however, it has the potential to become a promising noninvasive solution for many tinnitus suffers. Sound therapy is typically delivered to patients through hearing aids or ear-level sound generators. For approximately 50% of patients who have comorbid hearing loss, hearing aids alone provide relief from tinnitus (Del Bo & Ambrosetti, 2007). It is speculated that for these patients, providing the deprived auditory system with missing auditory stimulation is sufficient to reduce the perception of tinnitus (Del Bo & Ambrosetti, 2007). For patients in whom hearing aids are not adequate, sound generation can be employed, either via the hearing aids themselves or through sound generators. There are two separate objectives of sound generation: tinnitus masking and tinnitus habituation (Sandlin & Olsson, 1999). Tinnitus masking uses sound to barely mask the patient's tinnitus until they are no longer able to perceive it. This can be achieved with continuous noise, such as white noise or pink noise, or other soothing sounds, such as ocean waves and nature sounds (R. S. Tyler et al., 2017; Tyler et al., 2015). Tinnitus habituation involves presenting these same sounds at a level that is just below the patient's perceived tinnitus, but still audible (Jastreboff & Jastreboff, 2006). The goal of habituation is for patients to associate their tinnitus with a meaningless sound and then learn to consider their tinnitus meaningless. Patients who successfully habituate to their tinnitus may still perceive it but no longer react to it. Sound therapy generators, theories, and management plans are discussed in detail in Chapters 9 and 10.

Future Directions

Exposure to loud music and hazardous noise continue to be leading causes of hearing loss that consequently play a major role in the development of chronic tinnitus. A body of literature is emerging on neural sites and pathways that are involved in tinnitus perception and distress. For instance, the prefrontal cortex is believed to gate attention to tinnitus. Recent studies have used fMRI to quantify differences in prefrontal cortex activation in tinnitus patients relative to control participants when performing an auditory and visual spatial Stroop test (Araneda et al., 2018). The study found that participants with tinnitus exhibited poorer top-down cognitive control and poorer ability to inhibit cognitive interference. The poorer top-down control was related to changes in the dorsolateral prefrontal cortex and ventromedial prefrontal cortex that were not observed in the control participants. More recent data suggest that noninvasive transcranial magnetic stimulation (rTMS) of the dorsomedial prefrontal cortex (Ciminelli et al., 2020) or the dorsolateral prefrontal cortex and AC (Noh et al., 2017; Noh et al., 2019; Noh et al., 2020) may be effective at reducing the perception of tinnitus, further supporting the hypothesis that the prefrontal cortex is engaged in tinnitus attention.

Many patients with chronic tinnitus also display increased levels of anxiety and sympathetic nervous system activity (i.e., fight-or-flight responses). A possible mechanism to mitigate this tinnitus-related activity is by activation of the parasympathetic nervous system (i.e., "rest and digest") via the vagus nerve. Studies in humans and animals have shown that direct and transcutaneous activation of the auditory branch of the vagus nerve can be effective in reducing tinnitus loudness and distress. Noninvasive neurostimulation techniques have also shown promise, including somatosensory stimulation of the face or neck paired with auditory stimulation (Marks et al., 2018). This bimodal stimulation targets the parasympathetic nervous system and reduces spontaneous activity in the DCN. Participants reported clinically significant reductions in their tinnitus following bimodal stimulation as measured by the Tinnitus Functional Index (TFI) (Meikle et al., 2012). Taken together, the results of neurostimulation studies are intriguing and provide insight into the neural processes of tinnitus and potential targets for tinnitus treatment. Moving forward, studies that simultaneously work toward discovering the underlying mechanisms of chronic tinnitus and effective targets for treatment have the greatest potential to impact future research.

Currently, there is no universal standard for measuring the impact and severity of tinnitus, though guidelines have been proposed (Hall, 2017; Tyler et al., 2007), including loudness matching, minimum masking level, and quality-of-life questionnaires that measure the patient's self-perception of tinnitus and tinnitus distress. Standardized tools and more precise measurements of tinnitus could greatly improve study design and methodologies by facilitating direct comparisons between treatment results.

Ultimately, noise- and music-induced tinnitus represent the second largest category of tinnitus after aging. In most cases, this type of tinnitus is preventable, and efforts for public education and federal guidelines can effectively reduce the number of cases. When prevention is not possible, noninvasive neural stimulation could play a major role as an emerging standard of care. Research in both animals and humans suggests that tinnitus distress and tinnitus percepts may be driven by separate neural mechanisms that could be used to personalize treatment strategies. The last decade of research has demonstrated that much work on tinnitus remains, but the advances in our understanding of tinnitus and the efficacy of innovative treatments hold promise for the future.

Key Messages

- Occupational and recreational noise overexposure can lead to both hearing loss and tinnitus.
- Unlike other types of hazardous noise, few regulations or guidelines exist to limit music overexposure.
- Human and animal studies have begun to reveal unique neural signatures involved in tinnitus perception and tinnitus distress.
- In addition to peripheral hearing loss, auditory and nonauditory areas of the brain appear to contribute to the perception and reaction to tinnitus.
- Tinnitus distress and perception may occur in different cortical areas linked by a global network.
- The results of both human and animal studies can provide a framework for better understanding the pathophysiology of tinnitus, reducing the perception of tinnitus, reducing tinnitus distress, or both.

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2 GENETIC BASIS OF TINNITUS

Ishan Sunilkumar Bhatt

Introduction

The completion of the Human Genome Project (HGP)—which allowed researchers to document the complete genetic blueprint of humans—was one of the major milestones in biological sciences. It initiated a new era in biomedical research in investigating the genetic architecture of complex human diseases. Studies in the post-HGP era have identified numerous compelling genetic associations with human diseases. Genetic studies continue to generate insights into the pathophysiology of human diseases. The application of genetic research is beginning to improve clinical care for disease prevention and intervention. This chapter describes recent advances in our understanding of the genetic basis of tinnitus. Also discussed are genetic and nongenetic factors associated with tinnitus phenotypes and clinical applications of genomics in tinnitus prevention and management.

Background

An Overview of Biochemistry of the DNA

Before we begin our discussion on the genetic basis of tinnitus, it is important to understand the basic biochemistry surrounding deoxyribonucleic acid (DNA). DNA is a heritability material that most cells in the human body need to maintain active metabolism. Most DNA content of the cells is found in the cell nucleus. A small portion of the DNA content is found in the mitochondria. The DNA molecule is formed from nucleotides arranged in a manner that creates a polymer. Nucleotides contain a deoxyribose sugar base, one of the four possible nitrogenous bases, and a phosphate group. The deoxyribose sugar structure is shown in Figure 2–1A. The carbon atoms of the sugar molecule are primed (or numbered) (e.g., 1′, 2′). The sugar base is referred to as deoxyribose to indicate the missing hydroxyl group at the 2′ position present in the ribose molecule. The carbon molecule at the 1′ position is attached to a nitrogenous base. The four possible nitrogenous bases include adenine (A), guanine (G), cytosine (C), and thymine (T) (Figure 2–1A). The nucleotides are attached by a phosphodiester bond between the 3′ carbon of one nucleotide with a 5′ carbon of the adjacent nucleotide. The process can be repeated to generate a polynucleotide structure (Figure 2–1B). The DNA molecule contains two polynucleotide chains to create a double helix structure where one strand runs in 5′ to 3′ while the other strand runs in 3′ to 5′ direction. The DNA

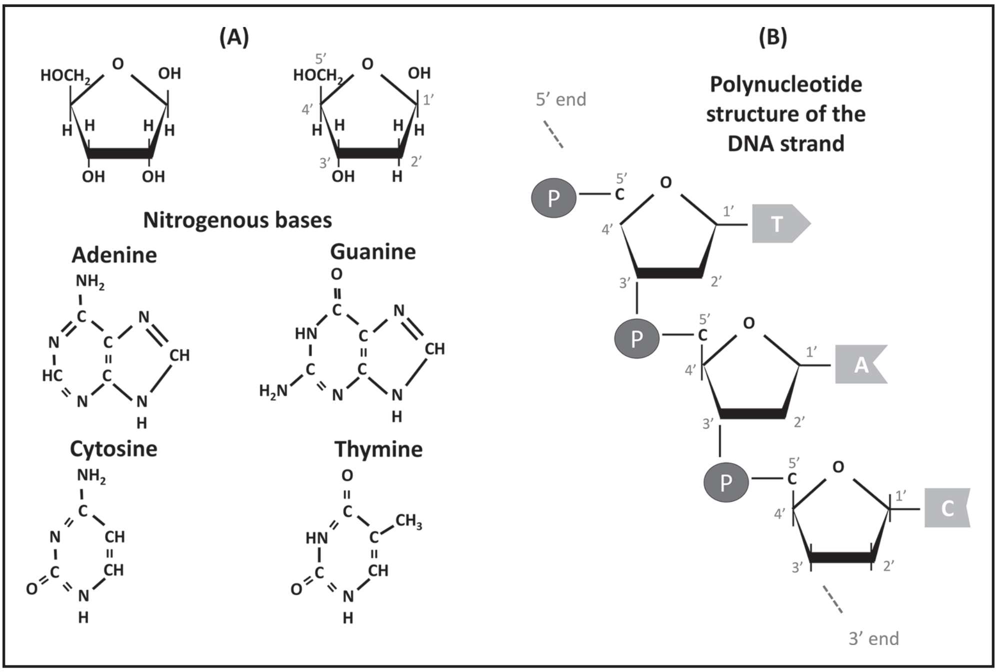

Figure 2–1. A. Structure of ribose, deoxyribose, and nitrogenous bases. **B.** Polynucleotide structure of the DNA strand. The nitrogenous bases are attached to the carbon atom at the 1′ position. The nucleotides are attached by a phosphodiester bond between the 3′ carbon of one nucleotide with a 5′ carbon of the adjacent nucleotide.

nitrogenous bases pair up with each other through hydrogen bonds—A with T and C with G. The two polynucleotide chains are held together by the hydrogen bonding between complementary bases of the two strands.

The word *genome* is used to refer to an organism's complete set of genetic instructions. The word *gene* refers to a segment of DNA where the nucleotide sequence can be used to produce ribonucleic acid (RNA) and protein molecules. Genes are responsible for protein synthesis, and proteins are vital for maintaining active metabolism. Typically, human DNA contains about 3 billion nucleotide bases, and more than 99% of the base-pair sequences are common in all humans (National Human Genome Research Institute (NHGRI, 2019). About 1% of the DNA base pair sequence can be slightly different among humans. This genetic variability collectively contributes to an individual's phenotypic variations (such as differences in height, eye color, or skin color).

Single-nucleotide polymorphisms (SNPs) are the most common genetic variations found in human DNA among different individuals. SNPs are the substitution of a single base pair at a specific location within the genome. Figure 2–2 shows a SNP in the DNA, where C in chromosome 1 is replaced by T in chromosome 2 at a specific location. The DNA sequence in chromosomes 1 and 2 are otherwise identical. An individual's entire genome can include about 84.7 million SNPs (The 1000 Genomes Project Consortium, 2015). Some SNPs might influence protein synthesis by altering protein structure and function, which might lead to changes in anatomy and physiology at the

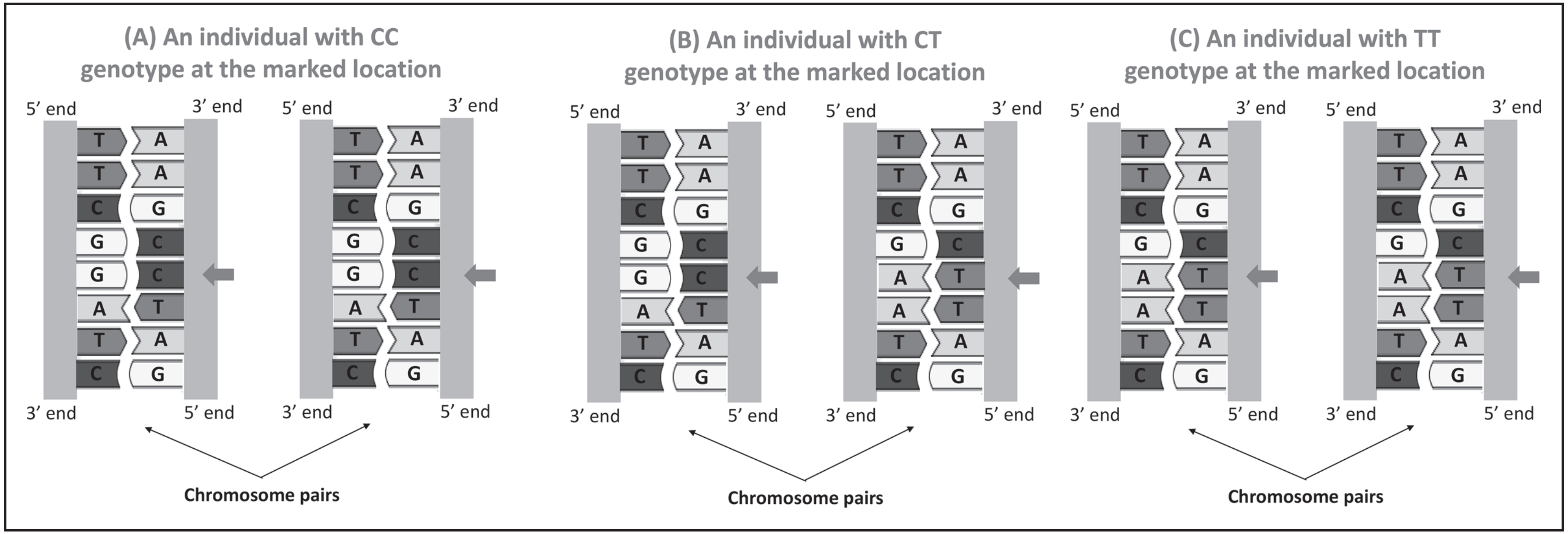

Figure 2–2. An example of single-nucleotide polymorphisms at the specified location on DNA marked with the gray arrow. A chromosome pair is shown for three individuals. **A.** Both chromosomes include C, suggesting that the genotype at the marked location is CC. **B.** One chromosome contains C while the other has T, suggesting that the genotype at the marked location is CT. **C.** The DNA sequence includes T at both chromosomes, suggesting that the genotype at the marked location is TT. The frequency of the CC, CT, and TT genotypes in a population is dependent on the frequency of the alleles C and T.

level of the cell, tissue, organ, or system. It is also possible that some SNPs might have no influence on protein functioning and subsequently have no anatomical or physiological relevance. The central objective of genetic association studies is to identify genetic variants (e.g., SNPs) that underlie individual variations in the phenotype under investigation (e.g., health conditions such as tinnitus and hearing loss).

It is important to note that other types of genetic variability (e.g., duplication, deletion) can also be observed in the human genome. This genetic variability may influence protein structure and function and may ultimately contribute to increasing an individual's risk for acquiring a health condition. The biochemistry surrounding genetic variability and its influence on protein structure and function and on metabolism is beyond the scope of the present chapter. Interested readers are directed to Wilson and Walker (2010) and Korf and Irons (2012) for a more detailed review.

Phenotype: A Key for Identifying Genetic Links

The genetic investigation of a health condition often starts by defining a phenotype of interest. The term *phenotype* is used in the field of biology to describe observable traits or characteristics of an organism, specifically its anatomy, physiology, and morphology at the level of cell, organ, body, and behavior (e.g., Robinson, 2012). The phenotype can be categorical (e.g., blood group, biological sex) or continuous (e.g., body mass index, blood pressure). In the audiological context, the term phenotype is often used to describe a group of individuals with a hearing disorder typically diagnosed by identifying deviation from normal morphology, physiology, or behavior. A phenotype should accurately represent a hearing health condition and should show correspondence with the underlying biology. This is important for accurately identifying the genetic underpinnings.

Tinnitus is a self-reported hearing health condition. It is usually a symptom of an ear disorder such as noise-induced hearing loss. There are no clinically reliable objective biomarkers for its diagnosis (e.g., Henry et al., 2014). The diagnosis and management of tinnitus almost exclusively relies on self-reported measures. These measures (e.g., a visual analog scale for tinnitus) are used to identify individuals with tinnitus and to quantify tinnitus severity. To date, most genetic studies have utilized temporal characteristics to categorize individuals with tinnitus. Table 2–1 (later in this chapter) lists phenotypic strategies used in previous research to identify genetic variants associated with tinnitus. It is worth noting that most studies used chronic tinnitus—typically defined as a tinnitus perception for more than 3 months to a year—as a tinnitus phenotype.

Chronic Tinnitus: A Complex Trait

Complex traits, such as chronic tinnitus, are generally considered multifactorial health conditions as their phenotypic spectrum can be influenced by genetic and environmental factors in combination with lifestyle and health-related habits. Environmental and health-related factors such as loud noise or music exposure, hearing loss, middle ear infection, smoking, stress, head injury, ototoxic medications, and systemic diseases are associated with chronic tinnitus (e.g., Bhatt, 2018; Degeest et al., 2017; Kim et al., 2015).

Noise exposure is a predominant environmental risk factor associated with chronic tinnitus in young adults. A cross-sectional study of 678 young adults aged 18 to 30 years investigated noise exposure among individuals with chronic, acute, subacute, and no tinnitus (Bhatt, 2018). On average, individuals with chronic tinnitus reported significantly higher noise exposure compared to those with acute, subacute, and no tinnitus. However, evaluation of individual differences in noise exposure with dot plots revealed that noise exposure was not entirely predictive of chronic tinnitus (Figure 2–3). Only a small fraction of the variability in tinnitus measure could be exclusively attributed to noise exposure (Bhatt, 2018). Figure 2–3 shows a group of "sensitive" individuals who experienced chronic tinnitus despite low noise exposure and a group of "resistant" individuals who reported no tinnitus despite high noise exposure. Importantly, epidemiological studies have shown that almost 50% of tinnitus cases are not attributable to any known causes (Stouffer & Tyler, 1990). This unexplained variability in tinnitus phenotype might indicate genetic influence on tinnitus.

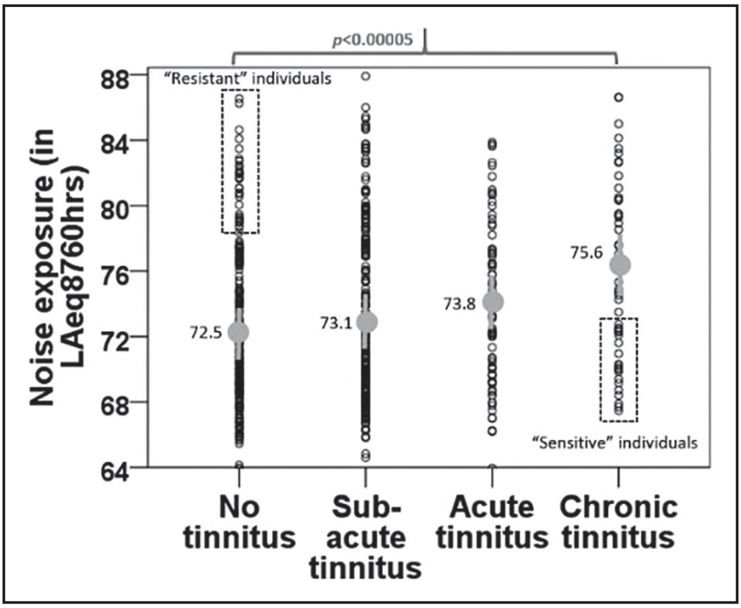

Figure 2–3. A dot plot showing noise exposure for individuals with chronic tinnitus, acute tinnitus, subacute tinnitus, and no tinnitus (Bhatt, 2018). Individuals with chronic tinnitus revealed a significantly higher noise exposure compared to other groups. However, the dot plot revealed a large intrasubject variability in noise exposure scores between the experimental groups. Some "sensitive" individuals revealed chronic tinnitus despite showing a substantially lower noise exposure score, while some "resistant" individuals reported no tinnitus despite showing a substantially high noise exposure score. The comparison between resistant and sensitive subjects might be helpful to identify genetic variants underlying tinnitus. Data published in *Ear and Hearing* (Bhatt, 2018).

Further evidence of genetic influence on tinnitus comes from twin studies. Twin studies can evaluate and estimate the genetic and environmental contributions to a complex trait. The principle of twin studies in differentiating and quantifying the overall contribution of genetic and environmental factors stems from the fact that monozygotic twins are genetically identical, and dizygotic twins share on average 50% of their genome. An estimate of the degree of variation in a complex trait that can be ascribed to shared genes, known as heritability (h^2), can be calculated by comparing the correlation in traits among monozygotic twin-pairs with the correlation among dizygotic twins (e.g., Maas et al., 2017). The h^2 value ranges from 0 to 1, where <0.3 suggests a low genetic contribution, 0.30 to 0.60 suggests a moderate contribution, and >0.60 suggests a high genetic contribution. In the Maas et al. (2017) study, bilateral tinnitus exhibited a higher h^2 value (0.56) than unilateral tinnitus (0.27). These results suggest that genetic factors can explain about 56% of the variability in patients reporting bilateral tinnitus compared to about 27% variability in patients reporting unilateral tinnitus, indicating that certain tinnitus-related phenotypic features might exhibit higher heritability (e.g., bilateral tinnitus) and are more likely to be influenced by genetic factors than other features. The heritability score might be affected by environmental factors as family members are likely to share the same environment. Cederroth et al. (2019) investigated tinnitus heritability among adoptees to account for the environmental influence. Adoptees share the environment with the adopted parents while they share genes with their biological parents, which can provide an opportunity to quantify the genetic influence on tinnitus. The study found that tinnitus in biological parents increased the odds of tinnitus among adoptees. In contrast, tinnitus in adopted parents showed no significant association with tinnitus among adoptees, suggesting that genetic factors can explain the family clustering of tinnitus. In summary, the studies investigating the heritability of tinnitus have suggested a genetic basis of tinnitus.

Recent Advances

Genetic Approaches for Identifying Genotype-Phenotype Associations for Tinnitus

Most genetic association studies have employed a case-control experimental design to identify the genetic risk factors for tinnitus (see Table 2–1). There are two major genetic approaches used in these studies: candidate gene and genomewide association (GWA). The candidate gene approach requires researchers to identify a set of genetic variants in candidate genes. This approach, by necessity, is highly subjective in the process of choosing candidate genes. It requires preexisting theoretical support for selecting candidate genes and genetic variants. As a strength, it requires smaller sample sizes to identify statistically significant associations as only a subset of SNPs (typically in the hundreds or less) in the candidate genes are used to evaluate the phenotype-genotype relationships (Zhu & Zhao, 2007).

In contrast, genomewide association studies (GWAS) evaluate common genetic variants (typically hundreds of thousands of SNPs) across the genome. The GWAS design requires a large sample size (typically in the thousands) and a stringent *p*-value threshold (typically 5×10^{-8}) to correct for the multiple comparisons while identifying statistically significant genotype-phenotype associations (e.g., Wasserman & Roeder, 2009). As a strength, the GWA approach is shown to produce more reliable results than the candidate gene approach (Tam et al., 2019). Most previous genetic studies have utilized a candidate gene approach, while some recent studies are beginning to employ the GWA approach (see Table 2–1).

Genetic Links to Tinnitus: A Review of Human Genetic Studies

Table 2–1 presents a list of major case-control studies of the genetic influence on tinnitus. These studies categorize individuals into two groups: participants self-reporting tinnitus and participants who do not report tinnitus. The genetic influence on tinnitus is investigated by statistically evaluating the frequency distribution of genotypes between participants with and without tinnitus. Genetic risk is often reported as an odds ratio (OR). The OR expresses the odds of an event (e.g., tinnitus) occurring in one group compared to the odds of the same event occurring in another group. For example, if the prevalence of a tinnitus phenotype for individuals with CC genotype for a specific SNP in the population is 10% (see Figure 2–2), and if the prevalence of a tinnitus phenotype for individuals with either CT or TT genotype for the same SNP is 20%, then the odds ratio (i.e., OR = 20/10 = 2) will express the magnitude of risk for those with CT or TT genotypes compared to those with CC genotype.

Case-control study designs have been used to investigate potential candidate gene set, including genes essential for cardiovascular physiology (ACE, ADD1), ion recycling in the inner ear (i.e., KCNE1, KCNJ10, SLC12A2, GJB family), serotonin receptor and transporters (e.g., SLC6A4), and neurotrophic factors (e.g., BDNF, GDNF). Two SNPs (ADD1, rs4961 and KCNE1, rs915539) were associated with chronic tinnitus (Pawelczyk et al., 2012; Yüce et al., 2016). SNP in SLC12A2 (rs10089) was associated with tinnitus and hearing loss (Pawelczyk et al., 2012). Marchiori et al. (2018) investigated polymorphism in TNFα and found that individuals with the TNFα -308 G allele were less likely to have tinnitus secondary to occupational noise exposure when compared to those carrying the A allele. However, these associations have not been validated or replicated to date. A GWAS of 4,000,000 SNPs showed no statistically significant associations with tinnitus. The study identified novel target genes and SNPs that showed a promising association trend with tinnitus (Gilles et al., 2017). A recent large-scale GWA study—with the UK biobank database as a discovery sample and the U.S. Million Veteran Program as a replication sample (Clifford et al., 2020)—identified six genomewide significant loci and 27 genes in the discovery cohort. The study replicated three out of the six loci and eight out of the 27 genes. Interestingly, the SNP-based heritability analyses across a range of tinnitus phenotypes explained only 6% of heritability, suggesting the polygenic nature of tinnitus phenotypes.

Table 2–1. A Nonexhaustive List of Studies Investigating the Genetic Influence on Tinnitus

Study	*Phenotype*	*Sample*	*Sample Size*	*Targeted Genes*	*Major Findings*
Kleinjung et al. (2006)	Tinnitus severity as assessed by the German version of the Tinnitus Questionnaire. Chronic tinnitus was defined as tinnitus perception for ≥1 year	**Cases:** Outpatients, aged 50.5 ±13.6 years, consulting for chronic tinnitus were included. All participants were Caucasians with subjective tinnitus. Participants with a history of vestibular schwannoma, Meniere's disease, or middle ear conditions were excluded. **Control:** None. The results were compared with a large control population of European ancestry.	N_{Case} = 88	5-HT1A	No significant genetic association was observed.
Sand et al. (2010)	Tinnitus severity, as assessed by the German version of the Tinnitus Questionnaire. The definition of chronic tinnitus was not specified.	**Cases:** Outpatients, aged 49.9 ±12.0 years, consulting for chronic tinnitus were included. All participants were Caucasians with subjective tinnitus **Controls:** None. The results were compared with a large control population of European ancestry.	N_{Case} = 201	KCNE1	No significant genetic association was observed.
Deniz et al. (2010)	Tinnitus perception for more than 1 year. Tinnitus evaluation was performed.	**Cases:** Patients, aged 20 to 51 years, with tinnitus complaint. **Controls:** Healthy volunteers with no tinnitus.	N_{Case} = 54 $N_{Control}$ = 174	SLC6A4	A weak association between SLC6A4 (5-HTTLPR) and tinnitus-related quality of life measure was observed.

Study	*Phenotype*	*Sample*	*Sample Size*	*Targeted Genes*	*Major Findings*
Sand et al. (2011)	Tinnitus severity, as assessed by the German version of the Tinnitus Questionnaire. Chronic tinnitus was defined as tinnitus perception for >6 months.	**Cases:** Outpatients, aged 50.1 ±12.6 years, consulting for chronic tinnitus were included. All participants were Caucasians with subjective tinnitus. Participants with a history of vestibular schwannoma, Meniere's disease, or middle ear conditions were excluded. **Controls:** None. The results were compared with a large control population of European ancestry.	$N_{Case} = 288$	KCNE3	No significant genetic association was observed.
Sand, Langguth, Itzhacki, et al. (2012)	Tinnitus severity, as assessed by the German version of the Tinnitus Questionnaire. The definition of chronic tinnitus was not specified.	**Cases:** Outpatients, aged 50.6 ±12.1 years, consulting for chronic tinnitus were included. All participants were Caucasians with subjective tinnitus. **Controls:** None. The results were compared with a large control population of European ancestry.	$N_{Case} = 95$	KCTD12	A weak association between tinnitus severity and KCTD12 (rs34544607) was observed.
Sand, Langguth, Schecklmann, et al. (2012)	Tinnitus severity, as assessed by the German version of the Tinnitus Questionnaire. The definition of chronic tinnitus was not specified.	**Cases:** Outpatients, aged 50.3 ±12.9 years, consulting for chronic tinnitus were included. All participants were Caucasians with subjective tinnitus. **Controls:** None. The results were compared with a large control population of European ancestry.	$N_{Case} = 240$	GDNF, BDNF	GDNF (rs1110149, rs884344, rs3812047) and BDNF (rs2049046, rs6265) genotypes jointly predicted tinnitus severity in females (uncorrected $p = 0.04$), but not in males.

continues

Table 2–1. *continued*

Study	***Phenotype***	***Sample***	***Sample Size***	***Targeted Genes***	***Major Findings***
Pawelczyk et al. (2012)	A response of "Yes" to the question "Do you suffer from tinnitus?"	The study conducted a retrospective analysis on 626 male participants—313 "sensitive" and 313 "resistant" to noise exposure after statistically controlling for the effects of age, gender, and noise exposure. **Cases:** Participants responding positively to the tinnitus question were included. Participants with history of major hearing problems were excluded. **Controls:** Participants reporting no tinnitus were included. These participants were from "resistant" and "sensitive" groups.	$N_{Case/male}$ = 128 $N_{Control/male}$ = 498	GJB1, GJB2, GJB3, GJB4, GJB6, KCNJ10, KCNQ4, KCNQ1, KCNE1, SLC12A2	KCNE1 (rs915539) was associated with tinnitus, independently of hearing loss. SLC12A2 (rs10089) was associated with tinnitus and hearing loss.
Orenay-Boyacioglu et al. (2016)	Tinnitus perception for at least 3 months. Tinnitus evaluation was performed	**Cases:** Patients, aged 18 to 55 years, with a tinnitus complaint were included. Patients with a history of major depressive disorder were excluded. **Controls:** Healthy volunteers aged 18 to 55 years without any otologic or systematic diseases were included.	N_{Case} = 52 $N_{Control}$ = 42	GDNF	No significant genetic association was observed.

Study	Phenotype	Sample	Sample Size	Targeted Genes	Major Findings
Yüce et al. (2016)	Patients suffering from chronic tinnitus for >6 months. Participants also responded to Strukturiertes Tinnitus-Interview and Tinnitus Handicap Inventory.	**Cases:** Patients, aged 48.1 ±13.5 years, with a complaint of tinnitus were included. Participants with acute and objective tinnitus, middle ear problems, and other health-related concerns were excluded. **Controls:** Participants reporting no otologic or systemic diseases were included.	$N_{Case} = 89$ $N_{Control} = 104$	ACE, ADD1	ADD1 (G460W) genotype ($p < 0.01$) and allele frequency ($p = 0.021$) revealed statistically significant association with chronic tinnitus.
Gilles et al. (2017)	A response of "Yes" to the question "Nowadays, do you ever hear noises in your head or ear(s) (tinnitus) which usually last longer than 5 minutes?"	**Cases:** Participants, aged 55 to 65 years, responding positively to the tinnitus question were included. Participants with major middle ear or health-related concerns were excluded. The selection of genotyped samples was based on the audiometric criteria discussed in Fransen et al. (2015). **Controls:** Participants reporting negatively to the tinnitus question and with no major otologic or systemic diseases were included.	$N_{Case} = 167$ $N_{Control} = 749$	Genome-wide association study	None of the SNPs achieved statistical significance. VDAC1, NKTR, COG3 showed promising main effects. Coenzyme A biosynthesis, 5HT2-type receptor, and NDK dynamin showed promising interaction effects. NRF2 and ER overload response showed promising joint test results.
Marchiori et al. (2018)	Participants were asked to give a score from 0 to 10 to the loudness of their tinnitus; where *0* represented the total absence of tinnitus while *10* indicated a maximum loudness of tinnitus, requiring going to a hospital to receive care.	A sample of 179 independent elderly participants above 60 years of age was collected from the "Study on Aging and Longevity." Cases and controls were defined on a continuous scale using tinnitus severity rating (0–10).	$N_{Case} = 77$ $N_{Control} = 102$	TNFα	The elderly with TNFα -308 G allele were less likely to have tinnitus due to occupational noise exposure when compared to those carrying the A allele (OR = 2.74; 95% CI: 1.56–4.81; $P < 0.0005$)

continues

Table 2–1. *continued*

Study	*Phenotype*	*Sample*	*Sample Size*	*Targeted Genes*	*Major Findings*
Clifford et al. (2020)	Mainly self-reported tinnitus: “Do you get or have you had noises (such as ringing or buzzing) in your head or in one or both ears that last for more than 5 minutes at a time?” Other information related to tinnitus was used in combination with the above definition.	The U.K. Biobank (UKB) sample with 172,995 participants. **Cases:** “Yes” to the data field 4803, “Do you get or have you had noises (such as ringing or buzzing) in your head or in one or both ears that last for more than 5 minutes at a time?” was used. **Controls:** “No” to the data field 4803. The GWAS findings were replicated with the U.S. Million Veterans Program. **Cases:** Those with the classification of diseases (ICD) code for tinnitus; those who checked the box to “Please tell us if you have been diagnosed with the following conditions: Tinnitus or ringing in the ears.” **Control:** Those with no ICD diagnosis, or those who did not check the box for tinnitus.	$N_{Discovery} = 172,995$ $N_{Case} = 52,769$ $N_{Control} = 120,226$ $N_{Replication} = 260,832$ $N_{Case} = 94,755$ $N_{Control} = 166,077$ (U.S. MVP)	Genome-wide association study	The study identified six genomewide significant loci and 27 genes in the discovery cohort. The study replicated three of the six loci and eight of the 27 genes.
Wells et al. (2021)	Mainly self-reported tinnitus: “Do you get or have you had noises (such as ringing or buzzing) in your head or in one or both ears that last for more than 5 minutes at a time?”	The U.K. Biobank (UKB) sample with 91,424 participants.	$N_{Case} = 14,829$ $N_{Control} = 119,600$	Genome-wide association study	Three variants in PCOR1 gene—rs4906228, rs4900545, 14:103042287_CT_C—showed significant association with tinnitus.

Tinnitus Phenotyping: A Critical Challenge for Genetic Association Studies

Tinnitus phenotyping remains a key challenge for investigating the genetic architecture of tinnitus due to several reasons. First, numerous studies have been conducted to identify pathophysiological mechanisms underlying tinnitus. However, the explanatory mechanism remains largely elusive (e.g., Henry et al., 2014). In animals, tinnitus is associated with cochlear hair cell damage, cochlear synaptopathy, and neural hyperactivity in certain central auditory nuclei (e.g., Hickox & Liberman, 2014; Kaltenbach et al., 2002). In humans, tinnitus is associated with indirect measures of cochlear damage (e.g., the reduced amplitude of otoacoustic emissions and auditory brainstem response [ABR] wave I) and presumed measures of increased central gain (e.g., a higher ratio of ABR wave V amplitude/wave I amplitude) (e.g., Gu et al., 2012). Additionally, nontraditional auditory structures such as the amygdala, hippocampus, middle and superior frontal gyri, cingulate gyrus, precuneus, and the parietal cortices are also associated with tinnitus (e.g., Landgrebe et al., 2009). However, a clinically reliable physiological biomarker for tinnitus is not known. In other words, a statistically significant group difference can be observed in the physiological measures using well-defined case-control groups, but these measures are not sensitive and specific enough to efficiently identify individuals with tinnitus.

Second, as noted, tinnitus is a symptom that often accompanies most hearing disorders (e.g., noise-induced hearing loss, presbycusis, ototoxicity, temporomandibular joint disorders, Meniere's disease, acoustic tumors, and reoccurring middle ear infections). Systemic diseases such as hypertension and diabetes can also influence tinnitus perception (e.g., Figueiredo et al., 2015; Gibrin et al., 2013). In addition, psychological factors such as stress, anxiety, depression, and mood also modify tinnitus and tinnitus-related distress in daily living (e.g., Bhatt et al., 2017). These comorbid conditions are likely to contribute to phenotypic variability.

Third, the clinical manifestation of tinnitus is highly variable. Tinnitus has a multidimensional clinical representation. It can be categorized using temporal features (i.e., acute, chronic), severity (i.e., mild, moderate, severe), pitch (i.e., low, mid, high), loudness (i.e., soft, loud), residual inhibition (i.e., temporary tinnitus suppression by exposure to sounds), forms (i.e., subjective/objective, constant/intermittent, unilateral/bilateral), and response to management (i.e., improving, worsening, no effects) (e.g., Vona et al., 2017).

The accurate classification of the tinnitus phenotype can be helpful to stratify tinnitus patients into subsets with a common biological basis. It can be argued that tinnitus patients with a common biological basis share more genetic elements than those with a different biological basis. The accurate tinnitus classification can thereby influence the efficacy of the genetic association studies for identifying the genetic risk factors for tinnitus. An initial tinnitus classification that may be useful to define tinnitus phenotypes was proposed by the Tinnitus Research Initiative (Landgrebe et al., 2010), followed by the Tinnitus Holistic Simplified Classification (Cianfrone et al., 2015). The Tinnitus Holistic Simplified Classification categorizes tinnitus according to involvement and interaction of auditory, somatosensory, and psychological systems in tinnitus genesis: (a) auditory tinnitus (due to auditory alteration only), (b) somatosensory tinnitus (due to complex auditory-somatosensory interactions), (c) psychopathology-related tinnitus (due to psychopathological interaction with the auditory system), and (d) combined tinnitus (two or three previous mechanisms combined). Others have classified tinnitus in three groups: originating from auditory, somatosensory, or a combination of auditory and somatosensory mechanisms (Levine & Oron, 2015). Tinnitus classifications have advanced in the recent past and now provide a common language for classifying tinnitus origin across different sites and countries. A weakness, however, is that simple categorical tinnitus classifications may not empirically reflect the phenomenological reality of tinnitus or may not directly correspond with the underlying biological processes. The phenotypic heterogeneity within tinnitus categories is necessary to be quantified for the genetic association analyses. There is a need for a quantitative and empirical deep phenotyping approach to tinnitus phenotyping.

Deep phenotyping can be described as the precise and comprehensive analysis of phenotypic characteristics in which the individual aspects of the phenotype are observed and quantified, generally in such a way as to be computationally accessible (e.g., Robinson, 2012). In the absence of a clinically reliable biomarker, a spectrum of phenotypic features is necessary to define the phenomenological reality of tinnitus. Deep phenotyping can allow the classification of tinnitus into subpopulations that differ in susceptibility (e.g., susceptible versus resistant to noise), phenotypic subclasses based on psychometric properties (e.g., high-pitch versus low-pitch tinnitus) and physiological manifestation (e.g., with versus without a higher ratio of ABR wave V amplitude/wave I amplitude) and pathological causes (e.g., age, noise exposure, ototoxic agent), or the likelihood of positive or adverse response to a specific intervention (e.g., a positive response to sound therapy). It is essential to delineate the clinical manifestation of tinnitus and related comorbidities such as hearing loss, hyperacusis, and other psychological factors to identify and differentiate genetic elements that control tinnitus manifestation from those playing modifying roles.

Recent studies have investigated phenotypic heterogeneity in tinnitus. A case history instrument has been developed to investigate tinnitus-related history and relevant comorbidities (Genitsaridi et al., 2019). The questionnaire is translated into six European languages for facilitating collaboration. Tinnitus subclassification has been proposed for deep phenotyping tinnitus (Genitsaridi et al., 2020). Some recent studies have employed an audiogenomic approach for documenting genetic influence on audiometric phenotypes (e.g., Bhatt et al., 2020; Bhatt et al., in press). The audiogenomic approach utilizes audiometric measures and self-reported tinnitus descriptors to quantify the tinnitus phenotypic spectrum. A wide range of measures (e.g., tinnitus matching, electrophysiological measures, and psychoacoustic measures) can be useful to quantify tinnitus features. The genomic data along with the environmental (e.g., noise exposure) and lifestyle-related (e.g., smoking) risk factors can be used to identify the genetic variants associated with features of the tinnitus phenotypic spectrum. A similar framework is proposed by the Swedish Tinnitus Outreach Project to investigate phenotypic subtypes of tinnitus in Sweden (e.g., Lugo et al., 2020).

Tinnitus, like height and other common human traits and diseases, likely has a highly polygenic genetic architecture (as recently demonstrated by Clifford et al., 2020). In other words, it is likely that a large number of common genetic variants exert small effects on the tinnitus phenotypic spectrum. Therefore, it is necessary to create a polygenic risk score (PRS) that takes into account a large number of genetic variants associated with tinnitus. PRS can help summarize this complex genetic susceptibility to the tinnitus phenotypic spectrum, thus helping develop clinical tools for tinnitus prevention and treatment. When combined with demographic, environmental, and audiological factors, PRS models can influence clinical decision-making for tinnitus prevention. A global interrogation of tinnitus with genetic and nongenetic risk factors can substantially advance our understanding of the underlying biology of tinnitus in a manner that is not currently possible without involving genomic tools.

Clinical Implications

Human genetics is revolutionizing healthcare by contributing to disease diagnosis, prevention, and treatment and by informing reproductive decisions. The genetic association to tinnitus can be instrumental for constructing a genetic risk profile for identifying susceptible individuals before they are exposed to environmental risk factors (e.g., noise, music, and ototoxic medications) and before they acquire irreversible damage to their auditory system. The genetic association to tinnitus will facilitate the development of preventative audiological care and targeted personal hearing health programs for individuals predisposed to tinnitus. Genetic biomarkers to tinnitus are critical in developing personalized intervention strategies, such as precision pharmaceutical approaches, the use of hearing protection devices, dietary changes or supplements, behavioral modifications, and hearing care education.

Key Messages

- The success of individualized tinnitus prevention and intervention programs depends on the stratification of tinnitus patients into subsets with a common underlying biological basis.
- Genetic studies have identified a polygenic nature of the tinnitus phenotypic spectrum. Precise and more detailed descriptions of clinical manifestations will be essential in future efforts to understand the morbid anatomy of the human genome underlying the biological processes responsible for tinnitus and related health concerns.
- Tinnitus deep phenotyping data, combined with an increasing amount of genomic data, appears to have immense potential to accelerate the identification of genetic association to tinnitus for developing individualized prevention and treatment strategies.

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3 HEALTH DETERMINANTS AND MODIFIABLE RISK FACTORS OF TINNITUS

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Introduction

There is long-standing interest in the risk factors for tinnitus. Some risk factors such as age and sex are not modifiable, but many speculated risk factors such as diet, exercise, and lifestyle can be modified. In this chapter, we review associations between modifiable risk factors, other health factors, and the incidence and prevalence of tinnitus. For a detailed discussion of public health research including prevalence, incidence, and epidemiological investigation of risk factors for health conditions such as tinnitus, readers are encouraged to review Biswas and Hall (2021).

Background

Much of what is known about tinnitus prevalence and related factors is based on cross-sectional retrospective analyses. This study design limits the ability to determine causal relationships and can lead to variable estimates of prevalence and relationship to modifiable factors (McCormack et al., 2016) but does serve a function in identifying common associations. Additional important considerations in examining tinnitus are the lack of an objective measure and lack of a common operational definition of tinnitus.

In the United States, many such descriptive studies have drawn on the National Health and Nutrition Examination Survey (NHANES) data sets for insights into tinnitus prevalence and risk factors (Cooper, 1994; Folmer et al., 2011; Mahboubi et al., 2013; Shargorodsky et al., 2010). NHANES is a large, nationally representative study enrolling thousands of participants in each 2-year cycle, providing cross-sectional insights into health status and health-related risk factors, including changes in cross-sectional data over time. Shargorodsky et al. (2010) estimated that some 50 million U.S. adults have episodic tinnitus (based on 25.3% prevalence in participants), and some 16 million have frequent tinnitus (based on 7.9% prevalence). Among youth, tinnitus lasting 5 minutes or more in the preceding 12 months was reported by 7.5% of the 12- to 19-year-old participants, translating into an estimated 2.5 million U.S. adolescents who likely experience episodic tinnitus. With 4.7% of participants reporting chronic tinnitus, some 1.6 million U.S. adolescents may experience chronic tinnitus (Mahboubi et al., 2013).

Early (1971–1975) NHANES data revealed the highest prevalence of tinnitus in Black and female participants (Cooper, 1994). In contrast, extrapolating from participants in more recent (1999–2004) cycles, Shargorodsky et al. (2010) reported that frequent tinnitus had the highest prevalence in older adults, non-Hispanic White participants, former smokers, and adults with hypertension, hearing impairment, loud noise exposure, or generalized anxiety disorder. Tinnitus has also been reported to be more prevalent in males than females, a finding attributed to a presumed greater exposure to noise (Sharma et al., 2018). Recent (1999–2006) analyses of the NHANES data comparing male veterans to nonveteran civilian males revealed higher rates of tinnitus in veterans (11.7%) than nonveterans (5.4%), with exposure to noise being an important factor (Folmer et al., 2011).

More recently, dietary quality has emerged as a risk factor for tinnitus. Controlling for age, sex, race/ethnicity, diabetes, noise exposure, and smoking status, Spankovich et al. (2017) found decreased odds of persistent tinnitus with healthier diets (i.e., diets that score higher on the Healthy Eating Index due to factors such as higher fruits and vegetables, lower salt and fat, and wide variety of foods) when evaluating NHANES 1999–2002 data. Diet quality also emerged as a significant factor in a follow-up study evaluating hearing difficulties, with tinnitus being significantly associated with poorer diet, noise exposure, diabetes, arthritis, neuropathy, vision difficulty, use of alcohol, and analgesic use when the sample was limited to normal hearing adults from the NHANES 1999–2002 cohort (Spankovich et al., 2018).

In another analysis including data from adolescent and young adult participants in NHANES (2005–2008), both overall and chronic tinnitus were associated with female gender, low income, exposure to passive smoking, type A tympanogram, and occupational and recreational noise exposure (Mahboubi et al., 2013).

A second major cross-sectional data source that has been used to investigate tinnitus and hearing loss prevalence is the Korean NHANES (see, for example, Cho et al., 2010; Kim et al., 2015; K. H. Park et al., 2014; Park & Moon, 2014). The first (2008) cycle of the Korean NHANES detected subjective hearing loss and tinnitus in 12.0% and 20.3% of participants, respectively (Cho et al., 2010). Later investigations exploring risk factors for tinnitus in additional cycles of the Korean NHANES revealed outcomes consistent with those of the U.S. NHANES, including noise exposure (Kim et al., 2015; Park & Moon, 2014), hearing loss (Kim et al., 2015; K. H. Park et al., 2014; Park & Moon, 2014), increasing age (Kim et al., 2015; K. H. Park et al., 2014), female sex (Kim et al., 2015; K. H. Park et al., 2014), cardiovascular disease (K. H. Park et al., 2014), and smoking (Kim et al., 2015).

The U.K. Biobank is a more recent large cross-sectional dataset containing data from more than 500,000 U.K. adults aged 40 to 69 years, and it has also been used to investigate tinnitus prevalence and risk factors (Dawes et al., 2020; McCormack et al., 2014). When data from 34,576 participants were evaluated, the prevalence of self-reported hearing difficulties was 26% and the prevalence of self-reported tinnitus was 16.9%. Of these, 9.2% reported both tinnitus and hearing difficulties (Dawes et al., 2020). With approximately 17% of the U.K. sample, approximately 20% of the Korean sample, and some 25% of the U.S. sample reporting tinnitus, it is clear that tinnitus is a common health issue even though the study-to-study differences in the definition and reporting of tinnitus symptoms reduce the ability to make direct comparisons of different international cohorts.

Longitudinal data are available in other large datasets. One of the major longitudinal studies in the U.S. is the Epidemiology of Hearing Loss Study (EHLS), with a large cohort of approximately 3,700 participants in Beaver Dam, Wisconsin (Cruickshanks et al., 1998). The EHLS has since been extended to include participant offspring as part of the Beaver Dam Offspring Study (BOSS), with approximately 3,200 participants (Zhan et al., 2010). The prevalence (i.e., percent affected cross-sectionally) and incidence (i.e., new cases within the longitudinal cohort) of moderately severe tinnitus have been tracked in these cohorts. Identified risk factors include hearing impairment (Nondahl et al., 2011; Nondahl et al., 2010), noise exposure (Nondahl et al., 2011), smoking (Nondahl et al., 2010), and the use of nonsteroidal anti-inflammatory (NSAID) medications (Nondahl et al., 2011).

Other very large epidemiological studies provide additional insights into hear-ing loss and tinnitus and their associated risk factors. In the Health Professionals Follow-Up Study, more than 50,000 male health professionals (dentists, optometrists, osteopaths, pharmacists, podiatrists, and veterinarians) enrolled, with self-reported professionally diagnosed hearing loss used to assess risk factors for hearing loss (Shargorodsky, Curhan, et al., 2010a, 2010b). Two additional very large epidemiological studies are the Nurses' Health Studies I and II, enrolling some 121,000 and 62,000 female nurses, respectively, with self-reported hearing problems tracked in both NHS I and II (Curhan et al., 2020; Curhan et al., 2018; Glicksman et al., 2014). In the following text, we draw from insights into tinnitus risk factors using studies of these and other populations.

Recent Advances

Cardiovascular Health and Tinnitus

A number of epidemiological studies have considered cardiovascular health issues including hypertension, stroke, heart disease/heart attack, diabetes mellitus, and smoking as risk factors for hearing loss and tinnitus (Curti et al., 2020; K. H. Park et al., 2014). In general, studies show a significant relationship between cardiovascular disease and hearing loss or tinnitus; however, the relationship is weak, even with these factors combined. Engdahl et al. (2015) reported that cardiovascular risk factors including smoking, resting heart rate, waist circumference, and physical inactivity only explained 0.2% to 0.4% of variance related to hearing loss. Stohler et al. (2019) found significant inverse relationships (meaning lower odds of reporting tinnitus) between tinnitus and numerous lifestyle factors and comorbid diseases including smoking, alcohol consumption, diabetes, and dementia in a U.K. sample. Stohler et al. (2019) investigated the incidence of tinnitus within a primary care database (i.e., tinnitus recorded by general practitioners); thus, tinnitus may have been underreported relative to Engdahl et al. (2015), who prospectively followed a population-based cohort.

Hypertension

Yang et al. (2015) performed a meta-analysis to study the relationship between hypertension and tinnitus. They included 19 studies and found the pooled odds ratio (OR) was 1.37, suggesting a 37% increase in the odds of reporting tinnitus among persons with hypertension. However, the data were limited to case-control and cross-sectional studies; thus, causal relationships could not be established. Other studies have reported no statistically significant relationship between hypertension and tinnitus (Deklerck et al., 2020; House et al., 2018; K. H. Park et al., 2014; Stohler et al., 2019).

Medications

Common medications for cardiovascular disease (e.g., loop diuretics) have also been implicated in tinnitus and hearing loss. However, the relationship is generally weak and highly dependent on factors such as dose, duration of use, age, and comorbidities (e.g., kidney dysfunction). Borghi et al. (2005) completed a prospective study of hypertensive patients and the incidence of tinnitus in patients receiving treatment with different antihypertensive drugs. Of the 476 patients, 82.4% reported no tinnitus percept, while 17.6% reported occasional or transient tinnitus. The study did not report any participants with constant tinnitus. The study enrolled patients receiving treatment with angiotensin-converting enzyme inhibitors, diuretics, beta-blockers, calcium channel blockers, antithrombotic drugs (mainly acetylsalicylic acid), 3-hydroxy-3-methylglutargyl coenzyme A (HMG-CoA) reductase inhibitors, alpha-blockers, and angiotensin II receptor blockers. In general, the prevalence of occasional or transient tinnitus was low, and higher prevalence was observed with diuretic use. In contrast, Lin et al. (2016) did not find a significant relationship between diuretics and risk of hearing loss in the large sample of female nurse participants in NHS I. Joo et al. (2020) examined numerous drugs with potential ototoxic properties including analgesics, loop diuretics, quinine, chemotherapy, and intravenous-delivered antibiotics for relationships with hearing loss in participants of the EHLS. Loop diuretics were related to a higher 10-year incidence of hearing loss, and both loop diuretic and NSAID use was associated with risk of progressive hearing loss. The lack of some expected relationships between known ototoxins and hearing loss may be explained by the general low utilization of medications with higher ototoxic properties in that population.

Low-dose aspirin is sometimes included in physician-supervised treatment plans for patients with a history of heart attack or stroke. Although high levels of aspirin induce temporary hearing loss and tinnitus in animals and in humans (Boettcher & Salvi, 1991; Chen et al., 2010; Kim et al., 2013; Sheppard et al., 2014), low-dose aspirin has not shown a relationship to tinnitus or hearing loss (Al-Khatib et al., 2018; Pokharel & Bhandary, 2017). However, the effects of low-dose aspirin on hearing cannot be excluded as larger longitudinal clinical trials may have greater sensitivity for detecting effects of low-dose aspirin on hearing (Lowthian et al., 2016).

Effects of low-dose aspirin and other analgesics on hearing have also been investigated in large epidemiological studies. For example, data from the Health Professionals Follow-Up Study and NHS I and II were used to examine the potential relationship between analgesics and incident hearing loss (Curhan et al., 2010; Curhan et al., 2012; Lin et al., 2017). Regular use of analgesics (e.g., aspirin, NSAIDs, and acetaminophen) in men was associated with increased risk of self-reported hearing loss, with greater effects in those younger than 50 years old and greater risks associated with longer duration of use (Curhan et al., 2010). Use of ibuprofen or acetaminophen for 2 or more days per week was associated with an increased risk of self-reported hearing problems in women (Curhan et al., 2012).

Similarly, longer duration of acetaminophen or NSAID use (other than aspirin) was associated with a slightly higher risk of self-reported hearing problems in women (>6 years of NSAID use compared with <1 year) (Lin et al., 2017). Although the increase in relative risk ratios has generally been small and studies have not controlled for other risk factors such as noise exposure, the data are notable because of the large number of consumers using over-the-counter analgesics.

In contrast to the above reported associations, Joo et al. (2020) did not identify a relationship between analgesics and incidence of hearing loss measured using pure-tone audiometry in participants of the EHLS; thus, additional research is warranted, potentially in the form of longitudinal studies as suggested by Lowthian et al. (2016). Interestingly, despite the potential for temporary auditory and gastric side effects, salicylate (the active ingredient in aspirin) has been pursued as an otoprotection strategy in both preclinical models and human clinical trials with some success (Behnoud et al., 2009; Chen et al., 2007; Li et al., 2002; Sha et al., 2006; Sha & Schacht, 1999).

In addition to the medications discussed above, tinnitus has been reported in combination with ototoxic medications such as cisplatin (Frisina et al., 2016; Niemensivu et al., 2016) and aminoglycoside antibiotics (Blankenship et al., 2021; Harruff et al., 2021; Sabur et al., 2021; Wangchuk et al., 2021). Recent data indicate a threefold increase in self-reported tinnitus during extended survival times after cisplatin treatment of either childhood cancer or testicular cancer, suggesting increases in risk relationships (Meijer et al., 2020; Skalleberg et al., 2021).

Genomewide association studies suggest possible genetic mediation of cisplatin-induced tinnitus (El Charif et al., 2019). The Tinnitus Handicap Inventory (THI) (Newman et al., 1996) has been used in several clinical trials for ototoxicity (Campbell et al., 2017; Campbell et al., 2003). Campbell and Le Prell (2018) noted that the Tinnitus Functional Index (TFI; developed by Meikle et al., 2012) has been adopted in a variety of clinical trials (Beukes et al., 2017; Henry et al., 2017; Theodoroff et al., 2017). The TFI has more recently been used to document ototoxicity (Harruff et al., 2021). The THI (NCT04226456) and TFI (NCT04262336) are both being used in studies on prevention of cisplatin-induced tinnitus using investigational medicines for the inner ear. Detailed review of the use of tinnitus surveys as one component of auditory test batteries within clinical trials assessing investigational medicines for different auditory indications is available in Le Prell (2021).

Diabetes Mellitus

Self-reported diabetes mellitus appears to be an independent determinant of hearing loss (Bainbridge et al., 2008, 2011). Spankovich et al. (2017, 2018) reported a significant relationship between diabetes and tinnitus in NHANES data, supporting a relationship that Gibrin et al. (2013) had previously described. Shih et al. (2017) found that people with a combination of diabetes and chronic kidney disease also have a higher risk of tinnitus. However, other studies did not identify a significant relationship between diabetes and tinnitus (Deklerck et al., 2020; House et al., 2018; Martines et al., 2015; Stohler et al., 2019). It should be noted that management of diabetes sometimes includes drugs with auditory side effects such as “ear pounding,” complicating the assessment of relationships between diabetes and tinnitus (DiSogra & Meece, 2019).

Smoking

A systematic review and meta-analysis found tobacco to be a general health risk factor for incidence of tinnitus (Veile et al., 2018). Notably, individuals who smoked tobacco were also more likely to be exposed to occupational or leisure noise without hearing protection devices, as well as other factors (e.g., poor diet quality and poorer general health) that could contribute to tinnitus separately from tobacco alone (further described below). There is also evidence suggesting that secondhand smoke exposure may be related to tinnitus. For instance, a study conducted in Serbia found that children in secondary school who were exposed to secondhand smoke had higher incidence of tinnitus (Marmut et al., 2014). However, as noted previously, there are numerous studies that do not support a relationship between smoking and hearing loss or tinnitus (see review by Deklerck et al., 2020) and even some that show a negative relationship (i.e., lower incidence of tinnitus with smoking). For example, Stohler et al. (2019) found significant inverse relationships (meaning lower odds of reporting tinnitus) with smoking. Additional research controlling for potentially confounding factors is needed to clarify potential relationships between tinnitus, smoking, and health conditions associated with smoking.

Confounding Factors

An interesting paradox for the relationship between tinnitus and hearing loss and cardiovascular health is observed in the African American ethnic group. African Americans have a lower prevalence of hearing loss and tinnitus compared to non-African American populations even though African Americans have higher prevalence of cardiovascular disease. For example, House et al. (2018) did not find a relationship between tinnitus and cardiovascular health factors among participants of the Jackson Heart Study, an African American longitudinal cohort study. Despite the lack of a relationship between cardiovascular health and reports of tinnitus, tinnitus severity as measured by the THI did show a relationship between hypertension and tinnitus and between waist circumference and tinnitus among participants of the Jackson Heart Study. These results suggest that persons who are obese with comorbid disease have greater reaction to their tinnitus due to increased stress, anxiety, or depression related to cardiovascular disease (Kalyani et al., 2017). A similar finding was reported from an analysis of the Korean NHANES. Tinnitus was not related to cardiovascular factors after adjusting for confounding variables; however, a relationship between cardiovascular risk factors/cardiovascular disease and annoying tinnitus was observed (K. H. Park et al., 2014).

Interaction Among Factors

Cardiovascular health factors (e.g., hypertension, stroke, heart disease/heart attack, diabetes mellitus) and smoking may influence each other (i.e., smoking is associated with heart disease and other health issues). In addition, adjusting for multiple health factors can alter the significance of the relationships between tinnitus and individual health factors. For example, even though smoking has shown some association with tinnitus and hearing loss (Nondahl et al., 2010), many studies find that smoking is no longer retained as a statistically significant factor after adjusting for other cardiovascular and lifestyle factors (Curti et al., 2019; Lin et al., 2011; Nondahl et al., 2002; K. H. Park et al., 2014; Rigters et al., 2018; Spankovich & Le Prell, 2014). Interestingly, Stohler et al. (2019) observed *reduced* odds of tinnitus report in smokers compared to nonsmokers and a similar relationship with alcohol intake; i.e., reduced odds of tinnitus among drinkers compared to nondrinkers, even in persons reporting >20 drinks per week. Deklerck et al. (2020), in a systematic review of nonotologic factors related to tinnitus, identified multiple cardiovascular, psychological, neurological, and lifestyle factors related to the report of tinnitus. However, for almost every risk factor listed above, studies that showed no significant relationship between tinnitus and the risk factor were found as often as studies that did show statistically significant relationships, while some studies even showed inverse relationships (e.g., lower odds of tinnitus with smoking). Reliance on correlations and associations is problematic as relationships cannot be assumed to be causal. Confounding factors must be carefully controlled; inclusion of different factors within association studies can influence the reliability of the detected relationships, as discussed above.

Exercise and Tinnitus

Three studies evaluating potential relationships between exercise habits and tinnitus severity are summarized in Table 3–1. Each of these studies used different tinnitus inventories or surveys. Loprinzi et al. (2013) evaluated data from the 2005–2006 NHANES cycle, which includes an initial yes/no question ("In the past 12 months, have you ever had ringing, roaring, or buzzing in your ears?"), followed by questions about frequency, duration of symptoms, bothersomeness, and how big a problem their tinnitus is. Carpenter-Thompson et al. (2015) used the TFI and additionally assessed participants' global quality of life using the Satisfaction With Life Scale (SWLS) (Diener et al., 1985) and their health-related quality of life using the Medical Outcomes Study 36-item short form (SF-36) (Ware & Gandek, 1994). Finally, Bazoni et al. (2019) used a basic survey that included yes/no responses regarding tinnitus. The variable of exercise was assessed in either a survey format or by using an accelerometer in each of the studies.

Two of the three studies revealed a negative correlation between tinnitus and exercise (Carpenter-Thompson et al., 2015; Loprinzi et al., 2013); i.e., increased exercise associated with decreased tinnitus questionnaire scores. With respect to quality of life and tinnitus, individuals who exercised more generally had higher quality of life, and individuals with more bothersome tinnitus tended to have poorer quality of life (Carpenter-Thompson et al., 2015). The third study did not find any statistically reliable correlation between exercise and tinnitus, but individuals with tinnitus who did not exercise had a higher risk factor for headaches (Bazoni et al., 2019). We are not aware of any intervention studies prospectively evaluating physical exercise for alleviation of tinnitus symptoms.

Caffeine and Tinnitus

Glicksman et al. (2014) studied the relationship between caffeine and tinnitus, drawing on the large Nurses' Health Study II. Participants were asked if they experienced tinnitus, how often they experienced tinnitus, and when they started to notice their tinnitus. To assess caffeine consumption, Glicksman et al. (2014) used the validated semiquantitative food frequency questionnaire about the average consumption of 130 foods over a 4-year period. The authors concluded that higher caffeine intake was reliably associated with a lower risk of incident tinnitus in women. In another study of caffeine intake as a possible risk factor, Petersen Schmidt Rosito et al. (2011) used

Table 3–1. Research Studies Investigating Relationships Between Exercise and Tinnitus

Study	***Sample***	***Tinnitus Criteria***	***Exercise Criteria***	***Results***
Loprinzi et al. (2013)	963 adolescents (12–18 y/o) and 473 older adults (70–85 y/o) drawn from NHANES.	Participants were asked if they experienced tinnitus in the last 12 months for longer than 5 minutes, and how long they were bothered by tinnitus.	Accelerometers were used to measure activity in 1-minute intervals over 7 days within age groups.	Physical activity negatively correlated with subjective tinnitus, with age-specific differences reported.
Carpenter-Thompson et al. (2015)	618 people completing online survey.	TFI; SWLS; SF-36	Godin Leisure-Time Exercise questionnaire, assessing frequency of three levels of exercise per week: strenuous, moderate, and mild.	Physical activity negatively correlated with tinnitus (as activity increased, subjective tinnitus decreased). Physical activity and tinnitus severity had independent effects on QOL.
Bazoni et al. (2019)	494 independently living individuals ≥60 y/o and enrolled in primary care in Londrina, Brazil.	Tinnitus queried as part of general health questionnaire asking about age, gender, tinnitus, headache, and comorbidities.	Participants asked if they exercised regularly. If yes, queried how often and for how long they exercised.	No statistical correlation between physical exercise and tinnitus. In individuals with tinnitus, possible association between lack of physical activity and headache.

Abbreviations: NHANES: National Health and Nutrition Examination Survey; QOL: Quality of Life; SWLS: Satisfaction With Life Scale (global quality of life); SF-36: Medical Outcomes Study 36-item short form (health-related quality of life); TFI: Tinnitus Functional Index

the Tinnitus Handicap Scale (THS) and a visual analog scale (VAS) to assess tinnitus. These researchers found no correlation between caffeine consumption and tinnitus severity (see Table 3–2).

Despite mixed results from association studies, several intervention studies evaluating whether reducing caffeine consumption alleviates tinnitus yielded conflicting conclusions (Table 3–2). In the first study, Claire et al. (2010) used the Tinnitus Questionnaire (TQ; described by Hallam et al., 1988) and measured caffeine using the Dietary Caffeine and Health Study Questionnaire

Table 3–2. Research Studies Investigating Relationships Between Caffeine Intake and Tinnitus

Study	***Research Design***	***Sample***	***Tinnitus Scale***	***Caffeine Consumption Criteria***	***Results***
Claire et al. (2010)	Intervention	66 volunteers who experienced bothersome tinnitus and regularly consumed at least 150 mg of caffeine per day.	TQ measured after day 1, 15, and 30 of reduced caffeine consumption; DASS, DSI, and IPQ-R.	Dietary Caffeine and Health Study Questionnaire	No association between caffeine abstinence and change in perceived tinnitus; caffeine withdrawal may be associated with headache, nausea, and increased tinnitus burden.
Petersen Schmidt Rosito et al. (2011)	Observational	136 clinic patients whose main complaint was tinnitus.	THS; VAS	Participants were asked about number of cups of black coffee they drank per day.	No significant correlation between black coffee consumption and THI or VAS.
Figueiredo et al. (2014)	Intervention	26 patients with tinnitus who consumed at least 150 mL of coffee every day.	THI (excluded if THI < 16)	Cups of coffee; intervention included 50% reduction in coffee consumption and no more than 150 mL coffee/day during intervention.	Individuals who drank <300 mL/day coffee had greater THI improvement; individuals <60 y/o perceived more change than those >60 y/o.
Glicksman et al. (2014)	Observational	65,085 nurses aged 30 to 44 years who participated in 2009 health survey (Nurses' Health Study II).	Participants asked: do you have tinnitus? If yes, asked how often and when tinnitus was first noted.	Validated semiquantitative food frequency questionnaire.	Inverse correlation between caffeine consumption and incidence of tinnitus.

Abbreviations: DASS: Depression, Anxiety, and Stress Scales; DSI: Daily Stress Inventory; IPQ-R: Illness Perception Questionnaire–Revised; THI: Tinnitus Handicap Inventory; THS: Tinnitus Handicap Scale; TQ: Tinnitus Questionnaire; VAS: Visual Analog Scale (from Heatherley et al., 2006) in addition to the Depression, Anxiety, and Stress Scales (DASS; from Lovibond & Lovibond, 1995), Daily Stress Inventory (DSI; from Brantley et al., 1987), and the Illness Perception Questionnaire-Revised (IPQ-R; from Moss-Morris et al., 2002). Reducing caffeine had no effect on TQ scores of participants. In fact, individuals experienced higher amounts of acute caffeine withdrawal symptoms (e.g., headache and nausea) that made the burden of tinnitus greater. In the second investigation, Figueiredo et al. (2014) measured subjective tinnitus using the THI and measured caffeine consumption based on the amount of coffee participants drank on a regular basis. Participants were asked to reduce caffeine consumption by half if they drank less than 300 mL of coffee, or to 150 mL if they drank more than 300 mL of coffee every day. The authors reported improved THI scores as well as decreased VAS scores after reduction of caffeine consumption, although participants who drank more than 300 mL of coffee before intervention perceived less benefit than those who drank less than 300 mL of coffee. Reductions in THI and VAS scores were greater in participants younger than age 60 than in those older than age 60. Hofmeister (2019), following a review of studies evaluating purported relationships between caffeine intake and tinnitus, concluded there is no scientific basis for guidance to avoid caffeine.

Substance Use and Tinnitus

Alcohol

A number of studies using tinnitus measures or national health questionnaires have found no association between alcohol consumption and tinnitus prevalence (Bhatt et al., 2017; Gallus et al., 2015; B. Park et al., 2014). When Pugh et al. (1995) asked patients in a tinnitus outpatient clinic if alcohol made their tinnitus worse, better, or had no effect, a majority of patients (62%) reported alcohol had no effect on their tinnitus, with the remainder reporting alcohol made their tinnitus worse (22%) or better (16%). In contrast to these negative results, Stephens (1999) found that 84% of participants recruited from a tinnitus clinic reported alcohol made their tinnitus worse. Greater awareness and increased loudness of tinnitus were the two most commonly reported interactions between alcohol and tinnitus.

Cannabis

There has been little human research on the prevalence of tinnitus in individuals who use recreational drugs. Smith and Zheng (2016) reviewed the literature on mechanisms of cannabis action and concluded that cannabis might be expected to exacerbate tinnitus. More recently, Qian and Alyono (2020), using data from 2011–2012 NHANES cycle, reported associations between tinnitus and marijuana use. However, these analyses did not detect dose-response relationships (i.e., there was no correlation between tinnitus severity and quantity or frequency of marijuana use). The data did not establish directionality between the two factors; i.e., whether individuals with tinnitus used marijuana as self-medication or whether tinnitus developed as a new symptom related to marijuana use.

Cocaine, Heroin, Hallucinogens, and Inhalants

No relationship was shown between tinnitus and use of cocaine, methamphetamines, or heroin in the report by Qian and Alyono (2020). These data are consistent with those of Han et al. (2010), who evaluated potential associations between health disorders and various illicit drugs (e.g., marijuana, cocaine, heroin, hallucinogens, and inhalants). While illicit drug use was associated with negative health conditions, the only drugs associated with tinnitus were hallucinogens and inhalants. One case report described hearing loss and tinnitus related to ecstasy use; however, the patient also experienced renal failure and other overdose effects—likely responsible for the sudden hearing loss and tinnitus (Sharma, 2001).

Prescription Opioids

Rare case reports of opioid- and heroin-associated hearing loss and tinnitus exist. However, in many cases, recovery occurs and hearing loss is generally limited to high-level drug abuse or overdose (Aulet et al., 2014). Campbell et al. (2017) reported that the opioid hydrocodone (Vicodin®) used at prescribed levels posed no significant risk of ototoxicity based on data from 1,207 patients in two Phase 3 clinical trials. There are reports of significant hearing loss with long-term use and/or short-term abuse of hydrocodone (Friedman et al., 2000; Ho et al., 2007; Oh et al., 2000). However, studies in animal models attribute this toxicity to the acetaminophen within this combination drug (Yorgason et al., 2010). Oral morphine was identified as the probable cause of sudden hearing loss and tinnitus in a patient with multiple disorders including type 2 diabetes mellitus, depression, sleep disorder, and hypertension (Leache et al., 2016). Reversible hearing loss has been reported after use of oxymorphone, the active metabolite of oxycodone (Boyle & Rosenbaum, 2013; MacDonald et al., 2015). A recent 20-year review of New Jersey Poison Center records (ToxiCALL®) identified 41 cases of hearing loss and/or tinnitus in association with recent opioid exposure. Of these 41 cases, the most common opioid exposures were heroin (51%), oxycodone (17%), methadone (10%), or tramadol (7%) (Mozeika et al., 2020). Thus, there is increasing evidence that overdose of opioid drugs has the potential for adverse auditory effects. However, it is unlikely that opioids used as prescribed pose significant ototoxic risk.

Diet and Tinnitus

Better overall dietary quality is significantly associated with decreased tinnitus prevalence (Spankovich et al., 2017, 2018). As summarized in Table 3–3, several specific dietary components and nutrients are also associated with reduced odds of tinnitus, including vitamin B12 (Dawes et al., 2020), protein (Dawes et al., 2020), fish (McCormack et al., 2014), fruit (Spankovich et al., 2017), brown bread (McCormack et al., 2014), and chocolate (Lee et al., 2019). Consuming a low-fat diet (Spankovich et al., 2017) and avoiding eggs (McCormack et al., 2014) are also associated with decreased tinnitus prevalence. Several specific dietary components and nutrients that are associated with increased odds of tinnitus include calcium (Dawes et al., 2020), iron (Dawes et al., 2020), fat (Dawes et al., 2020), wholemeal/wholegrain bread (McCormack et al., 2014), and fruits and vegetables (McCormack et al., 2014). In contrast, dairy avoidance (McCormack et al., 2014) and decreased vitamin B2 (Lee & Kim, 2018) are associated with increased tinnitus prevalence. Dawes et al. (2020) offer a comprehensive discussion of the specific ways in which each nutrient might contribute to the prevention or development of tinnitus. However, it must be noted that while certain foods and nutrients are associated with decreased odds of having tinnitus, this does not mean that consuming these foods will alleviate tinnitus symptoms. There is little systematic research address-

Table 3–3. Research Studies Investigating Relationships Between Diet and Tinnitus

Study	*Sample*	*Tinnitus Criteria*	*Hearing Criteria*	*Dietary Analysis*	*Nutrients Associated With Reduced Odds of Tinnitus or Hearing Loss*	*Nutrients Associated With Increased Odds of Tinnitus or Hearing Loss*
McCormack et al. (2014)	U.K. Biobank (171,122 participants aged 40–69 years)	Subset reporting transient tinnitus.	Speech-in-noise ratio (SNR) measured using triple-digit test; not used to determine study eligibility.	Semi-quantitative nonvalidated questionnaire	**Tinnitus:** Caffeinated coffee (OR 0.98 per cup/day); brown bread OR 0.94. **Hearing Loss:** Not reported.	**Tinnitus:** Dairy avoidance OR 1.18. **Hearing Loss:** Not reported.
McCormack et al. (2014)	U.K. Biobank (171,122 participants aged 40–69 years)	Subset reporting persistent tinnitus.	Speech-in-noise ratio (SNR) measured using triple-digit test; not used to determine study eligibility.	Semi-quantitative nonvalidated questionnaire	**Tinnitus:** Fish, nonoily OR 0.91; fish, oily OR 0.95; egg avoidance OR 0.87; caffeinated OR 0.99 per cup/day. **Hearing Loss:** Not reported.	**Tinnitus:** Fruit/ vegetable intake OR 1.01 per portion/day; wholemeal/ wholegrain bread OR 1.07; other bread OR 1.20; dairy avoidance OR 1.27. **Hearing Loss:** Not reported.
McCormack et al. (2014)	U.K. Biobank (171,122 participants aged 40–69 years).	Subset reporting bothersome tinnitus.	Speech-in-noise ratio (SNR) measured using triple-digit test; not used to determine study eligibility.	Semi-quantitative nonvalidated questionnaire	**Tinnitus:** Wholemeal or wholegrain bread OR 0.86. **Hearing Loss:** Not reported.	**Tinnitus:** N/A **Hearing Loss:** Not reported.

Study	***Sample***	***Tinnitus Criteria***	***Hearing Criteria***	***Dietary Analysis***	***Nutrients Associated With Reduced Odds of Tinnitus or Hearing Loss***	***Nutrients Associated With Increased Odds of Tinnitus or Hearing Loss***
Spankovich et al. (2017)	1999–2002 U.S. NHANES; 2,176 adults aged 20–69 years.	Ringing, roaring, or buzzing in the ears in past 12 months.	Required to have threshold data at 0.5, 1, 2, 3, 4, 6 and 8 kHz; participant excluded if PTA512 or PTA346 were >3 SD above the mean for their age group or >15 dB right-left difference.	Food-frequency questionnaire scored using HEI	**Tinnitus:** HEI OR 0.67; lower fat intake OR 0.69; higher fruit intake OR 0.61. **Hearing Loss:** N/A	**Tinnitus:** N/A **Hearing Loss:** N/A
Spankovich et al. (2018)	1999–2002 U.S. NHANES; 1,177 normal-hearing adults aged 20–69 years.	Ringing, roaring, or buzzing in the ears in past 12 months.	N/A: PTA5124 required to be ≤25 dBHL	Food-frequency questionnaire scored using HEI	**Tinnitus:** HEI OR 0.98 **Hearing loss:** N/A	**Tinnitus:** Alcohol OR 2.05; analgesics OR 1.90. **Hearing loss:** N/A
Lee and Kim (2018)	2013–2015 Korean NHANES; 7,621 normal-hearing adults aged 40–80 years without noise exposure.	Ringing, buzzing, roaring, or hissing sounds in past year.	Self-reported hearing problem	Semi-quantitative food frequency questionnaire	**Tinnitus:** N/A **Hearing Loss:** N/A	**Tinnitus:** Less vitamin B2 intake OR 1.253 **Hearing loss:** N/A

continues

Table 3–3. *continued*

Study	*Sample*	*Tinnitus Criteria*	*Hearing Criteria*	*Dietary Analysis*	*Nutrients Associated With Reduced Odds of Tinnitus or Hearing Loss*	*Nutrients Associated With Increased Odds of Tinnitus or Hearing Loss*
Lee et al. (2019)	2012–2013 Korean NHANES; 3,575 adults aged 40–64 years.	Presence of tinnitus; tinnitus-related annoyance.	PTA5124 ≥20 dBHL; PTA 346 ≥20 dBHL	Food frequency questionnaire; chocolate consumption	**Tinnitus:** N/A **Hearing Loss:** PTA5124: Chocolate OR 0.83; PTA346: Chocolate OR 0.777.	**Tinnitus:** N/A **Hearing Loss:** N/A
Dawes et al. (2020)	U.K. Biobank (34,576 participants aged 40–69 years)	Response to question about noises in the head or in one or both ears, that last for more than 5 minutes at a time.	Self-reported hearing difficulty	Oxford Web-Q 24-hour dietary recall questionnaire completed two to five times over 1 year.	**Tinnitus:** Vitamin B12 OR 0.85; protein OR 0.90. **Hearing Loss:** Vitamin D OR 0.90; fruits and vegetables OR 0.89; protein OR 0.88.	**Tinnitus**: Calcium OR 1.20; iron OR 1.20; fat OR 1.33. **Hearing Loss:** Fat OR 1.16

Abbreviations: HEI: Healthy Eating Index; kHz: kilohertz; N/A: Not Applicable (no significant results reported); NHANES: National Health and Nutrition Examination Survey; OR: Odds Ratio; PTA: pure-tone average threshold; PTA512: PTA at 0.5, 1, and 2 kHz; PTA5124: PTA at 0.5, 1, 2, and 4 kHz; PTA346: PTA at 3, 4, and 6 kHz; SNR: signal to noise ratio ing the potential for dietary changes to influence tinnitus symptoms.

The multiple observed relationships between dietary nutrients and tinnitus have contributed to long-standing interest in the use of supplements to alleviate tinnitus symptoms. As noted by Spankovich and Le Prell (2019), essential dietary nutrients support cellular stress response, immune response, cardiometabolic status, neural status, and psychological well-being. The study of these specific relationships is complicated, however, by the diversity in how animal species metabolize, utilize, and excrete nutrients as well as differences between animal species and humans. Potential benefits of dietary nutrients continue to remain poorly understood given the large number of possible nutrients and nutrient combinations that could be considered as possible investigational tinnitus therapies (Spankovich & Le Prell, 2019).

Over-the-Counter (OTC) Supplements and Tinnitus

Vendra et al. (2019) found more than 40 over-the-counter products (i.e., dietary supplements composed of vitamins, minerals, herbal ingredients) marketed for tinnitus relief despite the lack of research data. Patients regularly seek and use these over-the-counter products. A University of Iowa survey distributed to participants in tinnitus group sessions and national tinnitus self-help associations revealed that approximately 23% of survey participants reported taking supplements for tinnitus relief, with 71% reporting no benefit, 19% reporting improvement, and 10% reporting worsening of symptoms (Coelho et al., 2016). The data across studies are mixed, and few studies use randomized placebo-controlled double-blind studies to generate high quality data (Allman et al., 2016; Coelho et al., 2016; for reviews, see Dobie, 1999; Enrico et al., 2007). One notable exception is a well-designed clinical trial by Petridou et al. (2019) that demonstrated reduction in tinnitus loudness and minimum masking level with multivitamin-multimineral therapy. Caution is clearly required with respect to any recommendations for use of such agents as adverse effects of herbal remedies including herb–drug interactions are possible (Izzo et al., 2016) and increased rates of tinnitus after exposure to loud music have been reported for at least one supplement (Le Prell et al., 2016). Please refer to Chapter 14 for additional information on tinnitus supplements.

Mental Health and Tinnitus

The negative psychosocial effects of bothersome tinnitus are well established. Compared to individuals without tinnitus, those who report tinnitus are more likely to experience concurrent depression, anxiety, frustration, sleep disorders, reduced quality of life, and attention deficits (Henry et al., 2019; Leong et al., 2020; Liu et al., 2015; McKenna et al., 2014; Pattyn et al., 2016; Tyler & Baker, 1983). In rare instances, tinnitus is related to suicidal ideation and even suicide (Lewis et al., 1994; Szibor et al., 2019). The relationship between tinnitus and mental health has been explored within the NHANES datasets. Using data from the 2005–2006 NHANES cycle, Loprinzi, Maskalick, et al. (2013) found statistically significant associations between tinnitus and depression in adults aged 70 to 85 years, suggesting that those who perceive tinnitus as a moderate problem are more likely to be depressed than those who do not perceive their tinnitus as a problem.

Post-Traumatic Stress Disorder (PTSD)

The mutual reinforcement of the relationship between tinnitus and psychological issues is particularly evident in individuals with psychological injury such as PTSD (Fagelson & Smith, 2016). Tinnitus is the most common disability claim among recently discharged veterans (Yankaskas, 2013). Veterans with tinnitus are more frequently diagnosed with mental health disorders than veterans without tinnitus (Carlson et al., 2019). As part of the Noise Outcomes in Service Members Epidemiology (NOISE) study, Henry et al. (2019) reported a significant relationship between tinnitus and work performance, concentration, sleep, reported hearing ability, emotional well-being, and quality of life for active service members and veterans. Among service members in the tinnitus group, 21% were classified as having mild to moderate depression versus 6% of service members in the no tinnitus group. For veterans in the tinnitus group, 35% were classified as having mild to moderate depression compared to 12% in the no tinnitus group. Other authors have reported similar findings in the veteran population (Liu et al., 2015).

Fagelson and Smith (2016) compared tinnitus severity and distress among three groups: veterans with PTSD and tinnitus, veterans with other psychological health conditions and tinnitus, and veterans with tinnitus alone. The results showed that veterans with PTSD and tinnitus had significantly higher tinnitus severity and distress compared to the other two groups. Veterans with PTSD and tinnitus were also more likely to have sound tolerance issues. A possible interpretation is that the tinnitus is a constant reminder of the stressful events the veteran experienced that could, then, lead to an interpretation that the person can neither escape their tinnitus nor their memories.

COVID-19

A recent emerging concern is the relationships between incidence of SARS-CoV-2 (COVID-19), its otolaryngological symptoms (such as dizziness, tinnitus, and hearing loss), and mental health. An early review of the literature suggests that auditory and vestibular symptoms are more likely with COVID-19 than previous coronaviruses and the Middle East Respiratory Syndrome (MERS) (Almufarrij et al., 2020). A more recent review with pooled estimates of prevalence for tinnitus, hearing loss, and rotatory vertigo, primarily using retrospective symptom recall, was 14.8% (CI: 6.3–26.1), 7.6% (CI: 2.5–15.1), and 7.2% (CI: 0.01–26.4), respectively (Almufarrij & Munro, 2021). There is indeed a growing and rapidly evolving literature suggesting tinnitus as a possible comorbidity of COVID-19.

One early example of work in this area is a retrospective review of 50 patients with confirmed COVID-19 infection in Italy that revealed tinnitus was associated with other neurological effects such as loss of smell (Freni et al., 2020). A second retrospective review of 155 patients with confirmed COVID-19 infection in Turkey revealed otolaryngological side effects in 57% of patients. This study showed a higher prevalence of symptoms in females than in males, and greater frequency in the 18- to 30-year-old group than other age groups (Elibol, 2021). Of 116 Turkish patients with confirmed COVID-19, the proportion of those with auditory and vestibular symptoms was 11% for tinnitus, 5.1% for hearing loss, and 32.8% for dizziness. There were higher rates of dizziness, headache, smell/taste impairment, sore throat, and voice complaint in females than in males. The greatest frequency of dyspnea and cough was in participants older than 60 years, whereas tinnitus, true vertigo, headache, smell/taste impairment, sore throat, and voice impairment were more common in participants under 60 years of age (Özçelik Korkmaz et al., 2021). In an Italian multicenter study of 185 patients enrolled 30 to 60 days post-diagnosis, 18% reported equilibrium disorders (e.g., dizziness or vertigo), 23% reported tinnitus, and 7.6% reported both tinnitus and balance disorders (Viola et al., 2021). In contrast to these high rates of tinnitus, a study including 86 patients hospitalized with confirmed COVID-19 in China revealed only 3.5% with tinnitus symptoms (Liang et al., 2020). Not all studies report sex differences, and the recent systematic review by Almufarrij and Munro (2021) did not note sex differences in hearing and balance deficits associated with COVID-19.

An additional related concern is that proposed treatments for COVID-19 (including chloroquine and hydroxychloroquine) can have auditory side effects. The doses of chloroquine used in COVID-19 patients significantly exceed doses recommended for treatment of malaria, increasing the likelihood of side effects (Prayuenyong et al., 2020). Other medications proposed as COVID-19 therapeutics, including azithromycin, lopinavir-ritonavir, interferon, ribavirin, and ivermectin, have also been identified as having potentially ototoxic side effects (Little & Cosetti, 2021). As use of these therapeutics increases, it will be important to distinguish tinnitus associated with COVID-19 and tinnitus that may be related to experimental therapeutics with potentially ototoxic side effects.

Separate from COVID-19 related comorbidity, it is possible that stress and anxiety associated with the pandemic may influence tinnitus distress. Based on data from 16 patients in the United Kingdom, Munro et al. (2020) suggested that the anxiety that patients experienced during COVID-19 recovery may have exacerbated the anxiety they reported related to their tinnitus symptoms. An ongoing study of tinnitus-related anxiety in German patients queried 122 participants regarding tinnitus-related distress and depressive symptoms during the 2020 lockdown (Schlee et al., 2020). Significant relationships between the perceived lockdown-related stress and worsening of tinnitus distress relative to 2018 data were noted. In a third study assessing anxiety, tinnitus was not specifically explored; however, increased anxiety about communication needs was expressed by patients with hearing loss, based on concerns about the negative impact of mask use and social distancing on audibility and communication ability (Naylor et al., 2020). Interested readers are directed to Chapter 19 for additional information on the relationship between COVID-19 and tinnitus.

Dementia

The Lancet Commission on Dementia recently reported that hearing loss incurred in midlife is one of the strongest modifiable predictors of dementia (Livingston et al., 2020; Livingston et al., 2017). Some findings have also identified tinnitus as a potential factor in predicting cognitive decline, but the data do not consistently reveal such relationships. It has been postulated that the attention effects of tinnitus and influence on mental health may deplete or occupy cognitive resources (Jafari et al., 2019; Tavanai & Mohammadkhani, 2018). Additional research is necessary to understand relationships between hearing loss, tinnitus, and dementia.

Pharmacotherapy

The concurrent existence of negative psychological experience and tinnitus has led many healthcare providers to prescribe psychopharmacological treatments to help mitigate tinnitus-related anxiety, depression, or sleep disturbance (Hall et al., 2011). Reviews of psychopharmacological interventions show mostly no benefit in modulating the tinnitus signal. However, psychopharmacological interventions may help patients with the emotional reaction to their tinnitus (Palumbo et al., 2015). Nonetheless, the U.S. Food and Drug Administration (FDA) has not approved any pharmacological drugs for the treatment of tinnitus (Allman et al., 2016). Clinical practice guidelines of the American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS) published by Tunkel et al. (2014) recommend against the use of antidepressants, anticonvulsants, anxiolytics, or intratympanic medications for treatment of persistent bothersome tinnitus. The guidelines also do not recommend ginkgo biloba, melatonin, zinc, or other dietary supplements (Tunkel et al., 2014). However, it is recommended that patients with comorbid depression, anxiety, or sleep disturbance be referred to mental health professionals for assessment and treatment (Tunkel et al., 2014). The evidence-based AAO-HNS guidelines recommend cognitive behavioral therapy (CBT) for patients with persistent bothersome tinnitus (Tunkel et al., 2014). Indeed, psychotherapy such as CBT has consistently shown significant benefit in mitigating the emotional reaction and fear related to tinnitus (Cima et al., 2014; Cima et al., 2018; Fuller et al., 2020; Jun & Park, 2013) (see Chapter 11 for additional details).

Future Directions

It is unlikely that cardiovascular disease, lifestyle factors, mental health disorders, or medications commonly prescribed to treat cardiovascular disease or mental health disorders cause tinnitus. Nonetheless, these factors should be on the radar of the tinnitus practitioner as variables that may exacerbate patients' reaction to their tinnitus. In particular, medication and general health history should be evaluated to rule in or rule out factors contributing to tinnitus onset or change in tinnitus perception even if the correlation cannot establish a causal relationship. It is clear that persons with multiple comorbidities and medications are more likely to experience stress, anxiety, and depression that, in turn, can compound the perception of bothersome tinnitus. Of course, well-known ototoxic medications can cause tinnitus and hearing loss and can be evaluated as potential causal factors. Ototoxic drugs include aminoglycoside antibiotics, platinum-based neoplastics, high-dose aspirin, quinine, and loop diuretics, particularly those delivered intravenously (for detailed review, see Campbell & Le Prell, 2018).

Management of tinnitus should include general health and lifestyle considerations. Eating healthy, exercising, and reducing or discontinuing a nonototoxic medication is not likely to eliminate the patient's tinnitus or hearing complaints. However, a healthy lifestyle can improve overall physical and emotional well-being and potentially enable the patient to better habituate to their bothersome tinnitus.

Additional research is required to better define the possible relationships between tinnitus and individual variables such as diet, exercise, and caffeine. Control groups should be carefully considered in the research design, including masking (i.e., blinding), to treatment condition wherever possible. For instance, unlabeled coffee containing various ratios of caffeinated and decaffeinated beans could be considered to avoid bias. Quantitative tinnitus matching techniques should be considered and included, when possible, to separate changes in tinnitus perception from changes in tinnitus reaction. Finally, the potential for confounds should be carefully considered in future research. For instance, caffeine-containing foods (such as chocolate) or beverages other than coffee (such as caffeinated beverages, energy drinks, or tea) might be inadvertently consumed by participants and should be considered as part of trial design.

Clinical Implications

Tinnitus represents a multifaceted perception. In diagnosis of tinnitus and causal determination, we need to be cognizant of comorbid factors with inclusion or exclusion of the most likely suspect—peripheral auditory dysfunction (commonly due to noise, age, ototoxic drugs). In addition to factors that may underlie the onset or cause of tinnitus, we must further recognize factors that may influence the bothersome nature of tinnitus. General health (physical and psychological) and lifestyle changes may not cure tinnitus but can improve overall health and well-being and reduce the reaction to tinnitus.

Key Messages

- Health factors, including cardiometabolic health and lifestyle, are related to tinnitus perception and the bothersome nature of tinnitus. However, the strength of the relationships is in general insignificant and lacks support for causal relationships.
- Mental health represents an important risk factor for tinnitus. Although it is unlikely that depression or anxiety cause tinnitus, tinnitus can contribute to depression/anxiety, and depression/anxiety can exacerbate the reaction to tinnitus.
- Medication, supplement, and drug use should be considered as possible factors related to tinnitus perception, particularly those with well-established ototoxic properties (e.g., cisplatin, aminoglycoside antibiotics, high-dose aspirin). Other medications such as NSAIDs, opioids, hypertension-, and lipid-lowering drugs have limited associations with tinnitus perception when taken as prescribed.

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4 TOWARD INTEGRATION OF SOUND MAPS IN TINNITUS RESEARCH

Tae Hong Park

Introduction

Human activities generate environmental footprints that largely define modern urbanity and culture. Some of these activities result in fleeting acoustic footprints that can be categorized as *noise*—a type of sound that is unwanted from the receiver's perspective. With the growing global population and the rise of megacities that act as magnets for economic opportunities, culture, education, and entertainment, acoustic byproducts have similarly increased, leading to environmental noise below and above ground. In places like New York City, for example, noise is one of residents' top complaints (New York City Open Data, n.d.). The unyielding honking, constancy of traffic noise, and the omnipresence of loud music, regardless of time and space, is something New Yorkers have learned to endure. Adapting to noise, however, can lead to associated health risks. According to environmental psychology expert Arlene Bronzaft, "It means you've adapted to the noise . . . you're using energy to cope with the situation. That's wear and tear on your body" (Haberman, C., n.d.). Such wear and tear not only contributes to hearing impairment and tinnitus, but also to nonauditory health risks, including hypertension; sleep deprivation; and gastrointestinal, cardiovascular, and physiological disorders; as well as adverse impact on children's learning skills (Bronzaft, 2002; Evans et al., 2001; Kryter et al., 1970; Lang et al., 1992; Passchier-Vermeer & Passchier, 2000; Van Dijk et al., 1987; Ward, 1987; Woolner & Hall, 2010; Zhao et al., 1991). City centers are particularly loud during peak hours, when frequent and prolonged noise encounters can trigger tinnitus that often lasts well into the evening (Hurst et al., 2015). Urban sonic circumstances have become complicated in part due to rapid population growth and expansion of ever denser and larger megacities worldwide. These gigantic cities are now, for the first time in history, inhabited by more than 50% of the world's population (Zhao et al., 2017). By 2050, 68% of the global population is expected to live in such megacities (United Nations Department of Economic and Social Affairs, n.d.).

Given the context of sound, noise, and urbanity, the Citygram project (Park et al., 2012; Park, Musick, et al., 2014; Park, Turner, et al., 2014; Shamoon & Park, 2014; Mydlarz, Nacach, Park, et al., 2014; Hodge et al., 2016; Park, 2017) was launched in 2011 as an effort to measure, visualize, quantify, and automatically classify environmental sound or "soundscapes" and create dynamic sound maps to augment our understanding of the environment. Citygram, as further described in the forthcoming sections, is guided by a "3D" sound mapping approach that embraces *data-driven*, *community-driven*, and *art-driven* paradigms. In this chapter, we will summarize the 3D modules and examine application potential of sound maps in dynamically informing noise-induced hearing loss and tinnitus research.

Background

Beginning in the 1970s, environmental psychologists began to examine urban noise and its effects on wellness. While these studies did not place emphasis on comprehensively measuring and classifying urban noise events per se, they attempted to link community sound exposure to well-being, including its impact on cardiovascular stress (Knipschild, 1977), early developmental issues in children (Evans & Lepore, 1993), and students' school performance (Slater, 1968). These early studies also played a central role in developing noise codes and the language for discussing noise in public policy settings (Fidell, 1978).

In recent years, a variety of software applications have been developed to capture city noise by leveraging advances in communication, computer technologies, handheld computing devices, and the Internet of Things (IoT). Many of these applications (apps) have embraced the mobile device platform as a way to explore citizen science-centric noise measurement feasibilities. In 2008, the *NoiseTube* app was developed at Sony's Computer Science Laboratory (CSL) to measure personal noise exposure using smartphones, leading to the creation of crowd-sourced noise maps (Maisonneuve et al., 2009). This project aimed to create a participatory noise monitoring system involving the general public by harnessing the power of smartphones to measure personal environmental noise exposure. The CSL app relied on measuring site-specific average sound pressure levels to visualize data on web-based maps. Similar projects have followed, incrementally refining instrumentation, access, interaction, and visualization aspects. For example, *WideNoise* (2009) achieved substantial global popularity in citizen science noise exposure metering (WideNoise, n.d.), attracting thousands of worldwide users by (a) featuring a social user experience, (b) providing a sound tagging feature, and (c) including a microphone calibration module to address measurement discrepancies between smartphone manufacturers and models. Another more recent app is *SoundPrint* or "Yelp for noise" that aims to " . . . connect [you] with your friend, family, date, or colleague by discovering quiet and moderate places" (SoundPrint, n.d.). In the case of *SoundPrint*, data and readings are collected from its users to create ranked recommendation of places—such as best restaurants to visit—as a function of sound levels.

A recent academic research project example is Sounds of New York City (SONYC, n.d.) which was launched in 2015 and previously called the Citygram-Sound project. Its core researchers, who started collaborating with the Citygram team in 2013, are currently focusing on general aspects of urban noise pollution in New York City. The project also embraces the idea of a low-cost sensor network using custom Micro-Electro-Mechanical System (MEMS) microphones and network architectures built on foundational Citygram research (Mydlarz, Nacach, Park, et al., 2014; Mydlarz, Nacach, Rosenthal, et al., 2014; Park, Lee, et al., 2014; Park, Musick, et al., 2014; Park, 2017; Park, Turner, et al., 2014; Shamoon & Park, 2014). Its recent MEMS microphone module includes a microcontroller unit, building on the original *Citygram-Sound* MEMS analog design (Mydlarz, Rosenthal, et al., 2014) to render the mic into a fully digital data communication sensor (Virtanen et al., 2018). The custom sensor unit runs continuously in a self-contained rugged box placed in outdoor public spaces. Compressed, lossless audio data are streamed back from the sensor to a server in 10-second encrypted "snippets, interleaved with random durations" (Virtanen et al., 2018). While the benefit of this approach is that massive raw audio data are collected for scrutiny, it raises privacy concerns as unlike many of the other examples above, SONYC employs long-term sound monitoring devices that record public spaces: Even short 10-second audio clips can include an average of 23 words (Dahl & Friberg, 2003).

In the area of tinnitus smartphone apps, a systematic review by Mehdi et al. (2020) shows that apps topically fall into six categories: (a) tinnitus relief, (b) cognitive behavioral therapy (CBT), (c) hearing protection, (d) hearing testing, (e) hearing enhancement, and (f) smartphone-based electroencephalogram (EEG). These six categories address various aspects of tinnitus where, for example, apps in Category A provide tinnitus relief by generating synthetic sounds to mask problematic frequencies. What is missing, however, are apps that provide environmental sound measurement and analysis features—i.e., dynamic sound maps. Having such sound maps at one's fingertips has the potential to increase the awareness of noise-induced hearing loss (NIHL), thereby minimizing the incidence of NIHL and noise-induced tinnitus. The following sections summarize Citygram's 3D sound mapping research and its potential contribution to NIHL and tinnitus research.

Recent Advances

Citygram: Sound Mapping Our World in 3D

Citygram was developed with a 3D sound mapping approach in which each module focuses on three adages for creating a practicable pathway toward mapping urban soundscapes:

- *Data-driven:* "you can't fix what you can't measure";
- *Community-driven:* a sensor network "of, by, and for the people"; and
- *Art-driven:* urban noise awareness by embracing the notion of "music is the universal language of humankind."

The three "dimensions" and adages serve as foundational guidelines for creating sensor networks and sound maps that are: (a) based on environmental sound measurements, (b) robustly scalable and engage with the community, and (c) detailed across space and time. In the following sections, we focus on *data-* and *community-* with a brief overview of *art-driven* efforts in the context of the aforementioned dimensions.

Data-Driven

You Can't Fix What You Can't Measure. Measuring and collecting spatial data is critical in capturing environmental noise realities. These realities include *when* and *where* noise occurs, which in turn can bring insights into environmental impact on community well-being. Hurst et al. (2015) suggest that such data and information may help tinnitus sufferers avoid daily peak noise areas through predictions and visualizations. Sensor networks for capturing environmental sound data, however, are nontrivial in that it is difficult to simultaneously overcome system accuracy, scalability, and cost. High-end systems are accurate but costly, whereas low-end systems are cost-effective but typically suffer in accuracy. Systems falling in between are moderately priced and moderately accurate, but all systems are difficult to scale spatiotemporally from both technical and cost perspectives. For example, while Class 1 reference sound-level meters deliver maximum accuracy, each instrument can cost more than $1,000, not including the costs of preamplifiers, sturdy outdoor enclosures, power supply complications, and data access issues necessary for continuous, long-term noise measurement.

"Bigger [Data] is Better." Measuring environmental sound levels is one of the most critical steps in creating sound maps. However, in the context of noise maps, it is similarly important to determine what characteristics and what type of sound is associated with a given acoustic event, which in turn can further bring insights into the characteristics of hearing loss and tinnitus. There are ample studies showing populations suffering from tinnitus in urban centers like Assiut, Egypt, and São Paulo (Oiticica & Bittar, 2015). In Assiut, for example, researchers found significantly more tinnitus patients among urban dwellers compared to rural inhabitants (Khedr et al., 2010). Such studies provide insights into populations suffering from tinnitus in terms of population age, gender, income, and geographical locations. However, elements such as noise levels and the ebb and flow of soundscape patterns over space and time are typically absent in such studies. Soundscape data integration into the study of tinnitus has been a challenging task as noise constantly changes over time and significantly varies over geographical areas due to acoustic properties where sound energy decreases exponentially with distance. In particular, long-term noise monitoring and sound event characterization, or labeling sound events manually, is severely impractical due to (a) manual labor requirements to cover the vastness of space and time and (b) resulting massive data that need to be analyzed and managed. Even when considering a single sensor for a few days and for one specific location, the task becomes not only impractical, but only provides, at best, a spatiotemporally localized perspective. Thus, we argue for an automated sound collection and analysis system. In the case of Citygram, we deploy sensor devices that run deep convolutional neural networks and audio signal processing techniques to automatically extract and classify specific acoustic events from background and ambient sounds. The results are then summarized and transmitted to the cloud for storage and further analysis. Citygram accomplishes the majority of its audio computation including prediction at the source or edge. Commonly referred to as "edge computing," this computing approach is underexplored in the field of soundscape sensing (Shi et al., 2016). This design renders the sensor network highly scalable as the cloud module's primary task is relegated to archiving and collecting valuable data (e.g., prediction and noise event descriptors). Each edge device processes low-value, high-bandwidth raw audio data into high-value, low-bandwidth data that are transmitted to the cloud. This edge computing design simultaneously facilitates robust sensor network scaling and allays privacy concerns as raw audio data are not archived and never leave the edge device. With this approach, it's not possible to invert data such as sound decibel levels or prediction values into the original audio signal.

Community-Driven

To address the shortcomings of existing sound sensor network system designs, and in particular scalability, a *plug-and-sense* (PnS) sensor system design was created as part of the Citygram project. The PnS sensor system enables rapid scaling through a community-driven network model. This model harnesses common household resources to provide a sensor system that is easy to install and operate by the general public as follows: (a) The sensor software can run entirely on a web-browser; (b) the sensor software runs on most computing hardware systems including desktops, laptops, tablets, phablets, smartphones, and single-board computers; (c) while personal microphones and smartphones with built-in microphones can be used, Citygram custom sensors make practicable long-term sound monitoring via its sticker mics that can be attached to the outside of windows as shown in Figure 4–1A; and (d) sensor data are stored and managed on computer servers (i.e., cloud) using Wi-Fi or ethernet connections. Once set up, the sensor system then communicates with the servers to archive analyzed data by connecting to the home Wi-Fi. While the PnS sensor software can be entirely run on standard web-browsers like Chrome (Park et al., 2013; Park, Musick, et al., 2014), we have developed a custom sensor device for the Unix-based Raspberry Pi (RPi) single-board computer (Raspberry Pi, n.d.).

The PnS microphone system was inspired by decal stickers commonly attached to automobile windshields. It is essentially a type of window sensor that can be stuck to the outside of a window. The sticker or window sensor design allows the microphone unit to be decoupled from the computing unit to minimize footprint and cabling complications (e.g., power and data) and to address adverse weather conditions. The microphone is installed outdoors whereas the computing unit is protected indoors.

Figure 4–1A shows an early "*FlatCat 5*" sticker mic prototype that is stuck to a tabletop sign holder. Figure 4–1B depicts sensor installation on the outside of a window. A flat wire passes through the windowsill frame to provide wired connections to the outdoor mic unit while the RPi remains securely indoors.

Sound Map Portal: "Seeing Is Believing."

In addition to capturing raw audio data, measuring sound levels, and extracting high-value/low-bandwidth data, Citygram provides data access and visualization interfaces. Figure 4–2 shows a sound map visualization prototype with heat map layers that are used to display up to 1-second resolution dB measurements from sensor devices: Each heat map sensor node represents a unique sensor and changes its radius and color, reflecting increase and decrease in noise levels.

Figure 4–3 shows a picture-in-picture (PIP) visualization that appears when the user clicks on one of the sensor nodes in the zoomed-in heat map interface. The PIP visualization shows three different temporal resolution dB values: second resolution (top), minute resolution (middle), and hour

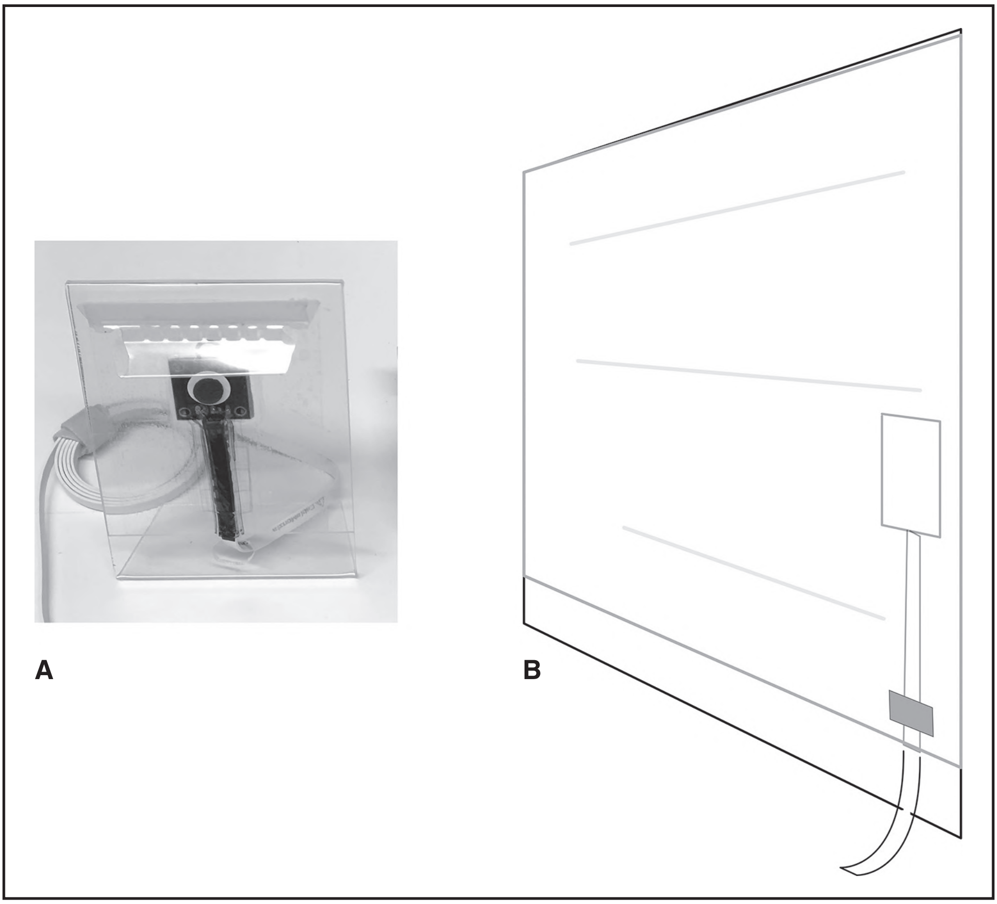

Figure 4–1. A. Early "FlatCat5" sticker mic prototype (*left*). **B.** Window sticker sensor on window depiction (*right*).

resolution (bottom). Users can also access location, date, and time of the sensor data that are being displayed.

Figure 4–4 shows a visualization example of a globe interface with dynamically changing vertical bars, indicating relative sound levels captured by sensors from a 10,000-foot global perspective. The globe interface allows users to rotate the globe in all directions using a pointing device such as a mouse or trackpad.

Lastly, Figure 4–5 shows a transport control menu at the top with icons typically used for audio players. Clicking on these icons enables visualization of noise from the beginning of a sensor's birthdate (beginning icon), specific past date and time (rewind icon), and real time (play icon). To create a sensor node, users can sign up and press the Citygram logo at the top lefthand corner to start sensing (see Figure 4–4).

Art-Driven: "Music Is the Language of Humankind"

While Citygram is primarily a technical research project that focuses on sound sensor networks and artificial intelligence (AI)

Figure 4–2. Heat map layer prototype indicating dynamic sound characteristics with 1-sec temporal resolution: Louder noise increases radius of heat map node.

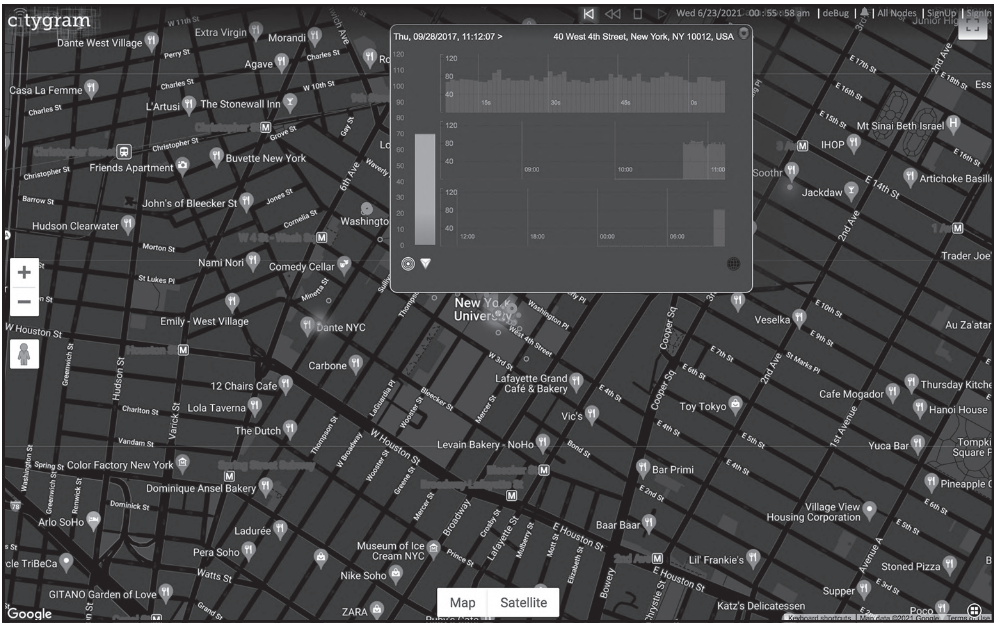

Figure 4–3. Picture-in-picture (PIP) showing dynamic sensor dB levels when a sensor is clicked: second resolution (*top*), minute resolution (*middle*), and hour resolution (*bottom*) resolutions. PIPs also show date/time and (optional) location of sensor.

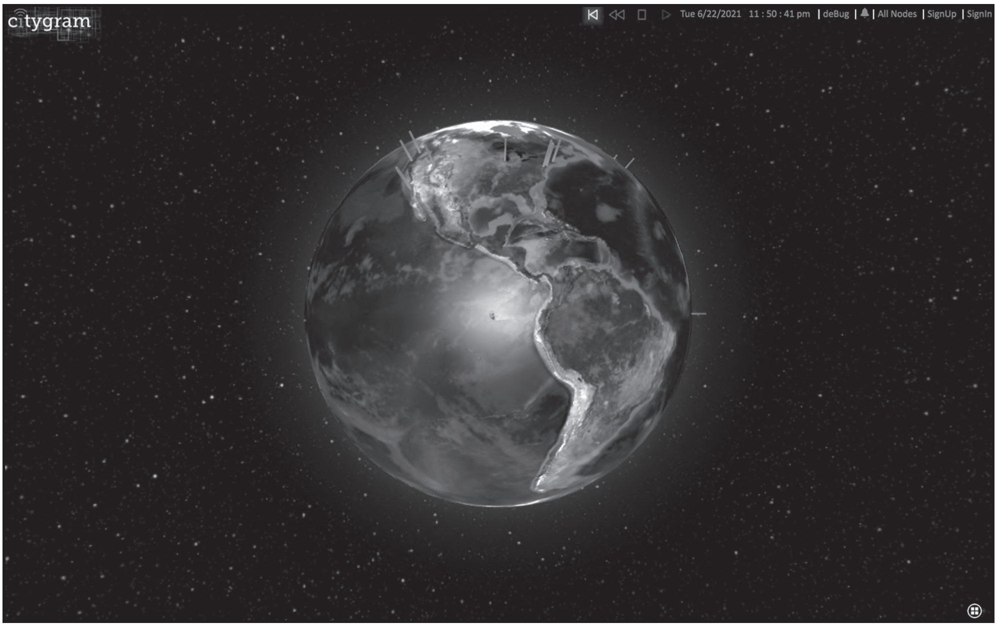

Figure 4–4. Globe interface prototype where vertical beams provide a “10,000-foot view” of spatial sound levels.

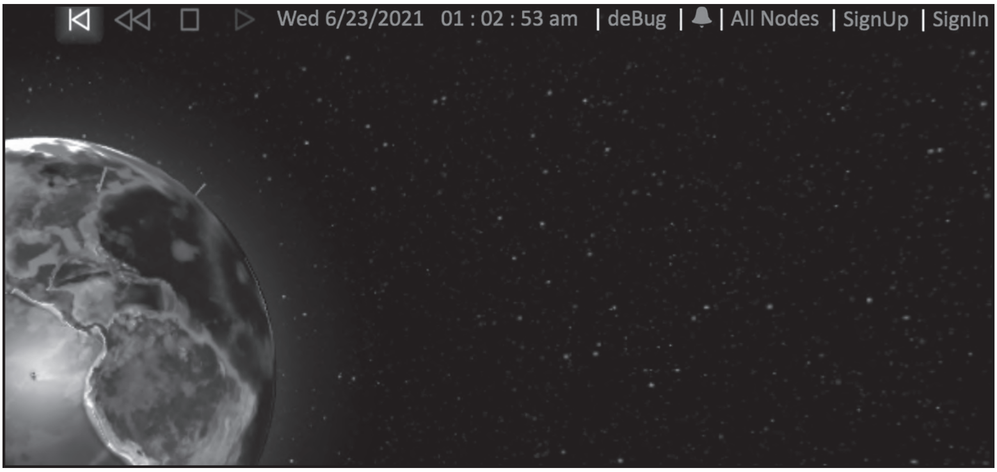

Figure 4–5. User controls including transport controls for noise animation options, sign in, and sign up for creating a new sensor node entry.

to track, classify, and visualize environmental noise, their efforts have also involved artwork creation using various Citygram modules. This effort, formalized under the third *D* or *art-driven* effort, embraces the notion of “music is the language of humankind” to address two main goals: (a) bring public awareness to the modern noise pollution phenomenon and (b) exploit the power of art to disseminate research results beyond traditional academic communities. The art-driven initiative has resulted in a number of multimedia artworks using Citygram sensor data including *S*(*e*)*oul Sound*(*e*) *scapes* (2017), *Sin*(*e*)*escapes* (2018), *and Bbb—Big cities, big noise, big data* (2015). *Bbb* was performed at Carnegie Hall at the United Nations—SDSN Music for a Sustainable Planet Concert in collaboration with Noisegate Festival, New York University, United Nations Global Arts Initiative, NYC Department of Environmental Protection, Harvestworks, Ircam, Music Hackathon at NYC Spotify, and ThinkCoffee.

Piloting Citygram: Community Aircraft Noise

Citygram was launched to create real-time sound maps leading to the development of a community-driven sensor network model, as summarized in the preceding sections. To determine its viability outside of the lab environment, Citygram is currently adapting the technology to measure, map, and visualize aircraft noise under the project name NOISY.

NOISY is an example of a research project transitioning from academia to the real world. The emphasis currently entails adjusting core Citygram technologies to render a sociotechnological system by: (a) reducing the scope of Citygram's general sound map creation goal and focusing on a specific noise type, (b) acknowledging community aircraft noise as a phenomenon experienced across cities worldwide, (c) considering aircraft noise impact and its classification as the most annoying noise source among standard transportation groups (Miedema & Vos, 1998), and (d) taking into account inadequacies of Federal Aviation Agency (FAA) sanctioned day-night average sound level (DNL) contour lines models that are based on airport operational activities (ISO, n.d.; Schomer, 2005). The FAA does not use sound sensors to create DNL contour lines, likely because airports have only a small number of costly sound sensors around them. For example, The Port Authority of New York and New Jersey manages 30 Brüel and Kjaer Noise Sentinel stationary sensors that cost approximately $29,000 per installation (Brüel & Kjaer, n.d.; CBS New York, n.d.). While these type 1 sound level meters provide accurate measurements (±0.7 dB), cost factors make coverage of large areas very difficult.

Over the past 11 years, noise complaints by citizens have increased significantly. For instance, at Chicago's O'Hare Airport, approximately 14,000 annual airplane noise complaints were filed in 2009 and 2010. By 2017, the complaints exponentially increased to approximately 5.5 million per year (Lunde, n.d.). These numbers are, however, insufficient in fully assessing residents' realities and sentiments as "high levels of annoyance can exist at low levels of noise exposure and low levels of annoyance can exist at high levels of noise exposure" (FICON, 1992; Fidell, 2003; Schultz, 1978). This situation benefits neither the airports nor their surrounding communities.

There are a significant number of active community organizations concerned with aircraft noise pollution in cities across the United States including New York and Chicago. In New York alone, there are seven such organizations including Queens Quiet Skies, Prospect Park Quiet Skies, and Eastern Queens Alliance. These organizations partake in community-organized roundtables where invited presentations are followed by question-and-answer segments. However, communities cannot do much other than voicing concerns and submitting complaints.

Studies have, unsurprisingly, reported on general correlations between aircraft noise and its impact on hearing (Lindgren et al., 2009; Takihata et al., 2020; Tarnopolsky et al., 1980; Yankaskas, 2013). For example, an analysis conducted at Heathrow Airport in the U.K. showed an increase in aircraft noise correlated with an increase in tinnitus among the 6,000 people surveyed (Tarnopolsky et al., 1980). In this study, as is usually the case with other such studies, noise levels were derived from average air traffic counts rather than from actual aircraft noise measurements. Typically, when physical measurements are conducted, they are made from the perspective of the individual via audiometric tests (Takihata et al., 2020). While these tests provide valuable insights into the individual's hearing health, little information about the actual acoustic environmental conditions is known. Thus, comprehensive spatiotemporal noise measurements and analyses around airports may help provide additional insights regarding the impact of aircraft noise on a community's hearing abilities.

One of the main objectives of the NOISY project is to discover *when*, *where*, and *why* aircraft sound is perceived as aircraft noise. To accomplish this objective, Citygram is developing a community-driven smart aircraft noise sensing and reporting system. The project has three main components: (a) a community-driven sensor network model using the Citygram PnS sensor system, (b) a smart aircraft noise reporting system that automatically detects and tracks aircraft noise, and (c) a data visualization and monitoring system available to all participating members who have NOISY devices installed. Citygram will report findings from this project and will address the when and where of sound-to-noise transformation with the goal of contributing to an understanding of *why* sound is perceived as noise.

Clinical Implications and Future Directions

This chapter summarized a data-driven, community driven, and art-driven sound mapping system guided by sociotechnological research and development efforts to create a sound mapping system that is scalable, dynamic, and smart. As urban centers are becoming bigger, denser, and more complex, the infrastructural machines that keep them functional—subways, buses, jackhammers, sirens, air conditioners, helicopters, and airplanes—inevitably produce acoustic byproducts that can adversely impact residents' health and well-being. In this context, sound mapping research has the potential to further our understanding of the ebbs and flows of noise, which in turn can inform development of data-driven strategies in improving urban residents' quality of life.

As described in other chapters in this book, hearing science research has contributed to more accurate diagnosis and description of tinnitus from the perspective of the patient. However, day-to-day environmental sound dynamics are not typically known, measured, or understood. Integrating spatiotemporally accurate and long-term environmental noise measurements into tinnitus research has been challenging due to difficulties in acquiring, storing, and sharing such data. The potential for applying highly granular spatiotemporal noise data in tinnitus research holds promise not only for tinnitus researchers, but also for policy makers, academics in various disciplines, individuals with bothersome tinnitus, and the general public. Application of dynamic soundscape data in tinnitus research could potentially resemble the following workflow: (a) automatic, semiautomatic, or manual capture and automatic analysis of locative noise measurements, (b) automatic classification of sound sources, (c) automatic analysis of particular frequency emissions over time, and (d) development of data-driven strategies that create sonically optimal pathways for individuals and communities. Outputs of such a system could lead to identification of harmful sound sources for individuals, dampening specific frequencies emitted by such sources, informing sound absorber installation strategies to reduce frequencies adversely affecting tinnitus, and creation of interactive sound maps accessible on smartphones to generate optimal sound paths with minimal harmful noise characteristics. Applied research may contribute to the dynamic management of personal sound environments and improve therapeutic practices such as tinnitus retraining therapy (TRT) (Jastreboff, 2011), specifically in the context of retraining the brain at subconscious (i.e., subcortical) levels to minimize annoyance to tinnitus sounds.

While generating dynamically accurate city sound maps may seem a distant future possibility, this future could be already closer than meets the eye, as virtual assistant AI technologies and smart speakers are commonplace items in modern households today.

Key Messages

- Dynamic sound mapping technologies are underexplored in hearing science.
- Research on dynamic sound mapping can create awareness about NIHL and tinnitus.
- Mobile computing is a widely accessible resource for tinnitus researchers, tinnitus patients, and the general public.
- Personal dynamic sound maps can be employed to reduce the incidence of NIHL and tinnitus in the future.

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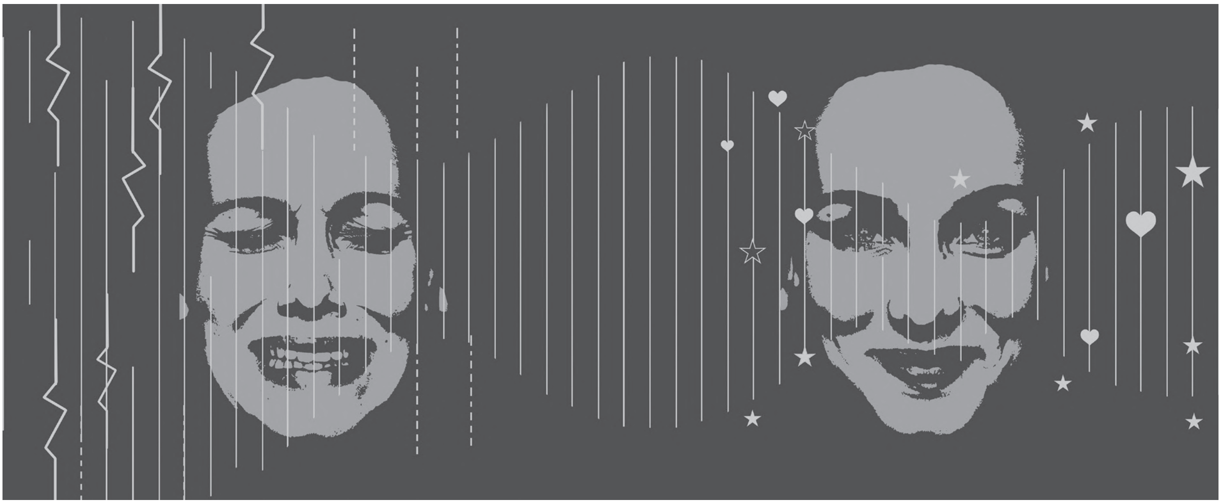
SECTION II

ASSESSMENT OF TINNITUS



5 THE IMPORTANCE OF PATIENT HISTORY

Patricia C. Mancini and Richard Tyler

Introduction

Although tinnitus is a very common symptom among individuals with hearing loss, its characteristics and impact differ greatly from one patient to another. Indeed, no two patients experience their tinnitus in the same way. This great variability occurs because the overall impact of tinnitus is influenced not only by characteristics of tinnitus, such as pitch, loudness, and quality, but also a patient's traits and reactions to the tinnitus (Dauman & Tyler, 1992; Tyler et al., 2006; Tyler et al., 2014; Tyler et al., 2015). We can suppose that tinnitus is more likely to be annoying if it is reported as having a screeching quality or is very loud (Stouffer & Tyler, 1990; Tyler, 2006). Psychoacoustic characteristics of tinnitus are indeed relevant, but there are many other aspects to consider for a complete understanding of the consequences that tinnitus has on a person's life and how debilitating it can be. When tinnitus affects concentration, thoughts, emotions, hearing, and sleep, patients can experience limitations in secondary activities such as socialization and work, as well as general quality of life (Tyler et al., 2014; Tyler et al., 2020). Therefore, to help tinnitus patients, it is important to address each patient's individual problems and needs.

One of the most important aspects of helping tinnitus patients is to develop a positive professional relationship to connect with them (Coles & Hallam, 1987; Tyler et al., 2001). Show them you care. Listen to them! Many tinnitus patients have some misconceptions regarding tinnitus, which make them more distressed (Mancini et al., 2018). Some may just want a pill to cure their tinnitus (Tyler, 2012). Taking the time to obtain a careful case history, and to understand the patient's individual problems and needs, is a critical first step in connecting with the patient and developing an effective management plan. A detailed case history will allow the audiologist to answer three main questions: (a) How much is the tinnitus bothering the patient? (b) What do they expect from me? and (c) How can I help the patient to cope with tinnitus?

In this chapter, we discuss aspects of patient history and relevant questionnaires that are intended to measure the patient's reactions to tinnitus. The history and questionnaires provide audiologists with enough information to start counseling sessions, to test patients' hearing abilities, and/or to refer them to otolaryngologists or other healthcare professionals, when necessary.

Background

Taking a case history is essential for all tinnitus patients. A thorough initial case history is crucial to (a) understand the problems associated with tinnitus the patient is experiencing, (b) identify areas to address in counseling sessions, (c) distinguish tinnitus that is bothersome from that which is not, and (d) educate the patient about the probable cause of tinnitus and its consequences (Coles & Hallam, 1987; Tyler, 2006; Tyler et al., 2008).

It is often helpful during the initial appointment to go over patients' tinnitus history and the findings on questionnaires and self-assessments (Tunkel et al., 2014). It is recommended that patients' case history include questions on (Tyler et al., 2006):

- Characteristics and perception of tinnitus—for example, how long the patient has perceived bothersome tinnitus; the localization of tinnitus, tinnitus pitch, quality, and loudness; and the patient's annoyance with the tinnitus; and
- Consequences or impact the tinnitus has on the patient's life, including consequences on sleep, concentration, thoughts and emotions, hearing ability, and general quality of life.

The Tinnitus Research Initiative group developed the Tinnitus Sample Case History Questionnaire, an instrument for standardized collection of information on the case history and the characteristics of the tinnitus patient. This questionnaire is available for download in many languages in the resources for researchers section at the Tinnitus Research Initiative website (Tinnitus Research Initiative, 2021).

Recently, the European School for Interdisciplinary Tinnitus Research Screening Questionnaire (ESIT-SQ) (Genitsaridi et al., 2019) was developed with specific attention to questions about potential risk factors for tinnitus (including lifestyle, demographics and general, medical, and otological histories) and tinnitus characteristics (including perceptual modulating factors, characteristics, and coexisting conditions). Therefore, this questionnaire assists clinicians and researchers in collecting important information about patients' tinnitus. It was first developed in English, and then translated into Dutch, German, Italian, Polish, Spanish, and Swedish, thus having broad applicability and supporting international collaboration.

Open-ended and closed-ended questions are used to collect information regarding the patient's case history. Open-ended questions ask patients to think and reflect, and to offer their opinions and feelings about tinnitus. Closed-ended questions are quick and easy to answer, and help to quantify and categorize patients' responses. Examples of questions to create a patient's case history are shown in Table 5–1.

Since tinnitus frequently co-occurs with hearing loss, this symptom shares many of the same risk factors as hearing loss, including occupational noise, exposure to toxins, work-related diseases, medications or drugs, nonoccupational noise exposure, otological diseases, head injury, dizziness, and general health status (Kochkin et al., 2011; Tunkel et al., 2014). In Table 5–1, question 16 addresses the main causes of hearing loss and tinnitus. It is important to gather appropriate information in the case history to be able to carry out directive counseling. All facts from the case history are useful in explaining to the patient the possible causes of tinnitus.

Table 5–1. Examples of Key Questions When Creating a Tinnitus Patient's Case History

1. What is your gender? ( ) M ( ) F
2. What is your age? _________ years old
3. Where is your tinnitus located?
    a. Left ear
    b. Right ear
    c. Both ears, equally
    d. Both ears, but worse in left ear
    e. Both ears, but worse in right ear
    f. In the head, but no exact place
    g. More on the right side of head
    h. More on the left side of head
    i. Outside of head
    j. Middle of head
4. Does your tinnitus affect your everyday life? If so, how?
5. Does your tinnitus keep you from falling asleep or wake you during the night? If so, how?
6. Does your tinnitus interfere in your ability to communicate with others? If so, how?
7. *If there is a hearing loss:* Which is more bothersome to you, your hearing loss or your tinnitus?
8. Does the PITCH of the tinnitus vary from day to day? ( ) Yes ( ) No
9. Does the LOUDNESS of the tinnitus vary from day to day? ( ) Yes ( ) No
10. Describe the typical ANNOYANCE of your tinnitus using a scale from 0–100. (*0* = not annoying at all; *100* = extremely annoying): _______________
11. Which of these qualities BEST describes your tinnitus?
    a. Ringing or whistling
    b. Cricketlike
    c. Roaring, "shhh," or rushing
    d. Buzzing
    e. Humming
    f. Hissing
    g. Other, please specify: ___________
12. On an average, how many days per month are you bothered by your tinnitus? ________ days
13. How many months or years have you had tinnitus? ______ months OR ______ years
14. When you have your tinnitus, what makes it WORSE?
    a. Alcohol
    b. Being in a noisy place
    c. Being in a quiet place
    d. Caffeine (coffee/tea/cola)
    e. Drugs/medicine
    f. Eye movement
    g. Food (please specify): ___________
    h. Moving your head or neck
    i. Physical activity
    j. Relaxation
    k. Touching your head
    l. Wearing a hearing aid
    m. When you first wake up in the morning
    n. Being tired
    o. During your menstrual period
    p. Emotional or mental stress
    q. Lack of sleep
    r. Shooting guns, rifles, etc.
    s. Smoking
    t. Nothing makes it worse
    u. Other, please specify: _______________

continues

Table 5–1. *continued*

15. Which of the following REDUCES your tinnitus?
    - a. Alcohol
    - b. Being in a noisy place
    - c. Being in a quiet place
    - d. Caffeine (coffee/tea/cola)
    - e. Drugs/medicine
    - f. Eye movement
    - g. Food (please specify): __________
    - h. Moving your head or neck
    - i. Physical activity
    - j. Relaxation
    - k. Touching your head
    - l. Wearing a hearing aid
    - m. When you first wake up in the morning
    - n. Nothing makes it better
    - o. Other, please specify: ________________

16. What do you think originally caused your tinnitus?
    - a. Aging
    - b. Autoimmune disease
    - c. Brain tumor
    - d. Cochlear implant, after surgery
    - e. Cochlear implant, after switch on
    - f. Cochlear implant, unknown
    - g. Deafness from birth, genetic
    - h. Deafness from birth, syndromic
    - i. Deafness from birth, unknown
    - j. Diabetes
    - k. Electrical trauma
    - l. Head injury
    - m. Medication/drug
    - n. Ménière's Disease
    - o. Middle ear, blood vessel
    - p. Middle ear, muscle
    - q. Middle ear, unknown
    - r. Noise exposure
    - s. Noise exposure (nongunfire, impulsive)
    - t. Noise exposure (hunting/gunfire)
    - u. Noise exposure (military service)
    - v. Otosclerosis
    - w. Problems with teeth or jaw
    - x. 8th nerve tumor (acoustic neuroma)
    - y. Sudden hearing loss
    - z. Surgery
    - aa. Thyroid
    - bb. Unknown
    - cc. Other (please specify): __________

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During the initial appointment, clinicians educate patients about the probable causes of tinnitus and the relation of tinnitus to hearing loss. It is also necessary to provide appropriate reassurance that the tinnitus does not represent a progressive condition or a grave illness, based on the results of a previously conducted medical evaluation. Of course, before starting audiological management, it is critically important for an otologist to first evaluate patients with pulsatile tinnitus, worsening or sudden onset tinnitus, asymmetrical hearing, and signs or symptoms of other diseases of the auditory system.

Questionnaires are used to assess the impact of tinnitus on a patient. Many questionnaires are available to quantify the patient's reactions to tinnitus, tinnitus-related distress, severity of tinnitus, the primary functions affected by tinnitus, and other domains. These questionnaires help clinicians to (a) choose the appropriate intervention or referrals, (b) identify areas that need to be addressed, and (c) document changes when administered before, during, and after intervention. The choice of which questionnaire to use is at the discretion of the clinician. Validated questionnaires should be used, for instance, in the assessment of tinnitus severity and psychiatric comorbidity (e.g., depression and anxiety). Table 5–2 summarizes information from the principal questionnaires available to assess other problems related to tinnitus, such as depression, anxiety, and sleep disturbances. Importantly, patients presenting with severe tinnitus accompanied by warning signs such as depression, anxiety disorder, severe insomnia, unrealistic thoughts or actions, suicidal ideations, isolation from family and friends, and aggression should be referred promptly to a mental health professional (National Institute for Health and Care Excellence [NICE], 2020; Tunkel et al., 2014; Tyler et al., 2015). It is important to note that although audiologists do not typically administer them, they must be aware of these questionnaires that measure problems related to tinnitus to facilitate care when interacting with psychologists and mental health professionals. Additionally, it is important to highlight that many of the questionnaires are subject to copyright and may have fees for usage. Information related to hyperacusis assessment can be found in Chapter 17.

Recent Advances

An estimated 10% to 15% of adults experience tinnitus (Davis & El Rafaie, 2000; Kochkin et al., 2011). While some people with tinnitus are able to relegate their tinnitus to the background and continue with their daily routine, others are not able to do so. It is estimated that 1% to 2% of the population experiences significant psychological difficulties that stem from bothersome tinnitus (Baguley et al., 2013; Tunkel et al., 2014). There are a few guidelines (NICE, 2020; Tunkel et al., 2014) to assist health-care professionals with the assessment, investigation, and management of tinnitus in primary, community, and secondary care. The guidelines provide recommendations for assessment and management of tinnitus patients, and offer advice to clinicians about supporting tinnitus patients as well as about referrals for specialized care.

The clinical practice guidelines (Tunkel et al., 2014) strongly recommend that audiologists distinguish between patients with bothersome and nonbothersome tinnitus. The guidelines define bothersome tinnitus as that which “distresses the patients and affects their quality of life (QOL) and/or functional health status” (Tunkel et al., 2014, p. S15). These patients need management strategies to alleviate their response to tinnitus. Patients with nonbothersome tinnitus do not have reduced QOL but they may have concern or curiosity about the natural history of the condition, the cause, and management options. For these patients, it is usually adequate for a clinician to listen to their concerns during initial contact and to provide general information about tinnitus (Tyler, 2006). The clinical practice guidelines (Tunkel et al., 2014) provide clinicians with a logical framework to improve tinnitus patient care and to mitigate the personal and social effects of persistent (i.e., lasting 6 months or longer) bothersome tinnitus. Answers to questions 4, 5, 6, 10, 11, 12, and 13 in Table 5–1 may also assist clinicians in differentiating bothersome and persistent tinnitus from nonbothersome tinnitus.

Tinnitus has two components: (a) the *perception* of a sound, and (b) the *reaction* to this sound (Dauman & Tyler, 1992; Henry et al., 2014; Tyler, 2006). The *perception* of tin-

Table 5–2. Principal Questionnaires to Evaluate Problems Related to Tinnitus (Depression, Anxiety, and Sleep Disturbances)

Questionnaire	***Purpose***	***Number of Items***	***Response Format***
Beck Depression Inventory* (Beck et al., 1961)	To assess the severity of the patient's depression.	21 multiple-choice items.	Patients are asked to indicate which choice is most representative of their feelings. The response is scored numerically from 0–3 to calculate a total score ranging from 0–59. A higher BDI score represents a higher level of depression.
State-Trait Anxiety Inventory (Spielberger et al., 1970)	To measure the general state or feelings of a patient.	40 items (20 items for assessing trait anxiety and 20 for state anxiety). A children's version is also available.	Each item is assigned a number from 1–4 by the patient that represents how they feel about themselves. The responses produce a total score from 20–80. A higher total score represents a higher level of anxiety.
Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983)	To be used as a screening instrument to detect states of depression and anxiety in the setting of a hospital medical outpatient clinic.	14 items (seven items for assessing depression and seven items for anxiety).	Each item is assigned a number from 0–3 by the patient that represents how they have been feeling in the past week.
Pittsburgh Quality Sleep Index** (Buysse et al., 1989)	To assess the patient's sleep habits.	24 items (five of which are completed by a patient's bed partner).	Seven subscores, ranging from 0–3 each. The subscores are tallied, yielding a global score that can range from 0–21. A global score of 5 or more indicates poor sleep quality; the higher the score, the more severe sleep difficulties patients experience.
Depression, Anxiety, and Stress Scales (DASS) (Lovibond & Lovibond, 1995)	To measure depression, anxiety, and stress.	42 items and 21 items (short form) that evaluates the degree of depression, anxiety, and stress (normal, mild, moderate, severe, and extremely severe).	A simple scale is used to rate each statement (*0* = never; *1* = sometimes; *2* = often; *3* = almost always).

Table 5–2. *continued*

Questionnaire	***Purpose***	***Number of Items***	***Response Format***
Patient Health Questionnaire (PHQ-9) (Kroenke et al., 2001)	To measure depression severity.	Self-administered nine questions that evaluate how often the patient have been bothered by some depression feelings.	A scale from *0* (not at all) to *3* (nearly every day) is used to rate each statement.
Insomnia Severity Index (Bastien et al., 2001)	To measure insomnia and evaluate management response.	Seven-item self-report questionnaire assessing the nature, severity, and impact of insomnia.	A 5-point Likert scale is used to rate each item (e.g., *0* = no problem; *4* = very severe problem), yielding a total score ranging from 0–28. A higher total score represents a more severe insomnia.

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**It is required to complete a request form for permission to use.

nitus can be assessed through standardized test protocols (see Chapter 6). A patient's *reactions* to tinnitus include sleep disturbances, emotional problems, hearing and communication difficulties, and problems with concentration (Tyler & Baker, 1983). These effects vary from patient to patient.

The clinical practice guidelines on tinnitus (Tunkel et al., 2014) recommend that audiologists incorporate established questionnaires into their clinical practice, since they provide an important tool for understanding the problems faced by the patient. These questionnaires help characterize the type of tinnitus-related disability and quantify its severity. These instruments also provide a baseline measure to assess the effect of interventions and help clinicians to determine who needs urgent or emergent psychiatric referral. An understanding of the severity of the problem and the areas impacted by tinnitus is important to provide adequate management to the patient. As noted, there are many validated and useful questionnaires available for quantifying a patient's reactions to tinnitus (see Newman et al., 2014, for a review). These questionnaires primarily differ on the (a) number of questions, (b) functions assessed, and (c) scales used. Table 5–3 summarizes the information from established self-administered questionnaires that are easily available to audiologists. The selection of the optimal measurement tool largely depends on the intended purposes of the test. In most cases, more than one tool may be needed.

The Tinnitus Handicap Inventory (THI) (Newman, et al., 1996) is commonly used to assess tinnitus handicap. The Tinnitus Primary Functions Questionnaire (Tyler et al., 2014) is another valid, reliable, and sensitive questionnaire focused on the primary handicaps of tinnitus, and provides initial guidance to understand what areas are affected for each patient (Tyler et al., 2014; Tyler & Deshpande, 2015). Most patients have diffi-

Table 5–3. Validated Questionnaires to Evaluate Functional, Emotional, and Other Effects of Tinnitus

Questionnaire	***Purpose***	***Number of Items***	***Response Format***
Tinnitus Questionnaire (Hallam et al., 1988)	To assess tinnitus-related distress.	52	Three levels: true, partly true, not true.
Tinnitus Handicap Questionnaire (Kuk et al., 1990)	To assess tinnitus severity.	27	Level of agreement to each statement (0–100; *0* = completely disagree; *100* = completely agree).
Tinnitus Reaction Questionnaire (Wilson et al., 1991)	To assess the psychological distress associated with tinnitus.	26	5-point scale (not at all, a little of the time, some of the time, a good deal of the time, almost all the time).
Tinnitus Severity Index (Meikle, 1992; Meikle et al., 1995)	To measure the negative impact of tinnitus on a patient's life and how bothersome patients perceive their tinnitus to be.	12	Three to four levels; response choices varied between questions (original version); changed to five levels in later version.
Client-Oriented Scale of Improvement for Tinnitus (Searchfield, 2019)	To identify problems associated with tinnitus, set goals for therapy, and determine effectiveness of management.	Up to 5	Open-ended questionnaire in which the patient is asked to nominate up to five goals for tinnitus management.
Tinnitus Handicap Inventory (Newman et al., 1996)	To assess the impact of tinnitus on patient's daily life.	25	Three levels: yes, sometimes, no.
Tinnitus Functional Index (Meikle et al., 2012)	To measure the negative impact of tinnitus as well as management-related changes.	25	11-point scale (0–10).
Tinnitus Primary Functions Questionnaire (Tyler et al., 2014)	To evaluate the primary functions affected by tinnitus.	20- and 12-item versions	0–100 (*0* = completely disagree; *100* = completely agree)
Meaning of Life (Tyler et al., 2019)	To evaluate the everyday difficulties associated with hearing loss and tinnitus.	23	0–100 (*0* = completely disagree; *100* = completely agree)

culty with thoughts, emotions, and hearing loss. Others also have difficulty with sleep and/or concentration. The brief 12-question version of this questionnaire can be completed quickly and contains the directions necessary to provide more comprehensive counseling (Table 5–4). After appropriate information is gathered during clinical history and via questionnaires, tinnitus counseling can be targeted to the patient's individual needs in thoughts, emotions, hearing, concentration, and/or sleep.

Table 5–4. The 12-Item Version of the Tinnitus Primary Function Questionnaire

Please indicate your agreement with each statement on a scale from *0* (completely disagree) to *100* (completely agree).

#	Concentration	*Agreement*
1	I feel like my tinnitus makes it difficult for me to concentrate on some tasks.	
2	I have difficulty focusing my attention on some important tasks because of tinnitus.	
3	My inability to think about something undisturbed is one of the worst effects of my tinnitus.	
	Emotion	
4	My emotional peace is one of the worst effects of my tinnitus.	
5	I am depressed because of my tinnitus.	
6	I am anxious because of my tinnitus.	
	Hearing	
7	My tinnitus masks some speech sounds.	
8	In addition to my hearing loss, my tinnitus interferes with my understanding of speech.	
9	One of the worst things about my tinnitus is its effect on my speech understanding, over and above any effect of my hearing loss.	
	Sleep	
10	I am tired during the day because my tinnitus has disrupted my sleep.	
11	I lie awake at night because of my tinnitus.	
12	When I wake up in the night, my tinnitus makes it difficult to get back to sleep.	

Future Directions

Audiologists receive adequate training to help patients with hearing loss and are taught how to manage the consequences of hearing loss in all domains—social, educational, psychological, physical, and emotional. However, many audiologists do not have adequate training in managing the consequences of tinnitus. A survey conducted by Husain et al. (2018) highlighted the needs and expectations of patients with tinnitus and compared these results with the expectations of audiologists providing management to tinnitus patients. Interestingly, 59% of the audiologists reported that they wanted more graduate school training on tinnitus management, suggesting that audiologists need more resources on tinnitus management. Similarly, 57% of the patients reported that the audiologist or physician did not fully answer their questions (Husain et al., 2018; Tyler & Perreau, 2019), emphasizing the need for more information about tinnitus for both patients and audiologists.

It is clear that audiologists benefit from detailed training on tinnitus management. Properly trained audiologists can help tinnitus patients. Patients with bothersome tinnitus often have hearing loss and benefit from hearing aids (Searchfield, 2006). In addition, sound therapy can often be helpful (Folmer et al., 2006; Kochkin et al., 2011; Tyler et al., 2015). Fortunately, there has been more interest in recent years in enabling both patients and audiologists to improve tinnitus awareness and management (Husain et al., 2018; Tyler & Perreau, 2019).

Hearing healthcare providers can expand their services by including tinnitus counseling and management. Audiologists can help patients by providing specialized counseling for tinnitus, hearing aids, and sound therapy devices using comprehensive and patient-centered care. Audiologists need to be nurturing, knowledgeable, and equipped to effectively assist patients with bothersome tinnitus. We hope that more audiologists will deepen their knowledge in counseling options and connecting with tinnitus patients to provide appropriate support.

Clinical Implications

Fortunately, people with tinnitus are now becoming more aware of the significance of hearing loss and tinnitus (Tyler et al., 2020). As a communication problem, hearing loss makes it difficult for some tinnitus sufferers to connect to their partners and significant others. It is important to consider that partners play an important role in tinnitus management, since they have a close personal relationship with patients. The patient's partner or significant other is welcome to attend the initial clinic visit, if the patient feels comfortable with their presence. In the authors' clinic, partners and significant others are usually encouraged to attend and participate in the first appointment and follow-up sessions, as they can better understand the patient's problem, provide emotional support, and help motivate the patient to comply with the recommendations. The difficulties patients with tinnitus may experience can also affect their significant others' lives, impacting their relationship and activities of everyday life (Mancini et al., 2018; Tyler & Baker, 1983; Tyler et al., 2006; Tyler et al., 2014).

Partners usually have a limited knowledge regarding tinnitus and its possible consequences (Mancini et al., 2018; Perreau et al., 2019). In our experience, the inclusion of partners in the initial visit and counseling sessions of tinnitus patients allows both to find appropriate strategies for managing tinnitus in home and social environments, and can further help patients to cope with tinnitus (Mancini et al., 2019; Perreau et al., 2019).

Key Messages

- Taking the time to obtain a careful case history, and to understand the patient's individual problems and needs, is a critical first step in connecting with the tinnitus patient and developing an effective management plan.
- Be a good listener! Encourage patients to share their thoughts and understanding on tinnitus and what their expectations are.
- A detailed case history provides the audiologist the information on how bothersome the tinnitus is and the effects it has on a patient's life.
- There are many validated questionnaires intended to measure the patient's reactions to tinnitus, its severity, and other problems related to tinnitus, such as depression, anxiety, and sleep disturbances.
- Clinical history and questionnaires provide the audiologist with enough information to start counseling sessions, to test the patient's hearing, and/or to refer the patient to otolaryngologists or other healthcare professionals when necessary.
- Partners and significant others should be encouraged to attend and participate in the first appointment and follow-up sessions, since they can better understand the patient's problem, provide emotional support, and help motivate the patient to comply with the audiologist's recommendations.
- When appropriate information is gathered during clinical history and via questionnaires, tinnitus counseling can be targeted to the patient's individual needs in thoughts, emotions, hearing, concentration, and/or sleep.
- Audiologists can help patients by providing specialized counseling for tinnitus, hearing aids, and sound therapy devices using comprehensive and patient-centered care.

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6 AUDIOLOGICAL ASSESSMENT OF TINNITUS

James W. Hall III

Introduction

Readers will note that the organization of this chapter deviates from the format followed in other chapters in the book. Headings in this chapter reflect, in a rather typical clinical sequence, the major steps in comprehensive audiological assessment of hearing and tinnitus. The subject matter of the chapter did not lend itself to the topical headings found in other chapters; specifically, recent advances, future directions, clinical implications, and key messages.

The six main goals of audiological assessment of patients with bothersome tinnitus are to: (a) rule out or confirm disease or pathology underlying tinnitus, (b) document health conditions and other factors contributing to or playing a role in the patient's perception of tinnitus, (c) comprehensively evaluate auditory function to identify peripheral or central auditory dysfunction associated with the mechanisms of tinnitus, (d) describe the nature of and quantify the severity of the patient's tinnitus, (e) define the impact of tinnitus on quality of life, and (f) contribute to decisions regarding an effective management plan. In assessing any patient, it's important to keep in mind that tinnitus is a symptom, not a disease. Much of the audiological assessment is focused on determining whether a patient's tinnitus is a symptom of a specific disease or pathology that requires medical evaluation and possibly medical or surgical management. Consistent with long-standing clinical practice and more recent evidence-based clinical practice guidelines (e.g., Tunkel et al., 2014), unilateral or asymmetrical tinnitus is a criterion for prompt audiological referral of a patient to otolaryngology. However, the vast majority of patients with bothersome tinnitus are not diagnosed with otologic, neurological, or other diseases or disorders. Most often, tinnitus is associated with auditory dysfunction and/or hearing loss associated with exposure to high-intensity sounds, advancing age, ototoxicity, general health factors for tinnitus such as certain systemic diseases, diet, and lifestyle (e.g., smoking). It's not uncommon to encounter patients whose tinnitus is related to a combination of these risk factors.

Clinical practice guidelines offer diverse and sometimes conflicting recommendations for the procedures and protocols that should be included in audiological assessment of patients with bothersome tinnitus. International clinical practice guidelines for tinnitus include those developed by task forces and committees of professional organizations (e.g., American Academy of Audiology, 2000; American Academy of Otorhinolaryngology—Head and Neck Surgery [AAOHNS], 2016; British Society of Audiology, 2019) and government agencies (National Institute for Health and Care Excellence [NICE] (2020). As Henry and colleagues (2020) noted recently: "*Methods of both tinnitus assessment and intervention are numerous, and consensual standards do not exist to inform inter-clinic consistency in conducting these procedures. As a result, audiologists who provide tinnitus services vary greatly in how the services are delivered.*" (p. 14) Selected discrepancies in recommendations among guidelines are noted throughout this chapter. Clinical experience with diagnostic audiological assessment of patients with bothersome tinnitus supports the following general guiding principles:

- Audiological assessment requires an evidence-based diagnostic test battery.
- The test battery consists of objective and behavioral auditory procedures.
- The test battery consists of multiple sensitive measures of peripheral and central auditory function.
- Efficiency is a priority for clinical audiological assessment of patients with bothersome tinnitus. The overall goal is to obtain, as quickly as possible, accurate diagnostic information needed to implement timely and effective management.
- The test battery is limited to value-added procedures that contribute to accurate diagnosis and effective management of auditory dysfunction and tinnitus.

This chapter provides a clinically feasible approach for audiological assessment of a patient with bothersome tinnitus. Key components of the assessment process include general and tinnitus-specific patient history, validated questionnaires or inventories for documenting patient reaction to tinnitus and the impact of tinnitus on quality of life, a test protocol for evaluating auditory function and hearing status, and psychoacoustic tests of tinnitus. Audiological assessment results lead directly to informed decisions on initial management options for patients with bothersome tinnitus.

Protocol for Assessment of Patients with Bothersome Tinnitus

Patient History

As reviewed in Chapter 5, information from a general patient history contributes in different ways to the assessment and management of patients with bothersome tinnitus. A patient history, and particularly the patient's chief complaint(s), plays an important role in an audiologist's decisions regarding the most appropriate procedures to include in the test battery for comprehensive and accurate diagnosis of auditory dysfunction and hearing loss. The patient's chief complaint and/or other pertinent information from a patient history typically points to a likely diagnosis that is then confirmed with a specific pattern of audiological test results. Certain patterns of test results and audiological findings prompt an immediate patient referral to a physician or another healthcare physician.

Recent research evidence published in peer-reviewed journals supports the use of the "paper and pencil" questionnaire or checklist approach for identifying persons who require medical referral, even before an audiological assessment. One such questionnaire is The Consumer Ear Disease Risk Assessment (CEDRA) (Klyn et al., 2019).

It is important to appreciate that the vast majority of adults with hearing loss who complain of tinnitus do not have underlying disease or pathology (e.g., Hall et al., 1994; Zapala et al., 2010). Exposure to high levels of sound (noise or music) or advancing age are by far the two most common etiologies for hearing loss in adults. In a general older adult population, the prevalence of otologic diseases requiring medical evaluation and possible management are rather uncommon (Zapala et al., 2010), including Meniere's disease (0.15%), sudden idiopathic sensorineural hearing loss (0.02%), cholesteatoma (0.01%), and vestibular schwannoma (0.002%). As Kleindienst et al. (2016) point out, " . . .the odds are 20:1 against encountering an ear condition that should be treated medically or surgically in individuals seeking hearing aids over the age of 50 years" (p. 225). Is it possible to identify with information from a history or questionnaire adults who are likely to benefit from referral to a physician? The CEDRA was designed for that purpose.

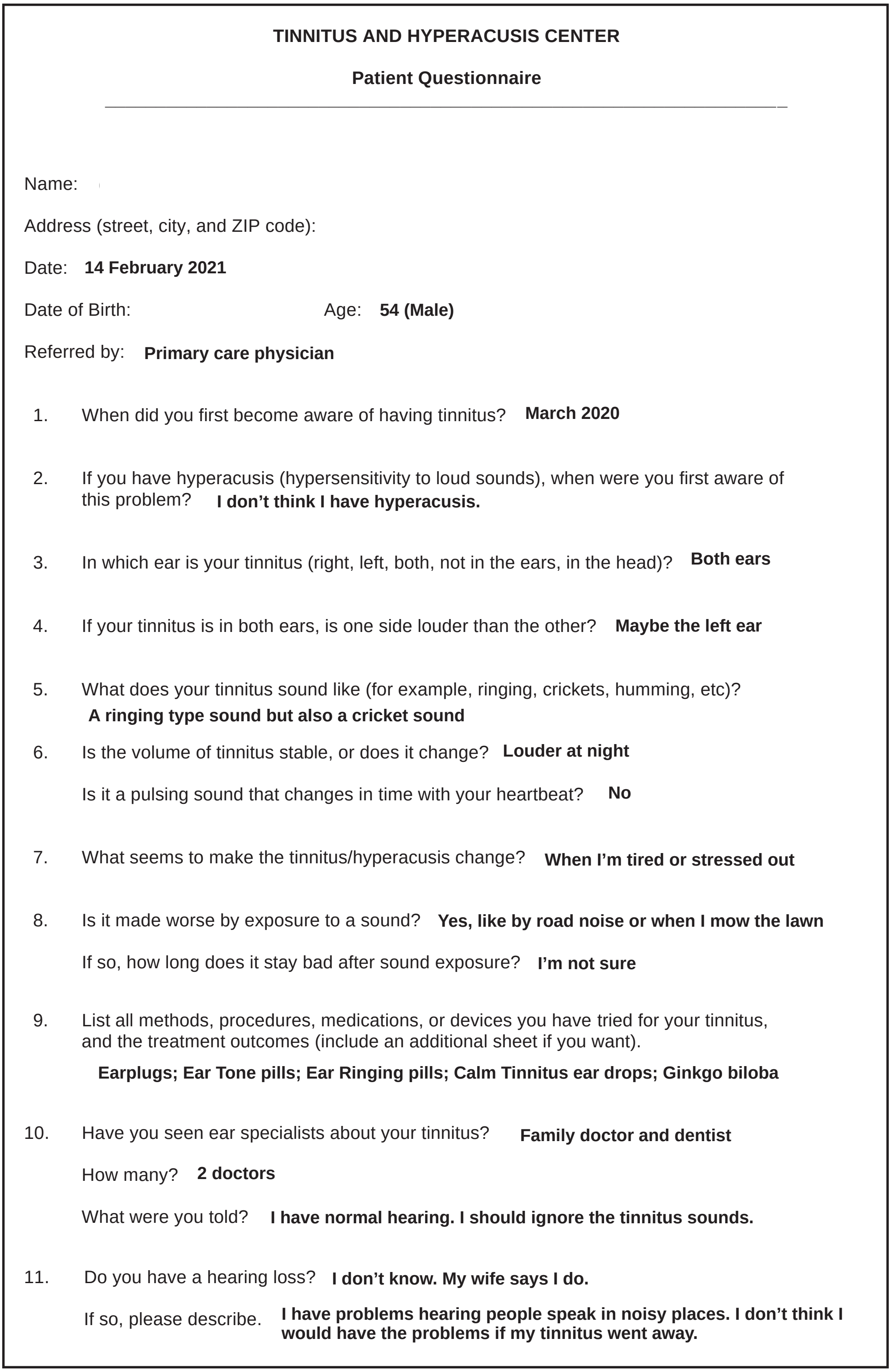
There are also indicators, often referred to as red flags, for medical referral of adults with hearing loss. The AAOHNS (2002) identified at least 10 categories of red flag warnings of ear disease. A partial list includes:

- hearing loss in persons with a history of a variety of factors such as ear infections, noise exposure, family hearing loss, Meniere's disease, otosclerosis, use of potential ototoxic drugs, and head injury, among others;
- history of pain or active drainage/bleeding from an ear;
- hearing loss that is progressive or sudden in onset;
- dizziness (acute, chronic, or recurrent);
- unilateral or asymmetric hearing loss;
- unilateral or pulsatile tinnitus; and
- asymmetry in word-recognition scores.

Tinnitus Questionnaires

Tinnitus-specific history forms and questionnaires are noted in other chapters in this book. An example of a detailed questionnaire designed for patients with bothersome tinnitus is depicted in Figure 6–1. The questionnaire or history form includes responses to questions for a hypothetical but rather typical type of patient with the chief complaint of bothersome tinnitus; namely, a 54-year-old male. In a typical setting, responses on a tinnitus-specific history form provide an audiologist with a logical starting point for more in-depth and probing verbal history relating to all aspects of the patient's bothersome tinnitus. The audiologist's review of a completed history form in the clinic with the patient, and perhaps a family member, usually generates an invaluable question/answer session. The resulting interaction with the patient is an excellent opportunity for the audiologist to:

- learn more about factors related to the onset of tinnitus;
- characterize the nature of the tinnitus (e.g., laterality, type of sound);
- identify how the patient has attempted to self-manage the tinnitus;
- document medical or psychological conditions possibly related to tinnitus;
- document therapeutic drugs or over-the-counter (OTC) substances possibly related to tinnitus;
- determine how the patient's tinnitus impacts daily activities, including sleep
- clarify the patient's perceived relation between tinnitus, hearing loss, and perhaps decreased tolerance to external sounds;
- determine whether the patient is a plaintiff in litigation related to the tinnitus (e.g., is the patient involved in a lawsuit and seeking compensation?);



TINNITUS AND HYPERACUSIS CENTER

Patient Questionnaire

Name:

Address (street, city, and ZIP code):

Date: **14 February 2021**

Date of Birth: Age: **54 (Male)**

Referred by: **Primary care physician**

1. When did you first become aware of having tinnitus? **March 2020**

2. If you have hyperacusis (hypersensitivity to loud sounds), when were you first aware of this problem? **I don’t think I have hyperacusis.**

3. In which ear is your tinnitus (right, left, both, not in the ears, in the head)? **Both ears**

4. If your tinnitus is in both ears, is one side louder than the other? **Maybe the left ear**

5. What does your tinnitus sound like (for example, ringing, crickets, humming, etc)? **A ringing type sound but also a cricket sound**

6. Is the volume of tinnitus stable, or does it change? **Louder at night**

   Is it a pulsing sound that changes in time with your heartbeat? **No**

7. What seems to make the tinnitus/hyperacusis change? **When I’m tired or stressed out**

8. Is it made worse by exposure to a sound? **Yes, like by road noise or when I mow the lawn**

   If so, how long does it stay bad after sound exposure? **I’m not sure**

9. List all methods, procedures, medications, or devices you have tried for your tinnitus, and the treatment outcomes (include an additional sheet if you want).

   Earplugs; Ear Tone pills; Ear Ringing pills; Calm Tinnitus ear drops; Ginkgo biloba

10. Have you seen ear specialists about your tinnitus? **Family doctor and dentist**

    How many? **2 doctors**

    What were you told? **I have normal hearing. I should ignore the tinnitus sounds.**

11. Do you have a hearing loss? **I don’t know. My wife says I do.**

    If so, please describe. **I have problems hearing people speak in noisy places. I don’t think I would have the problems if my tinnitus went away.**

Figure 6–1. A questionnaire specifically for patients with bothersome tinnitus scheduled for audiological assessment. Responses are for an illustrative case (a 54-year-old male with bothersome tinnitus). *continues*

12. Do you wear a hearing aid(s)? **No**

13. Are you uncomfortable around certain sounds? **Sometimes loud unexpected sounds.**

14. Do you wear ear protection (plugs or muffs)? **Only recently to keep me from hearing the tinnitus.**

If so, about what percentage of time do you wear them? **Maybe once every few weeks.**

15. Do you wear ear protection in quiet situations? **Yes, again to keep from hearing the annoying tinnitus sounds.**

16. Do you experience pain in the ears from loud sounds? **No**

17. Have you ever worked anywhere that exposed you to continuous loud noise? **Yes**

18. Estimate the percentage of time over the past month that you have been aware of the tinnitus. **90% of the time**

19. Estimate the percentage of time over a month period (not counting sleeping) when you are:

a) In a quiet environment (e.g., quiet home; you can be understood even when speaking softly) **60** %

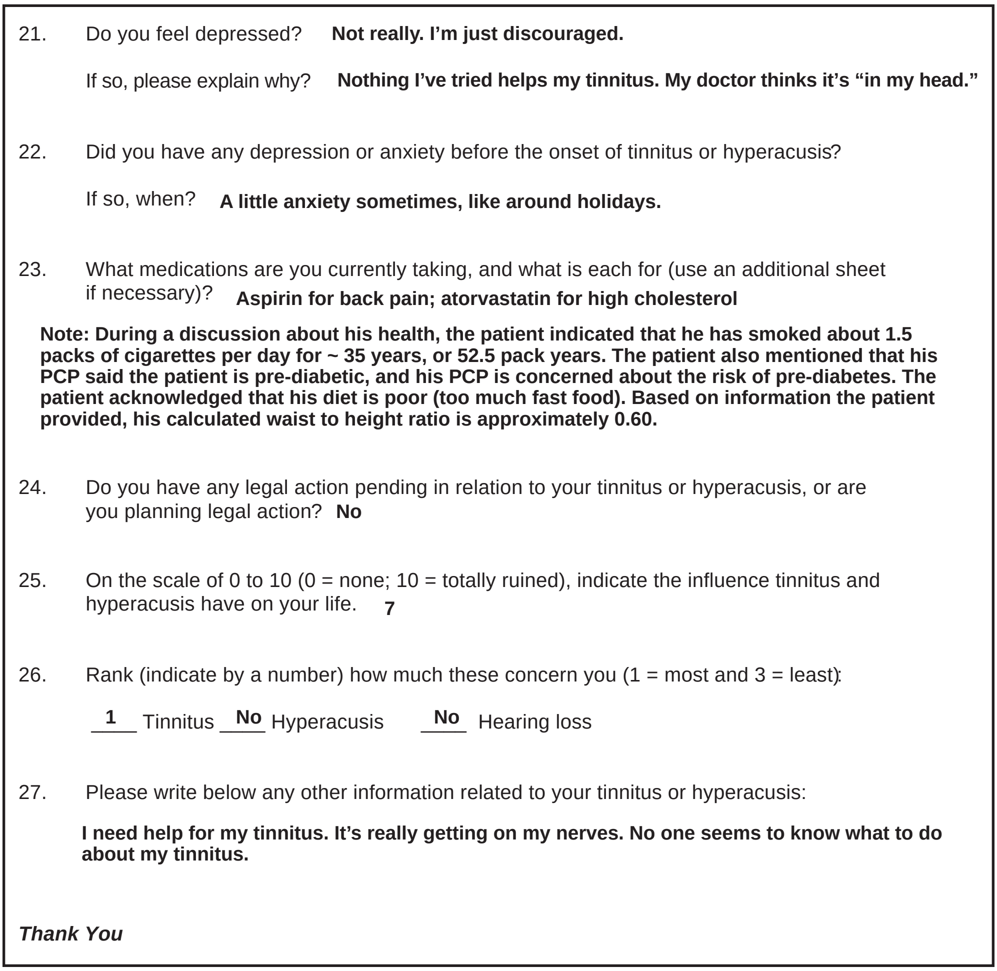
b) Moderate environment (e.g., average street, office, restaurant) **30** %

c) Loud environment (noisy workplace, very loud radio or TV) **10** %

20. Are there activities that you are prevented from doing, or that are affected by the tinnitus/hyperacusis? Indicate with an "X" your answers in the areas below.

Activity	Tinnitus			Hyperacusis		
	Yes	No	Not sure	Yes	No	Not sure
Concentration	**X**				**X**	
Falling asleep	**X**				**X**	
Staying asleep	**X**				**X**	
Restaurants			**X**		**X**	
Social events			**X**		**X**	
Church		**X**			**X**	
Sports events		**X**			**X**	
Quiet activities (such as reading)	**X**				**X**	
Concerts		**X**			**X**	
Other					**X**	

Figure 6–1. *continues*



21. Do you feel depressed? **Not really. I'm just discouraged.**

If so, please explain why? **Nothing I've tried helps my tinnitus. My doctor thinks it's "in my head."**

22. Did you have any depression or anxiety before the onset of tinnitus or hyperacusis?

If so, when? **A little anxiety sometimes, like around holidays.**

23. What medications are you currently taking, and what is each for (use an additional sheet if necessary)? **Aspirin for back pain; atorvastatin for high cholesterol**

Note: During a discussion about his health, the patient indicated that he has smoked about 1.5 packs of cigarettes per day for ~ 35 years, or 52.5 pack years. The patient also mentioned that his PCP said the patient is pre-diabetic, and his PCP is concerned about the risk of pre-diabetes. The patient acknowledged that his diet is poor (too much fast food). Based on information the patient provided, his calculated waist to height ratio is approximately 0.60.

24. Do you have any legal action pending in relation to your tinnitus or hyperacusis, or are you planning legal action? **No**

25. On the scale of 0 to 10 (0 = none; 10 = totally ruined), indicate the influence tinnitus and hyperacusis have on your life. **7**

26. Rank (indicate by a number) how much these concern you (1 = most and 3 = least):

1 Tinnitus **No** Hyperacusis **No** Hearing loss

27. Please write below any other information related to your tinnitus or hyperacusis:

I need help for my tinnitus. It's really getting on my nerves. No one seems to know what to do about my tinnitus.

Thank You

Figure 6–1. *continued*

- give nuanced and focused answers to patient-specific questions;
- begin to clear up misconceptions and inappropriate concerns the patient has about tinnitus (e.g., loss of hearing, likelihood of a serious acute medical issue like a stroke);
- reveal knowledge about tinnitus and demonstrate expertise in the assessment and management of tinnitus;
- demonstrate compassion and understanding; and
- develop a positive working relationship with the patient and family.

Space does not permit a detailed discussion about all of the information that can be acquired with a tinnitus-specific history form. Here are a few examples of how the completed history form in Figure 6–1 might shape the discussion between the audiologist and patient:

- further questioning about the onset of tinnitus in March of 2020; e.g., possible factors contributing to the perception of bothersome tinnitus;
- details from the patient about their expectations and experiences

with the various self-management attempts;

- more information about the opinions of the patient's family doctor and dentist regarding tinnitus;
- explanation of the patient's reasons for wearing earplugs;
- in-depth conversation about the patient's sleep problems and awareness of sleep hygiene techniques;
- anxiety or depression prior to and/or following the onset of bothersome tinnitus; and
- additional review of health history relative to tinnitus particularly comorbidities (e.g., diabetes), medications potentially associated with tinnitus (e.g., statin drugs), and lifestyle risk factors (e.g., poor diet and smoking). Interested readers are referred to a recent review article for more information about comorbidities (Hall, 2021).

Based on the author's experience, the efficiency of a scheduled assessment appointment with a patient who has bothersome tinnitus is enhanced substantially if the tinnitus-specific history form is completed in advance, rather than in the clinic on the date of the assessment. There are at least five clear advantages to routinely requesting that the patient complete the form at home in advance of the clinic visit. First, the patient will have an opportunity to consult with family members in answering questions. Second, the patient has access to their medications and sometimes relevant medical records. Third, in reviewing questions on the form the patient begins to appreciate that the audiologist understands bothersome tinnitus and how it might affect someone. Fourth, the patient is likely to conclude that the audiologist is interested in and concerned about how tinnitus is impacting their life. Finally, the audiologist who has an opportunity to review the completed history form in advance can develop a more logical and efficient strategy for assessment of the patient and perhaps an estimate of time required for the appointment. Information in the history might also indicate the need for referral to other health professionals, such as medical specialists or psychologists, and even a tentative plan for initial management of the patient.

In the past, front desk personnel typically forwarded the history form to the patient via regular mail well before the scheduled appointment, and the patient was instructed to return the completed questionnaire via mail in a prepaid envelope. Today, other options are available. A history form can be sent to the patient as an email attachment with the request that the patient print and complete it before mailing it to the clinic. Or, the history form could be sent via email or available on the clinic website as a fillable PDF document. Prior to initiating a protocol for electronic exchange of a completed history form, audiologists would be wise to verify with proper authorities compliance with institutional and government regulations and requirements for patient privacy and the security of personal health information.

Validated Tinnitus Inventories

In addition to the general audiological history, patients with complaints of bothersome tinnitus should be instructed to complete one or more validated questionnaires. A number of validated questionnaires or inventories are available to quantify the impact of tinnitus on quality of life, such as the Tinnitus Handicap Inventory (THI) (Newman et al., 1996), the Tinnitus Reaction Questionnaire (TRQ) (Wilson et al., 1991), the Tinnitus Functional Index (TFI)

(Meikle et al., 2012), the Tinnitus Severity Index (TSI) (Meikle et al., 1995), the Tinnitus Questionnaire (TQ) (Hallam et al., 1988), and the Tinnitus Handicap Questionnaire (THQ) (Kuk et al., 1990). Routine application of a validated questionnaire or inventory is standard practice in the assessment of patients with bothersome tinnitus. Administration of one or more validated self-report questionnaires or inventories in the assessment of bothersome tinnitus is typically recommended in clinical practice guidelines (e.g., British Society of Audiology, 2019; Tunkel et al., 2014) to distinguish patients with bothersome versus nonbothersome tinnitus. In contrast, NICE, an organization in the U.K., include in their "Tinnitus: Assessment and Management" guidelines the statement: "No evidence was identified that evaluated the clinical effectiveness of questionnaires and interviews to assess quality of life in people with tinnitus" (p. 27).

Findings from a validated questionnaire or inventory also serves a variety of other purposes including:

- quantification of the impact of a patient's tinnitus on quality of life;
- delineation of the patient's reactions to bothersome tinnitus, including psychosocial consequences (e.g., anger, annoyance, helplessness, frustration, irritability);
- identification of possible psychological distress associated with tinnitus, specifically depression and anxiety;
- a numerical metric or index that contributes to decisions regarding referrals to other health professionals; and
- a numerical metric or index that contributes to decisions regarding the most appropriate management options for the patient.

A completed THI is shown in Figure 6–2 for our hypothetical 54-year-old male patient with a complaint of bothersome tinnitus. The patient's responses are indicated with bold and underlined font. Scoring for the 25-item THI is as follows: *yes* or *always* = 4 points, *sometimes* = 2 points, and *none* = 0 points. The three domains for questions (indicated with an uppercase letter after the number) are: Functional (F), Emotional (E), and Catastrophic (C). The patient's responses yielded domain scores of 36 points for Functional, 24 points for Emotional, and 8 points for Catastrophic, for a total THI score of 68. Over 25 years of clinical research and experience confirm the validity of the total THI score in distinguishing among degrees of tinnitus severity and the impact of tinnitus on daily function, but questions have been raised regarding the validity of the subscores in describing bothersome tinnitus (Baguley & Anderson, 2003; British Society of Audiology, 2019).

The following guidelines for analysis of the THI are commonly employed: 0 to 16 points = Grade I (slight or no handicap), 18 to 36 points = Grade 2 (mild handicap), 38 to 56 points= Grade 3 (moderate handicap), 58 to 76 points = Grade 4 (severe handicap), and 78 to 100 points = Grade 5 (catastrophic handicap). Thus, the bothersome tinnitus for our patient would be considered a severe handicap, a finding that most certainly would warrant formal audiological management. Given the high THI score, including points for multiple questions within the catastrophic domain, professional counseling and perhaps psychology referral for cognitive behavioral therapy (CBT) might be warranted.

Depending on the quantitative and qualitative analysis of patient responses on tinnitus-specific questionnaires or inventories, some audiologists might opt to also administer simple inventories to screen for

TINNITUS HANDICAP INVENTORY (THI)

Name: Tinnitus Case **Age:** 54 years **Date:** February 14, 2021

Instructions to patients: The purpose of the scale is to identify the problems your tinnitus may be causing you. Circle "yes," "sometimes," or "no" for each question.

Item		**Patient response**		
1F.	Because of your tinnitus, is it difficult for you to concentrate?	[✓ Yes]	Sometimes	No
2F.	Does the loudness of your tinnitus make it difficult for you to hear people?	Yes	[✓ Sometimes]	No
3E.	Does your tinnitus make you angry?	Yes	[✓ Sometimes]	No
4F.	Does your tinnitus make you feel confused?	Yes	Sometimes	[✓ No]
5C.	Because of your tinnitus, do you feel desperate?	Yes	[✓ Sometimes]	No
6E.	Do you complain a great deal about your tinnitus?	[✓ Yes]	Sometimes	No
7F.	Because of your tinnitus, do you have trouble falling to sleep at night?	[✓ Yes]	Sometimes	No
8C.	Do you feel as though you cannot escape your tinnitus?	Yes	[✓ Sometimes]	No
9F.	Does your tinnitus interfere with your ability to enjoy social activities? *(Such as going out to dinner or to the movies)*	[✓ Yes]	Sometimes	No
10E.	Because of your tinnitus, do you feel frustrated?	[✓ Yes]	Sometimes	No
11C.	Because of your tinnitus, do you feel that you have a terrible disease?	Yes	Sometimes	[✓ No]
12F.	Does your tinnitus make it difficult for you to enjoy life?	[✓ Yes]	Sometimes	No
13F.	Does your tinnitus interfere with your job or household responsibilities?	Yes	[✓ Sometimes]	No
14F.	Because of your tinnitus, do you find that you are often irritable?	[✓ Yes]	Sometimes	No
15F.	Because of your tinnitus, is it difficult for you to read?	Yes	[✓ Sometimes]	No
16E.	Does your tinnitus make you upset?	[✓ Yes]	Sometimes	No
17E.	Do you feel that your tinnitus problem has placed stress on your relationships with members of your family and friends?	[✓ Yes]	Sometimes	No

Figure 6–2. Tinnitus Handicap Inventory (THI) for the illustrative case (54-year-old male with bothersome tinnitus). *continues*

possible psychological disorders often associated with tinnitus, particularly anxiety and depression. A substantial literature confirms personality profiles (Durai et al., 2017) and pre-existing psychological status that are risk factors for a greater-than-average

18F. Do you find it difficult to focus your attention away from your tinnitus and on other things?	Yes	**Sometimes**	No
19C. Do you feel that you have no control over your tinnitus?	Yes	**Sometimes**	No
20F. Because of your tinnitus, do you often feel tired?	**Yes**	Sometimes	No
21E. Because of your tinnitus, do you feel depressed?	Yes	**Sometimes**	No
22E. Does your tinnitus make you feel anxious?	**Yes**	Sometimes	No
23C. Do you feel that you can no longer cope with your tinnitus?	Yes	**Sometimes**	No
24F. Does your tinnitus get worse when you are under stress?	**Yes**	Sometimes	No
25E. Does your tinnitus make you feel insecure?	Yes	Sometimes	**No**

F = 36
E = 24
C = 8
Total THI = 68

Figure 6–2. *continued*

reaction to the perception of tinnitus and that are contributing factors for bothersome tinnitus (e.g., Salazar et al., 2019; Trevis et al., 2018). Audiologists also commonly encounter patients with bothersome tinnitus whose history, before the onset of tinnitus, revealed no sign or evidence of psychological concerns. The patient's anxiety and/or depression appears to be psychological sequelae of the perception of bothersome tinnitus. Of course, anxiety, depression, or other psychological consequences of bothersome tinnitus often fuel the patient's negative reaction and become major factors in the patient's reduced quality of life. This negative vicious cycle interaction between tinnitus and psychological status is well described in the research literature and well appreciated among health professionals who provide services to patients with bothersome tinnitus (e.g., Trevis et al., 2018)

The Beck Depression Inventory (BDI) (Beck et al., 1961), is an example of a screening tool for depression that some audiologists employ to identify patients with bothersome tinnitus who require a referral to a mental health professional like a psychologist or psychiatrist. The Beck Depression Inventory consists of 21 questions with four answer options. The outcome is analyzed by totaling up the scores for the questions and then referring to a table to determine the patient's level of depression from among six categories. An internet search will also reveal several simple questionnaires for anxiety, such as the seven-question Self-Test for Anxiety and Anxiety Screening Tool.

Again, the rationale for audiologist administration of one of these inventories of psychological status is to aid in decisions regarding referral to a mental health professional. Audiologists, especially those providing tinnitus services in a medical center or hospital setting, may elect to directly refer to a psychologist or psychiatrist based on the patient's history and pattern of scores on tinnitus inventories like the THI, TRQ, or the TFI.

Otoscopy

Patients with bothersome tinnitus require comprehensive audiological assessment and evaluation to specifically describe and characterize tinnitus. Key components of the diagnostic process, and the rationale for each, are summarized in Table 6–1. The process almost always begins with otoscopy that allows for a general description of the status of the external ear canal and tympanic membrane. Before performing any test procedure, an audiologist inspects the pinna and external ear canal to detect any evidence of abnormality. Visual inspection of the pinna and ear canal is usually made with a handheld otoscope equipped with a speculum and a bright light that adequately illuminates the tympanic membrane. Video otoscopes are now also available from numerous vendors. Video otoscopy offers at least two main advantages in comparison to traditional otoscopic inspection of the ear. First, images viewed through an otoscope-type earpiece are displayed on the screen of an electronic device, such as a computer, tablet, or smartphone. The larger image improves visualization of the external ear and tympanic membrane. In addition, the image can be stored and/or printed for documentation of the findings and later analysis.

Video otoscopy permits prompt and accurate identification of medically serious pathologies involving the pinna (e.g., squamous cell carcinoma), external ear canal (e.g., external otitis and osteomas), tympanic membrane (e.g., perforation), and a host of middle ear pathologies. Video otoscopy also provides clues about the possibility of ear canal collapse, an important observation for a patient about to undergo hearing assessment. And, relatively innocuous findings, such as cerumen, debris, and foreign objects within the external ear canal, are readily identified with video otoscopy. Although not serious from a medical perspective, any blockage of the external ear canal is very relevant in the assessment of a patient with bothersome tinnitus. On occasion, occlusion of one or both external ear canals with cerumen or a foreign object such as a sound-attenuating earplug or an earpiece transducer is directly linked temporally to a patient's onset of bothersome tinnitus. Fortunately, in these cases, the bothersome tinnitus is almost always truly cured with simple counseling and prompt removal of the occluding substance or object, perhaps by an otolaryngologist under a microscope.

Objective Auditory Procedures

Measures of Middle Ear Function

Audiological assessment of patients with bothersome tinnitus is performed using a combination of objective and subjective (behavioral) audiometric tests. Two objective auditory procedures provide valuable information on middle ear and cochlear function. *Tympanometry* is a sensitive and site-specific measure of functional status of the tympanic membrane and ossicular chain. A variety of screening and diagnostic tympanometry devices permit quick documentation of external ear canal volume and middle ear function, including static compliance, tympanogram peak pressure, and identification of evidence of dysfunction associated with middle ear disease.

Table 6–1. A Clinically Feasible and Efficient Protocol for Assessment of Patients With Bothersome Tinnitus. Components of the Diagnostic Protocol Are Described in the Sequence Often Followed in Their Clinical Application.

Component	***Description***	***Rationale***
Tinnitus History	Patient questionnaire focusing on history related to tinnitus to obtain information such as: • onset of tinnitus, • nature of tinnitus, • factors influencing tinnitus, • impact of tinnitus on daily activities, and • past management of tinnitus.	Information from the patient history questionnaire is important in determining whether the patient experiences bothersome tinnitus. The information is used to determine an efficient strategy for assessment, make referrals, and plan effective management. Patient responses to the questionnaire also guide the audiologist in asking more detailed and probing questions about the patient's tinnitus.
Tinnitus Inventory	Validated tinnitus inventory to quantify the patient's emotional response to tinnitus and the impact of tinnitus on daily activities (e.g., sleep, concentration) and overall quality of life.	A validated inventory is an essential component of the protocol for assessment of a patient with bothersome tinnitus. Responses and scores contribute importantly to management decisions, including the need for referrals to other health professionals. Scores on domains evaluated with an inventory are useful in documenting the benefits of management and monitoring the patient's status.
Otoscopy	Visual inspection of the external ear (including external ear canal), tympanic membrane, and middle ear. Video-otoscopy is a preferred option to provide an electronic image for documentation of findings and later analysis.	Otoscopy is a common clinical procedure prior to hearing assessment to identify or rule out external and/or middle ear disease or disorders. Results contribute to appropriate medical referrals and safe application of test procedures involving insertion of probes into the external ear canal. Otoscopy also may identify external or middle ear disorder that contributes to the perception of bothersome tinnitus.
Aural Immittance	Tympanometry and/or wideband reflectance/absorbance; conventional acoustic reflex measurements are not typically recommended.	Tympanometry and/or wideband reflectance/absorbance are objective measures with proven sensitivity to middle ear dysfunction. Normal findings in combination with no history of middle ear disease reduce the need for bone-conduction pure-tone audiometry. Abnormal findings often indicate the need for medical referral.

Table 6–1. *continued*

Component	***Description***	***Rationale***
Otoacoustic Emissions (OAEs)	Distortion product otoacoustic emissions (DPOAEs) or a combination of DPOAEs and transient evoked otoacoustic emissions.	OAEs are a highly sensitive measure of cochlear (outer hair cell) function and integrity. OAEs contribute importantly to documentation of cochlear dysfunction and are a possible cochlear origin for tinnitus, even in patients with normal pure-tone hearing sensitivity. OAE findings also play an important role in counseling patients with bothersome tinnitus (text includes detailed discussion).
Pure-Tone Audiometry (conventional)	Estimation of thresholds for pure-tone stimuli via air conduction (earphones). Pure-tone stimuli typically include octave frequencies from 250 to 8000 Hz, and interoctave frequencies of 3000 and 6000 Hz.	Air-conduction pure-tone audiometry is a typical component of a diagnostic audiological test battery and recommended in clinical practice guidelines. Tinnitus pitch often corresponds to the frequency region of hearing loss. Bone-conduction pure-tone audiometry contributes little or no diagnostic information for patients with normal aural immittance findings and with no history of middle ear disease.
Pure-Tone Audiometry (high frequency)	Estimation of thresholds for pure-tone stimuli via air conduction for frequencies > 8000 Hz using special high-frequency earphones.	Some patients perceive bothersome tinnitus for frequencies higher than 8000 Hz. High-frequency pure-tone audiometry is necessary to adequately assess tinnitus pitch and loudness for selected patients.
Speech Audiometry	Formal measurement of speech perception using word or sentence materials. Speech audiometry is conducted with calibrated equipment and earphones at specific intensity levels using established clinically researched test materials.	Although word recognition in quiet is typically performed in hearing assessment, the findings contribute little to diagnosis of hearing loss or verification of everyday communication impairment. Assessment of speech perception in noise adds more value to the diagnostic assessment. Also, research supports assessment of speech perception in noise in patients at risk for cognitive impairment. Measurement of speech reception threshold is generally not indicated for patients with bothersome tinnitus.

continues

Table 6–1. *continued*

Component	***Description***	***Rationale***
Psychoacoustic Tinnitus Assessment	Psychoacoustic measures in tinnitus assessment include: • threshold for broadband (white) noise, • matching tinnitus pitch, • matching tinnitus loudness, • minimum masking level for tinnitus, • loudness discomfort levels (LDLs), and • test of residual inhibition (RI).	There are at least three good reasons for audiologists to conduct psychoacoustic measurements in patients with bothersome tinnitus: • Findings contribute to decisions about management. • Patients expect and appreciate the concern for and attention to their chief complaint. • The test process provides an opportunity for the audiologist to develop a working relationship with the person with bothersome tinnitus. LDLs are typically estimated when a patient with bothersome tinnitus also complains of decreased sound tolerance, particularly hyperacusis. Residual inhibition is described in the text.
Auditory Brainstem Response (ABR)	Electrophysiological assessment of peripheral and central (brainstem) auditory function with click or tone burst stimuli.	ABR measurement is usually not a component of the protocol for assessment of a patient with bothersome tinnitus. However, ABR can play a role in the differentiation of cochlear versus neural auditory dysfunction, particularly in patients who do not agree to magnetic resonance imaging. The ABR procedure may be modified to minimize patient exposure to loud and annoying sounds.

Clinical aural immittance measurement often involves acoustic reflex measurement following tympanometry (Hall, 2014). Clinical practice guidelines offer conflicting recommendations regarding the application of acoustic reflex measurement in patients evaluated for bothersome tinnitus. For example, the British Society of Audiology (2016) guidelines include “stapedial reflexes” in the minimum audiology test battery for assessment of adults with tinnitus, whereas the NICE (2020) group recommends against the practice with unequivocal guidance: “Do not offer acoustic reflex testing or uncomfortable loudness levels/loudness discomfort levels testing as part of an investigation of tinnitus” (p. 12).

Audiologists are advised to follow a very cautious approach to acoustic reflex measurement with patients complaining of bothersome tinnitus. It is important to first assess the benefits of acoustic reflex measurement versus potential clinical contraindications. The diagnostic value of acoustic reflex data is negligible for patients who have already undergone otologic assessment, including possibly neuroimaging (e.g., magnetic resonance imaging) to rule out neural auditory disorders. In contrast, the possible clinical disadvantage of acoustic reflex measurement is substantial. Reduced tolerance to loud sounds is not uncommon in patients with bothersome tinnitus. Elicitation of acoustic reflex activity with pure-tone or noise stimuli at intensity levels of 85 dB HL or higher may produce extreme discomfort for such patients. For persons with bothersome tinnitus and decreased sound tolerance, the unfortunate result may be increased patient anxiety about the assessment process and decreased confidence and trust in the audiologist. As a rule, acoustic reflex measurement is not recommended for routine audiological assessment of most patients with bothersome tinnitus (e.g., British Society of Audiology, 2019; Tunkel et al., 2014).

Even though tinnitus does not originate in the middle ear system, the application of aural immittance in measurement of middle ear function is an important part of the diagnostic test battery. Patients yielding normal findings on tympanometry and/or wideband reflectance/absorbance, in combination with no history of ear problems plus normal otoscopy, may not need to be evaluated with bone-conduction pure-tone audiometry. Conversely, patients with abnormal aural immittance findings, suggesting the possibility of middle ear disease or disorder, typically warrant referral to an otolaryngologist or otologist. In addition, conductive hearing loss related to middle ear dysfunction may reduce the masking of tinnitus by ambient environmental sound and, therefore, may contribute to increased perception of pre-existing tinnitus. Prompt and effective management of middle ear disorders, and possible contributing medical conditions such as allergies and sinus infections, should be initiated for patients with bothersome tinnitus.

Distortion Product Otoacoustic Emissions (DPOAEs)

As summarized in Table 6–1, distortion product otoacoustic emissions (DPOAEs) play an extremely valuable role in the diagnostic audiological assessment of patients with bothersome tinnitus. Specifically, information from DPOAE measurement contributes in at least five ways to the assessment and management of patients with bothersome tinnitus (Dhar & Hall, 2018; Hall, 2021). First, DPOAEs permit more accurate diagnosis of hearing loss. For example, DPOAE amplitudes below a normal region or absent DPOAEs in patients with audiogram showing sensorineural hearing loss confirm a cochlear origin. Second, there is often a correlation between the patient's perceived tinnitus pitch and the test frequencies yielding abnormally reduced DPOAE amplitudes or no detectable OAE activity (Bartnik et al., 2004; Satar et al., 2003), although the relationship is not always precise (Shekhawat et al., 2014). For patients with bothersome tinnitus, it's useful to record DPOAE at five or more frequencies per octave to permit detection of cochlear dysfunction at frequencies not available with pure-tone audiometry. Indeed, the patient's perception of tinnitus pitch can be rather quickly and easily estimated during DPOAE measurement. The patient is instructed to raise a hand or even just a finger if stimulus frequencies are heard in the same pitch region as the perceived tinnitus.

A third way DPOAEs contribute to diagnostic assessment is by confirming cochlear dysfunction in patients with normal hearing sensitivity. There are numerous published reports of abnormal OAE findings in persons with bothersome tinnitus yet normal hearing sensitivity (e.g., Fabijańska et al., 2012; Modh et al., 2014; Mokrian et al., 2014; Park et al., 2012; Satar et al., 2003; Yenigün et al., 2014; Zhao et al., 2014). OAE abnormalities provide objective confirmation of subclinical cochlear dysfunction. This information provides to the audiologist, otolaryngologist, and patient a physiological explanation for subjective perceived tinnitus. Fourth, DPOAE findings provide evidence on the laterality of tinnitus (Satar et al., 2003). It is not uncommon for a patient to report the perception of unilateral tinnitus in the presence of bilateral cochlear dysfunction and/or hearing loss. Presumably, when tinnitus is more pronounced in one ear than the other, the tinnitus is perceived as unilateral. Bilaterally abnormal OAE findings suggest the possibility of bilateral tinnitus. Whether tinnitus is unilateral or bilateral may affect decisions regarding the most appropriate management strategy for the patient.

Finally, objective documentation of cochlear dysfunction validates an auditory explanation for bothersome tinnitus, particularly for patients with a normal audiogram. Ironically, patients are often relieved to learn that there is a physiological explanation for their bothersome tinnitus, and that they are not imagining the tinnitus and that it is not "just in their head." DPOAEs are preferable to transient evoked otoacoustic emissions (TEOAEs) in documenting cochlear dysfunction in the frequency region of perceived tinnitus because TEOAEs cannot be consistently recorded above 5000 Hz.

Practice guidelines offer mixed guidance on the role of OAEs in clinical assessment of patients with bothersome tinnitus. The British Society of Audiology (2016) guidelines include the option for further assessment with OAEs "if clinically needed." The AAOHNS guidelines (Tunkel et al., 2014) do not include any mention of OAEs. And, the NICE (2020) document states: "Do not offer otoacoustic emissions tests as part of an investigation of tinnitus unless the tinnitus is accompanied by other symptoms and signs" (p. 12).

Figure 6–3 shows DPOAE results for the illustrative 54-year-old male with a complaint of bothersome tinnitus who underwent comprehensive audiological assessment. Key features of the DPOAE test protocol were as follows: L1 = 65 dB SPL and L2 = 55 dB SPL; test stimulus frequency range = 500 to 8000 Hz; five frequencies per octave; f2/f1 ratio = 1.22. DPOAE amplitudes are plotted relative to a normative data for young adults specific to the device. Normal DPOAEs were observed only for the lowest stimulus frequencies in the region of 500 Hz. DPOAEs were present but abnormal within the 1000 to 2000 Hz region, and no DPOAEs were observed for stimulus frequencies above 2000 Hz. DPOAE findings provided objective evidence of extensive ochlear (outer hair cell) dysfunction bilaterally.

Auditory Evoked Responses

Auditory evoked responses, particularly the auditory brainstem response (ABR), are rarely included or indicated in the audiological assessment of patients with bothersome tinnitus. Electrophysiological estimation of hearing sensitivity is not required since almost all patients with bothersome tinnitus are capable of performing pure-tone and speech audiometry and yielding valid test results. The potential role of ABR in assessment of patients with bothersome tinnitus is in differentiating the rare patients with neural auditory dysfunction from those with more common sensory hearing loss. This neurodiagnostic application of ABR is typically not necessary because patients with bothersome tinnitus often undergo

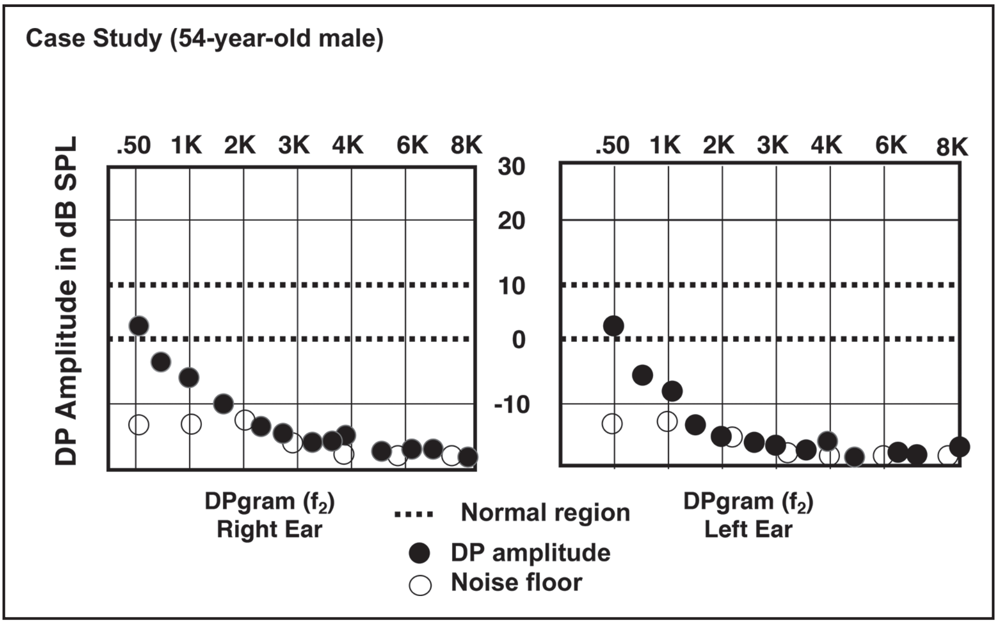


Figure 6–3. Distortion product otoacoustic emissions (DPOAEs) for the illustrative case (54-year-old male with bothersome tinnitus).

radiological studies, such as magnetic resonance imaging (MRI), to rule out neural auditory pathology. ABR measurement does, however, sometimes play a role in the diagnostic audiological assessment of patients with bothersome tinnitus, particularly those with decreased sound tolerance who refuse to undergo MRI due to legitimate concerns about exposure to distressingly high sound levels. A cautious ABR measurement approach is suggested in such cases, with avoidance of stimulus intensity levels exceeding the patient's established LDLs.

Pure-Tone Audiometry

Air-Conduction Pure-Tone Audiometry

Clinical practice guidelines recommend pure-tone audiometry to include interoctave frequencies (e.g., 3000 and 6000 Hz) (American Academy of Audiology, 2000; British Society of Audiology, 2019; Tunkel et al., 2014). Pure-tone audiometry contributes to description of the severity, configuration, laterality, and type of hearing loss including conductive, sensory, mixed, or neural. A simple modification in the methodology for pure-tone audiometry is justified in the assessment of patients with bothersome tinnitus. A rapidly pulsed pure-tone stimulus rather than the conventional longer presentation time is useful to help patients distinguish the test stimulus from their chronic tinnitus. Most diagnostic audiometers have a feature that permits the presentation of a calibrated pulsed pure-tone signal.

Audiologists should appreciate that patients with bothersome tinnitus may have pure-tone hearing thresholds within clinically normal limits. In fact, normal audiograms may be recorded in 20% to 50% of patients with bothersome tinnitus (Henry et al., 2008; Martines et al., 2015; Savastano, 2008; Xiong et al., 2019). Patients who have undergone simple audiological assessment limited to pure-tone audiometry, and perhaps speech-recognition threshold and speech-recognition performance in quiet, may be confused when told that they have normal hearing. Patients naturally may question whether their perceived tinnitus is real and whether their physician or audiologist really appreciates the seriousness of the problem. Of course, patients with bothersome tinnitus and difficulty hearing in background noise might reasonably wonder why the audiologist did not include measures of speech perception in noise in the diagnostic assessment.

In addition to traditional pure-tone audiometry for test frequencies of 250 to 8000 Hz, high-frequency audiometry with pure tones at frequencies > 8000 Hz is sometimes indicated in the assessment of patients with bothersome tinnitus. Measurement of high-frequency pure-tone thresholds requires a diagnostic audiometer that includes the option to produce calibrated high-frequency stimuli with earphones that have a broader frequency response than standard insert or supra-aural transducers. There are two straightforward indications for high-frequency audiometry in patients with bothersome tinnitus. One is the assessment of high-frequency hearing status and documentation of cochlear dysfunction in patients with normal hearing sensitivity for the traditional pure-tone frequency region. The other reason for high-frequency audiometry is to attempt to perform pitch and loudness matching for tinnitus with a patient who does not match tinnitus to a lower pure-tone frequency.

Pure-tone thresholds for the illustrative 54-year-old male with a complaint of bothersome tinnitus are plotted on the audiogram form shown in Figure 6–4. Results for the right versus left ear are plotted on separate graphs. Hearing thresholds were within clinically normal limits for pure-tone stimuli up to 2000 Hz bilaterally. The audiogram revealed a mild notching symmetrical high-frequency hearing loss. These findings prompt two comments. Readers will note that the patient's DPOAE findings were clearly abnormal within the 500 to 2000 Hz region, even though pure-tone thresholds remained within the typically defined normal region (e.g., <25 dB HL). Also, some readers may be curious, or even a bit concerned, that bone-conduction thresholds are not plotted on the audiogram. Based on multiple clinical findings available for the patient, the likelihood of middle ear dysfunction as reflected with an air-bone gap was nil. The rationale for bypassing bone-conduction pure-tone audiometry in this patient is described in some detail in the next section.

Bone-Conduction Pure-Tone Audiometry

Audiologists routinely measure both air- and bone-conduction hearing thresholds in the initial assessment of most patients. Almost every patient undergoes bone-conduction pure-tone audiometry (e.g., Windmill & Freeman, 2019). Several clinical practice guidelines (e.g., American Academy of Audiology, 2000; British Society of Audiology, 2019) do not specifically recommend bone-conduction pure-tone audiometry for all patients with bothersome tinnitus who are undergoing diagnostic hearing assessment. Rather, the specific pure-tone audiometry technique used with each patient is left up to the audiologist. However, at least one clinical practice guideline (Tunkel et al., 2014) strongly recommends routine application of bone-conduction pure-tone audiometry in the assessment of patients with

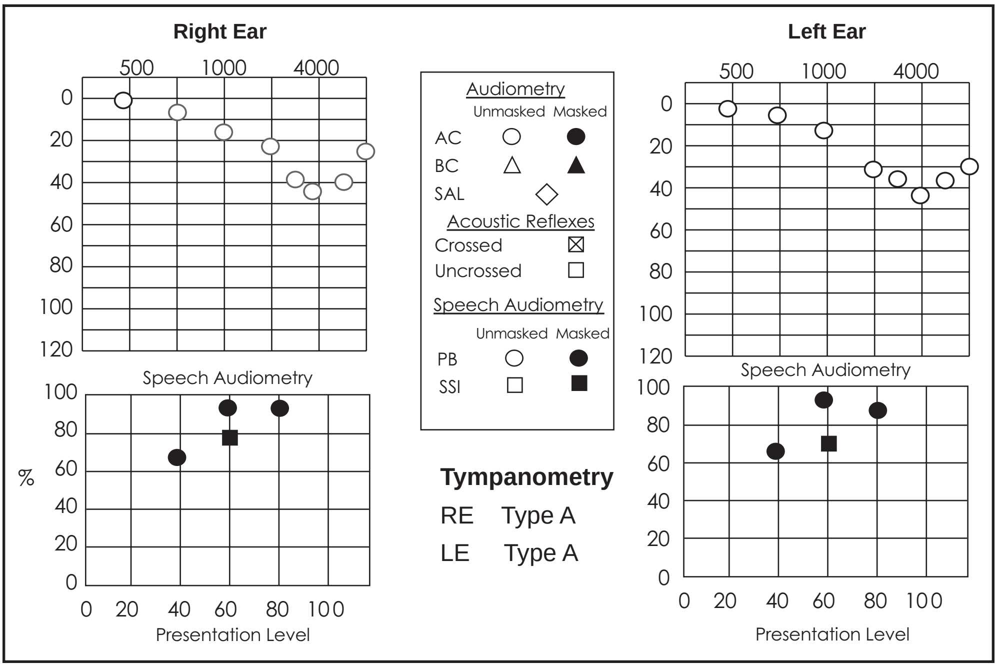


Figure 6–4. Audiogram showing pure-tone and speech audiometry findings for the illustrative case (54-year-old male with bothersome tinnitus).

bothersome tinnitus. This practice is not justified clinically. However, for the majority of adult patients encountered in an audiology clinic, and those patients complaining of bothersome tinnitus, bone-conduction pure-tone audiometry does not add value to the diagnosis or management of tinnitus.

Middle ear dysfunction and associated conductive hearing loss, presumably documented with a valid air-bone gap, is quite unusual in an adult population. Zapala et al. (2010), in a study of a large audiology and otolaryngology population (>1,500 patients), reported essentially no older adult patients with middle ear dysfunction who required referral to otology. Only 4.2% of all of the patients initially seen in an audiology clinic required referral to otolaryngology. The majority of the patients then underwent otologic workup for possible retrocochlear pathology, assorted sensorineural etiologies (e.g., Meniere's disease, sudden onset hearing loss), or a cochlear implant evaluation. Margolis and Saly (2008) described hearing loss characteristics in a very large population of patients (>27,000 ears) undergoing audiological assessment in a busy otolaryngology clinic. One would expect audiologists in such a clinic to encounter a rather high proportion of patients with middle ear dysfunction. Yet, almost 60% of the population yielded audiological and otologic findings consistent with either normal hearing sensitivity or sensorineural hearing loss.

Many audiologists rely on comparison of hearing thresholds for air versus bone conduction (the air-bone gap) for identification of middle ear dysfunction and quantification of conductive hearing loss. As described below, the air-bone gap is not a reliable or valid index of middle ear status. A more direct and clinically justified approach for determining when to perform bone-conduction pure-tone audiometry combines patient history, otoscopic inspection, findings from physician examination, and direct audiological measures of middle ear status, such as tympanometry. Bone-conduction pure-tone audiometry is not indicated or clinically justified for patients with bothersome tinnitus who meet two or more of the following evidence-based criteria:

- no history of middle ear disease, including no medical evaluation or management;
- normal otoscopic findings on physical examination;
- no mention of middle ear abnormality in the physician examination report;
- normal tympanometry; and
- normal OAEs for low test frequencies.

Of course, the comprehensive assessment of hearing should include bone-conduction pure-tone audiometry for patients at risk for or with a history of middle ear disease and for patients with abnormal findings on direct measures of middle ear function, such as tympanometry or wideband reflectance/absorbance. Bone-conduction pure-tone audiometry is also clearly indicated in patients with vestibular complaints and under evaluation for possible superior canal dehiscence syndrome, or SCDS. However, these clinical findings are uncommonly encountered in a population of adult patients with bothersome tinnitus.

Unnecessarily performing bone-conduction pure-tone audiometry is not an audiological asset but rather a liability in the diagnostic process (Hall, 2021). There are multiple practical disadvantages or drawbacks to routinely performing bone-conduction pure-tone audiometry in patients with bothersome tinnitus or in patients who lack risk factors or clinical findings associated with middle ear dysfunction. The investment of precious test time yields no diagnostic return. Bone-conduction pure-tone audiometry with masking of the contralateral ear requires more than 5 minutes of test time (Basar & Canbaz, 2015)—time that would be better spent on tests that contribute to validation of the patient's complaints, to accurate diagnosis of auditory dysfunction, and to providing tinnitus-specific counseling.

Also, routinely conducting air- and bone-conduction pure-tone audiometry when it's not clinically justified will inevitably lead to inappropriate suspicion, or even incorrect diagnoses, of patients with conductive hearing loss due to false or spurious air-bone gaps (Hall, 2021). Building on long-standing research dating back to the 1960s (Studebaker, 1967), Margolis extensively examined the statistical chance of recording air-bone gaps or bone-air gaps at different pure-tone frequencies in persons with clinically documented normal middle ear function (Margolis, et al., 2010). Much of this research was completed during the development and validation of Automated Method for Testing Auditory Sensitivity (AMTAS) software and clinical trials for an automated audiometer, now available as the GSI AudioStar Pro device. Apparent air-bone gaps or bone-air gaps of 10 dB, 15 dB, and even 20 dB HL are entirely predictable from a statistical perspective, even in patients with normal middle ear status. Indeed, an absence of an air-bone gap (i.e., 0 dB difference) for the four typical test frequencies of 500, 1000, 2000, and 4000 Hz occurs in less than 20% of cases. The problem with spurious air-bone gaps—that is, differences in persons with normal ear function—is most common and clinically serious when air- and bone-conduction thresholds are compared at a test frequency of 4000 Hz. As Margolis notes " . . . our data show a 12-dB air-bone gap at

4000 Hz for manual testing and 22-dB air-bone gap for automated testing" (Margolis, 2010, p. 14).

A final concern is perhaps most important. There is a chance that routinely performing bone-conduction audiometry in a futile attempt to document nonexistent conductive hearing loss in a patient with strong evidence of normal middle ear function may undermine patient and physician confidence in the audiologist's competence and even professional integrity. It would be entirely reasonable for a patient and/or the patient's physician to seriously question why an audiologist went to considerable efforts to perform a test to document middle ear dysfunction that was not suspected based on patient history, physician examination, or other audiological test findings.

The illustrative 54-year-old male with a complaint of bothersome tinnitus, whose audiogram was shown in Figure 6–4, met all of the above criteria that are important in ruling out the likelihood of middle ear dysfunction and/or an air-bone gap. Test time saved by not performing unneeded bone-conduction pure-tone audiometry in the patient was invested more wisely in other tests that did add value to the diagnostic process (e.g., assessment of speech perception in noise) and in an initial counseling session conducted immediately after completion of the audiological assessment.

Speech Audiometry

Speech Recognition (Reception) Threshold

The clinical practice guideline (Tunkel et al., 2014) that strongly recommended bone-conduction pure-tone audiometry in patients with bothersome tinnitus also emphasizes the importance of routinely performing speech reception threshold (SRT) tests. However, regularly performing SRT estimation wastes precious clinic time without providing auditory information that contributes to accurate diagnosis or effective management of the vast majority of patients with bothersome tinnitus. At least 5 minutes of test time is consumed with an explanation of the task to the patient plus the actual time required to estimate spondee threshold for each ear using rather detailed guidelines for measuring SRT (American Speech-Language-Hearing Association, 1988). To be sure, the SRT provides useful information in the hearing assessment of selected patient populations, especially young or difficult-to-test children, older patients with possible cognitive decline, and patients of any age where there is a suspicion of false or exaggerated hearing loss.

However, for the majority of adult patients with bothersome tinnitus who undergo clinical audiological assessment, measurement of the SRT doesn't contribute to the diagnosis or to decisions regarding management. Particularly for cognitively intact patients with normal hearing sensitivity, and those with normal hearing sensitivity within the low-frequency region, there is really no physiological or psychoacoustic explanation for a discrepancy between the pure tone average (PTA) and SRT, or for an SRT that is significantly better or poorer than the PTA.

Answers to three related questions will help to guide audiologists as they consider whether to include SRT measurement in the test battery for a specific patient complaining of bothersome tinnitus: (a) Will information from the SRT tell me more than what I already know about this patient's hearing from other tests, such as pure-tone audiometry or OAEs? (b) Will the SRT contribute to my diagnosis for this patient? and (c) Will I alter the management plan for this patient based on the SRT? If the answer is "no" for each of these questions regarding a specific patient, audiologists would be well advised to refrain from measuring the SRT.

For the reasons just cited, speech reception threshold was not estimated for the illustrative 54-year-old male with a complaint of bothersome tinnitus whose audiogram was shown in Figure 6–4.

Word Recognition in Quiet

Once again, the clinical practice guideline (Tunkel et al., 2014) that strongly recommended bone-conduction pure-tone audiometry and SRT in patients with bothersome tinnitus stresses the importance of routinely performing word recognition in quiet. Traditionally, word-recognition performance is assessed under earphones in a sound-treated room using single-syllable words presented in lists of 25 words that are phonetically balanced with regard to occurrence of phonemes in everyday speech (Hall, 2014). Patients with bothersome tinnitus and with high-frequency sensory hearing loss may experience difficulty with the task since recognition of single-syllable words is heavily influenced by perception of speech sound energy in the 2000 to 4000 Hz region. In fact, scores for word-recognition tests may overestimate problems some of these patients experience when listening to conversational speech.

The most common and serious clinical limitations or drawbacks associated with measurement of word recognition in quiet resemble those for air-conduction pure-tone audiometry. That is, recognition of single-syllable words in an atypically quiet setting is not consistent with real-world listening demands. Excellent word-recognition scores do not rule out deficits in central auditory processing and, specifically, daily struggles in perceiving and understanding complex speech in noisy settings. Audiologists commonly encounter patients who emphatically state, "I can hear you easily in this quiet room, but I really have problems understanding people speak when there is background noise." Audiologists who rely exclusively on word recognition in quiet to assess the communication ability of patients will underestimate the real-world problems that some patients experience throughout the day. Many patients with the chief complaint of bothersome tinnitus also express difficulty with speech perception in noise. These patients, and their referring physicians, understandably might question why an audiologist spends time evaluating their word recognition in quiet. For such patients, word-recognition scores in quiet will have little relation to the communication disorder that brought them to the clinic. In addition, word-recognition scores in quiet generally lack sensitivity to neural and central auditory dysfunction (Vaisbuch et al., 2019).

Performance on word recognition in quiet for the illustrative 54-year-old male with a complaint of bothersome tinnitus was depicted in the speech audiometry graphs in the lower portion of Figure 6–4. The key to symbols indicates that performance-intensity functions were plotted for word-recognition performance on lists of phonetically balanced (PB) words. Maximum (PBmax) scores were above 90% bilaterally.

Speech Perception in Noise

Clinical experience confirms that patients with bothersome tinnitus, particularly older patients, often report problems with hearing and understanding speech in noisy settings. Communication difficulties associated with hearing loss and speech-in-noise deficits presumably contributes to stress that, in turn, contributes to increased perception of and annoyance with tinnitus. Speech perception in noise tests are a more logical, sensitive, and effective measure of communication abilities than tests of word recognition in quiet. The relatively limited information about speech perception available from tests of word recognition in quiet is also available with speech-in-noise tests. Speech-in-noise tests provide additional clinically valuable information about real-world communicative skills and deficits (see Hall, 2014, for review). Results are superior in determining amplification needs and options, as well as in detecting neural auditory dysfunction. The latter diagnostic benefit is substantial. As Vaisbuch et al. (2019) report in a study of patients with confirmed vestibular schwannoma, performance of speech perception in noise is more sensitive than simple tests of word recognition in quiet for early detection of neural pathology. These authors note that speech-in-noise tests " . . . can replace word-recognition in quiet in most instances in the convention audiological test battery . . . allowing for better diagnosis and management of individuals with hearing loss" (Vaisbuch et al., 2019, p. S1). As summarized in Table 6–1, speech-in-noise tests almost always add value to the diagnosis of hearing loss and auditory dysfunction in patients with bothersome tinnitus, and the results contribute importantly to management decisions.

Cognitive functions such as memory, attention, and processing speed play an important integral role in hearing and processing auditory information. The link between peripheral hearing loss and cognitive impairment is now well documented. Persons with unmanaged or untreated hearing loss have greater likelihood of cognitive decline (Lin, 2011; Mamo et al., 2018). Perhaps more compelling is the strong connection between central auditory processing and cognitive decline and dementia. Over 25 years ago, Strouse et al. (1995) reported auditory processing disorders in patients with early-onset Alzheimer's dementia. Subsequent studies confirmed that deficits in central auditory processing were among the earliest clinical signs of dementia (Gates et al., 1998). Now, there is substantial research evidence confirming a strong correlation between auditory processing, including performance on clinical tests of speech perception in noise, and impaired cognitive performance for attention, memory, processing speed, and dementia. (e.g., Dryden et al., 2017; Hall, 2021; Thomson et al., 2017).

Routine evaluation of speech perception in noise in the assessment of patients with bothersome tinnitus is justified for reasons in addition to documenting central auditory processing deficits with or without peripheral hearing loss. Recent papers suggest a link specifically between cognitive impairment and bothersome tinnitus (e.g., Clarke et al., 2020; Waechter et al., 2021). As Clarke et al. (2020) point out, " . . .tinnitus is associated with poorer executive function, processing speech, short-term memory, and general learning and retrieval" (p. 1). Inclusion of a procedure for evaluation of speech in noise in the test battery for patients with bothersome tinnitus is clinically justified and supported with research evidence. The results of speech-in-noise assessment are likely to contribute to more appropriate and effective management of patients with bothersome tinnitus.

Performance on a measure of speech perception in noise for the illustrative 54-year-old male with a complaint of bothersome tinnitus was depicted in the speech audiometry graphs in the lower portion of Figure 6–4, the same graphs that also revealed word recognition in quiet. The key to symbols indicates that the Synthetic Sentence Identification (SSI) test was used to evaluate speech perception in noise. The patient's SSI score of 80% for the right ear and 70% for the left ear was well below his score for word recognition in quiet. Audiologists can select from more than a dozen commercially available and clinically researched word- or sentence-based tests of speech perception in noise. First reported in the late 1960s (see Hall, 2014, for review), the SSI test is particularly sensitive to deficits in real-world noisy listening settings and to the impact of decreased cognitive function on speech perception (Gates et al., 1998; Strouse et al., 1995). The relative difference in the patient's scores for word recognition in quiet versus speech (sentence) perception of a meaningful competing message suggests the possibility of central auditory processing disorder and/or cognitive impairment. These findings suggest the need for further audiological assessment and for referral of the patient to a psychologist for formal cognitive assessment.

Psychoacoustic Assessment of Tinnitus

Overview

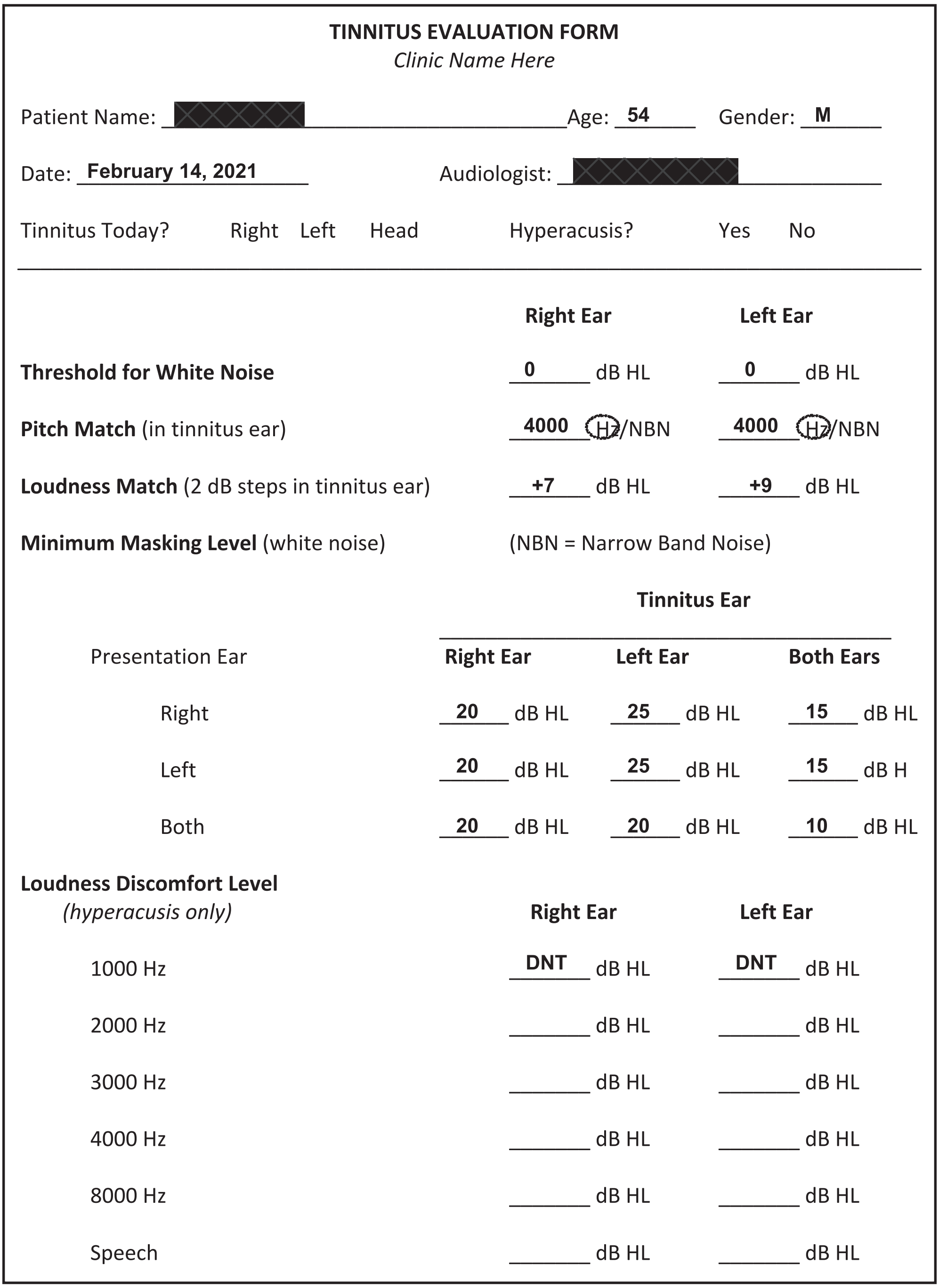
Pure-tone audiometry and even speech audiometry are psychoacoustic measures of auditory function. This section focuses, however, on psychoacoustical assessment of the perception of tinnitus in patients. Clinical practice guidelines offer conflicting opinions about psychoacoustic assessment of tinnitus. An American Academy of Audiology clinical practice guideline dating back to 2000 clearly endorses psychoacoustic assessment of tinnitus. The guideline identifies four different psychoacoustic tests: (a) pitch matching, (b) loudness matching, (c) minimum masking level, and (d) loudness discomfort levels. Psychoacoustic assessment of tinnitus is not mentioned in the otherwise very comprehensive and detailed evidence-based guidelines developed by a large task force of tinnitus experts for the AAOHNS (Tunkel et al., 2014). These guidelines devote considerable space to other components of the medical and audiological assessment process, including physical examination, imaging studies, validated tinnitus inventories, and audiological tests (except for DPOAEs). Yet, psychoacoustic assessment of tinnitus is, rather surprisingly, not cited. And, the most recent document entitled *Practice Guidance for Tinnitus in Adults* (British Society of Audiology, 2019) provides in-depth review of and strong recommendation for other components of the assessment process, such as general and tinnitus history questionnaires; validated inventories for tinnitus, depression, and insomnia; and a diagnostic audiological test battery, yet a rather stern warning about "assessment that should be avoided in a clinical setting" (British Society of Audiology, 2019, p. 19). Among the tests that audiologists should avoid include pitch matching, loudness matching (referred to as tinnitus sensation level), and loudness discomfort levels (referred to as uncomfortable loudness levels). Similarly, the NICE (2020) document, citing clinical and economic evidence (e.g., healthcare costs), found no published randomized control trials supporting the benefits of psychoacoustical measures. The group clearly recommends against the practice with the statement: "Do not offer psychoacoustic tests, for example pitch and loudness matching, to assess tinnitus" (NICE, 2020, p. 12).

As Tyler and colleagues point out, "Measuring the psychoacoustic aspects of tinnitus is helpful to confirm to the patient that the tinnitus is a real phenomenon, to monitor changes in the magnitude of tinnitus, to provide insight into the possible mechanism, and to aid in the fitting of a noise generator if results warrant" (Tyler et al., 2008). Psychoacoustic assessment of tinnitus also offers additional benefits to the patient and to the patient–audiologist working relationship. The author's 25+ year clinical experience in evaluating and managing patients with bothersome tinnitus suggest that the relatively brief test time (typically <15 minutes) devoted to psychoacoustic assessment of tinnitus yields the following additional advantages:

- Patients scheduled for a tinnitus assessment logically expect an audiologist to devote time to an actual assessment of the properties or nature of their tinnitus.
- Audiologists who conduct psychoacoustic assessment of tinnitus demonstrate their interest in and concern for the problem that prompted the patient or the patient's physician to schedule an appointment in the clinic.
- To paraphrase Tyler et al. (2008), psychoacoustic assessment validates the patient's expressed concerns about bothersome tinnitus.
- The give-and-take interaction between patient and audiologist during the psychoacoustic assessment of tinnitus helps to form a close and positive working relationship that later contributes to more effective counseling and management.
- Replicated findings for more than one psychoacoustic assessment of a patient help to confirm the validity of bothersome tinnitus, particularly when two or more audiologists conduct psychoacoustic assessments with the same patient. This advantage is especially important in patients who are involved in litigation regarding their perceived tinnitus.

The psychological benefits of psychoacoustic assessment for the patient are perhaps best illustrated with a scenario that the author has occasionally witnessed. Imagine a patient with bothersome tinnitus as indicated with high scores on a validated tinnitus inventory. The patient sobs consistently as the audiologist reviews the history and the tinnitus inventory. The audiologist and patient begin to develop a positive, trusting relationship during the routine audiological assessment. The audiologist provides appropriate encouragement to the patient and demonstrates constant compassion and understanding as the testing proceeds. Psychoacoustic testing begins approximately 30 to 45 minutes after the patient first arrives at the clinic. At some point during the psychoacoustic assessment process, the patient rather unexpectedly announces a new concern via the talkback system in the sound treated room. The audiologist somewhat hesitantly asks the patient to express the concern. Remarkably, the patient informs the audiologist that they are, for a very good reason, unable to complete the psychoacoustic assessment process. The patient no longer hears any tinnitus sound. Obviously, psychoacoustic assessment of tinnitus cannot be performed for a patient who doesn't perceive tinnitus.

The following is a brief explanation of the psychoacoustic assessment process readers may wish to refer during the discussion to the summary of findings for psychoacoustic assessment of the illustrative case; that is, the 54-year-old male with bothersome tinnitus shown in Figure 6–5. Audiologists may vary the sequence of tests in the psychoacoustic assessment. The author conducts the tests in the order described.



TINNITUS EVALUATION FORM
Clinic Name Here

Patient Name: [redacted] Age: 54 Gender: M

Date: February 14, 2021 Audiologist: [redacted]

Tinnitus Today? Right Left Head Hyperacusis? Yes No

	Right Ear	Left Ear
Threshold for White Noise	0 dB HL	0 dB HL
Pitch Match (in tinnitus ear)	4000 [✓ Hz]/NBN	4000 [✓ Hz]/NBN
Loudness Match (2 dB steps in tinnitus ear)	+7 dB HL	+9 dB HL

Minimum Masking Level (white noise) (NBN = Narrow Band Noise)

	Tinnitus Ear		
Presentation Ear	**Right Ear**	**Left Ear**	**Both Ears**
Right	20 dB HL	25 dB HL	15 dB HL
Left	20 dB HL	25 dB HL	15 dB H
Both	20 dB HL	20 dB HL	10 dB HL

Loudness Discomfort Level
(hyperacusis only)

	Right Ear	Left Ear
1000 Hz	DNT dB HL	DNT dB HL
2000 Hz	dB HL	dB HL
3000 Hz	dB HL	dB HL
4000 Hz	dB HL	dB HL
8000 Hz	dB HL	dB HL
Speech	dB HL	dB HL

Figure 6–5. Psychoacoustic assessment findings for the illustrative case (54-year-old male with bothersome tinnitus).

Threshold for White (Broadband) Noise

The patient is given the response button used earlier in pure-tone audiometry with instructions to press the button each time they hear a rushing water sound. The audiologist then presents a sample of the white noise (i.e., broadband noise [BBN]) sound at a suprathreshold level. Using 5-dB intensity increments, short durations (about 0.5 second) of the BBN are presented to the patient using a descending/ascending method similar to that employed in pure-tone audiometry.

The BBN threshold is measured for each ear and recorded on the form shown in Figure 6–5. BBN thresholds typically correspond to a patient's most sensitive hearing threshold in an audiogram. However, because the BBN signal includes essentially all frequencies within the range of earphones, including frequencies below 250 Hz and many interoctave frequencies, patients may yield a BBN threshold that is noticeably better (i.e., at a lower level) than any threshold reflected in the audiogram. A patient's BBN threshold is helpful in determining the lowest level of environmental sound, or sound produced by an ear-level sound generator, that is just audible. Audiologists should expect to encounter some patients with considerable hearing loss who have remarkably good BBN thresholds (e.g., <20 dB HL).

Pitch Matching

The goal with pitch matching is to estimate the general frequency region of the patient's perceived tinnitus. Precise identification of the frequency of a patient's tinnitus is not possible. Perceived tinnitus is rarely, perhaps never, a single pure-tone frequency. Even ringing type tinnitus presumably consists of complex combination of many frequencies. Also, the nature of a tinnitus sound varies from patient to patient. Indeed, it's not an exaggeration to state that there are as many different tinnitus sounds as there are patients who perceive tinnitus. The modest goal of the pitch-matching test within the psychoacoustic assessment is to identify a general frequency region representing the dominant sounds that a patient perceives. The information derived from pitch matching is useful in making decisions about the frequency response and potential effectiveness of sound generators and sound therapy in general.

There is no recommended or preferred method for conducting a pitch-matching test among audiologists. As already noted, some clinical practice guidelines fail to mention pitch matching in the assessment of tinnitus, and one guideline discourages use of any psychoacoustic tests.

Based on an informal review of published and unpublished reports of tinnitus assessment, two-alternative forced choice (2AFC) approaches are typically employed clinically in an attempt to determine the pitch of a patient's tinnitus. With each approach, an audiologist presents a reference sound using an audiometer. The reference sound is usually a pure tone, but it may also be a narrowband noise (NBN) or a combination of a pure tone and NBN. With one approach, the audiologist presents a reference sound to the ear opposite from the tinnitus ear that the patient is attending to, whereas with another approach, the audiologist presents a reference sound to the tinnitus ear that the patient is attending to during the task. The latter approach is briefly described here.

The audiologist instructs the patient to listen to their tinnitus in an ear and also to a tone that is presented to that ear. The patient is encouraged to only listen for the pitch (e.g., high or low) of the tone and tinnitus, not the loudness or the exact nature of the sound. The audiologist then presents a pure-tone signal at a comfortable level and at a frequency that is probably lower than the patient's perceived tinnitus pitch, such as 500 or 1000 Hz. Following presentation of the tone, the audiologists asks the patient if the tinnitus typically heard is higher or lower in pitch. Usually patients report that their tinnitus pitch is higher. The audiologist then presents progressively higher-frequency pure tones until the patient reports a similarity in the pitch of tinnitus and the reference tone. The perceived tinnitus frequency is then recorded on the form. For our 54-year-old male patient, the perceived tinnitus pitch or frequency in each ear was 4000 Hz. As this case suggests, perceived tinnitus pitch most often corresponds to a region where hearing loss is greatest or, in patients with normal hearing sensitivity, the frequency where DPOAEs are most abnormal.

Loudness Matching

Loudness matching is performed at the frequency obtained via the preceding pitch-matching test. Patients are instructed to listen closely to their tinnitus and also to the pure tone or other reference sound. The patient is told to tell the audiologist when the reference tone is about the same loudness as the constant tinnitus sound. Any differences in the nature or pitch of the two sounds should be ignored. The focus is only on the loudness of the tinnitus relative to the other sound.

The audiologist begins by presenting the reference sound at an intensity level 2 or 4 dB lower than the patient's threshold for the same sound; for example, at about 40 dB HL at 4000 Hz determined in the pitch-matching test for the illustrative case. Loudness matching is often performed with 2-dB steps rather than 5-dB increments as used in finding thresholds. As a rule, patients match their tinnitus to reference sounds that are within +10 dB of the threshold for the same sound. Loudness matching yielded expected findings for the illustrative case; i.e., +7 dB HL for the right ear and +9 dB HL for the left ear. The audiologist is certainly free to give the patient consistent encouragement during the pitch- and loudness-matching tasks. For the illustrative case, it would be entirely appropriate for the audiologist to comment, "You are doing very well on these tests. The results are quite consistent with your hearing tests and what I was expecting."

Masking of Tinnitus

The next test in the psychoacoustic assessment is performed to determine the lowest level of BBN that just masks or covers up a patient's tinnitus. Some audiologists only perform the test with masking sound presented to both ears, with the patient reporting when they no longer perceive the tinnitus in either ear. The results for this approach are recorded in the spaces for "both" presentation ears and "both" tinnitus ears in Figure 6–5. Or, as also shown in Figure 6–5, the tinnitus masking test can be conducted with various combinations of the masking-sound ear and the tinnitus ear.

The results of the tinnitus masking test —that is, the levels of BBN that just cover up tinnitus and make it imperceptible—are important clinically. The levels predict the amount of environmental sound or sound from an ear-level generator that are likely to give the patient some relief from tinnitus. It's not uncommon to discover that tinnitus masking levels are close to the patient's threshold for BBN, and at levels that are typically found in many everyday settings. Audiologists are advised to readily highlight that point in describing the results of psychoacoustic assessment and especially in the initial counseling session immediately following the overall audiological assessment. The author repeats this positive message to patients in stressing the importance of sound therapy as a key component of effective management for bothersome tinnitus.

Residual Inhibition

Another quick and useful component of the psychoacoustic assessment is estimation of residual inhibition (Danesh, 2019). The audiologist presents BBN or a NBN centered around the patient's perceived tinnitus pitch at a documented effective masking level for a duration of at least 1 minute. Then, the audiologist questions the patient about their perception of tinnitus after the masking noise is discontinued. As Danesh (2019) notes about residual inhibition, "For many patients, experiencing this suppression of their tinnitus provides hope since they realize that there are ways to manipulate tinnitus loudness" (p. 22).

Loudness Discomfort Levels (LDLs)

Measurement of loudness discomfort levels with tonal and speech signals is typically performed for patients with tinnitus who also report decreased sound tolerance; e.g., hyperacusis. The estimation of LDLs is a routine audiological procedure for patients with hearing loss and at risk of loudness recruitment, particularly potential hearing aid candidates. Interested readers are advised to review the procedure in any number of audiology textbooks (e.g., Hall, 2014). It should be noted, however, that some clinical practice guidelines (e.g., British Society of Audiology, 2019) expressly advise against the measurement of LDLs in patients with bothersome tinnitus.

Concluding Comments

For most patients with bothersome tinnitus, the audiological assessment process just reviewed can be competed in no more than 1 hour or, at most, 1.5 hours. Efficiency in testing is very important clinically. Considerable precious time in the audiological assessment is saved with adherence to test principles and protocols outlined in this chapter and described in more detail in a recent publication (Hall, 2021). Simple modifications in an audiological assessment strategy can save many minutes of test time without compromising diagnostic power or accuracy. As already noted, at least 15 to 20 minutes of test time can be eliminated by not performing procedures that lack diagnostic value, such as speech reception threshold estimation and bone-conduction pure-tone audiometry. The time spent on word-recognition testing, if performed in addition to speech-in-noise testing, can easily be reduced with the use of recorded word lists constructed with the 10 most difficult words first (see Hall, 2014, for details).

Time saved in the audiological assessment process can be wisely invested immediately in a brief, focused counseling session that includes elements of informational or content counseling, personal adjustment counseling, directive counseling, and even concepts borrowed from CBT.

Analysis and interpretation of patterns of findings from the entire assessment, including history, tinnitus questionnaires, tinnitus inventories, diagnostic procedures, and psychoacoustic assessment, allows for timely decisions regarding the most appropriate management options and necessary referrals to other healthcare professionals.

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7 APP-BASED TINNITUS ASSESSMENT

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Introduction

Technological advances in, and increased access to, mobile devices (such as smartphones) have resulted in an exponential growth in the number of health-related mobile (mHealth) applications. There are now more than 300,000 applications (apps) across different platforms that focus on prevention, diagnosis, and/or management of disease (Gordon et al., 2020). Better use of digital technology has the power to improve health, transform the quality of healthcare services, and reduce costs (National Information Board Department of Health, 2014). People are increasingly using technology to manage their health. For instance, 48% of healthcare workers use mobile or tablet apps, and around 90% of them are willing to share their health data with their physicians, nurses, or other healthcare professionals (Accenture, 2018).

Advantages of using apps to deliver healthcare include improved access, improved quality, and lowered costs (Zhenwei Qiang, 2012). However, there are also potential drawbacks of using mHealth, such as data misuse (Misra et al., 2013), reduced quality and effectiveness of healthcare delivery (Lewis, 2013; Murfin, 2013), and risk of fragmenting clinical practices due to the development and use of too many apps (Charani et al., 2014).

Background

Quality and functionality of healthcare apps, including tinnitus apps, can vary greatly. The IMS Institute for Healthcare Informatics (Aitken & Gauntlett, 2013) assessed the functionality of 16,275 healthcare apps based on 25 individual criteria, such as the type and quantity of information provided by the app, capturing and tracking of user data, communication processes utilized by the app, and the number of device capabilities included in the app. More than 90% of apps received a score of 40 or less out of a possible 100, indicating poor quality. A more recent study (Sereda et al., 2019) assessed the content and quality of 18 apps most often used for management of tinnitus. This study also concluded variable quality of apps with a range of Mobile App Rating Scale scores between 1.5 and 4.2 out of 5, with a score of *1* being inadequate and *5* being excellent.

The large number of healthcare apps, while encouraging, can also pose challenges for users and healthcare professionals. The search results for apps in app stores can be overwhelming. As an example, several hundred apps appear when searching for the keyword "tinnitus" on both Android's and Apple's app stores. As there is currently limited evidence for the effectiveness of apps for the assessment and management of tinnitus, and a lack of professional guidelines for their use in practice, clinicians' recommendations may reflect personal preferences or experiences. It is worth noting that most people who use tinnitus apps tend to use them as self-help, not in conjunction with the management provided by hearing healthcare professionals (Sereda et al., 2019).

This chapter provides an overview of apps for assessment of tinnitus, including their functions, features, benefits, and challenges. In this chapter, mobile apps are defined as software applications that are optimized for a variety of mobile platforms, such as smartphones and tablets.

Recent Advances

Overview of Tinnitus Assessment Apps

In clinical assessment of patients with bothersome tinnitus, it is important to determine how the tinnitus affects daily activities and quality of life. This information helps the clinician in three main ways: (a) making decisions about the need for referrals to other professionals, (b) marking baseline tinnitus characteristics to measure clinical improvement, and (c) creating a management plan (Cima et al., 2019). In research, these factors are also important in determining study design, eligibility, and outcomes such as identifying potential mechanisms, subtypes, or management options for tinnitus (Genitsaridi et al., 2019).

Studies have investigated mobile apps used in hearing healthcare, including apps developed specifically for the assessment of tinnitus. Paglialonga et al. (2015) identified and assessed hearing healthcare apps available from Apple, Google, and Windows app stores. The authors provided an overview of the current availability, affordability, and variety of hearing-related apps. Reviewed tinnitus apps offered functions such as tools for screening, assessing symptom severity, and estimating tinnitus pitch and loudness. The apps identified for review were intended to be used by hearing healthcare professionals or people with tinnitus, with or without the support of hearing healthcare professionals. No additional details about the apps were provided.

Deshpande and Shimunova (2019) also evaluated tinnitus apps available on three mobile platforms: Apple, Android, and Windows. The authors categorized the apps as: (a) tinnitus education, awareness, and prevention; (b) tinnitus assessment and measurement; (c) tinnitus management; and (d) tinnitus misinformation. Across the three platforms, 36 apps were found to have at least one tinnitus assessment feature. These apps offered options for (a) identification of type and laterality of tinnitus, (b) pitch and loudness matching, (c) annoyance ratings, and (d) measuring tinnitus symptom severity using questionnaires. Apps in the fourth category were designed to be quick assessment tools for individuals with tinnitus.

Sereda et al. (2019) analyzed the content and quality of tinnitus apps. The apps reviewed were identified by users in a web-based survey as the ones that they accessed for managing tinnitus. Two out of the 55 apps focused on assessment. One app measured tinnitus frequency and another assessed eligibility for tinnitus retraining therapy, or TRT (Phillips & McFerran, 2010).

Kalle et al. (2018) investigated how internet-based and smart services were utilized for clinical diagnosis and management of tinnitus. Studies that focused on tinnitus assessment used apps for ecological momentary assessment (EMA)—that is, repeated sampling of a person's current behavior or experience in real time (Schlee et al., 2016; Wilson et al., 2015)—and for tinnitus pitch matching (Hauptmann et al., 2016; Wunderlich et al., 2015; Yoo et al., 2015). In his overview of apps relevant for hearing healthcare, Hesse (2018) described tinnitus assessment apps like Track Your Tinnitus for documenting fluctuations of tinnitus quality and impact over time (Probst et al., 2016), an app for EMA of tinnitus (Wilson et al., 2015), and an app for recording tinnitus loudness and coping strategies (Henry et al., 2017). The review also described tinnitus management apps, such as notched music therapy and acoustic neurostimulation, that incorporate assessment features, including measurement of tinnitus loudness and pitch for creation of a custom notched music therapy (Teismann et al., 2019; Wegger et al., 2017).

Mehdi, Stach, et al. (2020) performed systematic searches of scientific databases and app stores to identify tinnitus apps, specifically smartphone-based app solutions. The authors described underlying technology used for app development and the effectiveness of apps for tinnitus patients. The review showed that tinnitus assessment apps: (a) collected data about fluctuations of tinnitus quality and impact over time (Pryss et al., 2017; Schlee et al., 2016), (b) performed hearing and tinnitus impact assessments as a part of a larger therapeutic program (Henry et al., 2017), or (c) used a tinnitus pitch estimator to inform the design of custom sounds for tinnitus therapy (Kim et al., 2017).

Hearing assessment apps are not directly related to the assessment of tinnitus quality or impact, but are often included in reviews of mobile apps for tinnitus (Hesse, 2018; Mehdi, Riha, et al., 2020). Tinnitus is often associated with some degree of hearing loss (Wallhäusser-Franke et al., 2017). Therefore, hearing assessment is recommended in clinical practice guidelines for tinnitus (Cima et al., 2019; National Institute for Health and Care Excellence, 2020; Tunkel et al., 2014). Mehdi, Riha, et al. (2020) also reported that apps for hearing testing are relevant to the procedure of tinnitus matching for loudness and pitch.

It is clear from the many reviews on the topic that mobile apps for tinnitus assessment can be divided into four categories: (a) assessment of primary tinnitus characteristics (such as loudness, pitch, and annoyance), (b) assessment of the effects of tinnitus on aspects of the individual's life (such as sleep, concentration, socialization, relaxation, and enjoyment), (c) EMA of tinnitus, and (d) assessment of hearing loss associated with tinnitus.

Assessment of Primary Tinnitus Characteristics

The most commonly assessed characteristics of tinnitus are loudness and pitch. Loudness matching is typically done by asking participants to adjust the loudness of a presented external tone or narrowband noise (typically a 1-kHz tone) until it matches the perceived loudness of their tinnitus (Hauptmann et al., 2016; Wunderlich et al., 2015). Alternatively, visual analog scales are used in mobile apps where the aim is to monitor how tinnitus loudness changes over time or with therapy (Hesse 2018; Mehdi, Riha, et al., 2020; Schlee et al., 2016).

There are several methods for estimating tinnitus pitch (Hoare et al., 2014; Wunderlich et al. 2015). Pitch-matching procedures vary between apps. However, in most cases, they incorporate some form of bracketing or two-alternative forced-choice methods. Some apps use methods that rely on adjustments of sound frequency using a slider (Deshpande & Shimunova, 2019; Hauptmann et al., 2016; Wunderlich et al., 2015). Hauptmann et al. (2016) tested a more complex approach to pitch matching with the aim of increasing its accuracy and reliability. The goal was to reliably identify appropriate sound therapy stimuli, that is, randomly ordered sequences of low-level tones centered around the tinnitus pitch. The method involved bracketing, similarity grading, and two-alternative forced choice in a single protocol. Hauptmann et al. (2016) and Wunderlich et al. (2015) compared mobile-based to standardized audiometric procedures for pitch matching. The authors concluded that it was feasible to use mobile technology for pitch matching but that further validation studies were needed.

Mobile apps that incorporate assessment of perceptual characteristics of tinnitus can be further categorized according to how the information collected is used. Some apps aim to inform users about the characteristics of their tinnitus without suggesting any interpretation or course of action. Others use assessment data to either: guide eligibility for specific types of therapy; guide the choice of stimuli for specific forms of therapy such as notched music or sound-based neuromodulation treatments; monitor changes in tinnitus over time; monitor changes in tinnitus depending on the environmental and/or emotional state; or assess the effects of therapy on the perceptual characteristics of tinnitus (Deshpande & Shimunova, 2019; Hesse 2018; Nagaraj & Prabhu, 2020; Paglialonga et al., 2015; Sereda et al., 2019).

Psychoacoustic measures of tinnitus percept, such as loudness and pitch, have been recommended as part of patient counseling to demonstrate stability of the percept over time (Henry et al., 2005). Psychoacoustic measures are also essential for prescription of some sound-based therapies such as notched noise and acoustic coordinated reset (CR®) neuromodulation that use sound stimuli relative to the tinnitus pitch (Pantev et al., 2012; Tass et al., 2012). They may also be used in clinical trials to infer an effect of treatments on tinnitus-related brain activity. Hence, a convenient approach to measuring tinnitus characteristics is very desirable. The method should demonstrate good agreement—that is, low absolute measurement error and reliability, or how well individual patients or participants can be distinguished from each other (Terwee et al., 2007). However, this is not an easy task.

Burns (1984) compared the reliability of pitch and loudness matching of two objective sounds with each other versus matching an objective sound to the subjective tinnitus sound. The latter was significantly less reliable. In the case of pitch matching, this difference occurred with a likeness or forced-choice double-staircase procedure, and the difference was greater for a bracketing (method of adjustment) task. Other aspects of the test procedure can also affect the agreement and reliability of psychoacoustic tests. For example, Penner and Saran (1994) found that tinnitus pitch matching using a forced-choice procedure was less reliable when participants could simultaneously adjust the level of the matching sounds than when the level of the matching sounds was fixed. Interestingly, the investigators did not find the same effect for loudness matching.

Different research groups have independently developed tools to evaluate tinnitus characteristics using likeness rating scales and a wide range of frequencies (Noreña et al., 2002, Roberts et al., 2006). One widely used example is the Tinnitus Tester, an adaptive, subject-directed, computerized procedure to estimate tinnitus loudness, pitch, masking levels, and the phenomenon of residual inhibition (Roberts et al., 2006, 2008). The Tinnitus Tester has been used to investigate the relationship between tinnitus pitch and hearing thresholds (Sereda et al., 2011), cochlear function as it relates to the tinnitus pitch (Zhou et al., 2011), and the effects of different interventions on tinnitus loudness or pitch (Hoare et al., 2012). In their validation of the Tinnitus Tester over a 2- to 3-week interval between two sessions, Roberts et al. (2008) found good agreement between measures of loudness and pitch matching for tinnitus. They reported that the group mean did not significantly differ across sessions for loudness or pitch matching. However, the evaluation was limited as it only involved two sessions and it did not account for individual or within-session effects. An independent validation by Hoare et al. (2014) involved 28 participants and testing at five time points over a 3-month period. Of note, the researchers found a significant difference in loudness-matching estimates between test sessions 1 and 2, but no significant difference in estimates across sessions 2 to 5. They concluded that the difference between sessions 1 and 2 was due to procedural or perceptual learning. Pitch matching was more variable overall, and most variable when assessments were separated by longer intervals.

In summary, collection of reliable estimates of the psychoacoustic characteristics of tinnitus is challenging, not just with mobile apps but also with standard clinical and research equipment. This has implications for the use of pitch- and loudness-matching data in counseling and for other potential clinical applications, such as the prescription of sound-based interventions.

Assessment of Reaction to Tinnitus

Several mobile apps assess tinnitus symptom severity, typically annoyance and/or distress, using questionnaires or visual analog scales (Deshpande & Shimunova, 2019; Nagaraj & Prabhu, 2020). Validated questionnaires used via apps (Henry et al., 2012; Mehdi, Riha, et al., 2020; Mehdi, Stach, et al., 2020) include the Tinnitus Functional Index (TFI) (Meikle et al., 2012), the Tinnitus Handicap Inventory (THI) (Newman et al., 1996), the Tinnitus Handicap Inventory—Screening Version (THI-S) (Newman et al., 2008), and the Mini Tinnitus Questionnaire (mini-TQ) (Hiller & Goebel, 2004). The rationale behind collecting such measures differs between apps. For instance, patients' responses to questionnaires may prompt an appointment with a hearing healthcare professional or may be used to assess the outcome of tinnitus therapies (Deshpande & Shimunova, 2019; Mehdi, Riha, et al., 2020). Patient responses to questionnaires can also be used to monitor changes in tinnitus symptom severity over time, to investigate the association between tinnitus severity and daily routines and activities, and to identify participants for recruitment into research studies (Mehdi, Riha, et al., 2020; Probst, Pryss, Langguth, Rauschecker, et al., 2017; Probst, Pryss, Langguth, Spiliopoulou, et al., 2017; Pryss et al., 2017; Schlee et al., 2016). In addition, there are app-based questionnaires and visual analog scales for assessing sleep difficulties, mood, stress, and hyperacusis (Chamoso et al., 2017; Schlee et al., 2016).

Few publications describe the validation of questionnaires delivered and completed through mobile devices. Henry et al. (2012) compared THI-S responses from participants obtained via a paper-and-pencil (traditional) version versus those completed through a personal digital assistant (PDA). The traditional scores were within 1 to 2 points of the PDA average of scores for 41.7% of the participants. However, for 45.8% of the participants, the traditional method estimated tinnitus severity as higher than the PDA format, whereas the traditional method estimated tinnitus severity as lower than the PDA estimate for 12.5% of the participants. The authors concluded that administering the THI-S through a device produced reasonable estimates of tinnitus symptom severity, but severity was under- or overestimated for some participants (Henry et al., 2012). Müller et al. (2016) reported a study that validated online versions of several tinnitus questionnaires translated into Swedish. The researchers concluded that the data supported good clinical validity of the tinnitus-related questionnaires delivered online.

Using tinnitus questionnaires as tools for self-assessment in people with tinnitus (i.e. without explanation and without interpretation of the results by a healthcare professional) can be challenging. Greenwell et al. (2019) used the THI as a self-assessment tool in the context of online cognitive behavioral therapy-based self-help treatment (the Tinnitus e-Programme). Participants found the THI useful for receiving feedback on their progress. Participants reported a sense of achievement and confidence that the intervention was beneficial. However, they also reported difficulties with scoring the response scale, understanding the feedback system, and interpreting results. The authors concluded that more user-friendly tools were needed for patients to set and review their personal goals.

Some mobile apps have attempted to combine an assessment of hearing with that of perceptual characteristics and/or severity of tinnitus. For instance, Chamoso et al. (2017) developed and reported on an Android app that combined hearing tests and administration of questionnaires about sleep (Pittsburgh Sleep Quality Index [PSQ]) (Buysse et al., 1989), hyperacusis (Hyperacusis Questionnaire [HQ]) (Khalfa et al., 2002), and tinnitus symptom severity (THI). The app controlled an *ad hoc* device and automated both the execution of hearing tests and the administration of questionnaires that measure the disability induced by the tinnitus. However, work beyond initial development is yet to be reported.

Ecological Momentary Assessment of Tinnitus

Collecting repeated measures of tinnitus in real time can provide information about: the relationship between tinnitus severity and changes in daily life and activity; the natural history of tinnitus symptom severity; and whether there are meaningful subgroups within the data (Hesse, 2018; Mehdi, Riha, et al., 2020; Mehdi, Stach, et al., 2020). For example, the Track Your Tinnitus app systematically records fluctuations of tinnitus symptoms over time and combines data actively provided by the individual, such as questionnaires and visual analog scales, as well as that passively collected by the app, such a tracking of location and noise level (Probst et al., 2016). The advantage of such an approach is that the data relate to real-time or very recent states, minimizing the bias associated with retrospective data collection (Kraft et al., 2020). Data related to tinnitus presence, loudness, and related distress allow patients to identify situations and circumstances causing changes in tinnitus perception and thus to take control of their tinnitus (Schlee et al., 2016). For example, data collected using the app have demonstrated a time-of-day-dependence of tinnitus (i.e., tinnitus is reported as louder and more distressing between the hours of 12 a.m. and 8 a.m. than at other times of the day) (Probst, Pryss, Langguth, Rauschecker, et al., 2017). Such repeated-measures data have also been used to understand the association between tinnitus and stress (Pryss et al., 2018). Additionally, data obtained via the app can shape and facilitate recruitment of participants for large-scale research studies (Probst, Pryss, Langguth, Spiliopoulou, et al., 2017).

One concern related to real-time continuous tracking of tinnitus with an app is that it may exacerbate tinnitus-related symptoms as constant attention is drawn to tinnitus (Hesse, 2018). Schlee et al. (2016) examined whether repeated measurements led to worsening of tinnitus symptoms in a group of participants using the Track Your Tinnitus app for at least 1 month. They found that using the app did not lead to significant increase in tinnitus loudness or worsening of tinnitus symptom severity. Authors therefore concluded that the app was a safe method for longitudinal assessment of tinnitus.

Audiological Assessment Related to Tinnitus

Approximately 80% of individuals with tinnitus report some degree of hearing loss (Wallhäusser-Franke et al., 2017). Many mobile apps offer assessments of hearing, including testing an individual's hearing ability, screening for hearing loss, comparing someone's hearing ability with that of others (e.g., family and friends), or testing hearing thresholds at different frequencies in quiet and noisy environments (Bright & Pallawela, 2016; Casale et al., 2018; Hesse, 2018; Mehdi, Riha, et al., 2020). However, few of these apps have been subjected to any robust form of validation. Some apps perform well in generating threshold values consistent with those obtained from standard audiometry (Mehdi, Riha, et al., 2020), while the accuracy of others is low (Bright & Pallawela, 2016). Bright and Pallawela (2016) found that only 20% (six out of 30) of the hearing assessment apps they reviewed were tested for validity. Although the performance of some apps was tested in comparison to pure-tone thresholds derived from standard audiometric procedures in the same individuals, the results were variable.

Several factors that can affect the accuracy of results obtained from hearing assessment apps are highlighted in a review by Bright and Pallawela (2016). First, the level of ambient noise in the testing environment has a significant impact on the accuracy of results. Second, the type of mobile devices and the headphones or earphones used to deliver stimuli affect results. Most studies of hearing assessment apps have used a single type of headphone with a single type of device. However, apps were used with different device–headphone combinations. Third, device calibration or lack there of may impact outcomes. Indeed, not all studies of apps performed calibration as part of their procedures. The authors postulated that this may be due to a lack of standardized procedures for calibration of smartphone-based tests and nonaudiometric headphones or earphones. Furthermore, individual users were unlikely to perform device calibration even if it was available. Finally, extended high-frequency testing may not be offered by all hearing assessment apps. Such testing is routinely used for hearing screening when ototoxicity or noise-induced hearing loss is suspected. Most apps currently available do not test hearing at frequencies above 8 kHz (Bright & Pallawela, 2016).

Several researchers have investigated the use of mobile apps for audiometric testing within clinical settings. In general, the findings suggest that reliable air-conduction thresholds, including extended high-frequency thresholds, are possible with mobile apps (Brittz et al., 2019; Louw et al., 2017; Sethi et al., 2018; van Tonder et al., 2017). Measuring bone-conduction (BC) thresholds is also possible via a smartphone app and a professional-grade bone oscillator. For instance, Dewyer et al. (2019) found that most BC thresholds were within 5 to 10 dB of those determined by an audiologist using a standard clinical setup. However, in the smartphone setup, almost all participants needed help placing the bone oscillator in the correct position. Therefore, more research is needed to identify strategies for obtaining reliable results with remote BC pure-tone testing.

In summary, the validation of audiometric apps, specifically in people with tinnitus, is still lacking. Most apps are used for hearing screening rather than diagnostic purposes. Although mobile apps allow for self-testing, the role of the clinician remains significant in interpreting app-generated data and in guiding clinical management (Mehdi, Riha, et al., 2020).

Future Directions

Sereda et al. (2019) recently performed a quality analysis of some of the most-cited tinnitus apps using the Mobile App Rating Scale (MARS) (Stoyanov et al., 2015). Future studies could incorporate inputs from both professionals and patients to create comprehensive ratings of tinnitus apps. Such data could complement traditional tinnitus management strategies. Future research should examine the possibility of incorporating apps into the clinical assessment of tinnitus and creating guidelines for the use of apps as part of tinnitus assessment and management. Further studies should also explore the desired content and usability features of apps for tinnitus assessment.

Clinical Implications

Use of mobile apps is increasingly becoming a part of our everyday lives for communication, entertainment, and learning. This also includes learning about health conditions such as tinnitus. Apps offer a medium for delivery of concise information about what tinnitus is, why it can be a problem, and what can be done both clinically and in self-help. Assessment of tinnitus with mobile apps has many potential uses. If apps can reliably estimate tinnitus pitch, then they can, for example, be used to remotely reset pitch-based sound therapies for tinnitus. In self-help, mobile apps offer an in-hand source of self-assessment. For example, patients can learn about situations where tinnitus is better or worse and about the effectiveness of coping strategies they have adopted. Patients can also use apps to learn about techniques for managing their tinnitus. Given their potential value in the delivery of tinnitus services, it is important that apps are continually appraised for validity and usefulness of their content.

Key Messages

- There are many smartphone apps that assess tinnitus characteristics and measure tinnitus symptom severity (see Deshpande & Shimunova [2019] for a complete list).

- Apps can also be used to monitor changes in tinnitus over time.
- Apps offer the possibility of remote clinical assessment; e.g., tinnitus pitch matching needed to support forms of sound therapy.
- Mobile apps offer an in-hand source of self-assessment, providing feedback for the patients regarding their tinnitus and effectiveness of coping strategies applied.
- Ongoing research is important to ensure quality, optimal content, and usability of apps for tinnitus assessment.

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8 OBJECTIVE DIAGNOSIS OF TINNITUS

Jos J. Eggermont

Introduction

Tinnitus is often a subjective phenomenon. Tinnitus is a conscious percept, and its properties have been quantified by several questionnaires. Quantification of tinnitus attributes is not simple. Based on my own experience, the perception of my tinnitus depends on the environment I am in. For example, my tinnitus is loud when I am hiking in quiet Rocky Mountain parks. However, it is often inaudible when I am surrounded by the city's din, and I don't hear it at all as I am concentrating on writing this book chapter—unless I get stuck!

Just as with hearing loss, there is a need for objective quantification of the presence of tinnitus as well as its attributes, such as loudness, pitch, and annoyance. The favorite objective tests of hearing thresholds are evoked responses or potentials such as the auditory brainstem response (ABR), auditory steady-state response (ASSR) and, less frequently, cortical auditory evoked potentials (CAEPs). Based on the assumption that tinnitus would affect such measurements, the ABR has been proposed as an objective test for tinnitus presence—specifically the reduction of wave I amplitude relative to that of wave V (Kujawa & Liberman, 2009). However, a recent study (Möhrle et al., 2019) found just the opposite. Tinnitus may have its putative ignition point either in the brainstem (e.g., in the dorsal cochlear nucleus [DCN]) or in more central locations such as auditory cortex (AC) or parahippocampus. Representation of tinnitus in the auditory cortex or limbic regions is unlikely to affect the ABR.

ASSRs or CAEPs may be more relevant than the ABR for assessing a central site of tinnitus. Furthermore, neural imaging might be even more useful in localizing nonauditory sites that are affected in tinnitus patients. As noted in other chapters of this book, tinnitus is not a stand-alone phenomenon. Tinnitus often occurs in persons with hearing loss, including high-frequency hearing loss beyond the frequency limits of conventional audiometry (>8 kHz). Tinnitus is also often accompanied by hyperacusis. This intolerance to sounds may exacerbate tinnitus loudness (Eggermont, 2020). Even more problematic for location searches in the nervous system are comorbidities such as distress and depression that, together with hearing loss, appear to have a much greater impact on the brain than tinnitus itself. Differentiating the effects of comorbidities from direct effects of tinnitus is one of the challenges in using objective measures of tinnitus. This chapter provides an overview of recent advances in, and clinical implications of, objective measures for the quantification of subjective tinnitus.

Background

Several techniques can be utilized for the objective measurement of tinnitus. Neural activity in the human auditory system can be objectively measured from nearly all levels in the auditory system, from the cochlea to the cortex. Examples of objective measures include diverse techniques such as otoacoustic emission recordings that probe the function of the outer hair cells (OHCs), evoked potentials or magnetic fields registering synchronous brain activity, and various imaging techniques. Measurements of human cortical activity are noninvasive, as they are generally confined to scalp-recorded activity using electro- or magnetoencephalography (EEG/MEG) or functional imaging with positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) (Eggermont, 2012, pp. 59–72). Several of these techniques are discussed next.

Electroencephalography and Magnetoencephalography

Neural oscillations, often called brain rhythms, are clearly visible in the EEG. They consist of repetitive neural activity in the central nervous system (Gourévitch et al., 2020; Figure 8–1). This spontaneous EEG or MEG likely relates more to tinnitus than stimulus-evoked activity does (Eggermont, 2012, p. 65). The stimulus-evoked activity (e.g., reflected in CAEPs), may largely represent hyperacusis (Eggermont, 2012, p. 43). An early study (Weisz et al., 2005) showed that, in comparison to normal-hearing control participants, spontaneous MEG activity in a group of individuals with tinnitus was characterized by a marked reduction in the alpha band (8–12 Hz) power over the temporal cortex, together with an enhancement in delta (1.5–4 Hz) power. Correlations with tinnitus-related distress revealed strong associations with this abnormal spontaneous activity pattern, particularly in the right temporal and left frontal areas (Weisz et al., 2005). Using continuous scalp recordings, Vanneste et al. (2010) focused on the cortical and subcortical source differences in resting-state EEG among tinnitus patients with different grades of distress. They found more synchronized alpha activity in tinnitus patients with greater distress, with the largest activity localized to various emotion-related areas. These areas included the subcallosal anterior cingulate cortex, the insula, the parahippocampal area, and the amygdala. In addition, less alpha-synchronized activity was found in the posterior cingulate cortex, precuneus, and dorsolateral prefrontal cortex (DLPFC) in patients with greater distress. In combination, these two studies illustrate that such objective findings indicate differences in group makeup and varying comorbidities.

Neuroimaging

Several neuroimaging techniques such as fMRI and PET have been used to identify brain regions (Brodmann Areas [BA]) responsible for the generation and maintenance of tinnitus. In patients who suffer from bothersome tinnitus, intravenous applied lidocaine can suppress this phantom sensation for a short time. Group analysis of PET data (Plewnia et al., 2007) showed

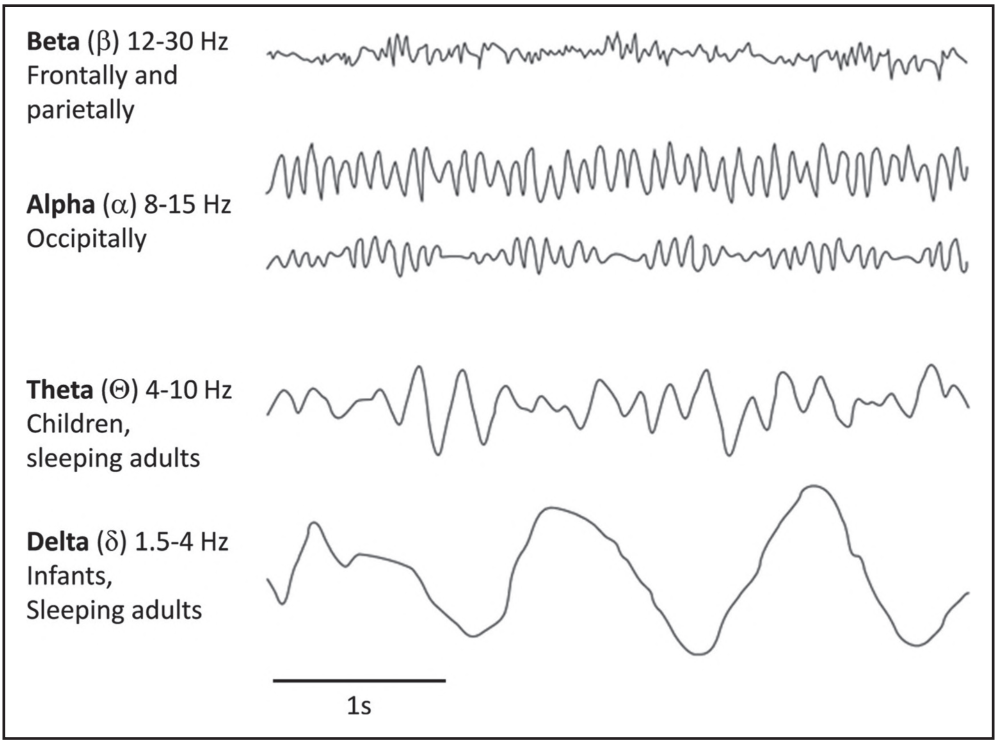

Figure 8–1. Dominant brain rhythms in the EEG/MEG. From Gourévitch, B., Martin, C., Postal, O., and Eggermont, J. J. (2020). Oscillations in the auditory system and their possible role. *Neuroscience & Biobehavioral Reviews*, *113*, 507–528. With permission from Elsevier.

tinnitus-related increases of regional cerebral blood flow in the left middle- and inferior-temporal cortex as well as the right temporoparietal cortex and posterior cingulum before lidocaine when compared to activity following intravenous lidocaine that induced a suppression of tinnitus. Like prior imaging studies, the group data from Plewnia et al. (2007) showed no significant tinnitus-related hyperactivity—that is, hyperactivity blocked by lidocaine—in the primary auditory cortex (PAC, BA 41) (Eggermont, 2012, p. 60).

The regions involved in lidocaine-related changes in perception of tinnitus were in the human equivalent (BA22) of the parabelt areas of the auditory cortex in monkeys. This finding does not imply that tinnitus is generated in those regions; only that they are needed for the conscious perception of tinnitus.

Recent Advances

Auditory Brainstem Responses

Milloy et al. (2017) conducted a review of ABR outcomes in tinnitus patients and found a high level of heterogeneity in the ABR outcomes. Amplitude and latency differences between tinnitus and control participants were not consistent among studies. Longer latency and reduced amplitude of

ABR wave I for the tinnitus group with normal hearing compared to matched controls (i.e., individuals with normal hearing but no tinnitus) was the most consistent finding across studies. However, audiogram matching did not include frequencies above 8 kHz. Therefore, these findings need to be interpreted with caution, as generation of ABR wave I, in contrast to wave V, is dominated by high frequencies in humans (Don & Eggermont, 1978). Shim et al. (2017) measured ABRs in patients with unilateral tinnitus and normal symmetric hearing thresholds versus control participants with bilateral normal audiograms. The amplitudes of wave I and V from the peak to the following trough were measured twice at 90 dB normal hearing level (nHL). Uncomfortable loudness levels (UCLs) at 500 and 3000 Hz pure tones were assessed separately in tinnitus ears (TE) and nontinnitus ears (NTE) of the same persons. Participants in the control group with normal audiograms were also tested; i.e., ABRs and UCLs. The within-subject comparison between TEs and NTEs showed no significant differences in wave I and wave V amplitude, or wave V/I ratio, in both male and female participants. Again, no high-frequency audiometry was performed, so the V/I amplitude ratio test is inconclusive. Guest et al. (2017) recorded ABRs, envelope following responses (EFRs), and noise exposure histories in young adults with tinnitus and matched controls. Tinnitus was associated with significantly greater lifetime noise exposure, despite close matching for age, sex, and audiometric thresholds up to 14 kHz. However, tinnitus was not associated with reduced ABR wave I amplitude, nor with significant effects on EFR measures of synaptopathy. Möhrle et al. (2019) found that "animals [rats] with tinnitus had reduced neural response gain and delayed ABR wave I and IV latencies, while animals with hyperacusis showed none of these changes. Preliminary studies, aimed at establishing comparable noninvasive objective tools for identifying tinnitus in humans and animals, confirmed reduced central gain [reduced wave V/wave I ratio] and delayed response latency in human and animals." Note that wave IV in rats corresponds to wave V in humans.

Cortical Auditory Evoked Potentials (CAEPs)

Jacquemin et al. (2019) explored the value of CAEPs in the evaluation of high-definition transcranial direct current stimulation (HD-tDCS) for tinnitus treatment. The results showed a significant shortening of the N1, P2, N2, and P3 latencies after HD-tDCS treatment. Moreover, the increased amplitude of the P2 and N2 peaks resulted in more salient and clear peaks, with the amplitude of N2 being significantly larger after HD-tDCS. However, the CAEP changes were not significantly correlated with the change in the Tinnitus Functional Index (TFI) (Meikle et al., 2012) total score.

In summary, the presence of tinnitus is generally not reflected in ABR or CAEP components.

Brain Rhythms

Weisz et al. (2005) showed that the resting-state neuronal brain activity measured with MEG (see Figure 8–1) for a group of individuals with tinnitus was characterized by a marked reduction in alpha power together with an enhancement in delta as compared to a normal-hearing control group. This pattern was especially pronounced for temporal cortical regions. Overall, effects were stronger for the alpha than for the delta frequency band. Using MEG in tinnitus patients compared to control participants, Schlee et al. (2014) found a significant decrease of auditory (8–10 Hz) alpha activity but not for the upper alpha band (10–12 Hz). Pierzycki et al. (2016) examined the evidence for a parametric relationship among numerous commonly used psychoacoustic and psychosocial tinnitus variables, and the whole EEG power spectra. They found no relationship among the whole scalp EEG band powers and psychoacoustic or psychosocial variables. These findings of Pierzycki et al. (2016) counter the results of Weisz et al. (2005) and many subsequent studies (Lorenz et al., 2009; Schlee et al., 2014). This indicates that EEG power measurements are unreliable.

Vanneste and De Ridder (2016) analyzed resting-state source EEG recordings in tinnitus patients and correlated these sources with the average hearing loss (across octave frequencies from 0.125 to 8 kHz, as well as midoctave frequencies of 3 and 6 kHz), the frequency range of their hearing loss, and the hearing loss at the tinnitus pitch. They found that in patients with little or no hearing loss, the tinnitus related more to auditory cortex activity, but not to (para)hippocampal memory related activity. In contrast, for patients with more severe hearing loss, tinnitus was related to (para)hippocampal mechanisms. They also found that hearing loss may drive the communication among the auditory cortex and the parahippocampus (Figure 8–2).

Structural Brain Changes

Husain et al. (2011) used magnetic resonance imaging (MRI) methods including voxel-based morphometry (VBM) and diffusion tensor imaging (DTI) to explore changes in the nerve tracts of tinnitus patients. They found no significant changes in the gray matter based on VBM compared with normal-hearing participants in the control group. There were also no significant differences in white matter (based on DTI) in participants with tinnitus and hearing loss compared to those with hearing loss but no tinnitus. Studies by Melcher et al. (2013) and Boyen et al. (2013) corroborated these results. Allan et al. (2016) found that the main tinnitus-related significant changes were outside the classical auditory structures. These results support the notion that structural changes in the brain are not specific to tinnitus, but rather result from auditory deafferentation (Adjamian et al., 2014).

Yoo et al. (2016a) used DTI to analyze how white matter was influenced by tinnitus-related factors. They found that tinnitus was likely not related to any robust white matter changes, with the possible exception of the right parahippocampal integrity reduction in a group of young participants without hearing loss. Using MRI, Yoo et al. (2016b) found that the primary factors of long-term structural changes in chronic tinnitus patients were age and age-related hearing loss (Eggermont, 2019), rather than hearing loss per se. Tinnitus loudness, tinnitus duration, and tinnitus-related distress were not correlated to important morphometric changes in their study.

In summary, only sporadic changes in gray matter volume were found that could be specifically attributed to tinnitus. Most changes, including those outside the auditory areas, can be attributed to hearing loss.

Tinnitus Brain Networks

A multitude of brain regions have stronger or weaker interconnections in patients with tinnitus compared to control participants. From a meta-analysis in tinnitus patients, Husain and Schmidt (2014) found changes

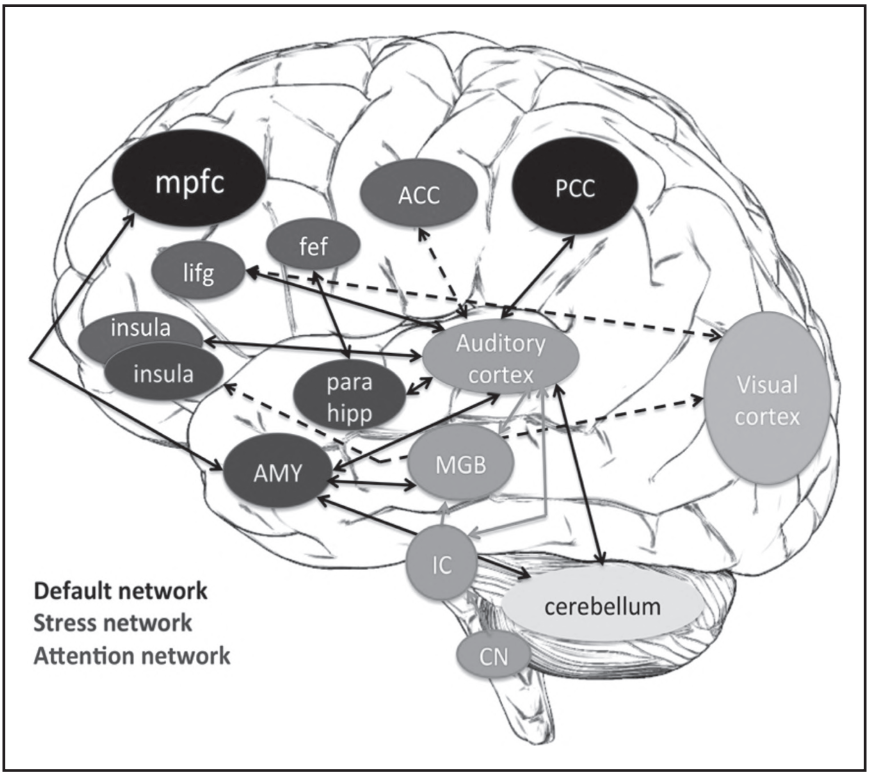

Figure 8–2. Figure 8–2. Summary of main results of resting-state functional connectivity studies in tinnitus. The major networks highlighted are default-mode network (DMN, shown in *blue* i.e., mpfc and PCC), limbic network (*green* i.e., insula, AMY, and parahipp), auditory network (*red* i.e., auditory cortex, MGB, IC, and CN) with connections indicated by red lines, visual network (*in orange* i.e., visual cortex), and several attention networks (specifically the dorsal attention network and the executive control of attention, shown in purple i.e., insula, lifg, fef, and ACC). Positive correlations (*full black lines*) between regions that are stronger in tinnitus patients than controls are shown in solid lines, while negative correlations are dashed black lines. This figure shows modifications to the networks and does not represent the networks in their entirety. Abbreviations: PCC: posterior cingulate cortex; mpfc: medial prefrontal cortex; lifg: left inferior frontal gyrus; parahipp: parahippocampus; aud cortex: auditory cortex; fef: frontal eye fields. *The color version is available on the companion website.* Modified from Eggermont, J. J., and Roberts, L. E. (2015). Tinnitus: Animal models and findings in humans. Cell and Tissue Research, 361, 311–326. Open access.

in the default mode network (DMN), in the connectivity among the auditory cortex (AC) and the limbic system that mediates stress, in the connection of the auditory system with the limbic system and dorsal attention network (DAN), in connections among the visual and auditory cortices, and among the visual cortex and the attention network (see Figure 8–2). It should be noted that Davies et al. (2014) did not find "significant differences in auditory network connectivity [among tinnitus and normal hearing participants] after correcting for multiple statistical comparisons" (p. 197).

Based on EEG and MEG data, De Ridder et al. (2014) proposed a tinnitus core network where communication among the subnetworks is proposed to occur at discrete oscillatory frequencies. According to this model, the gamma (>30 Hz) network reflected changes in the auditory system such as hearing loss. The lower frequency rhythms (8–30 Hz) reflected distress and mood (particularly 10–12 Hz), and may therefore not be unique to tinnitus either. The connection between gamma frequencies and the lower-frequency brain rhythms, putatively reflecting tinnitus, appeared to take place in the parahippocampus. Leaver et al. (2016) demonstrated tinnitus-related reductions in resting-state functional connectivity (rsFC) between specific brain regions and resting-state networks (RSNs). In tinnitus patients, Leaver et al. (2016) identified one RSN not apparent in hearing-matched participants without tinnitus. Tinnitus loudness was positively correlated with rsFC between the mediodorsal nucleus and the tinnitus RSN, indicating that this network may underlie the auditory-sensory experience of tinnitus. Only some hubs in this network were similar to those in the model of De Ridder et al. (2014), namely the orbitofrontal cortex (OFC), AC, and thalamus. The differences largely occurred in the distress and mood hubs, which were missing in the Leaver et al. (2016) network. Schmidt et al. (2017) then examined the effects of tinnitus severity and tinnitus duration on the connectivity of neural networks. They found that DMN-precuneus decoupling was a potential marker of long-term tinnitus, though increased tinnitus severity exaggerated this disruption. Further, coupling of the precuneus and DAN at rest was associated with bothersome tinnitus. According to Schmidt et al. (2017), mild, recent-onset tinnitus showed similar resting-state functional connectivity patterns compared to control participants. Chen et al. (2018) obtained resting-state fMRI scans from chronic right-sided tinnitus patients and control participants, both with clinically normal hearing. Compared with the control group, chronic tinnitus patients showed disrupted rsFC patterns of the anterior cingulate cortex (ACC) within several brain networks, including the AC, prefrontal cortex (PFC), visual cortex, and DMN. Tinnitus Handicap Questionnaire (THQ) (Kuk et al., 1990) scores showed positive correlations with increased rsFC between the rostral ACC and left precuneus, as well as the dorsal ACC and right inferior parietal lobe. Hullfish et al. (2019) analyzed rsFC in a large sample of patients with chronic tinnitus and age-matched control participants with comparable hearing loss (measured via pure-tone audiometry). The strongest rsFC in tinnitus participants was between the nucleus accumbens (NAc) and ventromedial PFC, OFC, and subgenual ACC. In the control group, however, connectivity was mainly localized to the voxels in and immediately around the NAc. Resting-state functional connectivity between the NAc and the left parahippocampal cortex correlated with both tinnitus loudness and duration after controlling for the effects of age and hearing loss. Based on these findings, Hullfish et al. (2019) suggested that the parahippocampus was either a tinnitus generator or a structure involved in maintaining memorized tinnitus (De Ridder et al., 2014; Schmidt et al., 2017).

It is clear that the dominant factors involved in the changes in cortical networks of tinnitus patients are primarily the degree of hearing loss and comorbidities, such as distress and mood. So far, no definite changes have been attributed to the tinnitus itself. Changes in connectivity between the dorsal attention network and the parahippocampal area, as well as between ACC and precuneus appear to be potential candidates.

Future Directions

Minami et al. (2018) investigated functional connectivity in tinnitus patients with and without hearing loss. They found that associations among auditory-related networks (e.g., Heschl's gyrus, planum temporale, planum polare, operculum, insular cortex, superior temporal gyrus) were weakened in tinnitus patients, even those with normal hearing sensitivity. *It is thus possible that rs-fMRI can be a tool for objective examination of tinnitus by focusing on the auditory-related areas.*

Chen et al. (2020) investigated the differences in white matter (WM) volume and integrity between patients and healthy control participants, all with clinically normal hearing. No WM volume changes were detected in tinnitus patients. However, the altered WM integrity of the corpus callosum, left cingulum, and right superior longitudinal fasciculus differentiated the two groups, reaching a sensitivity of 100% and a specificity of 77.3%. *Their findings suggest that tinnitus without HL is associated with significant alterations of WM integrity. These changes may be irrespective of the duration of tinnitus and other clinical performance. These results, if corroborated, could be used as valuable imaging indices for early diagnosis of tinnitus.*

Clinical Implications

- Auditory evoked potentials may not be useful in detecting tinnitus in individual patients. Specifically, tinnitus without hyperacusis is not reflected in ABR and CAEP changes.
- Gray matter volume changes cannot be specifically attributed to tinnitus; however, there may be white matter changes in tinnitus patients. Most of these changes, including those outside the auditory areas, can be attributed to hearing loss. However, tinnitus without hearing loss may be associated with significant alterations of white matter integrity. Thus, differences in white matter integrity may prove to be promising in the early diagnosis of tinnitus.
- Finally, brain network changes in tinnitus primarily reflect comorbidities of tinnitus. So far, no definite changes can be attributed to tinnitus, albeit changes in connectivity between the dorsal attention network and the parahippocampal area, as well as between the anterior cingulate cortex and the precuneus, appear to have potential for initiating or maintaining tinnitus.

Key Messages

- Tinnitus without hyperacusis is not reflected in ABR and CAEP changes.
- Most gray matter changes, including those outside the auditory areas, must be attributed to hearing loss, not to tinnitus.
- Brain network changes in tinnitus patients primarily reflect comorbidities of tinnitus.
- Changes in connectivity between the dorsal attention network and the parahippocampal area, as well as between the anterior cingulate cortex and the precuneus, have potential for initiating or maintaining tinnitus.

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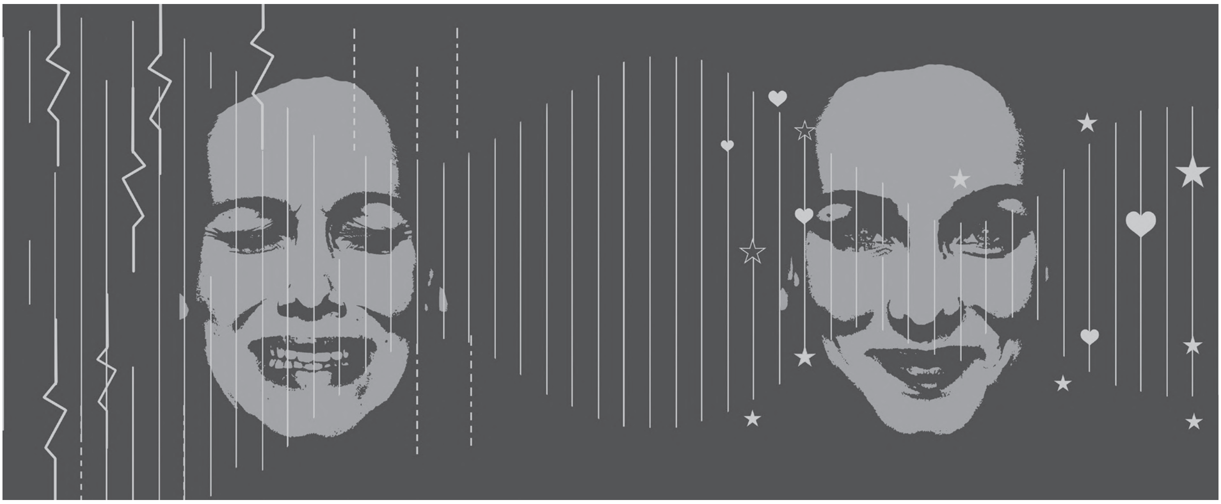
SECTION III

MANAGEMENT OF TINNITUS



9 SELF-DIRECTED TINNITUS THERAPY: A REVIEW OF AT-HOME TINNITUS THERAPY OPTIONS

Grant D. Searchfield and Sun-Jae (Jay) Kim

Introduction

The first step in managing tinnitus is a medical assessment. A medical assessment is important because tinnitus is a symptom of a disease and, rarely, treatment of that disease may lead to a reduction of tinnitus. Clinicians may provide counseling alongside hearing aids and/or sound therapy, but many people experiencing bothersome tinnitus also seek to reduce it by tools readily at hand and easily accessed (Sereda & Hoare, 2016). Consultation-based therapy is the traditional clinic-based approach for management of bothersome tinnitus. In person-centered care (also known as patient-/client-centered care) the patient takes an active role in decision making, but the clinician drives the process. In contrast, interventions in which a clinician is not involved are called *self-help*, while interventions in which the patient directs and the clinician assists can be called *self-directed*. The term *guided self-help* is sometimes used to describe what we refer to as *self-directed care*. We do not use the term guided self-help, as the phrase is an oxymoron. Self-help is undertaken without clinicians, whereas self-directed therapy is undertaken with clinician support but is directed by the patient.

Because individuals who experience bothersome tinnitus often have underlying health problems and are at risk of developing comorbid conditions such as hyperacusis, anxiety, or depression (Andersson et al., 2003; Beukes et al., 2017), the authors recommend that clinicians specializing in tinnitus management be involved in addressing the tinnitus problem. The degree to which a clinician is hands-on in the rehabilitation can vary, from advice and referral to offering a systematic clinic-focused therapy. Tinnitus is traditionally managed as a chronic problem, with current management strategies relying on structured audiological or psychological approaches (Dobie, 1999; Henry et al., 2005; Hesser et al., 2011). It appears that many people with tinnitus do not access any therapy, and when they do, therapy is, at best, moderately helpful (Kochkin et al., 2011). For many people with tinnitus, the best option may be an approach in which they take responsibility for their therapy, but in conjunction with evidence-based support from clinicians. In this self-directed approach, most of the therapy can be done at home with the clinician acting as a coach supporting the tinnitus rehabilitation process. The clinician assists in providing information and strategies that individuals with tinnitus would otherwise have to discover themselves. In self-directed therapies, the clinician is not as active in the implementation of the strategy chosen by the patient as in person-centered practice. In the self-directed approach, the clinician offers advice and support that would not be available with a self-help approach, but the patient takes responsibility for driving the management. Recent U.K. National Institute for Health and Care Excellence (NICE) guidelines (NICE, 2020) describe the importance of support and information throughout the tinnitus assessment and management process.

In the following sections, we describe approaches to addressing common needs of patients with bothersome tinnitus through a self-directed approach. We refer to evidence from research of self-help and self-directed approaches to discuss the benefits and shortcomings of at-home therapy options. We refer to the person with tinnitus as the patient and the professional facilitating the therapy (e.g., audiologist, otologist, or therapist) as the clinician.

Background

Advantages of Self-Directed Care

Self-directed care may improve access to services (Sereda & Hoare, 2016). The delivery of management options remotely—over the internet or via apps—may provide help for tinnitus patients who are on a waiting list for a clinic appointment (Sereda & Hoare, 2016). Moreover, patients with bothersome tinnitus can prevent relapse by revisiting therapy material on the internet at little or no additional cost (Sereda & Hoare, 2016). The self-directed approach also offers patients a sense of control and empowers them to take on a more proactive role in their own healthcare, thus boosting their self-efficacy (Sereda & Hoare, 2016). Another benefit of this approach is that individuals can engage in self-management via the internet in the comfort of their own homes. This would be particularly advantageous for those who have difficulty with clinic attendance due to health, mobility issues, isolation due to living in remote geographical areas (Cuijpers et al., 2008; Sereda & Hoare, 2016), or isolation due to emergencies (such as COVID-19). Due to the limited number of tinnitus specialists, patients often do not receive the time and attention they should receive for therapy (Guitton, 2013; Sereda & Hoare, 2016). The service delivery gap may be particularly large in populous developing countries with limited healthcare services.

Decision Making and Self-Directed Care

It can be difficult for patients with bothersome tinnitus to self-select the most appropriate therapy. This problem partly arises from the inconsistency of information from professionals and a lack of rigorous clinical studies outlining treatment effectiveness (Dobie, 1999; McKenna & Irwin, 2008). Readily available information sources, primarily the internet, contain both useful and misleading information. It is important that clinicians support patients in making informed decisions about therapy choices. As part of an ethical practice, clinicians should provide patients with evidence-based information about the complications and chances of success of therapy.

In the current clinical setting, there is a shift in focus from a one-size-fits-all approach to one that is personalized and tailored to address the patient's specific needs and priorities (Searchfield, 2019; Searchfield et al., 2017). It has become standard protocol for audiologists to perform a formal needs-based assessment for hearing aid selection (Dillon, 2012). Searchfield et al. (2017) suggest that similar principles should be applied in tinnitus clinics whereby audiologists consider the needs of individual tinnitus patients and thus provide personalized management approaches. Completion of the Client-Oriented Scale of Improvement in Tinnitus (COSIT) (Searchfield, 2019) can be used to identify individual goals and priorities. The patient and clinician can consider the best means to meet therapy goals. Common goals derived from administration of the COSIT include: (a) reducing the effect of bothersome tinnitus on hearing, which can be in the form of interference with the ability to concentrate or hear external sounds; (b) improving well-being and reducing depression; (c) coping with or controlling the tinnitus; (d) managing the effect of the environment (i.e., context) on tinnitus; (e) improving sleep, and (f) understanding tinnitus (Searchfield, 2019). Solutions to these problems may include self-directed application of lifestyle changes, psychological and audiological therapies for tinnitus, and possible support services and devices.

Evolution of Support and Recent Advances

Education Through Provision of Information for Patients

Historically, information has been obtained from bibliotherapies using self-help books or brochures. However, with recent advances in telecommunication technologies and the growth of the internet, such information is now delivered online (Sereda & Hoare, 2016).

Books and Brochures

Tinnitus books were a common sight in the self-help section of libraries, and prior to the internet they were a common source of easy-to-understand information describing and discussing tinnitus. These books were typically written by tinnitus sufferers who shared their experiences and interpretation of science (e.g., Saunders, 1992) or by experts in the field of tinnitus who attempted to distill their knowledge into lay language (e.g., Tyler, 2008). Such books, retailed directly to the consumer or borrowed from libraries, are primarily self-help tools. Clinicians may also make printed brochures available in waiting rooms or provide patients with these in addition to consultations (Sizer & Coles, 2006). PowerPoint presentations and videos on tinnitus management can also be used as resources for tinnitus patients (http://www.tinnitustunes.com). Common topics included in written format are listed in Table 9–1. While appropriate knowledge gained from text material may be useful, it might not always be sufficient as stand-alone therapy (Coates & Boore, 1996; Gibson et al., 2003). Loumidis et al. (1991) investigated benefits of a two-page written informational leaflet. The leaflet included information about physiological and psychological aspects of tinnitus, effects of tinnitus on patients and their families, and available coping strategies for tinnitus. The results showed that providing information alone did not significantly reduce tinnitus distress or negative beliefs associated with tinnitus. However, the authors reported that some patients receiving information had fewer unmet needs and were less motivated to seek specialist care.

Table 9–1. Typical Topics Covered as Part of Information-Based Self-Help

Self-Help Brochures	***Self-Help Books (Experts)***	***Self-Help Websites (Home Page)***
What is tinnitus?	Overview	What is tinnitus?
Your hearing system	Causes of tinnitus	Who gets tinnitus?
Selectivity and attention	The neural mechanisms of tinnitus	What causes tinnitus?
Habituation	Reactions to tinnitus	What should I do?
Anxiety, tension, and relaxation	Changing reactions	Does it improve?
Relaxation exercises	Your life and tinnitus	Talking to someone
Sound therapy	Hearing loss and communication	Relaxation
Recreation and health	Sleeping better with tinnitus	Using a hearing aid
Hyperacusis	Concentration	Using sound
Earplugs	Tinnitus sound therapy options	Addressing sleep problems
Temporary deafness and tinnitus	What to expect from physicians	Cognitive Behavioral Therapy (CBT)
Further information and help	Medications and alternative medicines	Mindfulness
	Hyperacusis	Tinnitus retraining therapy (TRT)
		Hyperacusis

Collated from Saunders, 1992; Sizer & Coles, 2006; https://www.tinnitus.org.uk/

Online Tinnitus Information

The internet has become a very popular source of self-help information for tinnitus (Fackrell et al., 2012). A simple online search for “tinnitus treatment” yields millions of results. Such searches uncover numerous self-help options, government healthcare websites, commercial healthcare websites, and national charity websites. Users have instant access to resources through these websites. Such resources include podcasts, videos, and text about physiological and psychological aspects of tinnitus; available therapy options; counseling material; links to specially recorded therapy sounds (i.e., audio files); tinnitus forums; news; current tinnitus research; and professional resources to help sufferers locate their nearest tinnitus service centers. To some degree, online information replicates that found earlier in books (see Table 9–1).

The authors are unaware of any studies investigating the effectiveness of tinnitus information websites on minimizing patient concerns about tinnitus. Searching for credible information on the internet may reduce negative beliefs and help the tinnitus sufferer know where to turn next if necessary. On the other hand, false information about tinnitus may enhance negative beliefs and thus exacerbate patient concerns about tinnitus. Nevertheless, reading about health information prior to clinic attendance may equip patients with the knowledge necessary for informed and shared decision making about their own management with their clinician (Sereda & Hoare, 2016). Another benefit is that websites may be a helpful resource for tinnitus patients who experience difficulty remembering verbal information provided at clinic appointments. Patients can revisit material online at their own convenience (Sereda & Hoare, 2016).

There is an abundance of misleading information about tinnitus online, and the content and quality of the information on different tinnitus websites varies (Fackrell et al., 2012; Kieran et al., 2010). Fackrell et al. (2012) reviewed different tinnitus websites, including some that are registered charity websites in the United Kingdom (e.g., British Tinnitus Association [BTA], Action on Hearing Loss, government websites such as National Health Service Choices, and commercial healthcare websites such as Patient.co.uk). In regard to the reliability and quality of information on management options, the BTA website (https://www.tinnitus.org.uk) obtained the highest score. The BTA website had some limitations as well. For example, the same information was presented on different sections of the website. On the other hand, consistent with previous studies (Kieran et al., 2010), commercial websites scored the lowest in accuracy, completeness, quality, and reliability of tinnitus information (Fackrell et al., 2012). Many of the websites failed to reference the sources of information they used and, for some, there was no information about when the information was produced. Another aspect rated negatively across all the websites pertained to poorly described information about risks associated with different management options for bothersome tinnitus, and the consequences of no therapy. However, many of the websites did list extra resources for support and information (e.g., links to other websites) and prompted patients to discuss their therapy options with their family and clinicians (Fackrell et al., 2012). Fackrell et al. (2012) recommended that websites obtain independent accreditations. Such accreditations would presumably enhance users' engagement with sites that are associated with greater trust and reliability (Kaicker et al., 2010; Kieran et al., 2010).

Online Peer Support Groups

Online support groups (e.g., text and video discussions, forums, and blogs) serve as platforms for members to informally share information with and offer peer support to other individuals who may be going through the same problem (Guitton, 2013). Online peer support groups may complement clinic-based services (Damen et al., 2000). They may provide sufferers a way to overcome the social isolation often triggered by tinnitus (Guitton, 2013). Connecting and sharing with other people afflicted with tinnitus may be a source of social and emotional reinforcement. This process allows for social comparison, and tinnitus sufferers can evaluate their own situation in a broader context (Dibb & Yardley, 2006). Furthermore, online support groups may increase self-efficacy by empowering the individual to take control over issues affecting their lives. Some other notable advantages of online groups over face-to-face support groups include the ability for members to participate in their own homes, having 24-hour access to information, and anonymity (van Uden-Kraan et al., 2008). There is currently no research proving the effectiveness of online tinnitus support groups, and thus their therapeutic potential remains uncertain. There is also a potential issue with lack of control over the quality and reliability of the information being shared among members on online support groups (Guitton, 2013). Inaccurate information may spread through a community of tinnitus sufferers who are hopeful for a cure (Deshpande et al., 2018; Eysenbach et al., 2004; Guitton, 2013). Another issue is the risk that constantly focusing on and discussing tinnitus may raise anxiety and place the individual in a vicious cycle that reinforces their response to tinnitus (Guitton, 2013).

Cognitive Behavioral Therapy (CBT)

Cognitive behavioral therapists identify negative thought processes and try to change these to positive and more realistic thoughts in individuals who experience bothersome tinnitus. Research suggests that CBT is an effective management method for bothersome tinnitus (Hesser et al., 2011).

Books on CBT

Attempts have been made to manualize CBT and translate it to an at-home format. Twenty years ago, Henry and Wilson authored two books representing opposite sides of the same coin: a text for clinicians (Henry & Wilson, 2001) and a self-directed book for patients (Henry & Wilson, 2002). Key points in these books are summarized in Table 9–2. The combination of the two books enables the cognitive behavioral therapist and patient to work together, with a greater focus on at-home exercises for those able to do so and with the option for the clinician to provide most of the instruction and therapy. Use of the self-directed book, along with phone calls once a week for 7 weeks, was associated with a significant change in the Tinnitus Reaction Questionnaire in 32% of participants compared to a wait-list control (5%) (Kaldo et al., 2007).

Table 9–2. Contents of Clinician-Centered and Self-Directed Books Outlining a CBT-Based Tinnitus Management Approach

Clinician-Led	*Self-Directed*
Tinnitus: Features, causes and instructions Psychological aspects of tinnitus problems Interviewing the tinnitus patient: A cognitive-behavioral analysis of tinnitus problems Cognitive-behavioral therapy for tinnitus A cognitive-behavioral group therapy program for tinnitus Relapse prevention following psychological management of tinnitus Psychological interventions in the management of chronic tinnitus: Efficacy of treatment	It's time to take control Some facts about tinnitus Assessing your tinnitus: How does it affect you? Changing the way you think about tinnitus Relaxation and stress management Attention-control techniques Becoming your own coach Dealing with high-risk situations Reducing the impact of tinnitus on your daily life Maintaining gains in the longer term Some final tips on managing your tinnitus

Collated from Henry & Wilson, 2001, 2002.

The study design allowed low-level evidence in support of the use of a combined book–telehealth approach. The concepts have now evolved to online platforms.

Internet-Based Cognitive Behavioral Therapy (ICBT) Programs

Internet-based CBT is the most extensively researched form of online tinnitus therapy in the literature. ICBT programs typically consist of a comprehensive set of text-based modules for tinnitus patients to work through. The CBT approach to tinnitus management is discussed in detail in Chapter 11. Some ICBT programs are guided through regular interaction with a clinician via a support messaging system (e.g., email, telephone) and, therefore, are best described as self-directed rather than self-help programs. The clinician monitors the patient's progress, provides feedback on homework, answers questions, and tries to motivate the patient to complete the program (Andersson et al., 2002; Kaldo et al., 2013; Kaldo-Sandstrom et al., 2004). The 10-week Tinnitus E-program (Greenwell et al., 2015) is an example of the self-directed approach to information delivery and ICBT in which a clinician plays an integral role in tinnitus management. It consists of education and information about tinnitus, management, resources available, training for psychological strategies, social support, and monitoring of tinnitus. In addition to written information, behavior change techniques such as relaxation methods are available as downloadable MP3 files (Greenwell et al., 2015). The program is 12 weeks long and includes 2 one-on-one sessions with a hearing therapist (https://www.tinnituseprogram.org).

ICBT programs delivered with no or minimal clinician contact may be an effective intervention for tinnitus patients (Baumeister et al., 2014; Rheker et al., 2015). For instance, Nyenhuis et al. (2013) investigated the effectiveness of an ICBT program without therapist contact compared to a control condition (informational booklet) on reducing tinnitus distress levels. The results produced large effect sizes with greater improvement in distress for the unguided ICBT compared to the control group. Kaldo et al. (2013) studied a low-intensity version of the ICBT program for less distressed tinnitus patients deemed not suitable for full ICBT. Minimal clinician support was offered in the low-intensity version. Patients were free to ask questions of the clinician via email, but the clinician did not actively monitor or contact the patient. The results showed small to medium effect sizes for the reduction of tinnitus distress as well as for alleviation of associated symptoms (e.g., anxiety, depressive moods, and sleep disturbance).

Audiological Approaches

In many countries and geographical regions, audiologists are the primary source of tinnitus care. Recent guidelines from the American Academy of Otolaryngology–Head and Neck Surgery recommend audiological evaluation, counseling and education, and hearing aid fittings, with sound therapy as an option for tinnitus management (Tunkel et al., 2014). Because audiological approaches tend to have a strong technology focus (e.g., sound therapy), they are particularly amenable to self-directed care.

Counseling, Lifestyle Changes, and Homework

Tinnitus training in audiology degree programs is limited, but many clinicians are keen to extend their practice beyond the fitting of hearing aids (Searchfield, Fok, et al., 2020). Audiologists state a lack of materials and confidence in counseling as barriers to taking on this additional scope of practice (Searchfield, Fok, et al., 2020). To address the concerns, and to partially manualize the authors' own clinic's approach to tinnitus, the authors have developed and tested a framework for tinnitus therapy and associated supplemental materials (Searchfield, Boone, et al., 2020; Searchfield et al., 2019). The clinic categorizes audiological tinnitus management across four modalities based on Boothroyd's model of rehabilitation (Boothroyd, 2007): instruction, counseling, sensory management, and perceptual training, as illustrated in Figure 9–1. The instruction is directive, while the counseling is usually provided in a single patient-centered session. Instruction includes information about: the relationship between hearing and tinnitus, neurophysiology of tinnitus (perception and reaction), lifestyle changes (Table 9–3), sensory management (hearing aids and sound therapy), perceptual training (attention control through diverting focus to real-world sounds), and how sensory and affective adaptation can occur over time. The level of detail provided in the information session is tailored to the individual's needs; limits in ability to absorb information is managed by provision of printed or online resources (see Tinnitus Tunes section).

Folmer et al. (2006) described lifestyle recommendations as part of a comprehensive approach to tinnitus management. The recommendations are summarized in Table 9–3. Many of the recommendations can be undertaken by the patient independent of the clinician, or involve referral to other clinicians depending on needs.

The authors use a counseling approach adapted from the attend, react, explain, adapt (AREA) model of affective adaptation

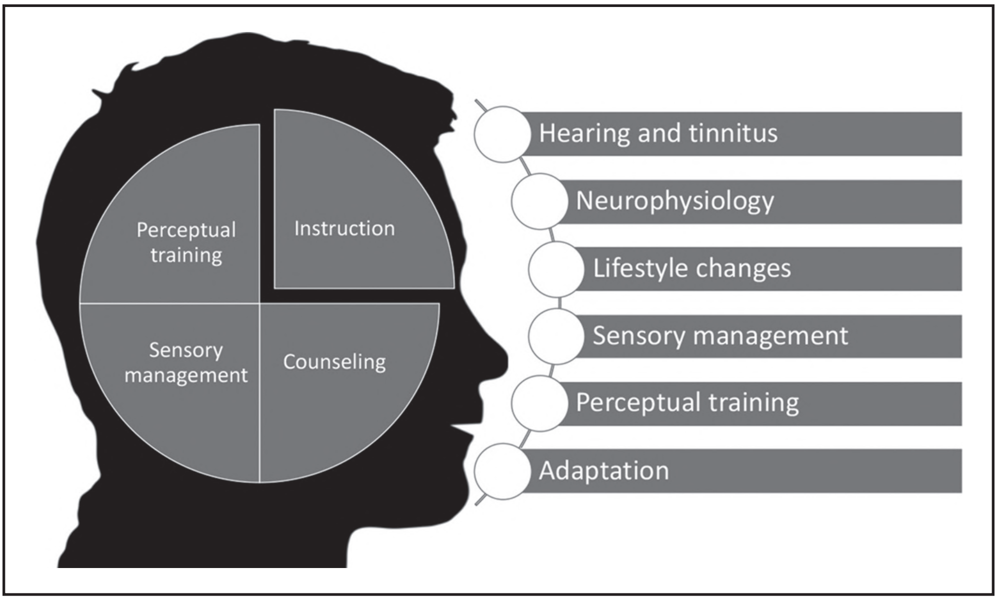


Figure 9–1. Four components of a comprehensive audiological approach to tinnitus and material typically covered within instruction.

Table 9–3. Typical Lifestyle Recommendations That Can Be Used as Part of a Self-Directed Care Plan

Topic	***Abridged Recommendations***
Expectations and perspective	Provide hope and coping strategies through information and counseling Make the patient aware of mental health services
Improve sleep	Recommend bedside sounds Describe over-the-counter sleep medication Refer to physician for prescription medication Refer to healthy sleep guidelines Recommend stress reduction and relaxation activities Recommend sleep clinic if problems persist
Reduce anxiety	Recommend seeing an anxiety therapist Suggest trying meditation, exercise, massage
Depression	Evaluation by a psychiatrist Psychotherapy
Break vicious cycle	Reducing fatigue, depression and anxiety will reduce tinnitus
Communication	Improving hearing through hearing aids or assistive technology should reduce tinnitus
Sound therapy	Recommend sound to make tinnitus less noticeable
Evaluate medications	Refer to prescribing physician to consider tinnitus risk profile of medications and if another medication is suitable
Diet	No universal recommendation, but recommend healthy diet
Exercise	Recommend variety of physical activities
Reduce noise exposure	Educate about hearing and how noise injuries can occur and be prevented
Desensitize to sound	Provide information on reduced loudness tolerance, risks of isolation from sound, value of low-level sound to reduce hypersensitivity
Employment and responsibilities	Engagement in activities is usually helpful Sometimes identifying tinnitus modifiers in the workplace and both short- and long-term options needed
Increase socialization	Recommend keeping busy Social contact helps provide perspective Sympathetic support from peers, friends, and family is helpful
Referrals	As needed

Collated from Folmer et al., 2006.

proposed by Wilson and Gilbert (2008). In this model—an excellent match for our worldview of tinnitus (Searchfield, 2014)—people with bothersome tinnitus attend to their tinnitus because it is a self-relevant but unexplained event. Attention to tinnitus can be reduced with sensory management and perceptual training. Patients with bothersome tinnitus react to the negative emotions associated with tinnitus annoyance. Explanation of tinnitus reduces the patient's emotional response to tinnitus. Patients with bothersome tinnitus adapt to their tinnitus if negative effects can be nullified and replaced by positive emotionality with less awareness and focus on tinnitus (Wilson & Gilbert, 2008).

Searchfield, Boone, et al. (2020) conducted a small study ($N = 16$) to explore the effects of one counseling session (duration 60 to 90 minutes) with and without homework. The homework consisted of either augmented visualization or a pen-and-paper workbook. Half of the participants ($n = 8$) received one of the homework activities. Participant outcomes were assessed 3 weeks following the counseling session. For the augmented visualization, participants were given the option of listening to five sounds files. The 30-minute sound files included gentle rain, forest by the sea, roaring surf, roaring fire, or calming meditative sounds (http://www.tinnitustunes.com). Participants were encouraged to find a quiet place where they would not be disturbed, to relax through methodical breathing, and then to create an imaginary scene in their mind that represented a calming and enjoyable experience for them. In addition, participants were instructed to associate their tinnitus with a pleasant sound and then to place their tinnitus, along with their chosen background sound, into the external environment they were imagining. The workbook was a 19-page booklet containing information reinforcing the instruction and counseling session. Activities included labeling hearing processes, diagrams of the ear and brain, writing down descriptions of how the participant's tinnitus sounded, identifying own tinnitus modifiers, word search and crosswords related to tinnitus and its management, and coloring pages of the ear and enjoyable scenes. Participants were asked to spend 30 minutes a day engaged with the workbook. According to Holmes and Mathews (2010), incorporating imagery into treatments such as behavioral therapy and attention retraining contribute to enhanced therapeutic effects.

Searchfield, Boone, et al. (2020) found the average Tinnitus Functional Index (TFI) (Meikle et al., 2012) scores for the counseling-alone group of participants were reduced from 52 to 37 points, whereas counseling with homework decreased from 37 to 20 points. There was a clinically meaningful reduction in TFI scores (13 points) for more than half of the participants. When asked about the most useful aspect of the counseling, few participants specified one particular attribute. Rather, participants reported that benefit was derived from the combination of counseling content, application, and homework.

Sound Therapy

The evolution of sound therapy follows that of consumer and healthcare electronics, from simple sounds in ear-level and bedside devices to the use of novel customized sounds downloaded from the internet to smartphone applications. However, sound therapy existed long before consumer electronics enabled its easy implementation (Stephens, 2000). There are many anecdotal stories of the benefits of natural sounds, such as fire and water sounds, disrupting the perception of tinnitus. In the authors' clinic, patients sometimes use electric fans or small indoor water features to mask tinnitus or aid in relaxation. Modern tinnitus masking was born from observations of the beneficial effects of natural sounds on tinnitus which, in turn, led first to the development of electronic maskers (Vernon & Schleuning, 1978) and then to the use of various generations of personal music players for the same purpose (Al-Jassim, 1987).

Do-It-Yourself (DIY) Options

The use of sound alone as a tinnitus therapy, without counseling, has been criticized (McKenna & Irwin, 2008). Users of DIY sound therapy are unlikely to achieve the full benefits of sound therapy without supplemental counseling.

Music is a potential sound for tinnitus therapy, both as part of a psychological therapy known as *music therapy* (Argstatter et al., 2012) and as a self-help intervention option (Hann et al., 2008). In the authors' clinical experience, many patients will attend clinic knowing that certain pieces of music reduce their focus on tinnitus and help them relax. Although certain types of music (e.g., nonvocal classical music) may be more effective than others in reducing perception of tinnitus (Hann et al., 2008), the end user's preference in music should determine its selection. If the listener does not like the music, or it elicits negative memories, it may offer no benefit. There are several tinnitus albums on iTunes (not to be confused with albums by the band "Tinnitus"!). The online tinnitus management albums contain nature sounds and new-age music that can be downloaded for use on MP3 players or smartphones. Personal music players with headphones pose limitations in where and how often they can be used (e.g., workplace constraints for safety). The authors often use MP3 players and headphones as low-cost tools when prototyping therapies (Durai et al., 2018). Many participants have difficulties using the MP3 players and headphones, and compliance with use may suffer as a consequence (Durai et al., 2018).

Purpose-designed desktop sound generators or sound conditioners are an alternative to headphones. Due to limited portability and wearability, these sound generators tend to be used at bedside as sleep aids. Desktop sound generators are simple to use and, while some can use downloaded sounds (e.g., http://www.soundoasis.com), they are functional without the internet. Some of these devices have a single function, such as production of sound for masking or relaxation to aid sleep (e.g., Naturecare Tinnitus Sound Relaxer, Wellcare Co. Ltd.), whereas for others the sound generator features are secondary to other consumer functions (e.g., Sony ICF-CIPJ clock–radio). Desktop devices can be used in conjunction with sound pillow speakers. Approximately 80% of users with tinnitus achieve substantial sleep improvement with a bedside device (Benton, 2016). Users tend to select natural sounds over white noise due to positive emotional effect that aids sleep (Handscomb, 2006).

Online Options

Online sound therapies may be based on a single novel strategy (e.g., notched sound) or they may be the digital equivalent of a tinnitus clinic. Examples of these two approaches are described below.

Notched Sound. Notched sound therapy options appear to be common online approaches for tinnitus management. Notched sound involves customizing masking sound (such as music or white noise) with removal of sound energy at and around the patient's reported tinnitus pitch (e.g., https://www.audionotch.com and https://www.tinnitracks.com/en). The approaches are based on findings from a series of studies from the University of Münster that used music to achieve lateral inhibition (e.g. Okamoto et al., 2010). The user chooses the audio signal they wish to have notched (e.g., music or white noise) by a computer software algorithm. Next, patients listen to their customized masking sound using devices that are capable of playing sound files (e.g., MP3 player, smartphone, tablet, or laptop). The effectiveness of online notched sound therapy in tinnitus management has not been studied, but a review of tinnitus therapies indicates there is insufficient evidence for notched sound, dispensed in person, to be recommended (Zenner et al., 2017). It may be difficult to obtain an accurate tinnitus pitch match using self-assessment online. Tinnitracks tinnitus therapy has an online matching for familiarization but recommends that professional measurements of pitch are used in their therapy.

Online Clinics for Self-Directed Audiological-Based Management of Tinnitus. Online counseling and sound therapy provided by audiologists is an alternative to iCBT. Tinnitus Tunes (http://www.tinnitustunes.com) is a subscription-based online "clinic" for self-directed audiological-based management of tinnitus. It was established in 2016 as a spin-off of the University of Auckland's Hearing and Tinnitus Clinic. The website was created to address concerns about the quality and reliability of tinnitus information available to patients on the internet (Fackrell et al., 2012; Kieran et al., 2010), to extend the reach of clinicians to outside the clinic, to improve the breadth and depth of tinnitus services, and to equip clinicians with materials for their patients (Searchfield, Fok, et al., 2020). Although Tinnitus Tunes can be accessed directly as solely a self-help tool, audiologists may use the web-based materials to extend their services. Patients undertake self-directed activities to complement the clinician's role. Clinics and clinicians can incorporate Tinnitus Tunes content into their education, assessment, and management of tinnitus patients, as well as their business model. Clinic partners receive rebates when their patients subscribe to the website. The Tinnitus Tunes option facilitates remote care. For example, patients who find it difficult to travel to clinics are encouraged to use the online content to minimize their perception of tinnitus.

Patients who select the Tinnitus Tunes option undertake a structured 12-week program that provides advice, information, and management broken down into five separate actionable steps. The first step for care involves education and information so that members can remove any false beliefs they have about tinnitus. The second step involves information about what type of clinician (e.g., general practitioner, physiotherapist, audiologist) to consult for help based on the patient's symptoms and likely etiology for tinnitus, and about what to expect from clinic appointments. The third step for care involves the patient managing stress associated with tinnitus. Reduction of stress is achieved through the use of partial masking and relaxation sound files, audio podcasts on visualization and progressive relaxation, and tips on how to use other forms of technology such as hearing aids, bedside sound generators, and wireless headphones with noise cancellation. The fourth step for care involves training the patient's brain to ignore tinnitus through attention refocusing and adaptation. A wide range of sounds is provided to help achieve this. The fifth step focuses on prevention of relapse through lifestyle tips. Weekly emails are sent to users that include case studies and lifestyle tips to suit user needs. As with many of the therapy approaches cited in this chapter, research evidence underpins the content, but published evidence regarding the effectiveness of the internet method of delivery is limited (Kim, 2018).

Future Directions

To provide more comprehensive tinnitus services, clinicians need easy access to resources. A comprehensive private tinnitus service must also be sustainable from a cost and profit perspective and, in socialized healthcare systems, it must meet expectations for efficiency. A holistic tinnitus service need not be more time consuming or costly if the therapy framework is self-directed and includes remote clinical care. In the authors' opinion, these factors point to the need for smart solutions that consider the end user and the clinician. The authors have developed a digital therapeutic platform, Precision Sound Therapy™, and trials based on this concept have commenced. The platform consists of a clinician's dashboard that interfaces with an app and hardware run from the patient's smartphone and includes counseling, relief sounds (Searchfield et al., 2016), and retraining using serious games (Wise et al., 2016). This self-directed approach enables the clinician to tailor therapy for the patient, but the patient is responsible for implementation.

Clinical Implications

Barriers and Facilitators to Engaging With Online Tinnitus Therapies

Many patients prefer face-to-face therapy (Mohr et al., 2010), as they value the opportunity to discuss their condition on a personal level (Sanchez & Stephens, 2000). A survey in the authors' clinic of experiences with online therapies found that 40% of patients viewed the absence of face-to-face contact as a barrier to undertaking online therapies (Kim, 2018). A survey of 116 patients of Australian audiology clinics found the most prominent barrier for teleaudiology uptake was a greater preference for face-to-face clinic appointments (Eikelboom & Atlas, 2005). Patients may value the opportunity to receive explanations and to have their concerns addressed on a personal one-to-one level with a clinician (Sanchez & Stephens, 2000), which is often difficult to achieve online. Based on the authors' experience, a system where patients maintain contact with a supporting clinician is important. With this approach, therapy is guided while still based online. For instance, having a messaging system (e.g., SMS text, email, telephone, Skype, Zoom) to bridge communication between the patient and the clinician should enable motivation, feedback, and encouragement (Heinrich et al., 2016; Palmqvist et al., 2007; Whittaker et al., 2016). Lack of clinician guidance is associated with considerably greater dropout rates compared to guided online tinnitus therapy programs (Andersson et al., 2002; Donkin & Glozier, 2012). Early dropouts are mainly associated with time constraints and preference for face-to-face therapy and/or a desire for more online clinician interaction. On the other hand, later dropouts are mainly associated with lower motivation to undergo further therapy because some benefits have already been achieved (Kaldo et al., 2013). Including a support system in online tinnitus therapies may reduce dropout rates because it may help maintain motivation (Heinrich et al., 2016). For example, it appears from testimonials on the Tinnitus E-program website that interaction with a clinician is an important aspect for subscribers' success.

An individual's age is a factor in the uptake of and satisfaction with online healthcare interventions. Increasing age is associated with decreased levels of internet use for health-related information, and lack of computer literacy may be a prominent barrier inhibiting the use of online tinnitus therapies (Hardiker & Grant, 2011). In the survey of the authors' clinic population with a mean respondent age of 60 years, 84% used the internet (Kim, 2018), suggesting that the target population for online tinnitus therapies may be largely computer literate. The assistance of a clinician or an information technology (IT) assistant may be crucial for some user to access online tinnitus therapies without frustration (Pretorius et al., 2009). A lack of belief that internet therapy can make a positive difference may reduce motivation to try an online therapy option (Hardiker & Grant, 2011). Consistent with Hardiker and Grant (2011), Beukes et al. (2017) found that having low self-motivation for seeking therapy was the greatest barrier to patients undertaking online therapy.

For maximum efficacy, an intervention must be comprehensive and tailored to suit the individual patient's needs. Therefore, offering a wide range of materials that focus on addressing different types of tinnitus complaints may be important to maintain compliance (Beukes et al., 2016; Eikelboom & Atlas, 2005). Variation in content such as podcasts, videos, quizzes, and interactive diagrams may increase motivation to partake in online tinnitus therapies. Serious games for tinnitus may improve engagement in therapy (Wise et al., 2016). Not surprisingly, evidence indicating that a therapy works will also increase uptake (Heinrich et al., 2016). Eikelboom and Atlas (2005) identified that a common reason for willingness to use teleaudiology was the ability to reduce waiting times and costs for clinic appointments. These findings are consistent with the survey of patients in the authors' clinic (Kim, 2018). Patients who had accessed online therapies were asked to rank dimensions that they considered to be most important to continue or to start using therapies online, and features about online tinnitus therapies that should be added or changed (Table 9–4).

Respondents were also asked whether they would be interested in using online tinnitus therapies as a stand-alone self-help method with no clinician contact to treat tinnitus. The results were fairly evenly split, but a higher proportion of respondents (57%) indicated they would be interested in the self-help option. The preferred clinician-guided option for online tinnitus therapy was in person at the clinic (face-to-face). Receiving support from a clinician through email was the second-most preferred way of being guided. Receiving support from a clinician online through video chat was the least preferred way (Kim, 2018). The COVID-19 pandemic has exposed a greater number of people to the concept of online communication (for example via Zoom), with both clinicians and patients adjusting to a new form of one-on-one communication. It remains to be seen if social changes due to the pandemic translate into long-term change in delivery modes.

Apps

Many online solutions and DIY sound therapies described above are also available through smartphone applications (apps). Apps that link with hearing aids facilitate their use as part of a self-directed approach with clinicians remotely tuning

Table 9–4. The Most Important Reasons to Continue or to Start Using Therapy Online, and Users' Opinions of Features That Should Be Added to Online Tinnitus Therapies

Factors Influencing the Decision	***Suggested Additions or Changes***
Helps reduce tinnitus problem	More user-friendly
From a reputable source (e.g., a university)	Include clinician support
Accessible without waiting time	Tailored to specific needs
Less expensive than face-to-face clinic appointments	Less written information, more interactive
Accessible at a convenient location	Ability to download therapy resources offline
Accessed at a convenient time	Advice on the risks of different therapies
Accessed anonymously	Ability to track progress with therapy

Collated from Kim, 2018.

and advising (e.g., video call and messaging). Material available on tinnitus apps has expanded from a library of sounds that can be streamed to hearing aids via Bluetooth to include counseling and relaxation exercises. Many hearing instrument manufacturer apps can be used without the hearing aids, and other apps have been specifically designed to be used with consumer headphones. Similar issues exist for app use as for playback of music and other sounds via a smartphone; that is, headphone suitability and portability. The clinical efficacy of apps for tinnitus has not been substantiated. Available apps and their content have been assessed (Mehdi et al., 2020), tinnitus patients have been surveyed about their app use and preferences (Sereda et al., 2019), and outcomes of small field trials of a prototype app have been published (Henry et al., 2017).

Mehdi et al. (2020) identified 34 apps for tinnitus including apps consisting of various sound therapies or CBT. Only seven apps (Tinnitus Therapy Lite, ReSound Relief, SimplyNoise, Audio Notch, Wysa, Woebot, and Mindshift) scored highly on an evidence-based assessment. The authors do not expand on the level of evidence. However, it appears from analysis of available evidence for these seven apps, tinnitus apps in general, and internet sound therapy, that any benefit is related to content within the app rather than the mode of delivery. A survey of tinnitus app users identified 55 apps in use for tinnitus. For 70% of these apps, sound therapy was the mode of operation (Sereda et al., 2019). The five most commonly used apps in descending order were: (a) White Noise Free, (b) Oticon Tinnitus Sound, (c) Relax Melodies—Sleep Sounds, (d) myNoise, and (e) Tinnitus Therapy Lite (Sereda et al., 2019). There was no evidence of efficacy for the apps (Sereda et al., 2019). Henry et al. (2017) described the development of an app based on progressive tinnitus management. Small improvements in the TFI were shown with app use, but individual results suggest this was because of large changes for a few participants; most participants showed little or no change in TFI scores (Henry et al., 2017).

Key Messages

- There is a wide range of at-home solutions for tinnitus. Many of these can be applied either as self-help solutions or as part of a program that includes clinical guidance.
- Self-directed care appears, at face value, a good compromise between self-help home therapy and comprehensive in-clinic protocols.
- The value of the approaches has yet to be evaluated in high-quality trials, but many of the methods composing a holistic approach have been individually evaluated with low to moderate level of evidence to support their use.

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10 THE ROLE OF AMPLIFICATION IN TINNITUS MANAGEMENT

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Introduction

Tinnitus is a complex multifaceted condition, and its management is beyond the expertise of a single discipline. There is a wide range of management approaches to assist people with their tinnitus and its associated impact (Figure 10–1). In this chapter, we focus on the role of hearing aids for tinnitus management.

Background

Hearing aids have been used for tinnitus management for more than 70 years (Saltzman & Ersner, 1947). In scoping reviews, Shekhawat, Searchfield, et al. (2013) and Jacquemin et al. (2021) reported more than 61 studies of hearing aids in tinnitus management. Thirty studies were published before

Figure 10–1. Tinnitus management options.

2010 and more than 31 studies since then, confirming that more research has been conducted in the past decade than in the previous 70 years. Sound amplification is a popular tool in tinnitus management, as hearing loss is one of the possible risk factors for the development of this auditory symptom.

A high proportion of people with bothersome tinnitus have hearing loss (Axelsson & Ringdahl, 1989; Nicolas-Puel et al., 2002). Additionally, tinnitus pitch is often matched to frequencies where hearing is impaired (Noreña et al., 2002). Even in tinnitus patients with clinically normal hearing thresholds at conventional audiometric frequencies, cochlear damage can be found through high-frequency audiometry, otoacoustic emissions, or other psychometric tests (Epp et al., 2012; Gu et al., 2012a; Schaette & McAlpine, 2011; Weisz et al., 2006). Animal studies and models have demonstrated that induction of cochlear damage can lead to tinnitus due to changes in spontaneous neuronal activity and tonotopic map reorganization (Roberts et al., 2010; Schaette, 2014). After hearing loss, tinnitus might emerge as a side effect of the brain's attempt to compensate for a loss of auditory input (Schaette & Kempter, 2006, 2009). A causal relation between hearing loss and tinnitus is supported by the finding that simulation of conductive hearing loss with earplugs can induce phantom auditory sensations (Schaette et al., 2012a). Tinnitus induced with prolonged simulation of conductive hearing completely disappears within minutes to hours after removal of the earplugs (Schaette et al., 2012b). Even normal-hearing people with no history of tinnitus perceive tinnitus when they are placed in a soundproof room and are deprived of auditory input (Del Bo et al., 2008; Heller & Bergman, 1953). The phantom sounds also disappear after participants leave the booth and are exposed to normal sound levels. Hence, restoring the hearing of tinnitus patients with hearing aids may decrease the perception of tinnitus, according to the model in which tinnitus is the result of a distortion along the auditory pathway.

Multiple mechanisms for the effect of hearing aids on tinnitus perception are proposed in literature, including gain adaptation, masking, habituation, reduction in communication stress associated with hearing loss, and neuromodulation associated with bottom-up stimulation of the auditory cortex (Sweetow & Sabes, 2010). The influence of these mechanisms is depicted schematically in Figure 10–2. We briefly review each of the mechanisms for tinnitus management with amplification in the next sections.

Gain Adaptation

An immediate consequence of cochlear hearing loss is a reduction in sensory input to the brain. Neuronal response gain may be increased in the central auditory system to compensate for this reduction and to maintain neural homeostasis. The unfortunate result is overamplification of neural noise that generates tinnitus (Noreña, 2011; Schaette & Kempter, 2006, 2008, 2009). Additional sensory input with amplification from hearing aids compensates, to some degree, for the loss of auditory input, and thus facilitates a reduction in central gain and a reduction in the perception of tinnitus (Zeng, 2013).

Masking

Hearing aids restore auditory perception of soft sounds, enriching the perceived soundscape. Amplification can provide partial or complete masking of tinnitus with environ-

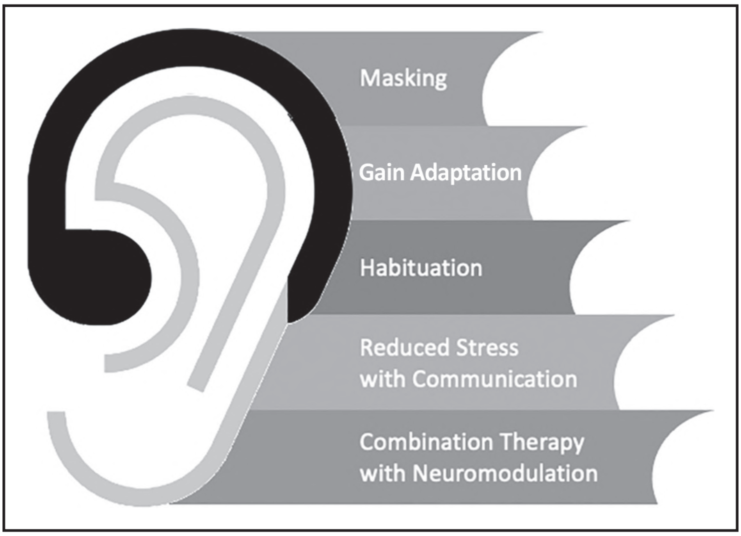

Figure 10–2. Mechanism of effect of hearing aids for tinnitus relief.

mental sounds (McNeill et al., 2012) while also diverting attention away from tinnitus to more meaningful sounds.

Habituation

Amplification of external background sounds may contribute to increased background level of neuronal activity in the auditory pathway. The increased activity in the central auditory nervous system can, in turn, interfere with central processing of tinnitus by reducing the contrast between tinnitus-related neuronal activity and the level of neural activation through background sounds. Hearing aids thus facilitate habituation to tinnitus and reduce awareness of tinnitus (Jastreboff et al., 1996).

Reduced Communication Stress

As hearing ability and speech recognition play a crucial role in social functioning (Hornsby, 2013), hearing aids can reduce the associated communication effort in patients with hearing loss (Beechey et al., 2020). This benefit might even be greater for patients with hearing loss and tinnitus, as these patients indicate higher fatigue ratings in communication. Moreover, noise-reduction algorithms in hearing aids may reduce their listening effort (Callaway et al., 2018).

Neuromodulation

Long-term use of hearing aids can facilitate neuroplastic changes in the brain that contribute to reversal of tinnitus-related cortical reorganization (Herráiz et al., 2009). This concept is supported with data from animal studies demonstrating that long-term exposure to a spectrally enhanced acoustic environment can result in altered cortical tonotopic maps (Eggermont, 2008; Noreña et al., 2006; Pienkowski & Eggermont, 2009), thus reversing a neuroplastic change that may contribute to tinnitus generation (Engineer et al., 2011).

Hearing aids are mainly programmed based on the degree of hearing loss; however, audiologists should take into account the presence of tinnitus (Del Bo & Ambrosetti, 2007). It is difficult to distinguish the impact of hearing aids on tinnitus directly from the indirect psychosocial benefits due to improved hearing. More research evidence is needed about the exact mechanism underlying the benefit of hearing aids for persons with bothersome tinnitus.

Recent Advances

The reported benefit of hearing aids for people with tinnitus varies among published studies. Multiple factors contribute to the differences among findings including different methods, technologies, research design, supplemental interventions (e.g., counseling, behavioral and sound therapies, prescription of gain), and outcome measures (Jacquemin et al., 2021; Shekhawat et al., 2013).

There is substantial literature on the use of hearing aids to mitigate tinnitus perception (Jacquemin et al., 2021). Recent studies have focused on optimizing the beneficial effects of hearing aids. Researchers have investigated different forms of amplification and attempted to predict which patients with tinnitus are most likely to benefit from hearing aid use. It is important to bear in mind that hearing aid fitting as a management tool for patients with chronic tinnitus can be challenging as different patients may require different fitting strategies (Jacquemin et al., 2021). Moreover, these patients might show increased aversion to sound amplification and decreased benefit in difficult listening situations with a hearing aid (Andersson et al., 2011). Decreased gain might be needed, specifically for patients who experience a lower tinnitus pitch (Shekhawat, Searchfield, Kobayashi, et al., 2013; Shetty & Pottackal, 2019). More advanced strategies, such as notch filter amplification and frequency lowering (Peltier et al., 2012), demonstrate promising results, though the added benefits are still debated. Similarly, the addition of noise generators in a combination device has resulted in tinnitus improvement without a clear added benefit compared to conventional amplification (Jacquemin et al., 2021). Amplification might be better tolerated over time, while noise generators might gradually become unpleasant (Jalilvand et al., 2015). The ideal noise settings probably depend on the individual and the situation. Furthermore, while there is a general preference for the use of binaural hearing aids in tinnitus patients, monaural hearing aids have also provided positive results, calling attention to cost efficiency (Shabana et al., 2018; Yokota et al., 2020). A recent Cochrane review (Sereda et al., 2018) reported that there was currently insufficient evidence to judge whether hearing aids, noise devices, or combination devices are more effective in tinnitus management.

Predicting which patients with bothersome tinnitus can most benefit from hearing aids remains challenging. For example, patients with a tinnitus pitch within the frequency range of the hearing aid device might perceive a larger tinnitus improvement than those with a tinnitus pitch outside the frequency range of their device (McNeill et al., 2012; Schaette et al., 2010b). It is clear that more research is needed to uncover what features work and for which patients.

The following factors should be addressed to ensure enhanced quality of evidence for hearing aid and tinnitus management research (Shekhawat et al., 2013):

1. ***Research Design:*** Few published randomized controlled trials (RCTs) focus on amplification as a management option for bothersome tinnitus. Most studies are retrospective analyses of patient data, prospective studies lacking a control group, or studies examining the benefits of hearing aids in conjunction with another management approach like counseling, tinnitus retraining therapy, or cognitive behavioral therapy. Moreover, sample sizes are often too small to derive meaningful conclusions. Future investigations would optimally be adequately powered RCTs with clearly defined research questions focusing on the impact of hearing aid use on tinnitus perception, as implemented in the protocol for a feasibility trial to investigate the effects of digital hearing aids on tinnitus perception (Haines et al., 2020). One challenge associated with larger trials is the cost associated with hearing aids. Also, the heterogeneous nature of tinnitus needs to be taken into account. Studies must utilize well-defined inclusion–exclusion criteria for tinnitus severity, laterality, nature, and the duration of hearing aid use.
2. ***Outcome Measures:*** Outcome of tinnitus management is primarily limited to questionnaires in pre–post designs. When choosing questionnaires, care should be taken to ensure that they assess specific tinnitus-related complaints that are critical to determine whether the tinnitus was treated effectively. For sound-based treatments, these outcome domains include tinnitus intrusiveness, ability to ignore, concentration, quality of sleep, and sense of control (Hall et al., 2018). Frequency of measurement is an important factor to consider when planning research studies. Frequent assessment measures can offer more specific insights about the evolution of hearing and tinnitus complaints over time with hearing aid use. However, overassessment poses the risk of directing patients' attention toward their tinnitus or decreasing its reliability (Cima et al., 2019). There is merit in including psychoacoustic measures of tinnitus such as tinnitus pitch, loudness, minimum masking level, and residual inhibition as they provide specific information about how tinnitus properties change with time or as a result of specific intervention used. It may also be advantageous to study electrophysiological measures and to use imaging techniques to enhance understanding of the impact of amplification on cortical networks.

Future Directions

Future studies of amplification as a management option for bothersome tinnitus could focus on the following topics:

1. ***Optimization of hearing aid gain/output for tinnitus relief:*** The most effective hearing aid setting for tinnitus suppression may be different from the one used to enhance communication (Wise, 2003). Hearing aid prescriptive procedures are used to determine the hearing aid amplification for a given hearing loss instead of the best gain needed for tinnitus relief. The two most commonly used prescriptive procedures for hearing

aid programming are (a) desired sensation level input/output (DSL [I/O]) (Cornelisse et al., 1995), a prescriptive gain method based on loudness normalization that provides more low- and high-frequency amplification at lower intensities; and (b) National Acoustic Laboratories—Nonlinear 1 (NAL [NL1]) (Byrne & Tonisson, 1976; Keidser et al., 1999), a prescriptive gain method based on loudness equalization aimed at optimizing intelligibility and normalizing overall loudness rather than for each frequency channel (Keidser et al., 1999). These quiet environmental sounds are important for reducing tinnitus audibility. Consequently, hearing aids programmed primarily for hearing loss, as they are in the majority of research studies, may not reduce tinnitus or tinnitus attributes.

Shekhawat et al. (2013) examined the effects of high-frequency modification of the DSL (I/O) v5.0 prescriptive procedure on short-term tinnitus perception in a laboratory setting. Speech files simulating different amounts of high-frequency amplification were used to ascertain the effects of a change in DSL (I/O) v5.0 prescription on participants' tinnitus perception. Overall, 71% of participants preferred a 3- to 6-dB reduction in output across all frequencies. For tinnitus pitch identified below 4 kHz, the authors recommended a target gain of 3 dB below DSL (I/O) v5.0 across the frequency range. However, further clinical versus laboratory investigation is required to document the long-term impact of these hearing aid settings on tinnitus perception. There is also a need to investigate specially designed prescriptive procedures targeting tinnitus suppression.

2. ***Tinnitus pitch:*** Tinnitus pitch is an important psychoacoustic measure that informs hearing aid programming and can have an impact on tinnitus relief. Tinnitus management with hearing aids may be less effective for patients with a tinnitus pitch outside the frequency range of the hearing aid amplification (Schaette et al., 2010a). As an example, for patients with tinnitus pitch above 8 kHz, acoustic stimulation provided by a hearing aid may not affect the tinnitus loudness and/or distress and, therefore, interaction between sound-evoked and tinnitus-related neuronal activity may not occur. More information is needed about whether hearing aids with an extended frequency range provide tinnitus relief for patients experiencing extremely high-pitched tinnitus.
3. ***Measurements to determine cochlear damage:*** Certain types of cochlear damage might limit or even prevent effective aided stimulation of the auditory system. Inner hair cell damage, auditory nerve fiber deafferentation, and cochlear dead regions have all been documented in individuals with tinnitus (Etchelecou et al., 2011; Gu et al., 2012b; Kiani et al., 2013; Tan et al., 2013; Weisz et al., 2006). Detailed measurements to determine the exact type and extent of cochlear damage might contribute to an understanding of the heterogeneity of tinnitus treatment outcomes with hearing aids. The measurements might also provide a basis for the development of amplification and stimulation strategies that maximize the effect of hearing aids for tinnitus.

4. ***Combination of hearing aids and other intervention strategies:*** It is important to explore novel ways to provide greater benefit from hearing aids by combining them with other existing tools such as noninvasive brain stimulation. Shekhawat, Stinear, et al. (2013) conducted a clinical trial to investigate the combined impact of hearing aids and transcranial direct current stimulation (tDCS) on tinnitus perception. In this double-blind, sham-controlled randomized trial, participants received either real or sham tDCS of the left temporoparietal area (LTA) delivered in five sessions on 5 consecutive days, followed by hearing aid use for 6 months. The trial demonstrated the effectiveness of tDCS for transient tinnitus suppression (few minutes to few days) and longer-term impact of hearing aid use for tinnitus management. Hearing aid use resulted in significant reduction in tinnitus perception after 3 months of usage that was sustained until 6 months of use. The hearing aid effects were independent of tDCS. The study was one of the first novel attempts to combine brain stimulation with hearing aid use. Subsequent research identified how this management option could be designed with optimized parameters, such as a more optimal washout period between the tDCS sessions instead of consecutive sessions (Shekhawat & Vanneste, 2017), use of high-definition instead of conventional tDCS, and stimulation of multisite brain areas instead of only LTA (Kok et al., 2020). It would be useful to know how specifically dedicated programs focusing on 3D masking (Searchfield et al., 2016), Zen therapy, and other programs impact the perception of tinnitus.

Clinical Implications

Currently, there is no universally accepted approach for hearing aid programming in the management of tinnitus, but national guidelines report similar recommendations. The clinical practice guidelines of the American Academy of Otolaryngology—Head and Neck Surgery recommend a hearing aid evaluation for patients with constant, bothersome tinnitus associated with documented hearing loss (Tunkel et al., 2014). The National Institute for Health and Care Excellence (NICE) in the United Kingdom also states that amplification devices should be offered to people with tinnitus and hearing loss, particularly a hearing loss that affects their ability to communicate (NICE, 2020). The European guidelines form a weak recommendation for hearing aids in patients with tinnitus and hearing loss. Considering tinnitus heterogeneity and the unique needs of patients, it is of paramount importance to adhere to a patient-centric, personalized approach for tinnitus management when considering hearing aids. Three significant sources of information are important to enhance success and usage of hearing aids for tinnitus management:

1. ***In-depth assessment:*** Detailed assessment is the foundation of a good management plan. Any patient with a primary complaint of tinnitus should undergo at least a three-step evaluation. An *otological evaluation* assesses the presence and extent of underlying diseases or pathologies and whether additional medical referrals should be arranged. *An audiological evaluation* is needed to assess the hearing status of the patient and the extent, type, and degree of hearing loss. High-frequency audiometry

should be conducted as indicated. The impact of tinnitus on the patient's day-to-day life should be evaluated using psychometric tools, such as the Tinnitus Functional Index (Meikle et al., 2012), Tinnitus Handicap Questionnaire (Kuk et al., 1990), Tinnitus Sample Case History Questionnaire (Langguth et al., 2007), Tinnitus Handicap Inventory (Newman et al., 1996), Tinnitus Severity Index (Meikle et al., 1995), Tinnitus Reaction Questionnaire (Wilson et al., 1991), and various visual analog scales of tinnitus (Herráiz et al., 2006). *Tinnitus testing* is the third component in the tinnitus evaluation. Psychoacoustic measurements of tinnitus (e.g., tinnitus pitch matching, loudness matching, minimum masking level, loudness discomfort level, and residual inhibition) are important aspects of a test battery approach.

2. ***Hearing aid fitting and information from patients:*** At every stage of the process, joint clinical decision-making is the best strategy to have a good outcome for the patient. Hence, patients' feedback and expectations should be addressed to avoid nonuse. This discussion can be about different hearing aid fitting procedures: initial fit of the hearing aids, fitting types (e.g., behind the ears, open fit, completely in the canal, receiver in the canal), initial gain level, and counseling. It is not uncommon for patients with bothersome tinnitus to have decreased sound tolerance. Hence, loudness discomfort levels should be measured with and without hearing aids to ensure hearing aids are not exacerbating the tinnitus. Hence, sound tolerance is a key factor to be considered when programming hearing aids for tinnitus patients. In some cases, programming results in providing less gain than needed based on the prescriptive method. Searchfield (2006) outlined in-depth insights about hearing aid programming for people with tinnitus.
3. ***Close monitoring and follow-up:*** Additional follow-up appointments should be scheduled to closely monitor patients with tinnitus. Occasionally, hearing aids can exacerbate tinnitus. Close follow-up and a conservative initial fitting in prescriptive gain may be a good starting point that can later be modified based on the patient's needs and discussion during the follow-up sessions. Every attempt should be made to ensure a comfortable hearing aid fit. However, not every patient with a hearing loss is a good candidate for amplification. Patients who have extended high-frequency loss or a profound degree of hearing loss beyond the range of hearing aids may not be suitable hearing aid candidates due to technical limitations. Other options such as cochlear implants may then be explored.

Although a wide range of studies indicate that hearing aids are important tools for the management of tinnitus, more research is needed to enhance the quality of evidence supporting the use of hearing aids for tinnitus management. Scientific evidence is also needed to develop approaches with specifically targeted adjustments to hearing aid fittings that take the characteristics of a patient's tinnitus into account to further increase the effectiveness of hearing aids for reducing tinnitus.

Key Messages

- Hearing aids have been used for tinnitus management for more than 70 years.
- There is strong quantitative evidence about the effectiveness of hearing aids for tinnitus management.
- There is a need for more research about the nature of hearing aid programming, specifically for tinnitus and gold-standard randomized control trials.
- When programming hearing aids for people with tinnitus, it is important to consider their tinnitus profile, such as pitch, loudness, and additional personalized support as needed.

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11

AUDIOLOGIST-DELIVERED COGNITIVE BEHAVIORAL THERAPY FOR TINNITUS

Eldré W. Beukes and Vinaya Manchaiah

Introduction

Experiencing conditions resulting in chronic symptoms can affect most aspects of day-to-day living and result in poorer health-related quality of life. Daily struggles with chronic conditions can be demoralizing, worrying, isolating, and frustrating (Andersson & Westin, 2008). One such chronic condition is tinnitus, characterized by individuals hearing sounds with no known external source. One of the biggest risk factors for developing tinnitus is hearing loss, although numerous other conditions can also lead to tinnitus. Although many people with tinnitus do not find it bothersome, others find it extremely problematic (Brüggemann et al., 2016; Davis & Rafaie, 2000). Those with severe tinnitus report many associated difficulties, including insomnia, concentration problems, and indirect psychosocial effects such as feelings of hopelessness, irritability, frustration, anxiety, and depression (Salazar et al. 2019; Trevis et al. 2018). Living with chronic tinnitus as well as the associated psychosocial comorbidities can be an insurmountable challenge. For this reason, individuals with severe tinnitus need appropriate clinical strategies to help manage the comorbidities, including anxiety and depression, to aid coping with tinnitus. This chapter provides an overview of an evidence-based intervention for bothersome tinnitus, namely cognitive behavioral therapy, and how it can be delivered by audiologists.

Background

Tinnitus management options can be broadly classified as (a) approaches targeting the tinnitus percept (e.g., medical management, sound therapy, and the use of hearing devices), (b) approaches targeting the reactions to tinnitus (e.g., psychological approaches such as mindfulness-based stress reduction [MBSR]; acceptance and commitment therapy [ACT]; and cognitive behavioral therapy [CBT]), and (c) combined approaches that target both the percept and reactions to tinnitus (e.g., tinnitus retraining therapy [TRT]) (Beukes et al., 2021). In addition, various alternative therapies such as acupuncture, ginkgo biloba, and vitamin supplements have been used in the management of tinnitus with limited effectiveness (see Chapters 14 and 15 for additional details). Despite the range of interventions, few are evidence-based. CBT is a psychological intervention approach supported by scientific evidence for management of tinnitus and other chronic conditions (Carpenter et al., 2018). Due to this strong evidence base, CBT is the preferred management option for tinnitus and recommended in most practice guidelines (e.g., the American Academy of Otolaryngology–Head and Neck Surgery [AAO-HNS] guidelines) over other approaches such as the use of medications (Fuller et al., 2017; Tunkel et al., 2014).

The evolution of CBT can be traced back to the developments in psychology as early as 1913, as seen by the work of behaviorist John B. Watson (Watson, 1957). CBT, as practiced today, originated from cognitive therapy, which was developed by Aaron Beck in the 1960s (Beck, 1976, 1995). Prior to this discovery, the emphasis in psychology was on behavioral therapy, focused on eliminating unwanted behaviors. Although this approach was successful, Beck (1976), identified thinking disorders at the core of problems such as depression and anxiety. Distorted cognitions, negative thoughts and beliefs, and biased interpretations of particular experiences played a critical part in maintaining behaviors associated with depression and negative self-views. These observations resulted in the development of cognitive therapy, aimed at identifying unhelpful thoughts and beliefs and proposing alternatives. Later, behavioral and cognitive principles were combined, resulting in the origin of CBT to address both unwanted behaviors and unhelpful thought patterns (Beck, 1995). CBT has been successfully used to manage various disorders including anxiety, depression, insomnia, and post-traumatic stress disorder (e.g., Luo et al., 2020; Natsky et al., 2020).

CBT Scope, Principles, and Components

CBT is based on the basic principle that what we think, how we feel, and how we behave are all closely connected, and each of these factors has a decisive influence on well-being, as shown in Figure 11–1. Due to this interconnectedness, addressing either unhelpful thoughts, emotions, reactions, or behaviors can lead to improvements associated with a disorder (Chawathey & Ford, 2016). CBT helps change how people think (cognitive) and what they do (behavior). *Cognitive techniques* identify distressing beliefs, dysfunctional assumptions, cognitive distortions, and exaggerated or negative automatic thoughts. These thoughts are challenged using cognitive restructuring and replaced with more realistic, balanced, and accurate thoughts. *Behavioral techniques* identify unhelpful behaviors, such as withdrawing, giving up hobbies, or experiencing high tension due to problems or medical conditions. Behaviorism is based on the principle that behavior is learned and that behavior can be unlearned or learned anew. Behavioral modification is suggested to re-enable participation, help reduce tension, and decrease isolation. Behavioral activation applies the following steps, using the acronym ACTION: Assess mood and behavior; Choose alternative behaviors; Try out alternatives; Integrate these changes into life; Observe the results; Now evaluate (Addis et al., 2001). Examples of behavioral modification include keeping a sleep diary, scheduling pleasant events, and activity monitoring.

Together with cognitive restructuring and behavior modification, there are other key components of CBT, such as exposure therapy. This involves graded exposure to feared situations to habituate to the situa-

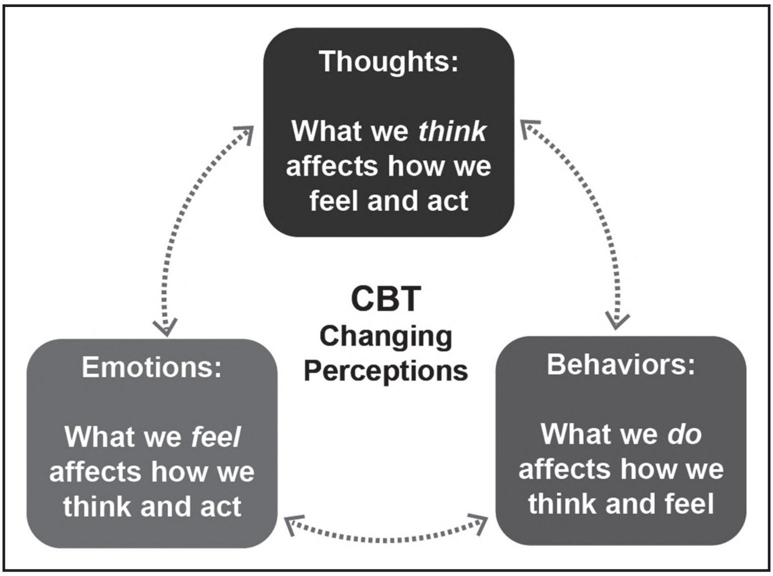

Figure 11–1. Illustration of the relationship between thoughts, emotions, and behaviors. From Beukes, E., Andersson, G., Manchaiah, V., and Kaldo, V. (2021). *Cognitive behavioral therapy for tinnituss* (p. 5). Plural Publishing. Copyright © 2021 Plural Publishing, Inc. All rights reserved.

tion and diminish the fear. The use of mental imagery is also incorporated using all five senses, as well as environmental adaptation to minimize problems pertaining to specific disorders.

Although CBT is structured, it can be tailored for different disorders (e.g., anxiety, insomnia) and each individual. CBT is problem-oriented and helps therapists find practical ways to reduce difficulties and comorbidities related to the presenting disorder and change behaviors. Thus, CBT focuses on current problems rather than on issues from the past. Goal setting is incorporated to monitor progress, and the therapist and patient collaborate to work toward achieving these goals. Therapy is closely monitored and evaluated to assess the effectiveness of specific strategies, often implemented in the form of homework assignments. A record of positive information is also kept in view of disconfirming negative thoughts. A CBT program can vary in length, between five and 20 sessions. For tinnitus, these sessions generally run for 6 to 10 weeks (Andersson, 2002) to provide enough time for individuals to gain insights or perspectives and learn new skills. Each session may address specific topics such as stress management, cognitive restructuring, and relaxation (Andersson, 2002).

CBT Research Evidence

Numerous systematic reviews and meta-analyses suggest that CBT is an effective management option for many psychological conditions such as anxiety, depression, and insomnia; for chronic pain and physical health conditions; and for various other conditions such as substance use disorder, anger, and aggression (Cuijpers et al., 2013; Hind et al., 2014; Hofmann et al., 2012; Michail et al., 2017; Trauer et al., 2015). Specific CBT management strategies vary significantly for different disorders, as there are characteristic themes of dysfunctional behavior patterns and cognitive distortions associated with each disorder.

Due to the relationship between tinnitus and psychological distress, CBT has been applied to target the distress caused by tinnitus (Andersson, 2002). Unhelpful thoughts and emotional reactions about tinnitus are addressed through behavior modifications. Various controlled trials, longitudinal studies, and systematic reviews confirm that CBT is the management approach with the broadest evidence base for tinnitus (for a review see Beukes et al., 2019; Fuller et al., 2020; Hesser et al., 2011).

CBT Delivery Mechanisms

CBT delivery methods can be broadly categorized as follows (British Association for Behavioral and Cognitive Psychotherapies, n.d.):

- **Formulation-driven CBT:** Licensed CBT therapists offer individual or group CBT for a range of people and problem areas. These professionals formulate and adapt management strategies uniquely for each individual. This method is appropriate when individuals require more intensive input (directive counseling) from trained experts.
- **CBT approaches specific to a problem area:** This method includes customized CBT interventions developed for specific problem areas (e.g., specific CBT intervention for those with depression). This form of intervention does not require professionals to formulate and adapt the management strategies uniquely for each individual, but rather within the limits of a previously evaluated management manual. CBT delivery using this method can be done more easily by someone who has domain-specific training (e.g., audiologists trained to provide management of tinnitus) with additional training on CBT.
- **Assisted self-help:** This method can include computerized CBT or other self-help materials presented to a support group or individuals by healthcare professionals (see Chapter 9 for additional details).
- **Self-help:** CBT delivery is through bibliotherapy or web applications, but without any support from a healthcare professional. Self-help CBT is thus fundamentally different from the traditional form of psychotherapy. Moreover, no CBT skills or training are required by the individual reading the self-help materials.

CBT has been successfully delivered face-to-face (Fuller et al., 2020), in group sessions (Kaldo et al., 2008), and online (Beukes et al., 2019). Different CBT delivery methods require different skills both from the therapist and the patient. For example, assisted self-help or self-help is appropriate for those who are highly motivated and have good health literacy. On the other hand, patients who may struggle with aspects of self-help may need more guidance or more regular one-to-one or group sessions.

Recent Advances

Although CBT has the most evidence of effectiveness for tinnitus management (Fuller et al., 2020), it is often not provided in clinical practice. For instance, a large-scale epidemiological study (*N* = 75,764) in the United States showed that medication, which had the least evidence, was discussed most frequently (i.e., 46%), while CBT with the most scientific evidence was discussed least frequently (i.e., 0.2%) with tinnitus patients (Bhatt et al., 2016). A possible reason for this finding may be the lack of accessible CBT intervention routes for tinnitus. Due to the evidence base for CBT, there has been a growing professional interest to increase access to CBT. Creative approaches have thus emerged. One such approach is the development of an internet-based CBT intervention (ICBT) (Beukes et al., 2016; Beukes et al., 2020; Manchaiah et al., 2020). The efficacy of ICBT has been shown in nine randomized control trials. Specifically, studies show a moderate effect size for both tinnitus distress and insomnia, and improvements in anxiety, depression, and quality-of-life metrics (Beukes et al., 2019).

In summary, CBT as a tinnitus management option is supported by research evidence but is often not available to those with tinnitus. This is partly attributed to a lack of experts able to provide CBT for tinnitus, which has hampered the availability of CBT for individuals with tinnitus.

Audiologist-Guided CBT for Tinnitus: Evidence

Originally, CBT was delivered only by licensed CBT therapists. Although only a licensed CBT therapist can offer formulation-driven CBT, other healthcare professionals can potentially offer CBT using assisted self-help approaches. When providing guided online interventions, the level of qualification and experience of the eHealth therapist has not affected treatment efficacy (Baumeister et al., 2014). For instance, outcomes have been comparable when CBT was provided by a psychologist versus a technical assistant for depression (Titov et al., 2010), social phobia (Titov et al., 2009), and anxiety (Robinson et al., 2010). Likewise, no significant difference in outcomes was found when comparing guidance by a clinical psychologist versus a student psychologist for social anxiety (Andersson et al., 2012), or between psychologists with and without specialized training for anxiety (Johnston et al., 2011).

The assessment and management of tinnitus are generally conducted by otolaryngologists and audiologists. Otolaryngologists provide medical examinations to assess and treat possible conditions associated with developing tinnitus (e.g., vestibular schwannoma or middle ear disorders). Audiologists—who are often the point of contact for tinnitus care—manage tinnitus by fitting hearing aids, providing sound enrichment, and offering informational counseling to address tinnitus. As audiologists are already frontline service providers for tinnitus patients, incorporating audiologist-delivered CBT is a natural progression of tinnitus management. This novel approach is beginning to gain momentum within the audiology community, as seen by studies undertaken in the U.K. (Aazh & Moore, 2018a; Beukes, Baguley, et al., 2018; Taylor et al., 2020) (Table 11–1). For example, Aazh and Moore (2018a) recently reported an uncontrolled trial in the United Kingdom in which audiologists delivered face-to-face CBT to 68 patients with bothersome tinnitus and hyperacusis. Four audiologists underwent a tinnitus training course provided by the authors before providing six weekly sessions. Participants who completed all visits with the audiologists showed significant improvements in tinnitus annoyance, loudness and distress, hyperacusis, and quality-of-life effects. In a similar

Table 11–1. Audiologist-Guided CBT/Psychologically Informed Tinnitus Intervention Studies

Reference	*Design*	*Intervention Group*	*Control Group*	*Tinnitus Severity Effect Size: Cohen's d (95% CI)*	*Pre-Mean (SD) Internet Intervention*
Beukes et al. (2017)	Pilot study	*n* = 37	None	Within group 1.18	Tinnitus Functional Index: 56.15 (18.35)
Aazh & Moore (2018a)	Uncontrolled trial	Face-to-face CBT *n* = 68	None	Within group 1.13	Tinnitus Handicap Inventory 59.7 (19.5)
Beukes, Baguley, et al. (2018)	2-arm efficacy RCT	Internet-based CBT *n* = 73	Delayed treatment group *n* = 73	Between group: 0.69 (0.35 to 1.02)	Tinnitus Functional Index: 59.79 (17.95)
Beukes, Andersson, et al. (2018)	2-arm effectiveness RCT	Internet-based CBT *n* = 46	Individualized face-to-face tinnitus therapy *n* = 46	Between group: 0.30 (-0.11 to 0.72)	Tinnitus Functional Index: 55.01 (21.58)
Beukes, Allan, et al. (2018)	Single group longitudinal follow-up	Internet-based CBT *n* = 104	None	Within group: 0.69 (0.28–0.61)	Tinnitus Functional Index: 59.49 (18.40)
Taylor et al. (2020)	Feasibility study	Face-to-face psychologically informed intervention *n* = 19	Treatment as usual: Individualized face-to-face tinnitus therapy	Unable to calculate due to the small sample size	Tinnitus Functional Index: 67.08 (23.64)

Acronyms: CBT = cognitive behavioral therapy; ICBT = Internet-based cognitive behavioral therapy; M = Male, F = Female, *n* = number.

Post-Mean (SD) Internet Intervention	*Pre-Mean (SD) Control*	*Post-Mean (SD) Control*	*Mean Age Internet Group (SD)*	*Gender Internet Group*	*Post-Intervention Attrition*	*Improvements in Secondary Outcomes*
37.35 (19.49)	N/A	N/A	Average age range: 50–59 years	49% M 51% F	22%	Insomnia
35.6 (20)	N/A	N/A	52.5 (13)	43% M 57% F	32%	Hyperacusis, tinnitus loudness and annoyance, effect on life, insomnia
38.67 (24.26)	59.18 (19.96)	53.72 (19.38)	56.8 (12.2)	59% M 41% F	15% ICBT 1% control	Insomnia, depression, hyperacusis, cognitive failures, life satisfaction
27.88 (20.84)	56.57 (20.61)	34.88 (24.91)	50.7 (12.2)	63% M 37% F	4% ICBT 4% control	Insomnia improved more than the inferiority margin for the internet-based CBT group
36.79 (24.84)	N/A	N/A	58.3 (12.5)	56% M 44% F	20% didn’t respond to the invitation	Insomnia, anxiety, depression, hearing disability, hyperacusis, and life satisfaction
26.53 (32.03)	N/A	N/A	53 (16.09)	67% M 33% F	53%	Tinnitus conditions, working alliance inventory

approach, Taylor and colleagues designed a psychologically informed manualized intervention for tinnitus for audiologists (Taylor et al., 2020). This manual included sections such as patient education, relaxation, and promoting sleep. Audiologists were trained to provide the intervention. In a feasibility study, nine participants found the content helpful, although audiologists felt that more training and supervision was required to be able to use the manual (Taylor et al., 2020)

Studies have recently been initiated to evaluate the role of an audiologist in providing internet-based intervention for tinnitus. This approach was evaluated in a three-phase clinical trial including a pilot study, a randomized controlled efficacy trial, and an effectiveness trial on 229 participants (Beukes et al., 2017; Beukes, Baguley, et al., 2018; Beukes, Andersson, et al., 2018). A trained audiologist provided weekly feedback and on-demand support during the intervention. In the efficacy trial with 146 participants, a medium effect was found for reducing tinnitus severity compared to a delayed management control group (Beukes, Baguley, et al., 2018). Improvements were found in tinnitus distress, insomnia, anxiety, and depression, and were maintained 1 year after undertaking ICBT (Beukes, Allen, et al., 2018). In the randomized, multicenter, noninferiority effectiveness trial of 92 adults, internet-based CBT led to outcomes similar to those of individualized face-to-face clinical care for tinnitus (Beukes, Andersson, et al., 2018).

The study by Taylor et al. (2020) also-evaluated whether audiologists can apply a psychologically informed manual during tinnitus management. Although outcomes were positive, recruitment was difficult and intervention uptake was low (only nine patients were retained for the trial). Likewise, audiologist provision of CBT in a clinical setting indicated low compliance, with only 17% of those offered the face-to-face clinical intervention completing the full course (Aazh & Moore, 2018b). In a process evaluation, Beukes, Manchaiah, Baguley, et al. (2018) identified that intervention uptake was low and that more efforts were needed to promote these interventions. Participants undertaking these interventions reported finding them effective and the audiology-support helpful (Aazh et al., 2019; Beukes, Manchaiah, Davies, et al., 2018). These studies provide some indication that audiologist-delivered CBT may be viable, as summarized in Table 11–1.

Audiologist-Guided CBT for Tinnitus: Resources

The provision of CBT for tinnitus is a new skill that audiologists can develop. Beukes et al. (2021) wrote a textbook to guide clinicians with this process. The book contains detailed information regarding CBT including ways of delivering CBT and how to monitor progress. Also included are intervention materials for patients that consist of different strategies described in 22 separate chapters. These components include a relaxation program; specific CBT techniques such as the use of positive imagery, shifting focus, and exposure techniques; and tips for dealing with everyday tinnitus problems such as sleep and concentration difficulties (Table 11–2).

Prior to embarking on CBT for bothersome tinnitus, an in-depth assessment of the presenting symptoms and auditory profile of the individual with tinnitus is required, as outlined in Figure 11–2. The first step is undertaking a thorough case history to assess whether other referrals are required. A full audiological assessment is also needed to establish hearing ability. Assessing the severity of tinnitus and its functional impact

Table 11–2. Tackling Tinnitus: CBT Program for Tinnitus

Component	***Chapters***
Overview	• Program outline • Tinnitus overview
Relaxation guide	• Deep relaxation • Deep breathing • Entire body relaxation • Frequent relaxation • Quick relaxation • Relaxation routine
CBT techniques	• Positive imagery • Views of tinnitus • Shifting focus • Thought patterns • Challenging thoughts • Being mindful • Listening to tinnitus
Dealing with effects of tinnitus	• Sound enrichment • Sleep guidelines • Improving focus • Increasing sound tolerance • Listening tips
Maintaining results	• Outcome measurement • Future directions

Adapted from Beukes et al. (2021). *Cognitive behavioral therapy for tinnitus.* Plural Publishing.

is important. Although various approaches exist, standardized questionnaires using a test battery approach that focuses on different domains, such as tinnitus severity, anxiety, depression, insomnia, and quality of life, are recommended. To identify whether the intervention has had a positive effect, the initial assessments should be repeated for pre–post comparison. If problems remain, the reasons for slow progress should be explored. There may be various reasons for the lack of progress; e.g., patients still seeking a diagnosis or cure or some difficulty preventing them from following the intervention advice. Once identified, these barriers should be appropriately addressed. Table 11–3 provides the result of an individual after they undertook an audiologist-guided internet-based intervention to provide an example of the range of outcomes that can be expected from such an intervention. It can be seen that, for this individual, the tinnitus severity reduced by 53 points to a range in which intervention was no

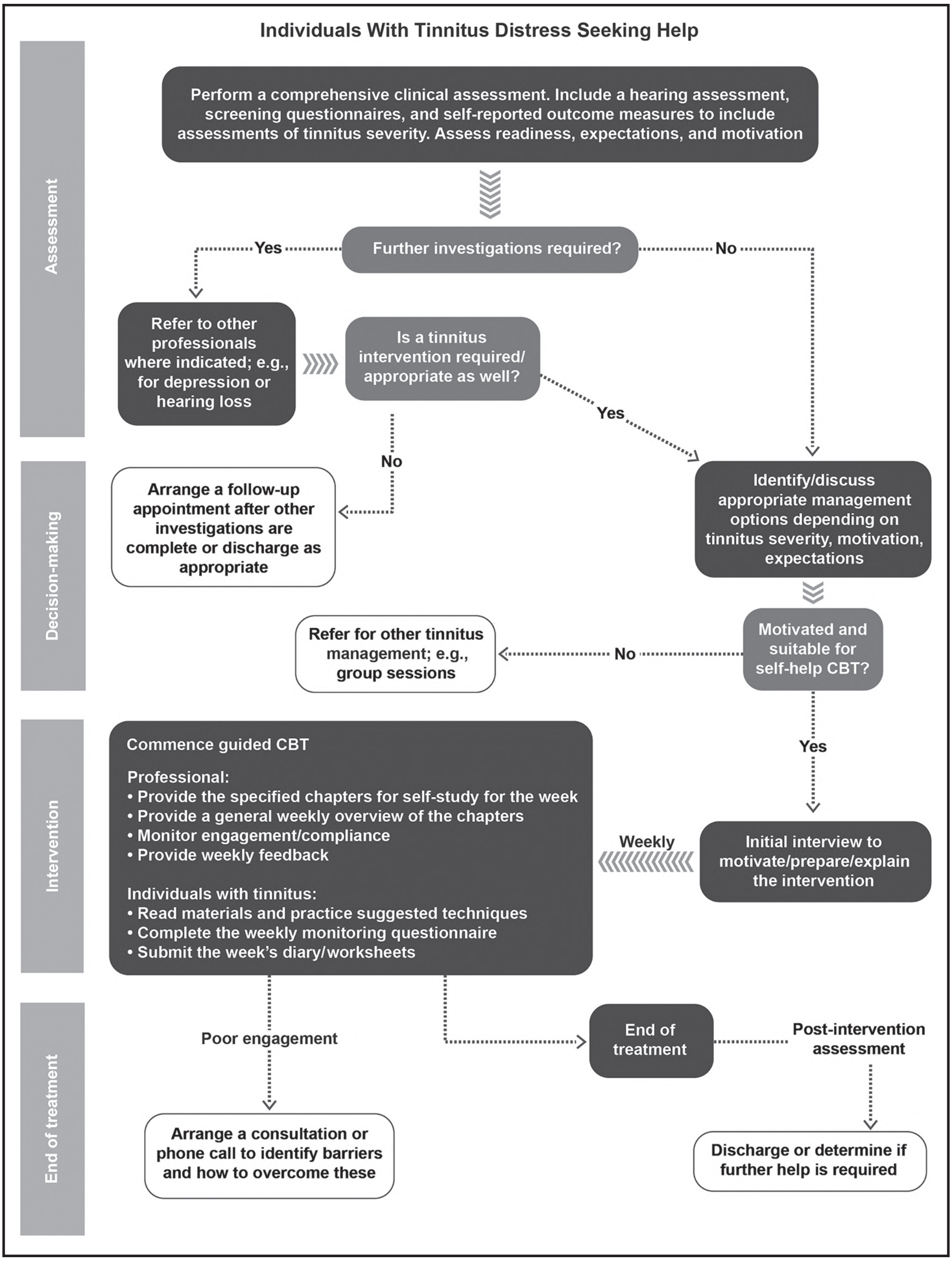

Figure 11–2. A flow chart with a step-by-step guide when planning a CBT intervention for individuals with tinnitus. From Beukes, E., Andersson, G., Manchaiah, V., and Kaldo, V. (2021). *Cognitive behavioral therapy for tinnitus* (p. 44). Plural Publishing. Copyright © 2021 Plural Publishing, Inc. All rights reserved.

Table 11–3. Clinical Outcomes From One Individual With Tinnitus After They Undertook an Audiologist-Guided Internet-Based Intervention for Tinnitus

Domain	*Outcome Measures*	*Range of Scores*	*Pre-Intervention Score*	*Post-Intervention Score*	*1-Year Follow-Up*
Tinnitus	Tinnitus Functional Index (TFI)	0–100, >25 = significant tinnitus	65	12	5
Anxiety	Generalized Anxiety Disorder Questionnaire (GAD-7)	0–21, >5 = mild anxiety	15	5	4
Depression	Patient Health Questionnaire (PHQ-9)	0–28, >5 = mild depression	12	3	0
Insomnia	Insomnia Severity Index (ISI)	0–28, >8 = subthreshold insomnia	18	2	0
Sound Sensitivity	Hyperacusis Questionnaire (HQ)	0–42, >28 = strong hypersensitivity	28	14	11

longer required. The tinnitus scores reduced even further at the 1-year follow-up. Likewise, improvements were found for anxiety, depression, insomnia, and hyperacusis, all reducing to a range where they were no longer problematic.

Future Directions

Audiologists play an important role in the rehabilitation process of patients with bothersome tinnitus. There is a potential to expand this skill set to include audiologist-delivered CBT. At present, this concept is in its infancy, and further training and guidance are required to help audiologists. This training should be included in graduate audiology programs by placing more emphasis on counseling to increase student confidence. CBT courses tailored for audiologists should be made available.

Audiologists can also guide patients using available manuals. The psychological manual by Taylor et al. (2020) is one example. Another resource is the book *CBT for Tinnitus* (Beukes et al., 2021) containing materials for both audiologists and individuals with tinnitus.

Further work is indicated to improve uptake, engagement, and outcomes using audiologist-guided CBT or psychological interventions. One option may be using a blended approach combining other aspects of tinnitus care such as the use of various sound therapy approaches with elements of CBT. Improving access to CBT is also required. Exploring further ways of increasing accessibility to CBT should be sought. Implementation of evidence-based approaches (such as the use of ICBT) and ensuring that third-party reimbursements are in place can assist in provision of CBT.

Clinical Implications

As tinnitus is one of the most frequently occurring hearing-related symptoms and may result in severe distress, patients should be offered evidence-based interventions. These interventions should improve not only the tinnitus severity, but also the associated difficulties such as insomnia, anxiety, and hyperacusis. Tinnitus management is often offered by audiological professionals, who seldom offer psychological-based approaches. Including such strategies, such as the use of CBT, for tinnitus management has several advantages. CBT is based on principles from both behavioral and cognitive psychology and helps alter unhelpful thoughts about tinnitus through behavior modifications. CBT is problem focused and action oriented to address the broader difficulties experienced by patients such as sound sensitivity, hearing disability, and insomnia. Emerging research findings and clinical tools for audiologist-assisted CBT approaches should be considered, as they offer several advantages such as:

- **Research evidence:** CBT has been researched over several years in controlled trials and longitudinal studies. It has a broad evidence base, consistently supporting CBT as a tinnitus management approach (Beukes et al., 2019; Fuller et al., 2020; Hesser et al., 2011).
- **Reducing tinnitus severity:** Results of extensive studies highlight the effectiveness of CBT in decreasing tinnitus distress and annoyance.
- **Decreasing difficulties associated with tinnitus:** CBT has been shown to decrease problems often associated with tinnitus such as anxiety, depression, insomnia, and hyperacusis. It also improves quality of life and daily life functioning.
- **Promoting self-management:** CBT is delivered using homework assignments to help individuals play an active role in their tinnitus management. It is also designed for relapse prevention, in that strategies for mitigating worsening tinnitus are planned beforehand.
- **Short-term management for long-term effects:** CBT programs generally run for less than 2 months (4 to 8 weeks), but the outcomes consistently remain stable for up to 1 year post-intervention (Beukes et al., 2018c).
- **CBT can be offered in different formats:** Research has indicated that CBT delivered in various formats can be helpful, including in groups, online interventions, and face-to-face sessions. CBT provided via both structured intervention and assisted self-help has been beneficial.
- **CBT offers various strategies:** CBT programs are holistic and provide various elements including relaxation, stress-reduction strategies, shifting focus, thought analysis, cognitive restructuring, and dealing with the effects of insomnia and sound sensitivity.

Key Messages

- CBT has the most evidence of effectiveness for tinnitus management but is infrequently available or accessible to individuals with tinnitus.

- Ways of increasing accessibility to CBT for tinnitus should be sought for those with distressing tinnitus. One way to increase accessibility is by providing assisted self-help options where clinical visits are not feasible.
- Initial results have indicated the effectiveness of audiologist-delivered CBT, irrespective of the format of delivery; i.e. face-to-face or internet-based assisted self-help (e.g., Beukes, Baguley, et al., 2018; Beukes, Andersson, et al., 2018; Kaldo et al., 2008, Aazh & Moore, 2018a. Due to this potential, further training should be offered to increase the scope of practice and confidence in providing CBT for tinnitus.

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12 APPLICATION OF TELEAUDIOLOGY TO THE CLINICAL MANAGEMENT OF TINNITUS

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Introduction

Teleaudiology is a specific application of telemedicine or telehealth to the discipline of audiology. Both terms refer to remote delivery of healthcare services (Chaet et al., 2017). Telehealth has been defined as "the use of electronic information and telecommunication technologies to support long-distance clinical healthcare, patient and professional health-related education, public health, and health administration. Technologies include video conferencing, the internet, store-and-forward imaging, streaming media, and terrestrial and wireless communications". (Health Resources and Services Administration, 2021) The Centers for Medicare and Medicaid Services (2020) offer a more generic definition: "Telehealth, telemedicine, and related terms generally refer to the exchange of medical information from one site to another through electronic communication to improve a patient's health."

The ability to provide audiology services remotely (teleaudiology) has greatly expanded opportunities for the delivery of hearing healthcare services, eliminating many barriers for patients and ultimately increasing accessibility to these services (Munoz et al., 2020). Teleaudiology has seen substantial development over the past decade due to advances in technology and connectivity via the internet.

The purpose of this chapter is to describe existing and potential applications of teleaudiology to provide tinnitus clinical services. Evidence for tinnitus interventions and options for delivering tinnitus intervention remotely via available telehealth modalities are reviewed and discussed. It is important to point out that there is no consensus on standards for tinnitus care either within or between the different healthcare disciplines that offer tinnitus services (Henry, McMillan, & Manning, 2019). In addition, access to evidence-based tinnitus services is extremely limited (Beukes, Andersson, et al., 2018). The content of this chapter is focused on teleaudiology programs that employ tinnitus interventions backed by substantial research evidence.

Background

To date, the only method that has been developed, validated, and utilized specifically for telehealth tinnitus management is the telehealth version of progressive tinnitus management (PTM), which is referred to as *Tele-PTM* (Henry et al., 2012; Henry, Thielman, et al., 2019). PTM is a stepped-care program, and Tele-PTM utilizes certain components of PTM. More specifically, delivery of Tele-PTM services involves educational counseling derived from a combination of teaching sound therapy skills and cognitive behavioral therapy (CBT) coping skills.

CBT for Tinnitus Management

Application of CBT in the management of tinnitus is reviewed in detail in Chapter 11. Briefly, CBT is a methodology that incorporates numerous distinctly different therapeutic components, though there is no consensus as to which components have the greatest effectiveness for tinnitus (Cima et al., 2014). Typical CBT for tinnitus includes applied relaxation, behavioral activation (i.e., replacing negative behaviors with positive alternatives), and cognitive restructuring along with psychoeducation regarding health, sleep hygiene, and the auditory system. Clinical implementation of CBT can involve different formats: individual or group sessions, different schedules and length of sessions, and in-person or telehealth sessions (Schmidt et al., 2017).

Sound Therapy for Tinnitus Management

Sound has been used throughout human history to mitigate the effects of tinnitus (Stephens, 1987). Patients often discover on their own how certain sounds can make their tinnitus less bothersome (Dobie, 2004). Sounds can vary with respect to their acoustic spectra, intensity, intermittency, and inherent meaning. Some sounds have generally relaxing effects (Durai & Searchfield, 2017; Felix et al., 2019; Hillecke et al., 2005) and some sounds typically create tension and stress (Skagerstrand et al., 2017); however, people have individualized reactions to sounds due to their particular beliefs, musical tastes, loudness tolerance, and other variables.

Whereas many sound therapy approaches have been developed with the aim of eliminating or reducing the sensation of tinnitus (i.e., the sound itself), there is insufficient evidence to support their effectiveness for this goal. However, sound can be used effectively to reduce tinnitus-related emotional distress or its impact on daily activities (Henry & Quinn, 2020; Hoare et al., 2014). That is, sound therapy can be used to target emotional and functional effects of tinnitus. Numerous research studies have examined sound therapies for tinnitus, including amplification (e.g., hearing aids), sound generators, tinnitus masking, tinnitus retraining therapy (TRT), and specialized sound therapy devices (Henry et al., 2006; Henry, Frederick, et al., 2015; Henry, McMillan, et al., 2017; Henry et al., 2016; Schad et al., 2017; Theodoroff et al., 2017). The literature does not support any one method of sound therapy as being the most effective (Hoare et al., 2014; Searchfield et al., 2017). Therefore, patients are best served if they are taught how to explore sound therapy options that are free or low cost before considering more expensive therapies to address bothersome tinnitus.

PTM

PTM is an interdisciplinary, stepped-care program that combines elements of sound therapy and CBT (Henry et al., 2010). PTM is made up of five levels. Level 1 (Referral) amounts to a set of guidelines for appropriately referring patients who complain of tinnitus. Whereas some patients might need to be referred to otolaryngology, mental health, or even emergency care, most patients are referred to audiology for Level 2 (Audiological Evaluation).

The great majority of people with chronic tinnitus also have hearing loss, hence the need to have their hearing evaluated (Henry & Quinn, 2019). The PTM Level 2 evaluation includes a brief assessment of tinnitus using the one-page Tinnitus and Hearing Survey (THS) (Henry, Griest, et al., 2015). The information derived from the audiological evaluation and the THS is usually sufficient to make recommendations regarding any intervention needed for tinnitus, hearing loss, and sound tolerance problems (e.g., hyperacusis). Some patients are candidates for hearing aids, which address their hearing difficulties and may mitigate effects of tinnitus (dos Santos et al., 2014; Henry, Frederick, et al., 2015; Henry, McMillan, et al., 2017; Shekhawat et al., 2013). A detailed algorithm has been published for providing these audiological services (Henry & Quinn, 2019). Level 2 takes care of the great majority of patients who complain of tinnitus, while a small number of patients require further intervention (Henry, Thielman, Zaugg, Kaelin, Schmidt, et al., 2017). These latter patients are advised to receive Level 3 (Skills Education).

PTM Level 3 involves two group or individual counseling sessions with an audiologist and three with a mental health provider. The audiologist teaches patients how to use sounds to manage reactions to tinnitus in situations where tinnitus is bothersome. The mental health provider teaches patients CBT-based coping skills, generally focusing on relaxation and distraction techniques, in addition to cognitive restructuring (identifying "thought errors" and framing thoughts about tinnitus more positively).

Learning coping skills satisfies the needs of most patients who receive these services (Beck et al., 2019; Edmonds et al., 2017; Henry, Thielman, Zaugg, Kaelin, Schmidt, et al., 2017). If further services are needed, then patients are advised to attend a Level 4 Interdisciplinary Evaluation which is conducted by both an audiologist and a psychologist (Henry et al., 2010). Patients are assessed in depth to determine why their tinnitus continues to be a problem and to recommend further intervention (i.e., Level 5, Individualized Support) as needed. Patients progressing to Level 5 attend one-on-one counseling sessions with an audiologist and/or a psychologist to work further on coping strategies for tinnitus.

Patients complaining of tinnitus require different levels of clinical services. The PTM protocol addresses this reality by providing care only to the level required by each individual patient (Henry et al., 2010). Although exact numbers are not available, studies have shown the number of patients requiring higher-level services declines precipitously following Levels 2 and 3 (Beck et al., 2019; Edmonds et al., 2017; Henry, Thielman, Zaugg, Kaelin, Schmidt, et al., 2017; Zaugg et al., 2020). The overall objective is to provide tinnitus clinical services as effectively and efficiently as possible.

Recent Advances

Tele-PTM

The telehealth version of PTM, termed Tele-PTM, provides the same educational content via telephone or other telehealth modality (Henry et al., 2012). A nationwide randomized controlled trial (RCT) of Tele-PTM provided strong support for this methodology for individuals with bothersome tinnitus (Henry, Thielman, et al., 2019). The study showed a significant improvement in both tinnitus impact and tinnitus management self-efficacy for participants completing Tele-PTM compared to wait-listed controls. The effect size for Tele-PTM was high for the primary outcome measure, the Tinnitus Functional Index (Meikle et al., 2012), and all other outcome measures showed significant improvement.

Tele-PTM provides PTM Level 3, 4, and 5 services via telehealth. Prior to receiving these services, patients must first receive a routine audiological evaluation (equivalent to Level 2 of PTM) from an audiologist, which would normally include pure-tone air- and bone-conduction audiometry, speech audiometry, and immittance measures. Patients are fit with hearing aids as needed. To assess tinnitus attributes, the evaluation includes the THS (Henry, Griest, et al., 2015). Other than the use of the THS, the audiological services are essentially the same as for any patient being assessed for auditory functioning (Henry & Quinn, 2019).

Patients referred to Tele-PTM should also undergo evaluation by a mental health provider to rule out active suicidal ideation and other risk factors. The evaluation would further identify mental health conditions requiring treatment or conditions for which telehealth would not be appropriate as an intervention format. After completing both audiology and mental health screenings, patients who qualify for Tele-PTM are scheduled to receive the first of five telehealth sessions that correspond with PTM Level 3 Skills Education.

In the Veterans Affairs (VA) hospital system in the United States, VA Video Connect (VVC) is used to provide face-to-face counseling between a VA clinician and a veteran directly into the veteran's home. VVC is being used increasingly by various healthcare disciplines (Myers et al., 2020). In the context of Tele-PTM, an audiologist and a mental health provider collaborate to provide PTM Level 3 counseling to veteran patients via VVC. A telephone call can replace the video call if VVC is not feasible for the veteran.

General Teleaudiology for Tinnitus Intervention

The COVID-19 pandemic greatly altered the delivery of many healthcare services, including audiological services. As of this writing, we do not know if or when these affected healthcare services will return to their pre-pandemic routines. It is therefore prudent to optimize the delivery of healthcare services remotely, as telehealth delivery of intervention is a potential solution for many tinnitus sufferers. As the delivery of live telehealth intervention for tinnitus via Tele-PTM has been shown to be effective in an RCT (Henry, Thielman, et al., 2019), it can be reasonably hypothesized that it would also be effective using other counseling methods, including acceptance and commitment therapy (ACT) and mindfulness-based stress reduction.

Ideally, people enrolled in a telehealth counseling program for tinnitus should first have their hearing formally evaluated, because 80% to 90% of all people with tinnitus have hearing loss (Kim et al., 2011). Further, considerable evidence reveals that hearing aids are beneficial for reducing emotional reactions and functional effects (such as sleep and concentration difficulties) caused by tinnitus (dos Santos et al., 2014; Henry, Frederick, et al., 2015; Henry, McMillan, et al., 2017; Shekhawat et al., 2013). Anyone considered for a telehealth counseling program for tinnitus should therefore already be using hearing aids if indicated for hearing loss.

Many audiological services important for tinnitus management can be conducted via teleaudiology, including hearing aid fittings and troubleshooting (Coco, 2020; Coco et al., 2018). According to Coco (2020), "much will be possible via teleaudiology, including hearing aid troubleshooting, aural rehabilitation, warranty questions, and tinnitus management" (p. 28). Interested readers are directed to Coco (2020) for a detailed discussion on helpful and practical measures to facilitate teleaudiology.

Teleaudiology services may require the patient to visit a clinical setting assisted by a trained on-site technician, allowing an audiologist to perform tasks such as hearing aid programming from a remote location. Systems are available for automated air- and bone-conduction pure-tone hearing testing with appropriate masking (Yu et al., 2011). Studies have also validated these systems' performance outside sound-treated audiometric test booths, paving the way for performing a diagnostic hearing assessment remotely (Govender & Mars, 2018; Mahomed et al., 2013; Ooster et al., 2020; Skjonsberg et al., 2019). A recent scoping review of teleaudiology services found no studies on teleaudiology diagnostic hearing assessment for adults (Munoz et al., 2020); however, companies are currently working to develop automated audiometers that will enable remote diagnostic threshold testing (Govender & Mars, 2018; Mahomed et al., 2013; Ooster et al., 2020; Skjonsberg et al., 2019; Yu et al., 2011).

Internet-Based CBT

Interventions delivered via the internet have emerged as a means for individuals to gain access to healthcare that is otherwise inaccessible and/or unaffordable (Beukes et al., 2018). As noted, creative options for providing CBT are reviewed in Chapter 11. Many patients who would benefit from CBT do not have access to clinicians who provide these services. The COVID-19 pandemic has also forced providers to explore telehealth-based solutions, following numerous researchers who have worked to develop internet-based versions of CBT. The first internet-based intervention for tinnitus was an RCT comparing CBT to a wait-list control group (Andersson et al., 2002). Results showed significant improvement for the CBT group based on a number of measures, although with a high dropout rate (which has occurred with some internet-based interventions [Arndt et al., 2020]). Many similar studies ensued, and a systematic review (Beukes et al., 2019) found significant reduction of tinnitus distress for CBT relative to control participants. Significant improvement was also observed for secondary outcomes including insomnia, depression, anxiety, and quality of life. These results indicated overall positive outcomes of internet-based intervention for tinnitus, usually with CBT. The authors of the systematic review concluded, "There is a need for additional high-quality evidence before conclusive results can be established" (p. 1).

Sound Therapy Applications

Hundreds of mobile applications (apps) offer sound therapy for tinnitus (Deshpande & Shimunova, 2019; Nagaraj & Prabhu, 2020; Skarzynski et al., 2019). These apps are either free of charge or relatively inexpensive, and can be a good option for tinnitus sound therapy because of the extensive number of sounds they provide as well as the ability to combine and/or spectrally modify the different sounds. Further, a plethora of relaxation apps, podcasts, and audio books are available (Henry & Quinn, 2020). The availability of various free apps enables anyone to experiment almost endlessly with different sounds at little or no cost (provided they have an adequate device and access to the internet). These apps are most helpful if users are first informed about how sound can affect tinnitus and reactions to tinnitus (Henry et al., 2008).

PTM educational materials include a self-guided workbook with plans and worksheets that accompany participants through the program. These elements of PTM lend themselves to translation to a digital platform. Henry, Thielman, Zaugg, Kaelin, Choma, et al. (2017) developed and tested a smartphone app with content based on PTM that supports self-guided learning and the use of coping skills for managing tinnitus. This approach has the potential to improve access to coping skills for those with bothersome tinnitus by making coping skills instruction available on a handheld device. The app is currently a limited prototype that may warrant additional design improvements.

A recent systematic review of smartphone-based apps for tinnitus intervention identified more than 200 apps available for this purpose. Most delivered different forms of sound therapy, and most lacked validation (Nagaraj & Prabhu, 2020). The review identified only five studies meeting the authors' review criteria, including the use of standardized and validated outcome questionnaires. Overall results indicated similar improvement with respect to tinnitus distress and quality of life. The authors concluded, *"This systematic literature review shows that there is a similar improvement in both the traditional as well as an internet-delivered form of tinnitus treatment in individuals with tinnitus. Looking towards the future treatment of tinnitus, the development of new apps or internet-delivered tinnitus treatment would have a huge impact. Hence, more user-friendly and therapy-assisted applications are required."* (p. 656)

Online Support

Both the American Tinnitus Association (ATA) and the British Tinnitus Association (BTA) promote and facilitate tinnitus support groups. Since the start of the pandemic, these groups have mostly stopped meeting in person. The ATA and BTA have pivoted to encouraging and providing online support groups. The ATA provides a list of support groups in the U.S. that hold regular virtual meetings. That list stays updated in its Tinnitus Today publication, and additional information is provided on its website (https://www.ata.org/). The BTA provides a list of all of its associated support groups, many of which meet online, and offers its own free online tinnitus support group (https://www.tinnitus.org.uk/). In addition, numerous webinars and online workshops are available for individuals to receive virtual care for their tinnitus.

Future Directions

App-Based Tinnitus Skills Education

A mobile app would offer a highly accessible and convenient method of delivering tinnitus intervention to patients. Information and counseling materials installed on a smartphone would make the intervention conveniently available to a patient at any time and place. An app could also access other functionalities on the smartphone, such as music and podcasts, thus facilitating the exploration of sounds for tinnitus distress reduction. In comparison with a workbook, an app allows a more interactive delivery of counseling activities, such as customizable checklists and worksheets; this may prove more engaging than static information contained in traditional printed material. A further advantage of an app over a workbook is integration of videos and text, improving the likelihood that all available media will be accessed by patients. Though apps cannot replace direct interaction with peers or providers, they can be very useful tools for programs with an educational component. In the future, apps could also provide a convenient and secure platform for patients and providers to exchange information, such as responses to tinnitus questionnaires, as a part of a tinnitus telehealth program.

App-based tinnitus intervention would also be useful for providing care to patients who are reluctant to visit a clinic due to COVID-19 or other infection risk, as well as rural populations for whom distance to clinics is a barrier. Given the move toward remote care during the COVID-19 pandemic, the use of video conferencing programs, electronic communication, and therapy apps has rapidly expanded (Wosik et al., 2020). Barriers to accessing in-person care may be overcome by moving to telehealth delivery models; however, it cannot be ignored that these models may create new barriers for some groups. For example, it may be a financial burden on some to purchase and maintain modern smartphones, cellular data plans, and home internet/Wi-Fi. Reliable home internet is not available for residents of many remote areas. Therapy apps may depend on users' ability to see and/or hear the content and may not provide alternative modalities for people who are hearing or vision impaired. Finally, there is an assumption of computer and technology savviness that may not be met by all persons seeking management for bothersome tinnitus. Apps must be developed with these barriers in mind to potentially serve as many people as possible. The reader is directed to Chapter 7 for a review of app-based tinnitus assessment.

Clinical Implications

The last decade has seen a proliferation of technical solutions for providing face-to-face counseling at a distance. Such counseling can include CBT, ACT, and mindfulness training. An RCT has shown that Tele-PTM is effective for this purpose (Henry, Thielman, et al., 2019). As already noted, Tele-PTM includes a structured program of tinnitus counseling that involves both CBT and teaching strategies for using sound. The implementation of remote tinnitus counseling using any of these methods would make tinnitus intervention available to the many people who currently do not have access to tinnitus clinical services.

The authors have reviewed options for telehealth delivery via internet and mobile devices. Using these electronic means, tinnitus therapy can be delivered efficiently to patients using devices that most people already own. The options for telehealth service delivery greatly expand the reach of tinnitus intervention, making it available to many more patients who are in need of intervention beyond basic audiological services.

Key Messages

- Evidence for tinnitus interventions:
  - Cognitive behavioral therapy (CBT) has the strongest research-based evidence.

  - Research also supports the effectiveness of sound therapy in general.
- Audiologists can learn to deliver components of CBT after receiving appropriate training and follow-up supervision by a qualified mental health provider.
- Patients with tinnitus require different levels of services, which is the basic premise of progressive tinnitus management (PTM) and its telehealth version, Tele-PTM.
- Prior to receiving telehealth services for tinnitus, patients must first receive an audiological evaluation and be fitted with hearing aids as appropriate.
- CBT delivered via the internet has shown significant benefit, although sometimes with a high dropout rate.
- Hundreds of mobile apps offer sound therapy for tinnitus.
- Tinnitus information and counseling materials installed on a smartphone would make the intervention conveniently available to a patient at any time and place.
- Telehealth can greatly increase the accessibility of tinnitus intervention.

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13 CUTTING-EDGE APPROACHES IN TINNITUS MANAGEMENT

Sook Ling Leong and Sven Vanneste

Introduction

Tinnitus is an auditory percept that occurs in the absence of an external acoustic source (Baguley et al., 2013) and is therefore also called a phantom percept. Worldwide, tinnitus is prevalent, perceived by 12% to 30% of the general adult population (Baguley et al., 2013; Shargorodsky et al., 2010), rising to 30% among those 50 years or older (Shargorodsky et al., 2010). Epidemiological studies have reported that the presence of tinnitus is higher among males, those with hearing loss, those with lower socioeconomic status, or those with less education, and may accompany a wide range of diseases such as hypo- and hyperthyroidism, hyperlipidemia, and osteoarthritis (Kim et al., 2015; Nondahl et al., 2012).

The clinical management of tinnitus shoulders a significant financial burden in a country's healthcare system. To illustrate, the estimated healthcare cost per annum for a patient in 2015 was $660 in the United States (Piccirillo et al., 2020), €1,544 in the Netherlands (Maes et al., 2013) and £717 in the United Kingdom (Stockdale et al., 2017). Healthcare systems may be strained further due to lack of successful treatment strategies as well as inability or reluctance of tinnitus sufferers to seek effective management, resulting in long-term disability payments, adding up in respective countries to an estimated USD $1.2 billion per year in 2012 (Goldstein et al., 2015) and GBP £750 million per year in 2016 (Stockdale et al., 2017).

Among tinnitus sufferers, the constant perception of tinnitus is often stressful, with approximately 20% of all cases reported as being severely debilitating (McCormack et al., 2016). It is well established that this disorder has a significant negative impact on a patient's quality of life (McCormack et al., 2016). Tinnitus can affect sleep and mood to the extent that it is challenging to carry out daily activities (McCormack et al., 2016). Studies have reported that the most pronounced effects of this phantom sound include concentration difficulties, negative emotions, work hindrance, interference with social interaction, and reduced overall health (McCormack et al., 2016).

The experience of tinnitus is extremely heterogeneous. It has been described as intermittent or constant, differing in perceived loudness, and occurring in one or both ears. The perceived sensations of tinnitus are diverse, reported as being hissing, ringing, or sizzling, as well as more intricate descriptions of musical hallucinations (Baguley et al., 2013). Tinnitus is subjective when noises are audible only to the patient, and objective when the tinnitus sound can be perceived by an outside observer. Objective tinnitus often has an identifiable origin related to disorders of the vascular or muscular systems, while subjective tinnitus is idiopathic and is more common. In this chapter, we focus our discussion on subjective tinnitus.

At present, although numerous advances have been made in both pharmacological and nonpharmacological management of tinnitus, these approaches are successful at decreasing the impact of tinnitus rather than eliminating the tinnitus percept itself. In the last decade, novel strategies such as noninvasive and invasive neurostimulation modalities for tinnitus management have gained traction among researchers and clinicians. Also, the regeneration of auditory hair cells could be a possible upcoming treatment option for hearing loss (Oshima et al., 2007), which is a risk factor of tinnitus (Baguley et al., 2013). In this chapter, we discuss the mechanisms of the different available noninvasive and invasive neuromodulation interventions for tinnitus, their risk profiles, and potential future directions and developments. We also explore the use of recent therapies applied in the regeneration of auditory hair cells for restoration of hearing function.

Background

At present, the pathophysiology of tinnitus is not well established. There are, however, multiple theories that have been postulated. The clinical manifestation of tinnitus has been linked to modifications in the auditory system and several nonauditory brain regions. The dorsal cochlear nucleus hyperactivity (Brozoski & Bauer, 2005) and the reorganization of tonotopic maps (Rauschecker, 1999) models are well-received mechanisms responsible for tinnitus. However, in this chapter, we briefly describe the central gain theory and the network models of tinnitus that are pertinent to the discussion of noninvasive and invasive neuromodulation interventions.

According to the central gain theory (Noreña, 2011), cochlear damage usually associated with hearing loss triggers an adaptation process to maintain default neural coding and firing efficiency (i.e., homeostatic plasticity mechanism) by increasing the rate of abnormal spontaneous firing or hyperactivity in the central auditory circuit. The decreased auditory input, in combination with amplification of neural activity due to sensitivity (i.e., increased gain) and reduced inhibition, heralds the generation of the tinnitus percept (Noreña, 2011). Therefore, in a theoretical sense, suppressive neuromodulation modalities have the potential to decrease central gain in the auditory system, thereby reducing tinnitus.

Tinnitus network models explore several brain regions beyond the classical auditory pathways. The theory of a unified tinnitus percept proposes a tinnitus network that consists of multiple dynamically adaptive overlapping subnetworks (De Ridder, Elgoyhen, et al., 2011). Each subnetwork embodies a clinical aspect of tinnitus—such as distress, lateralization, or sound characteristics—that can be modulated through specific hubs. For example, the suppression of tinnitus has been achieved through the modulation of the distress network (i.e., pregenual anterior cingulate cortex, dorsal lateral prefrontal cortex) and memory areas, which include the parahippocampal region (De Ridder & Vanneste, 2012).

One variation of the network model explored the emergent property of tinnitus. According to the thalamocortical dysrhythmia model (Llinás et al., 1999), tinnitus is a consequence of deafferentation that incites decreased neural firing in corresponding thalamocortical columns. This results in the edge effect, or hyperactivity in adjacent regions, and the distinct 40-Hz gamma oscillation that drives tinnitus perception (Llinás et al., 2005). Yet, because gamma oscillations are confined to small neural spaces, they may be responsible for encoding only tinnitus loudness (Ashton et al., 2007). The coactivation of the tinnitus network or the conscious perception of tinnitus requires the contribution of theta waves (Mukamel et al., 2005). It has been suggested that theta oscillations synchronize large networks and are carrier waves with gamma waves nested onto them (Varela et al., 2001). In fact, in a case study, theta connectivity increased when patients perceived tinnitus compared to when they did not (De Ridder, van der Loo, et al., 2011). Accordingly, the modulation of theta band functional connectivity could result in tinnitus suppression.

Recent Advances

While different theories assume the involvement of distinct brain regions in the generation of tinnitus, there is agreement that the clinical effects are a consequence of the disruption of neural activity in these brain structures (Langguth et al., 2013). One could argue that selective modulation of neuronal activity involved in the different circuits responsible for tinnitus processing and perception would interfere with the generation and maintenance of the tinnitus signal. In the previous decade, various noninvasive and invasive neuromodulation modalities have been investigated for tinnitus suppression. However, it is important to note that none of the discussed neuromodulation techniques are established as routine therapy options for tinnitus patients.

Noninvasive Neuromodulation for Tinnitus

The therapeutic role of the different types of noninvasive neuromodulation methods, such as transcranial magnetic stimulation (TMS), transcranial direct current stimulation (tDCS), and transcranial alternating current stimulation (tACS), is appealing considering the limited success of current pharmacological and nonpharmacological approaches (Langguth et al., 2019). The following sections provide a review of various noninvasive neuromodulation interventions for tinnitus (see Table 13–1 for a summary).

Transcranial Magnetic Stimulation (TMS)

A TMS coil in contact with the scalp produces a strong magnetic field that delivers electromagnetic pulses to the targeted brain region (Theodoroff & Folmer, 2013). The form of magnetic field generated depends on the shape of the coil. In tinnitus, a figure-eight coil is often utilized due to its greater focality when compared to other coil designs (Soleimani et al., 2016). Studies have shown that different TMS pulse frequencies have unique effects on cortical activity. Early TMS studies of the motor cortex reported a transient increase in neuronal excitability with the delivery of high-frequency pulses (i.e., 5 to 20 Hz) several times per session, a procedure termed *repetitive TMS* (rTMS) (Siebner et al., 2003; Zaghi et al., 2010). In contrast, low-frequency (i.e., 1 to 2 Hz) rTMS resulted in decreased cortical activity (Siebner et al., 2003; Zaghi et al., 2010).

Table 13–1. Summary of Noninvasive Neuromodulation Modalities for the Management of Tinnitus

Mode	*Delivery Method*	*Usage Requirements*	*Highest Supporting Evidence*
Transcranial Magnetic Stimulation (TMS)	Electromagnetic pulses delivered to the cortex using figure-eight or double-cone coils.	1. Repeated low-frequency (1 Hz) TMS daily for 10 days of the temporoparietal cortex and prefrontal cortical areas. 2. Repeated burst stimulation of the auditory cortex at 5 Hz, 10 Hz, and 20 Hz for two sessions.	1. Safety, feasibility, and potential therapeutic effect demonstrated in pilot studies. 2. Potential therapeutic effect demonstrated in an exploratory study.
Transcranial Direct Current Stimulation (tDCS)	Low electric current between 0.5 and 2 mA to the cortex via positive (anodal) or negative (cathodal) scalp electrodes.	1. Stimulation of the left-temporoparietal area (LTA) and the auditory cortex (AC) for 15 to 20 minutes ranging from single to multiple (up to 10) sessions. 2. Stimulation of the dorsal lateral prefrontal cortex (DLPFC) for 15 to 20 minutes ranging from single to multiple (up to 10) sessions. 3. High-definition (HD) tDCS with a 4x1 ring montage for 15 to 20 minutes ranging from single to multiple (up to six) sessions.	1. Results vary according to electrode positioning and duration from small-scale clinical trials. 2. Evidence of improvement in tinnitus distress and anxiety symptoms demonstrated in double-blinded clinical trials. 3. Inconsistent results in clinical trials demonstrating the superiority of HD-tDCS over conventional tDCS.
Transcranial Alternating Current Stimulation (tACS)	Delivery of prespecified frequency of rhythmic oscillating current independent of direction of current flow.	Modulation to decrease alpha and increase gamma bands in the AC for 20 minutes in a single session.	Lack of evidence for efficacy (consistent negative results for therapeutic effect).

Mode	*Delivery Method*	*Usage Requirements*	*Highest Supporting Evidence*
Transcranial Random Noise Stimulation (tRNS)	Alternating current to the cortical region with a constantly changing frequency from 0.1 to 600 Hz.	Stimulation of the AC using alternating current of 1.5 mA with 0-mA offset applied at random frequencies for 20 minutes in a single session.	Evidence of efficacy demonstrated in one exploratory study comparing tDCS, tACS, and tRNS.
Neurofeedback	Relevant recorded brain signals fed back to the individual to encourage self-regulated change (operant conditioning) using EEG or fMRI.	Reduction of amplitude of relevant frequency bands related to tinnitus loudness and distress for 10 sessions.	Potential therapeutic effect demonstrated in a randomized controlled trial.
Transcutaneous Electrical Nerve Stimulation (TENS)	Delivery of adjustable pulse amplitude (mA) electrical currents across the intact surface of the skin to activate underlying nerves.	Varied number of stimulation sites (temporomandibular joint, tragus of the ear, C2 dermatome) for 30 minutes for a single session.	Evidence demonstrated in clinical trials with effects comparable to tDCS and tRNS.
Transcutaneous Vagus Nerve Stimulation (tVNS)	Neuromodulation of the vagus nerve through a nerve branch innervating the skin of the external auditory canal.	Utilized for one session in combination with auditory stimulation for seven sessions, each lasting 45 to 60 minutes.	Potential therapeutic effects demonstrated in a pilot study.

Since tinnitus is associated with increased cortical activity, specifically in the temporoparietal region, low-frequency rTMS might be suitable as a treatment modality. Indeed, several studies (Chung et al., 2012; Lee et al., 2013; Mennemeier et al., 2011) have shown temporary suppression of tinnitus severity (Lefaucheur et al., 2014) with application of low-frequency rTMS to the temporal or temporoparietal areas compared to sham stimulation. Research has also focused on enhancing the therapeutic effect of rTMS by simultaneously stimulating the temporoparietal cortex and the prefrontal cortical areas. Studies (Lehner, Schecklmann, Kreuzer, et al., 2013; Lehner, Schecklmann, Poeppl, et al., 2013; Lehner et al., 2015) have demonstrated that low-frequency rTMS of the right, left, or both temporoparietal regions combined with left high-frequency prefrontal rTMS can produce transient suppression of tinnitus. These therapeutic effects are consistent with those produced by unilateral temporoparietal low-frequency rTMS (Lehner, Schecklmann, Kreuzer, et al., 2013; Lehner et al., 2015; Lehner, Schecklmann, Poeppl, et al., 2013). One advantage of a multisite stimulation design is that it can produce a pronounced long-term suppressive effect on tinnitus up to 3 months post-stimulation (Kleinjung et al., 2008).

Another tinnitus-TMS research avenue explored the employment of burst stimulation rather than tonic stimulation (De Ridder et al., 2007a, 2007b). In tonic stimulation, pulses are presented at a consistent frequency, pulse width, and amplitude. In contrast, burst stimulation delivers groups of pulses at a high frequency but at amplitudes that are lower than tonic stimulation. These groups of pulses are separated by periods of pulse-free intervals. In the motor cortex, burst stimulation produced more consistent and powerful long-lasting effects than tonic stimulation (Huang et al., 2005). When used as a therapeutic approach in tinnitus, burst stimulation applied to the auditory cortex suppressed not only pure-tone tinnitus but also narrowband tinnitus, in contrast to tonic rTMS (De Ridder et al., 2007a, 2007b).

To date, results from TMS studies are promising. Researchers are persistently exploring different TMS procedures that may improve clinical outcomes. For example, several studies have shown that increasing the number of sessions (e.g., from five to 10) of low-frequency rTMS in the temporoparietal region significantly improves intervention outcomes (Marcondes et al., 2010; Rossi et al., 2007; Smith et al., 2007), with the potential of long-lasting positive effects (Langguth et al., 2003). Other studies have investigated the use of functional magnetic resonance imaging (fMRI) as a neuronavigational tool for coil positioning to increase target accuracy (Cohen et al., 1990; Langguth et al., 2010), resolving one of the main limitations of TMS. Also, there are encouraging results from a study using the double-cone coil to modulate deeper brain areas (i.e., dorsal and subgenual anterior cingulate cortex) involved in the maintenance of tinnitus (Vanneste, Plazier, et al., 2011).

Transcranial Direct Current Stimulation (tDCS)

TDCS delivers a low electrical current, commonly between 0.5 and 2 mA, to the cortex via positive (anodal) or negative (cathodal) scalp electrodes (Woods et al., 2016). In participants with tinnitus, anodal tDCS typically increases neural excitability through depolarization (i.e., increased brain activity), while cathodal tDCS achieves the opposite effect by inducing neural hyperpolarization (i.e., decreased brain activity).

The effects of tDCS may last for an hour after a single treatment session and longer when stimulation duration is increased (Nitsche & Paulus, 2000, 2001).

Initial tinnitus-tDCS studies targeted the left temporoparietal area (LTA) and the auditory cortex (AC) with the goal of modulating the primary auditory cortex, auditory association areas, and parts of the limbic system, specifically the amygdala and hippocampus (Forogh et al., 2016; Garin et al., 2011; Henin et al., 2016; Hyvärinen et al., 2016; Joos et al., 2014; Minami et al., 2015; Pal et al., 2015; Shekhawat et al., 2015; Shekhawat, Stinear, et al., 2013). Study findings were diverse. Some reports suggested that cathodal tDCS of the LTA with anodal tDCS over the contralateral supraorbital area had no effect (Forogh et al., 2016; Garin et al., 2011; Shekhawat, Stinear, et al., 2013), whereas others demonstrated suppression of tinnitus loudness (Joos et al., 2014; Minami et al., 2015). It is important to note that protocols for tDCS of the LTA and AC are heterogeneous, differing in stimulation parameters, polarity, and sham procedures. There is a likelihood that higher cathodal stimulation intensity (2 mA) of the LTA and AC, coupled with repeated sessions, may induce beneficial effects on tinnitus severity.

A large number of research studies investigated the effect of tDCS targeting the dorsal lateral prefrontal cortex (DLPFC) (Faber et al., 2012; Frank et al., 2012; Vanneste, Fregni, & De Ridder, 2013; Vanneste, Langguth, & De Ridder, 2011; Vanneste, Plazier, Ost, et al., 2010). The DLPFC reportedly contains auditory memory cells and functions as a bilateral facilitator of auditory memory storage (Bodner et al., 1996). Additionally, the DLPFC exerts early inhibitory modulation of input to the primary auditory cortex (Voisin et al., 2006) and is associated with auditory attention (Mitchell et al., 2005), resulting in a top-down modulation of auditory processing (Vanneste, Plazier, Ost, et al., 2010). Also, the DLPFC may be a regulatory hub of brain structures that are involved in the emotional perception of tinnitus, including the anterior cingulate cortex, amygdala, and insula (Vanneste, Plazier, Van Der Loo, et al., 2010). The most successful tDCS-DLPFC modality involves bifrontal stimulation for 20 minutes, typically with 1.5 mA or 2.0 mA current, with the anode over the right and cathode over the left DLPFC. Results from these studies indicated successful modulation of tinnitus distress and anxiety symptoms, in addition to suppressing tinnitus severity (Faber et al., 2012; Frank et al., 2012; Vanneste, Focquaert, et al., 2011; Vanneste, Plazier, Ost, et al., 2010; Vanneste, Plazier, Van Der Loo, et al., 2010; Vanneste, Walsh, et al., 2013).

One main limitation of tDCS is the use of saline-soaked sponges that stimulate a broad cortical region. The focality can potentially be increased using high-definition-tDCS (HD-tDCS). The HD-tDCS 4x1 ring montage, where one central anode is surrounded by four cathodes, restricts the current flow within the ring, thus increasing focality. There is no significant difference between techniques with similar observed clinical improvements in tinnitus suppression for both approaches when comparing HD to the classical tDCS targeting the DLPFC (Jacquemin et al., 2018; Shekhawat et al., 2016; Shekhawat & Vanneste, 2018). Even though there is limited evidence regarding the superiority of HD-tDCS over conventional tDCS, the promise of increased stimulation focality merits further exploration.

Transcranial Alternating Current Stimulation (tACS)

An alternative noninvasive neuromodulation technique that has been investigated in tinnitus is tACS. In contrast to the use of a direct current in tDCS, tACS delivers a prespecified frequency of rhythmic oscillating current that is independent of the direction of current flow (Zaghi et al., 2010). Researchers have utilized tACS to modulate the decreased alpha and increased gamma bands in the auditory cortex that have been postulated to be associated with tinnitus percept (Vanneste, Fregni, & De Ridder, 2013; Zaehle et al., 2010).

To date, there is a lack of evidence that tACS can deliver therapeutic outcomes in tinnitus patients. For example, when comparing tACS with tDCS in a sham-controlled designed study, results indicated that a single session of bifrontal tDCS, with anodal over the right DLPFC and cathodal over the left DLPFC, can reduce suppression of both annoyance and loudness; yet alpha-frequency tACS of the DLPFC showed no significant effect (Vanneste, Walsh, et al., 2013). Similar tACS-tinnitus studies have presented consistently negative results (Claes et al., 2014; Vanneste, Fregni, & De Ridder, 2013), rendering a lack of merit in further pursuing trials examining the use of tACS in tinnitus management.

Transcranial Random Noise Stimulation (tRNS)

In contrast to tACS, the application of tRNS in tinnitus has generated more promising results. tRNS involves applying alternating current to cortical regions with a constantly changing frequency ranging from 0.1 to 600 Hz (Terney et al., 2008). Currently, there are three postulated principles in regard to the mechanism of tRNS: (a) long-term potentiation (i.e., strengthening of connections between neurons resulting from increased persistent synaptic excitability) (Fertonani et al., 2011), (b) repeated subthreshold stimulations that prevent the system from building up homeostasis and potentiating task-related neural activity (Fertonani et al., 2011), and (c) the occurrence of stochastic resonance where nonlinear neural signals are modulated by noise stimulation (Moss et al., 2004).

In a study comparing single sessions of tDCS, tACS, and tRNS on the AC, tRNS induced a larger transient suppressive effect on tinnitus loudness and distress, while tDCS and tACS generated small insignificant effects (Vanneste, Fregni, & De Ridder, 2013). Also, there seems to be added value when prefrontal anodal tDCS is followed by auditory tRNS compared to absolute tDCS of the prefrontal cortex (To et al., 2017). Although preliminary, findings from studies indicate that tRNS may be superior to tDCS and tACS in the management of tinnitus.

Another avenue of tRNS research has focused on the effects of low-frequency tRNS (lf-tRNS) and high-frequency tRNS (hf-tRNS) on tinnitus suppression. Preliminary results showed no differences in effectiveness between lf-tRNS and hf-tRNS, with both modalities eventuating in pronounced suppression of tinnitus loudness and distress (Joos et al., 2015; Kreuzer et al., 2019). A feasibility multisite stimulation study reported that 2 weeks of daily lf-tRNS over the AC preceded by hf-tRNS over the DLPFC produced significantly larger reductions in tinnitus loudness and distress compared to AC-lf-tRNS and sham (Mohsen et al., 2018).

Although promising, it should be noted that at present, there is no clear mechanistic explanation for differences in lf- and hf-tRNS. In addition to establishing the underlying mechanism, replication of the results for tRNS modalities in larger studies is needed to document their efficacy.

Neurofeedback

Neurofeedback is based on the proposition that autonomic functions can be altered through operant conditioning (Birbaumer et al., 2009). Using this technique, brain signals recorded with electroencephalogram (EEG), fMRI, or near infrared spectroscopy, and relevant signals (e.g., alpha waves) are fed back to the individual in real time to encourage self-regulation of brain activity (Birbaumer et al., 2009). If the task, such as change in brain activity, is fulfilled, the individual is rewarded using visual or acoustic signals (Birbaumer et al., 2009). Neurofeedback has been successfully applied in epilepsy and attention-deficit hyperactivity disorders (Lansbergen et al., 2011; Sterman & Friar, 1972).

In theory, the use of neurofeedback could be employed to train abnormal brain activity among patients with bothersome tinnitus, specifically by decreasing hyperactivity of the theta, gamma, and beta bands while increasing hypoactivity of the alpha band (Weisz et al., 2005). Studies examining this therapeutic method report that up-regulating the amplitude of alpha and down-regulating beta using EEG neurofeedback of the auditory cortex was associated with significant reduction in tinnitus-related distress (Dohrmann, Elbert, et al., 2007; Dohrmann, Weisz, et al., 2007; Gosepath et al., 2001). Moreover, changes in tinnitus loudness can be achieved by enhancing delta power and reducing tau power in temporal brain regions using EEG neurofeedback (Dohrmann, Elbert, et al., 2007).

A small pilot study showed that fMRI neurofeedback was successful in training two out of six chronic tinnitus patients to voluntarily reduce auditory activation, resulting in decreased subjective tinnitus (Haller et al., 2010). Main limitations of neurofeedback studies are small sample sizes and lack of control groups. In addition, fMRI neurofeedback is relatively noisy, lacks temporal resolution, and is expensive, decreasing its prospect as a feasible therapeutic treatment for tinnitus. On the other hand, EEG neurofeedback has a higher temporal resolution. If combined with EEG source-localized algorithms, which improve spatial resolution, EEG neurofeedback could have potential as a practical noninvasive treatment modality for tinnitus.

Transcutaneous Electrical Nerve Stimulation (TENS)

TENS is a safe, noninvasive neuromodulation method established in the field of chronic pain (Nnoaham & Kumbang, 2008). Research suggests that bothersome tinnitus may be successfully alleviated with application of TENS to a varied number of stimulation sites, with a wide range of modalities. Initial studies showed that tinnitus suppression could be achieved through TENS of the median nerve (Møller et al., 1992). Further studies reported reduction in tinnitus symptoms with application of TENS to the temporomandibular joint (Herraiz et al., 2007) and to the tragus of the ear (Steenerson & Cronin, 2003).

In most studies, TENS was applied to the C2 dermatome, an area of the skin behind the ear that sends signals to the brain through a spinal nerve. C2 stimulation reportedly increases activation of the dorsal cochlear nucleus (DCN) along the somatosensory pathway and, subsequently, enhances the inhibitory role of DCN on the central auditory nervous system. The result is suppression of tinnitus (Young et al., 1995). It has been reported that electrical stimulation of the C2 dermatome controls the inhibition and excitement of principal cells within the DCN (Young et al., 1995). In one study, 240 tinnitus patients received 10 minutes of 6-Hz stimulation followed by 10 minutes of 40-Hz stimulation and finally 10 minutes of sham (Vanneste, Plazier, Van de Heyning, et al., 2010). Significant transient improvement of 42.9% in tinnitus loudness was reported in 17.9% of patients (Vanneste, Plazier, Van de Heyning, et al., 2010).

When comparing the mechanisms of TENS, tDCS, and TMS, it has been suggested that TENS modulates the tinnitus brain circuit indirectly through the previously discussed somatosensory mechanisms. However, tDCS and TMS suppress tinnitus via a dual working method that involves a TENS-like somatosensory mechanism and a direct cortical modulating approach (Vanneste, Langguth, & De Ridder, 2011).

Transcutaneous Vagus Nerve Stimulation (tVNS)

A study published in the 1990s demonstrated that the generation and perception of tinnitus was associated with the degree of map reorganization in the auditory cortex (Noreña et al., 1999). The vagus nerve stimulation (VNS) technique can initiate the production of several neuromodulators that may heighten neuronal changes in the cerebral cortex (Kilgard & Merzenich, 1998). Moreover, pairing VNS with auditory tones can potentially reverse abnormal tinnitus-related neuronal activity in the auditory cortex (Engineer et al., 2013). The underlying mechanism of this phenomenon is not yet established. One theory suggests that long-lasting cortical reorganization can be achieved through stimulation of the cholinergic nucleus basalis (Kilgard & Merzenich, 1998). In noise-exposed rodents, the pairing of VNS with tones at frequencies outside the tinnitus range reversed tinnitus-associated plasticity and behavioral correlates (Engineer et al., 2013). Interestingly, there were no significant effects when VNS or acoustic stimulation were applied separately (Engineer et al., 2013). It has been theorized that VNS encourages cortical reorganization, whereas the acoustic tone is important in determining the target for neuroplastic changes (Engineer et al., 2013).

The main limitation of VNS stimulation is the need of an invasive procedure to stimulate the nucleus basalis. In parallel to the development of invasive VNS, studies have also investigated the possible use of transcutaneous VNS (tVNS). tVNS exerts an effect on the vagus nerve through a nerve branch innervating the skin of the external auditory canal (Kreuzer et al., 2012; Lehtimäki et al., 2013). Although still preliminary, studies have demonstrated that tVNS is feasible and safe in tinnitus patients (Kreuzer et al., 2014). More studies are needed to confirm the efficacy of tVNS in the management of bothersome tinnitus. To date, two studies, one utilizing only tVNS (Hyvärinen et al., 2015) and the other pairing tVNS with tinnitus frequency-filtered music (Lehtimäki et al., 2013), have demonstrated beneficial effects in tinnitus patients.

Invasive Neuromodulation for Tinnitus

The use of noninvasive neuromodulation induces transient changes to brain networks. Invasive techniques such as auditory cortex stimulation, DLPFC and anterior cingulate cortex (ACC) stimulation, implanted VNS, and deep brain stimulation (DBS) are required to generate long-lasting changes in the tinnitus neuronal network. Readers of this section should note that, unlike noninvasive neuromodulation, invasive procedures carry inherent operative risks such as possible infection of the surgical site and general anesthesiologic risks. A summary of the different types of invasive neuromodulation modalities can be found in Table 13–2.

Auditory Cortex Stimulation

The first study describing auditory cortex stimulation was a case report of a patient

Table 13–2. Summary of Invasive Neuromodulation Modalities for the Management of Tinnitus

Mode	*Delivery Method*	*Usage Requirements*	*Highest Supporting Evidence*
Auditory Cortex Stimulation	Extradural electrode implanted in the primary auditory cortex.	Requires individual optimization of parameters.	Potential therapeutic effects demonstrated in case studies.
Stimulation of the Distress Network	Extradural electrode implanted on the DLPFC or the dACC.	Requires individual optimization of parameters	Potential therapeutic effects demonstrated in case studies.
Deep Brain Stimulation (DBS)	Deep brain stimulation electrodes (mostly in the subthalamic nucleus in studies of Parkinson's disease).	Requires individual optimization of parameters	Not investigated as a treatment option for bothersome tinnitus; potential therapeutic effects for tinnitus demonstrated when DBS was used primarily as therapy for movement disorders.
Vagus Nerve Stimulation (VNS)	Implanted electrodes on the left vagus nerve.	1. Requires optimization of vagus nerve stimulation parameters. 2. Vagus nerve stimulation with paired acoustic therapy.	1. Safety, feasibility, and potential therapeutic effects demonstrated in case studies. 2. Safety, feasibility, and potential therapeutic effect demonstrated in a pilot study.

who suffered from severe left-sided tinnitus resulting from a sensorineural hearing loss after a cochlear nerve lesion (De Ridder et al., 2004). First, fMRI-guided tonic TMS was performed with successful complete suppression of the perception of tinnitus. The use of noninvasive TMS was included as a confirmatory step to ensure the patient would respond to stimulation. Subsequently, an extradural electrode was implanted in the primary auditory cortex and connected to an internal pulse generator located subcutaneously in the abdomen. When tonic stimulation parameters were fully optimized, tinnitus suppression was achieved and maintained at 10 months follow-up.

Encouraged by the positive effects in the above-described case report, De Ridder et al. (2006) reported results for 12 patients with moderate to severe tinnitus who were implanted with two electrodes, one positioned intradural on the primary auditory cortex and the other placed extradural on the secondary auditory cortex. Interestingly, results showed that implanted electrodes were more effective in suppressing tonal or unilateral tinnitus compared to white noise or bilateral tinnitus. Also, it was discovered that among those who suffer from both pure-tone and noiselike tinnitus, reducing both pure-tone and white noiselike tinnitus is pertinent to fully improve patients' satisfaction.

These case reports were followed with studies of a new stimulation modality called *burst stimulation* (Huang et al., 2005). When applied in tinnitus patients who were implanted with electrodes in the auditory cortex, burst stimulation yielded better suppression of narrowband noise tinnitus compared to tonic stimulation (De Ridder et al., 2010). In a follow-up study of 43 patients with severe tinnitus implanted with cortical electrodes overlaying the secondary auditory cortex, there was an average suppression effect of 38% for tonic stimulation and 51% for burst stimulation (De Ridder, Vanneste, et al., 2011).

Stimulation of the Distress Network

It has been agreed that tinnitus stems from overlapping brain networks that include the auditory as well as distress-related brain regions (Vanneste, Plazier, Van Der Loo, et al., 2010). Although the neural correlates of tinnitus-related distress are debatable, the DLPFC and the ACC, suggested to be key hubs of the tinnitus distress network, have been examined as locations for invasive cortical stimulation (Vanneste, Plazier, Van Der Loo, et al., 2010). In one case study, auditory fMRI-guided navigation was used to implant two extradural electrodes on the DLPFC in a patient experiencing intractable tinnitus (De Ridder et al., 2012). Postoperative results showed that tinnitus symptoms improved by 67% with continuous progression for more than 1 year.

In another study, two patients with severe intractable tinnitus were treated using implanted electrodes in the dorsal anterior cingulate cortex (dACC) (De Ridder et al., 2016). Intriguingly, only one of the patients responded to treatment, but this patient reported a dramatic reduction in tinnitus distress and loudness that was maintained for more than 2 years postsurgery. Further exploration of brain activity in both patients showed that the patient responding to treatment had increased functional connectivity from the dACC to the parahippocampal area, subgenual anterior cingulate cortex, and insula, while the patient who did not respond to stimulation had decreased functional connectivity within these areas of the tinnitus network.

Deep Brain Stimulation (DBS)

DBS is a treatment strategy applied successfully in therapy-resistant neurological disorders such as Parkinson's disease, dystonia, chronic pain, and tremors. DBS has not been investigated as a treatment option for bothersome tinnitus. However, there is some evidence that tinnitus can be alleviated in studies where DBS was used primarily as therapy for movement disorders (Cheung & Larson, 2010; Shi et al., 2009; Smit et al., 2016). In the first study showing this phenomenon, three out of seven patients implanted with DBS of the thalamic ventralis intermedius nucleus for movement disorders reported decreased tinnitus loudness (Shi et al., 2009). A research study to investigate the use of DBS in Parkinson's disease demonstrated that tinnitus loudness in both ears was suppressed with stimulation of the area of locus within the caudate neurons (Cheung & Larson, 2010). In one patient where the DBS lead was outside the locus of the caudate neurons, tinnitus loudness was unchanged. Based on these results, the researchers suggested that the locus of the caudate neurons, even though not a part of the auditory system, may be involved in the perceptual integration of phantom auditory sensations generated in the central auditory system (Cheung & Larson, 2010). In a more recent DBS study, a retrospective assessment comparing pre- to post-DBS revealed that tinnitus severity can most effectively be reduced by stimulation of the subthalamic nucleus (Smit et al., 2016).

Vagus Nerve Stimulation (VNS)

The utilization of implanted VNS has been demonstrated in three studies. In the first one, 10 patients with severe chronic tinnitus were implanted with electrodes on the left vagus nerve (De Ridder et al., 2014). After the surgery, the investigators delivered brief electrical stimulation that was paired with auditory tones that excluded the tinnitus-matched frequency for 2 and a half hours each day for 20 days. Results showed improvements in tinnitus symptoms up to 2 months post-therapy for patients who were not on medication compared to those who were taking medications that may have interfered with release of acetylcholine and norepinephrine induced by VNS. This study also established the safety profile of implanted VNS.

The second published study by the same research group was a case report of a patient with bilateral tinnitus who was successfully treated with 4 weeks of daily tone pairing with vagus nerve stimulation (De Ridder et al., 2015). Invasive VNS with paired acoustic stimuli has potential as a treatment option for tinnitus patients. In a recent 1-year follow-up study of 30 participants, VNS with paired acoustic therapy was associated with greater reductions in tinnitus severity in participants who did not have hissing tinnitus and/or blast-induced tinnitus. Results suggest that VNS with paired acoustic therapy may be effective only within certain tinnitus subgroups (Tyler et al., 2017).

Future Directions

Thus far, we have discussed different cutting-edge noninvasive and invasive neuromodulation tinnitus management strategies. The aim of the next section is to give a short and updated overview of other approaches that are accessible as tinnitus management modalities. Also, given that hearing loss is the main risk factor for the development of tinnitus, we will briefly describe the potential use of innovative genetics and stem-cell techniques for the regeneration of cochlear hair cells, and ultimately restoring hearing loss.

Neuronal Biomarkers

The identification of a biomarker reflecting the neural mechanisms of tinnitus would be useful in strengthening diagnostic and treatment outcomes of both noninvasive and invasive neuromodulation techniques. For example, higher gamma band activity could be used as a biomarker to predict the success of bifrontal tDCS. In one study, participants with higher gamma band activity in the right primary and secondary auditory cortex and the right parahippocampus responded to bifrontal tDCS compared to those with lower gamma band activity (Vanneste, Walsh, et al., 2013). Also, responders exhibited increased functional gamma band connectivity between the right DLPFC and parahippocampus as well as the right DLPFC and pregenual ACC. Research also suggests that auditory cortex gamma band activity is associated with tinnitus loudness (Varela et al., 2001). Given the heterogeneity of tinnitus, the ability to classify responders from nonresponders using such parameters would be pertinent in providing more tailored invasive and noninvasive treatment modalities.

Genetic Biomarkers

Another possible line of investigation for tinnitus management is the influence of brain-derived neurotrophic factor (BDNF) gene polymorphisms on treatment outcomes. BDNF is crucial for the regulation of neural plasticity. It has been reported that Vall66Met polymorphism negatively affects the anatomy and physiology of the prefrontal cortex and hippocampus (Bhang et al., 2011). These nonauditory regions may be involved in the development and maintenance of tinnitus (Vanneste, Plazier, Van Der Loo, et al., 2010). In fact, MRI scans have revealed significant gray matter decreases in the right inferior colliculus and left hippocampus in tinnitus patients (Landgrebe et al., 2009). Findings from these studies point toward the need for research to investigate the response of Vall66Met polymorphism carriers and noncarriers on invasive and noninvasive treatment modalities.

Alternative Approaches

Aside from noninvasive and invasive neuromodulation management modalities, researchers and clinicians have focused on other available approaches for tinnitus management. In this section, we will discuss the therapeutic efficacy of these alternative management strategies, the possible mechanisms of action, as well as future directions.

Pharmacotherapy

At present, there is no U.S. Food and Drug Administration (FDA)- or European Medicines Agency (EMA)-approved pharmacological therapy for tinnitus (Langguth et al., 2019). Studies investigating pharmacological interventions for tinnitus suppression have failed to demonstrate long-term beneficial outcomes in patients in excess of placebo effects (Langguth et al., 2019). Most prescriptions for tinnitus treatment are off-label, targeting comorbidities such as anxiety, insomnia, and depression (Langguth et al., 2019). Thus, there is an unmet need for an effective pharmacological option for management of tinnitus. Pharmacological treatments will be limited to reducing the severity of tinnitus, often by decreasing the emotional or psychological impact, until we have a better understanding of the underlying neural mechanism that generates tinnitus.

Multidisciplinary Approaches

Several research groups over the past years have proposed the combination of other treatment modalities with noninvasive neuromodulation in hopes of achieving potential synergistic effects. For example, a study investigated the use of tDCS to initially prime the brain to increase its response to sound therapy from hearing aids (Shekhawat, Stinear, et al., 2013). Although results indicated that improvements in tinnitus were primarily a result of hearing aids, this was the first study attempting to prime the auditory central nervous system for hearing aid-based tinnitus suppression. A similar study combined tDCS with tailor-made notched music training (TMNMT) and reported consistent results wherein significant reduction in tinnitus was predominantly modulated by TMNMT (Teismann et al., 2014). This line of research based on the central gain mechanism is still in its infancy. Further investigation with different modalities (i.e., target sites, stimulation protocols, treatment duration) is needed before any conclusions can be drawn regarding efficacy.

Cognitive Behavioral Therapy (CBT)

The use of CBT is one of the oldest and most established strategies in redirecting attention away from tinnitus and its associated distress. CBT relies on the brain's bias allocation of attention to certain stimuli, known as the *top-down mechanism*. Nonauditory brain areas, including the dorsal attention, salience, and executive function networks, functionally connected to the auditory cortex, are involved in linking tinnitus distress to attention of the tinnitus percept (Trevis et al., 2016). CBT considers attention to tinnitus as the crucial causal factor in the maintenance and amplification of distress (Aazh et al., 2019). Thus, management approaches focus on facilitating changes in attention through the development of adaptive coping thoughts (Aazh et al., 2019). CBT cannot eliminate the auditory percept. However, it is useful in reducing a patient's negative response to tinnitus, ultimately modifying the qualitative aspects of tinnitus (Aazh et al., 2019). For a more detailed discussion on CBT, see Chapter 11.

Bimodal Neurostimulation

In animal models, generation of tinnitus results from maladaptive long-term plasticity that integrates somatosensory inputs to the central auditory system at the level of the dorsal cochlear nucleus (Shore et al., 2016). This offers a framework for somatosensory tinnitus in which patients are able to modulate their tinnitus loudness with movements of the neck and face (Shore et al., 2016). The maladaptive auditory-somatosensory convergence could be a modulation target. In a crossover study, noninvasive somatosensory stimulation was provided in the region of the trigeminal ganglion or the C2 depending on tinnitus maneuver location, with auditory stimulation tailored according to the participant's tinnitus spectrum (Marks et al., 2018). Results showed that 28 days of bimodal stimulation suppressed loudness and intrusiveness compared to unimodal auditory stimulation. Another double-blinded, exploratory, three parallel arms study using combinations of different tongue and acoustic stimulations reported a reduction in tinnitus severity after 12 weeks of treatment with sustained effects at 1-year follow-up (Conlon et al., 2020).

Temporal Interference (TI)

A recent study reported a novel noninvasive technique that could be applied in reducing tinnitus severity (Grossman, 2018). Temporal interference (TI) requires delivery to a one-point focal site via two scalp electrodes at a current that is higher than the normal neuronal frequencies. The envelope of the meeting point of the current, termed *interference current*, results in a low-frequency activation of neurons in the designated brain regions (Grossman, 2018; Grossman et al., 2017). Of the noninvasive modalities, TI has the greatest focality, comparable to that of deep brain stimulation (Grossman, 2018). Results in animal models have supported this proposition, demonstrating that TI stimulation may selectively activate the hippocampus (Grossman et al., 2017). TI, while still in the developmental phase, offers a very promising alternative to deep brain stimulation with the benefit of lower risk and increased availability.

Auditory Hair Cell Regeneration

It is well established in the literature that hearing loss is one of the main risk factors for developing tinnitus (Baguley et al., 2013). The majority of patients develop tinnitus as a symptom caused by acute trauma or long-term hearing damage to the auditory system. A scoping review reported that results from 16 out of 17 studies support the use of hearing aids for tinnitus management (Shekhawat, Searchfield, et al., 2013).

The auditory system is complex, and any physiological or anatomical anomaly along the hearing pathway can result in hearing loss (Mittal, Aranke, et al., 2017). Dysfunction of cochlear hair cells is found in most patients with permanent hearing loss. In humans, cochlear hair cells do not regenerate after damage or dysfunction (Jacob et al., 2013). It has been reported that 50% of patients with hearing loss experience tinnitus, including many patients who are profoundly deaf (Cima et al., 2019).

In recent years, researchers have explored the potential use of genetics and stem cells strategies in restoring hearing function (White, 2020). Although stem-cell differentiation and transplantation are in the infant stages of development, it should be noted that if future results are positive, hearing function could possibly be restored (White, 2020) and thus decrease the risk of patients with permanent hearing loss developing tinnitus.

Stem-Cell Differentiation

In the early 2000s, the success of isolating infant mice stem cells from the organ of Corti and the sensory vestibular apparatus suggested the potential for utilization of endogenous stem cells to restore damaged hair cells (Oshima et al., 2007). The process of stem cell differentiation involves the switching of a cell to a more specialized cell type. There are two limitations to the therapeutic potential of stem cell differentiation in restoring damaged hair cells: (a) the cells are in a dormant state, having no ability to spontaneously differentiate when there is hair cell damage, and (b) the number of endogenous stem cells decreases with age, suggesting its possible use only in neonates with hair cell damage (Martinez-Monedero et al., 2007).

More recently, the discovery of cochlear progenitor cells in the neonatal mammalian ear has revived the importance of hair-cell regeneration research (Chen & Streit, 2013). The cochlear progenitor cells are in the transitional state between stem cells and their progeny, terminal differentiation cells. Cochlear progenitor cells offer the potential to differentiate into new hair cells with the correct promoting factor (Chen & Streit, 2013). To date, studies of inner ear development have suggested a considerable number of genes that can regulate the hair-cell differentiation process through their expression products, including transcription regulatory factors, growth factors, notch activation molecules, and cell division factor-dependent kinase inhibitors (Mittal, Nguyen, et al., 2017). Of the different progenitor cells, the Lgr5+ are currently in the pipeline as target cells as precursors to hair-cell regeneration (Bramhall et al., 2014; Chai et al., 2012). Studies have discovered that through the regulation of the Notch and Wnt signaling pathways (i.e., pathways that control proliferation), Lgr5+ are able to differentiate into hair cells (Bramhall et al., 2014; Chai et al., 2012).

Stem-Cell Transplantation

Another approach that has gained momentum in the past decade is the utilization of exogenous stem cell transplantation to restore damaged or to regenerate new spiral ganglion neurons. Briefly, neural degeneration is a subsequent result of hair cell damage that limits the functionality of cochlear implants. To a certain extent, the clinical therapeutic effect of cochlear implants relies on the quantity and quality of residual spiral ganglion neurons (Kujawa & Liberman, 2009). To date, several techniques to regenerate spiral ganglion neurons have been investigated. One promising research discovered that in vitro, embryonic stem cells could differentiate into glutamatergic neurons following BDNF and glial cell line-derived neurotrophic factor (GDNF) treatments (Reyes et al., 2008). Excitingly, these findings were replicable when conducted in vivo, with 50% to 70% of the transplanted embryonic stem cells expressing the Tuj1 and glutamatergic neural markers (Coleman et al., 2006). Other studies have explored the possible use of dorsal root ganglion (DRG) cells (Hu et al., 2009), mesenchymal stem cells (Bas et al., 2014), and neural progenitor cells as possible candidates for transplantation (Chen et al., 2017). However, these studies have been conducted in vitro and their in vivo capabilities are yet to be established.

Stem-cell transplantation in the cochlea is complex and challenging with many components that require consideration, such as the different stem cells, cell differentiation status, transplantation technique and site, and different surgical approaches (Mittal, Nguyen, et al., 2017). In addition, the cochlea's environmental factors have to be accounted for as its ionic environment affects the survival rate of cells that are transplanted (Matsuoka et al., 2007). For example, it has been reported that a high concentration of endolymph potassium leads to apoptosis and necrosis of stem cells that are transplanted (Wang et al., 2011). Also, the complex environment results in the inability to precisely regulate the proliferation of certain stem cells, risking the formation of cancer cells and lesions (Gao et al., 2018). However, research has identified that the CRISPR/Cas9 gene-editing tool can increase the precision of regulation of stem cells in vivo. In animal models, this technology has been applied in the treatment of autosomal dominant hearing loss (Gao et al., 2018). The combination of stem cell therapy with precise genetic editing tools is the future research direction of auditory hair-cell regeneration (White, 2020).

Clinical Implications

Advances in tinnitus research have led to paradigm shifts in frameworks, methods, and management approaches. Among others, brain network theories, the use of advanced neuromodulation techniques, brain-machine interfaces, and stem cell research have contributed to revolutionary alterations in our understanding of tinnitus and the application of therapeutic procedures.

Despite advances in noninvasive and invasive neuromodulation techniques for management of tinnitus, there are certain measures that, if implemented, could assist in establishing the efficacy of the different modalities as well as strengthening our understanding of the pathophysiological mechanisms underlying this phantom percept. The small sample sizes, lack of control groups, and heterogeneity in stimulation protocols (e.g., current amplitude, number of sessions, and total electrical dosage) compromise the quality of evidence. As a result, it is not possible to draw firm conclusions regarding study results. More importantly, clinical trials are needed to explore the beneficial effects of the various stimulation modalities over a longer period of time. Also, treatment outcomes are measured using a variety of procedures, with some studies revealing significant but small effect sizes and marginal clinical relevance.

Hence, sufficiently powered, well-designed, sham-controlled prospective studies evaluating cost effectiveness and clinically relevant effect sizes are needed to ascertain neuromodulation as a treatment tool in routine clinical practice.

Key Messages

- Recent advances in tinnitus treatment modalities are exciting, yet lacking in strong evidence partially due to the heterogeneous nature of tinnitus.
- Although noninvasive strategies are easier, cheaper, and carry fewer risks than invasive treatments, invasive procedures may induce prolonged therapeutic effects with low participant/patient engagement.
- Among the noninvasive modalities, tDCS is at present the preferred technique among researchers. Innovations in tDCS technology, such as HD-tDCS, which improves focality, and tailored-closed loop designs that allow adjustment of parameters based on real-time brain activity, permit the refinement of tDCS-tinnitus therapies.
- The application of stem-cell therapy in hearing restoration is in its infancy. With the combination of genetic editing tools, this therapeutic strategy has great potential in its application in restoring hearing loss.

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14 DIETARY SUPPLEMENTS, ESSENTIAL OILS, AND CANNABINOIDS FOR TINNITUS RELIEF

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Introduction

Because treatments for tinnitus are currently limited, many individuals turn to dietary supplements and other products as a self-help option. Although there are more than 80 dietary supplements, herbal products, and vitamins currently available over the counter and online that claim to offer a cure for and relief from tinnitus, none are approved by the United States Food and Drug Administration (FDA) at this time (DiSogra, 2017). Similarly, essential oils and cannabidiol (CBD) oil have recently been claimed to offer tinnitus relief. While individual user testimonials abound, there is no scientific evidence in support of their effectiveness for tinnitus alleviation. These products generally come with disclaimers that their use is not a replacement for professional medical diagnosis or treatment. This chapter offers an overview of dietary supplements, essential oils, and CBD-based products advertised for tinnitus relief, as well as an analysis of peer-reviewed data related to these claims.

Background

Humans have experienced tinnitus for centuries, and innumerable natural concoctions have been created in an attempt to relieve symptoms. Early Egyptians infused oil, frankincense, tree sap, herbs, and soil into the ear canal to reduce tinnitus, and early Greco-Roman remedies included vinegar, cucumber juice, and honey (Traynor, 2017). Throughout Asia, practitioners of traditional Chinese medicine (TCM) also used a variety of plant-based products to treat conditions like tinnitus (Yang, 1989). Early Native American ethnobotanists and Native Alaskan and Hawaiian healers used plants for medicinal purposes; however, there is no mention of intervention for hearing loss or tinnitus (Borchers et al., 2000; National Library of Medicine, 2020; Native Voices, n.d.). Ayurveda, one of the world's oldest medical systems, relies on a natural and holistic approach to health. Some Ayurveda clinics offer treatments claiming to cure tinnitus (AYUR Clinic, 2018) but the U.S. FDA warns that "the presence of metals in some Ayurvedic products makes them potentially harmful," (National Center for Complementary and Integrative Health, 2020). Interested readers are directed to Chapter 15 for a detailed discussion on the use of complementary and alternative medicine for tinnitus management.

Dietary Supplements

Dietary supplements are manufactured products ingested for the purpose of supplementing one's diet (Rehnquist, 2003) and are available in the form of tablets, capsules, powders, energy bars, or liquids (FDA, 2015). According to the Dietary Supplement Health and Education Act of 1994 (DSHEA), supplements are composed of multiple active compounds including vitamins, minerals, herbs, botanicals, amino acids, metabolites, or any combination of these ingredients (National Institutes of Health, Office of Dietary Supplements, 1994). Although the primary active ingredient is often unknown, supplements remain steadfastly popular. In the United States, revenue from dietary supplements was approximately $32 billion in 2019 (Shahbandeh, 2019). Berman and Straus (2004) articulate that the distinction between dietary supplements and drugs depends on their use, with supplements intended to sustain or improve bodily function while drugs function to prevent or treat a disease, although the authors suggest that this differentiation can be "an exercise in semantics" (p. 240).

Regulatory Oversight

In the United States, oversight on the manufacturing and sale of dietary supplements is provided by the FDA, the Office of Dietary Supplements (ODS) at the National Institutes of Health (NIH), and the U.S. Pharmacopeia (USP) (NIH ODS, 2020). Dietary supplement manufacturers must follow FDA regulations concerning the product's labeling, identity composition, purity, and strength, and all supplements must be registered with the FDA prior to the product being sold on the market. Although any regulation of dietary supplements must be enforced by the FDA, the USP is an independent, nongovernmental organization that offers quality and safety standards for medicines, food ingredients, and dietary supplements (Berman & Straus, 2004; U.S. Pharmacopeia, 2020). In Europe, similar oversight is provided by the European Food Safety Authority (EFSA, 2021).

Both the FDA and the EFSA regulate dietary supplements as a category of food products, not as drugs (FDA, 2015). While the FDA is responsible for monitoring product registration and labeling in the U.S., the Federal Trade Commission (FTC) regulates advertising and marketing related to these products (FTC, 2001). Dietary supplements are required to have the following disclaimer on their labels: "These statements have not been evaluated by the FDA. This product is not intended to treat, cure nor prevent any disease." (NIH ODS, 2020). It is important to note that the safety and efficacy of dietary supplement claims do not have to be demonstrated to the FDA, and supplements can be sold without regulatory review (FDA, 2015; Institute of Medicine, 2005). Likewise, in Europe, the food business operators that manufacture supplements are responsible for ensuring product safety (EFSA, 2021). Therefore, consistency and quality checks throughout the manufacturing process are not well regulated (Berman & Straus, 2004). Without knowledge of supplements' active ingredients or potential interactions, it is a challenge for manufacturers to set standards that bear any therapeutic meaning. Although the

FDA regards supplements as safe ("generally regarded as safe" or "GRAS"), adverse events can still occur (FDA, 2019).

Vitamins

Vitamins are a group of substances that help ensure proper bodily function and growth. The U.S. NIH currently identifies 13 "essential vitamins": A, B_1 (thiamine), B_2 (riboflavin), B_3 (niacin), B_5 (pantothenic acid), B_6, B_7 (biotin), B_9 (folate), B_{12} (cyanocobalamin), C, D, E, and K (NIH ODS, n.d.). While most individuals get all necessary vitamins and nutrients from foods, some may be advised by their physicians to take vitamins for certain deficiencies (National Institute on Aging, 2021). The World Health Organization (WHO) and Food and Agriculture Organization (FAO) of the United Nations offer guidance on nutritional needs and recommended vitamin dosages (2004). In the U.S., vitamins fall within the same class as dietary supplements and therefore are regulated by the FDA but are not tested for efficacy and safety before they are sold. Similarly, European regulations consider vitamins as food supplements and do not currently outline minimum and maximum levels of vitamins contained in these products (EFSA, 2021).

Essential Oils

Although aromatherapy practitioners and proponents commonly use the term *essential oils* to refer to oils extracted from plants, there is no United States federal regulatory definition of the term. Essential oils are natural compounds produced by and extracted from plants that generally have a fragrance (Bakkali et al., 2008). The "essence" of an oil is its volatility or speed of evaporation. Essential oils have been used in the fragrance, cosmetic, food, and pharmaceutical industries. Because of their potential antibacterial and fungicidal properties, essential oils are in-creasingly being used as a replacement for synthetic chemical ingredients (Bakkali et al., 2008).

Similar to dietary supplements and vitamins, the U.S. FDA classifies plant oils as food (FDA, 2015). Therefore, there are no requirements to support any claims or statements made by manufacturers concerning efficacy and safety of essential oils. However, the FDA does label the most commonly used essential oils as GRAS (FDA, 2019). The European Union has set mandatory requirements for essential oils, ensuring adherence to regulations related to natural ingredients contained in cosmetics (Centre for the Promotion of Imports from Developing Countries, 2021).

Cannabis-Derived Products and Cannabidiol (CBD) Oil

Cannabidiol oil (commonly referred to as CBD oil) is a cannabinoid extracted from the *Cannabis sativa* plant, which produces marijuana and hemp (NCCIH, 2019). The two main types of cannabinoids are delta-9-tetrahydrocannabinol or THC, which is the psychoactive component responsible for altered mental state, and CBD, which lacks THC and is nonpsychoactive (Blessing, 2015). Therefore, CBD users do not experience the high that marijuana users generally do. The most common mode of administration of CBD is oil, in which the cannabis flowers are dissolved into an edible oil such as olive or sunflower oil. CBD oil is odorless and has become the preferred mode of ingestion for many users as they can easily consume large doses of cannabinoids without the risk of intoxication (Hazekamp, 2018).

Regulatory Oversight

In the United States, the cultivation of hemp and CBD products was legalized in June 2018 with the passing of the Agriculture Improvement Act (also known as the Farm Bill of 2018). Under this law, hemp and CBD products with THC levels below 0.3% were removed from the Schedule I drug list, which the U.S. Drug Enforcement Agency (DEA) defines as any drug that has no accepted medical use and has high potential for abuse (e.g., heroin, LSD) (FDA, 2021). However, the legality of products containing CBD with higher levels of THC remains complicated because they are illegal at the federal level, but individual states have passed laws allowing medicinal and/or recreational use of these derivatives (Hazekamp, 2018).

Testimony from *Hemp Production and the 2018 Farm Bill* (2018) further explains the ambiguous legal and regulatory state of CBD oil in the U.S. Products like CBD oil containing less than 0.3% THC are legal in some states but are still required to meet FDA requirements and regulatory standards. It is important to note that THC or CBD products cannot be marketed as dietary supplements per current FDA guidelines (FDA, 2021). The FDA has not approved any CBD-based non-prescription products. Concerns remain regarding unsubstantiated claims by companies related to CBD products' therapeutic value and ability to prevent or treat conditions (*Hemp Production and the 2018 Farm Bill*, 2018). The FDA acknowledges potential opportunities for and interest in further developing the use of cannabis-derived products (FDA, 2021).

The complicated status of CBD is not an issue unique to the United States. In the European Union (EU), certain varieties of cannabis are permitted to be cultivated if registered with the EU's *Common Catalogue of Varieties of Agricultural Plant Species* and THC content remains below 0.2%. Canadian laws allow up to 0.3% THC content for CBD to be sold commercially as hemp (Government of Canada, 2020), while Switzerland's threshold of legality for CBD is 1.0% THC. Individual countries have additional regulations related to the cultivation, extraction, and quality control of hemp and CBD, adding additional obstacles to the distribution, sale, and regulation of these products (Hazekamp, 2018).

CBD products remain highly scrutinized by local, national, and global health organizations, and questions continue to emerge as to whether CBD should be classified as a supplement, a medicine, or a narcotic drug. Further research is needed related to dosing, labeling, potential drug interactions, and other possible side effects of CBD oil (Hazekamp, 2018). Even for CBD products with low levels of THC, safety concerns remain. In addition to studies that have found inaccurate and misleading labeling of CBD products (VanDolah et al., 2019), contamination of products by pesticides or microorganisms, unintentional ingestion by children, arbitrary dosing/administration due to uncalibrated droppers, and lung injuries caused by vaping CBD products have been reported (NCCIH, 2019).

While specific CBD regulations vary by country and/or state, the legalization of cannabis-derived products has created global interest in development of therapies and consumer products, as well as increased marketing of potential nonnarcotic benefits of CBD products (FDA, 2021). The 2018 *Cannabidiol Critical Review Report* released by the World Health Organization (WHO) acknowledges the unsanctioned use of products like CBD oil, but states that "CBD is generally well tolerated with a good safety program" (p. 5).

Therapeutic Properties

Clinical studies suggest that CBD possesses a wide range of therapeutic properties including antipsychotic (Kopelli et al., 2020), analgesic (VanDolah et al., 2019), anticonvulsant (Arzimanoglou et al., 2020), anti-inflammatory (Xu et al., 2020), antiarthritic (Miller & Miller, 2017), and antineoplastic (Malhotra et al., 2021). Investigations in humans have shown the effectiveness of CBD in reducing the severity of seizure disorders in children (Devinsky et al., 2017). Although mixed results exist in the literature, CBD has been shown to ease anxiety disorders when administered acutely (Blessing, 2015) and to improve sleep in adults and children with insomnia, sleep apnea, or post-traumatic stress disorder (Babson et al., 2017). Anecdotally, CBD oil has been used to treat various medical conditions, including Parkinson's disease, schizophrenia, neuropathic pain, chemotherapy-induced nausea, and glaucoma (FDA, 2021; Hazekamp, 2018; Narwani et al., 2020). Research into the therapeutic benefits of CBD is continuing to evolve, but at this time many of the claims related to CBD's effectiveness have not been substantiated by clinical data and are not approved by the FDA and other regulatory agencies (Hazekamp, 2018; FDA, 2021).

Recent Advances

Dietary Supplements Advertised for Tinnitus Relief

There are currently more than 80 nonprescription, over-the-counter (OTC) dietary supplement products for tinnitus available online or in stores (DiSogra, 2015). Commonly advertised supplements for tinnitus include gingko biloba, melatonin, and zinc (Tunkel et al., 2014). Despite their popularity, there are no dietary supplement products approved by the U.S. FDA or endorsed by the USP to relieve or cure tinnitus as of 2021 (USP, 2020). In fact, the *Clinical Practice Guidelines* of the American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS) state that "clinicians should not recommend dietary supplements for the treatment of tinnitus" (Tunkel et al., 2014, p. S1).

An international survey of 1,788 respondents from 53 countries analyzed dietary supplements and their effectiveness in the management of tinnitus (Coelho et al., 2016). The researchers found that 23% of respondents took dietary supplements for tinnitus, and the most commonly used substances were ginkgo biloba, lipoflavonoids, magnesium, melatonin, vitamin B_{12}, and zinc. More than 70% of the individuals who had taken supplements reported no effect on tinnitus, 19% reported improvement, and 10% reported exacerbation. Interestingly, individuals who used supplements were more likely to have louder tinnitus and to report hyperacusis. In line with AAO-HNS guidelines, the authors concluded that dietary supplements are not effective and can produce adverse effects, and therefore should not be recommended to manage tinnitus.

Ginkgo biloba is frequently discussed as an effective means of alleviating tinnitus. A double-blind study of 22 individuals found that 10 days of intravenous administration of ginkgo biloba followed by 12 weeks of oral administration appeared effective in alleviating tinnitus (Morgenstern & Biermann, 2002). However, several larger double-blind, placebo-controlled trials assessing ginkgo biloba in more than

1,100 adults showed no significant difference between the supplement and placebo groups. Thus, ginkgo biloba is not effective in treating tinnitus (Drew & Davies, 2001; Holgers et al., 2003) and the benefits of the supplement remain unclear (Kim et al., 2021).

Personal anecdotes and some studies suggest the role of zinc in reducing tinnitus, particularly in adults with a zinc deficiency; however, double-blind, randomized controlled trials with larger samples have shown no significant improvement in subjective tinnitus following administration of zinc (Coelho et al., 2007; Kim et al., 2021; Seidman & Babu, 2003). Overall, while some physicians feel that the risk-to-benefit ratio is reasonable, the highly variable individual responses to these supplements make it clear that they are not a guaranteed remedy for tinnitus amelioration (Seidman & Babu, 2003).

Claims by product manufacturers, as well as user testimonials, attesting to the effectiveness of dietary supplements to cure tinnitus are commonplace in advertising. However, because no supplements are approved by the FDA for tinnitus relief, these subjective reports of positive effects must be analyzed cautiously (Coelho et al., 2016). Patients must recognize and understand that anecdotal experiences are not a substitute for evidence-based research (Baguley et al., 2013). Also, there is no scientific research related to the effectiveness of any combination of the ingredients found in OTC tinnitus relief products that can support their use in a tinnitus management program (DiSogra, 2015). Kim et al. (2021) further describe that some of these advertised products, like quinine and chloroquine, can actually result in new-onset or worsened tinnitus. Overall, Vendra et al. (2018) refer to OTC tinnitus supplements as a "lightly regulated lucrative business, despite scientifically unjustifiable claims" (p. 1903) and there continues to be a need for evidence-based research related to dietary supplements for tinnitus relief.

Vitamins Advertised for Tinnitus Relief

Vitamins, including B_1, B_2, B_3, and B_{12}, are common ingredients in products claiming to offer tinnitus relief, but their efficacy currently lacks scientific support (Enrico et al., 2007). Theoretically, various research groups have suggested that deficiencies in certain vitamins may contribute to tinnitus and other cochlear dysfunction (Seidman & Babu, 2003). At this time, however, none of the 13 essential vitamins have been causally linked to tinnitus or are indicated for tinnitus relief. Baguley et al. (2013) refer to evidence for improving tinnitus with vitamins as "anecdotal at best" (p. 205). Slanina et al. (2016) provide an overview of the natural substances and vitamin supplementation related to possible tinnitus prevention and management. While the use of Vitamins C, B_6, and B_{12} is discussed, authors acknowledge that vitamin supplementation in humans remains controversial. Interestingly, Lasisi et al. (2012) report that in elderly individuals, low vitamin B_{12} levels strongly correlate with development of subjective tinnitus, possibly due to dysfunction of the auditory pathway, including demyelination of auditory nerve fibers. Researchers have suggested that increasing vitamin B_{12} levels to normal thresholds may reverse the presence of tinnitus in those already experiencing the condition, but studies have found vitamin B_{12} replacement treatment to be ineffective (Kim et al., 2021). Similarly, Seidman and Babu (2003) discuss the common use of B_3 (niacin) for tinnitus relief but conclude that clinical evidence does not currently exist to support its treatment of tinnitus.

Essential Oils Advertised for Tinnitus Relief

The use of plant oils for tinnitus relief dates back to the 11th century, when lily oil and spotted orchid oil were mentioned as tinnitus remedies in Persian physician Avicenna's *Canon of Medicine* published in 1025 AD (Mahdizadeh et al., 2015). Searching online for "essential oils for tinnitus" reveals several websites that claim essential oils, used either in isolation or in combination with other oils, can provide tinnitus relief (DiSogra, 2020). Despite their popularity, however, no published scientific data exist to support these claims (National Library of Medicine, 2020) and essential oils are not FDA approved for tinnitus relief at this time. A pilot study of aromatherapy use in 16 individuals with chronic tinnitus revealed that while the majority reported some benefits from the massage-administered essential oil blends, the improvements were general and short lived, and not related to relief of tinnitus specifically. Interestingly, several participants reported a worsening of tinnitus symptoms during aromatherapy treatments, potentially due to increased attention focused on the condition (Meehan et al., 2003).

Most websites advertising essential oils for tinnitus relief do not have a medical advisory board, yet it is common to see the words *certified* or *therapeutic/clinical grade* on essential oil product labels. This can be misleading to consumers because there are no national or international certifying agencies that set quality standards for essential oils, and therapeutic grade is a marketing term (Manion & Widder, 2017). Individual users may endorse positive effects of essential oils, but personal statements are not a substitute for peer-reviewed research.

Cannabidiol (CBD) Oils Advertised for Tinnitus Relief

As consumer interest in CBD products continues to grow, it is unsurprising that numerous CBD products are advertised as offering tinnitus management. As mentioned earlier, studies have suggested that CBD products with low levels of THC may help reduce anxiety (Blessing et al., 2015) and contribute to improved sleep (Babson et al., 2017). Anxiety and sleep disturbance are two challenging issues for many individuals with tinnitus, so some turn to this DIY remedy of legalized CBD (Perin et al., 2020). Additionally, it has been suggested that CBD products can help treat tinnitus by reducing hyperactive neuronal activity (Narwani et al., 2020), while other groups suggest that CBD can actually increase brain activity and exacerbate tinnitus (Zheng & Smith, 2019).

As of 2021, the FDA has not approved any CBD products for tinnitus relief, and there is no compelling evidence from human or animal studies to suggest that cannabinoids can alleviate tinnitus. No randomized controlled studies examining the impact of CBD on tinnitus have been published, partly because researchers in many countries face obstacles related to regulations and permissions. Several noncontrolled studies have been conducted, yielding conflicting results related to CBD's impact on tinnitus (Narwani et al., 2020). Smith and Zheng (2016) conclude that the effects of cannabis on humans are still unclear, with contradictory and inconclusive results suggesting both exacerbation and inhibition of brain activity. Overall, there is a dearth of clinical data assessing the role of CBD products on tinnitus severity, and it would be premature for a clinician to suggest CBD for tinnitus relief (Zheng & Smith, 2019). Additional research is needed to determine possible intervention strategies (Narwani et al., 2020).

Adverse Reactions to Dietary Supplements, Vitamins, Essential Oils, and/or CBD

Several studies have determined that dietary supplements are not effective in treating tinnitus symptoms, and that some individuals can have adverse side effects, including diarrhea, dizziness, bleeding, and headache (Coehlo et al., 2016). Hofmeister (2019) explains that dietary supplements can even cause serious side effects or negative drug interactions, especially if taken along with conventional medications like blood thinners or antibiotics. Specifically, ginkgo biloba has been reported to have serious drug interactions, resulting in increased bleeding, excessive sedation, and changes in mental state (Baguley et al., 2013). Unfortunately, tinnitus supplements do not typically advertise these possible side effects, interactions, or contraindications on their labels (Vendra et al., 2018).

In using vitamins for tinnitus treatment, Enrico et al. (2007) argue that potential harm may result from inappropriate use, including increased intrinsic toxicity and money wasted on a futile treatment. Baguley et al. (2013) argue that it is not difficult to ingest toxic levels of certain vitamins that are sold freely in supermarkets and on the internet, and the authors urge patients to exercise caution when self-medicating with vitamins and supplements.

Potential adverse effects of essential oils reported in the literature include skin irritation, allergy, and photosensitivity (Corazza et al., 2014); airway irritation (Manion & Widder, 2017); and prepubertal gynecomastia (Henley et al., 2007). There are also reports of epileptic seizures occurring in children following essential oil ingestion (Halicioglu et al., 2011), so safe storage of these products is advised (Manion & Widder, 2017).

Use of CBD products can also result in adverse reactions. While the World Health Organization (2018) asserts that CBD has a good safety profile and is generally well tolerated in humans, other studies of CBD efficacy have also reported some mild side effects of CBD, including drowsiness, fluctuating appetite, anxiety, diarrhea, dizziness, and fatigue. Similar to dietary supplements, adverse reactions are possible as a result of drug interactions between CBD and individuals' existing medications. For this reason, it is critical for individuals to consult their physicians before beginning CBD to avoid drug interactions (WHO, 2018). Patients experiencing an observed or suspected adverse reaction after use of a dietary supplement, vitamin, essential oil, or CBD product should inform their primary care physician or pharmacist immediately and can report the event to MedWatch, the FDA's online reporting portal (FDA, 2021).

Future Directions

There continue to be significant gaps in the regulation and research related to dietary supplements, essential oils, and CBD for management of tinnitus. While some clinical studies exist, randomized, double-blinded, placebo-controlled clinical trials are needed to further analyze efficacy of these commonly utilized products, including ginkgo biloba, zinc, B_{12}, essential oils, and CBD. Studies with larger sample sizes will enhance generalizability. Additionally, further research is needed into the pathophysiology of tinnitus to target effective treatment agents. As part of its mission, the NIH disseminates all information about clinical research investigating pharmaceuticals and/or dietary supplements through the Computer Access to Research on Dietary Supplements (CARDS) database (NIH ODS, n.d.).

The current environment of cannabis and CBD legality, regulation, and use is rapidly evolving throughout the world. Considering there have not yet been any randomized studies conducted in humans examining the effects of cannabinoids on tinnitus, this research is desperately needed. Additionally, Salami et al. (2020) articulate the benefits of promoting the use of and research on CBD and cannabis as they become more acceptable and legal. There are many cannabis compounds that remain unidentified, and the authors describe these cannabinoids as "promising tonic, analgesic, antipyretic, antiemetic, anti-inflammatory, antiepileptic, anticancer agents" (p. 1). It is inevitable that more individuals will be exposed to CBD oil and similar products, and additional research is critical in maintaining safety and efficacy.

Finally, increased transparency regarding the effectiveness of these products in relieving tinnitus is critical. Manufacturers frequently make ambiguous and unproven claims regarding the ability of dietary supplements to cure tinnitus. Similarly, the sale and marketing of CBD products are complicated, and manufacturer assertions are often obscure. Individuals with tinnitus often feel desperate for relief and may not understand the effectiveness and potential side effects of these products. Clinicians must make an effort to educate tinnitus patients about this situation and help them make appropriate decisions.

Clinical Implications

Audiologists, otolaryngologists, and other relevant clinicians should be cognizant that these OTC and CBD products are marketed for tinnitus relief and are available relatively easily to patients. It is advantageous for clinicians to ask tinnitus patients about their use of these products and be prepared to answer questions regarding the efficacy and safety of supplements and CBD products for tinnitus. As CBD oil and other cannabinoids become more acceptable and cannabis continues to be legalized, audiologists should now begin to ask patients about their use of such products, not only in regard to their tinnitus or hearing loss but also for any other condition. Due to variance in the symptoms and clinical presentations of many patients with tinnitus, it has been difficult to determine the effectiveness of different supplements, vitamins, oils, and CBD products on tinnitus alleviation (Kim et al., 2021). Therefore, clinicians should be cautious when discussing or suggesting use of these products since individual outcomes and side effects vary.

Self-medication poses new problems for both patients and healthcare practitioners (including audiologists). The World Health Organization (2000) has recognized and addressed this issue and raised concerns related to incorrect self-diagnosis, delay in seeking appropriate medical advice, inappropriate therapy, overlooked contraindications or drug interactions, and failure to report self-medication to relevant clinicians.

For this reason, it is paramount for audiologists and otolaryngologists to inquire about the use of self-prescribed supplements and CBD products.

Key Messages

- Despite lack of evidence for their efficacy in relieving tinnitus, dietary supplements, vitamins, essential oils, and CBD products remain popular and frequently advertised, with dozens of products claiming to have curative properties.
- As of 2021, none of these products are approved by the U.S. FDA to treat or prevent tinnitus, and clinical practice guidelines of several professional organizations explicitly advise clinicians against recommending these products for tinnitus management.
- To be sold as dietary supplements in the United States, products are expected to have statements on their label, such as "The information is not intended or implied to be a substitute for professional medical advice, diagnosis, or treatment . . ."
- At this time, no randomized controlled studies have been published examining CBD's impact on tinnitus, partly because researchers in many countries face significant obstacles related to regulation, legality, and permissions related to cannabinoids.
- While dietary supplements, vitamins, essential oils, and CBD products are generally considered safe, potential side effects, including serious drug interactions, have been reported. For this reason, it is critical for providers to be aware of any supplemental or self-management products taken by their patients, and to be cautious if recommending use of a certain supplement, essential oil, or CBD product for tinnitus relief.
- While user testimonials abound for over-the-counter dietary supplements, vitamins, essential oils, and CBD products to treat tinnitus, it is essential to remember that personal statements are not a substitute for well-designed peer-reviewed research studies.

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15 COMPLEMENTARY AND ALTERNATIVE MEDICINE AND TINNITUS

Gemma Crundwell and David M. Baguley

Introduction

Complementary and alternative medicine (CAM) encompasses healthcare practices that fall outside of mainstream medical practices rooted in modern science. CAM is used by individuals in varied contexts, including those with chronic conditions, to prevent illnesses, those who are dissatisfied with conventional medicine, or where conventional treatments are limited (Fischer et al., 2014; Harris et al., 2012). A range of CAM approaches have been suggested to reduce the symptoms of tinnitus. The potential tinnitus benefits that a person receives from CAM might be direct (such as a reduction in the loudness, severity, or intrusiveness of the tinnitus) or indirect (such as improved well-being associated with reduced depression, anxiety, and insomnia). Given that conventional medicine is not consistently effective in tinnitus management (McFerran et al., 2019), and that tinnitus patients report dissatisfaction with care they receive from otolaryngology and audiology (McFerran et al., 2018), it is not surprising that some people with tinnitus seek remedy within CAM approaches.

Background

The use of CAM has become increasingly popular in western societies over the past 30 years (Fischer et al., 2014). At a national level, countries with higher health expenditures typically offer access to a higher number of CAM interventions, and these interventions are reimbursed and integrated into established healthcare systems (Fjær et al., 2020). The use of CAM, however, is higher in health economies where access to conventional medicine is poor due to geographical or socioeconomic factors, or where CAM is preferentially affordable or highly congruent with cultural tradition. At an individual level, the use of CAM is associated with a range of socioeconomic, demographic, and health indicators (Fjær et al., 2020). In more affluent health economies, higher use of CAM is associated with female gender, higher educational status, middle age, and low income (Kemppainen et al., 2018). Tangkiatkumjai et al. (2020) undertook a systematic review of 231 relevant publications to determine why people around the world seek or avoid therapy through CAM. They concluded that the main reasons for CAM use were: (a) expectation of benefits of CAM, (b) dissatisfaction with conventional medicine, and (c) perceived safety of CAM. The reasons identified for avoidance were: (a) negative attitudes toward CAM and (b) satisfaction with the results of conventional medicine. While this study was not focused on tinnitus, it may have some insights for tinnitus researchers and clinicians interested in this topic. Each of the factors identified in the study pertain to tinnitus to a considerable extent; in particular, the dissatisfaction with conventional medicine, which may drive individuals with tinnitus toward CAM use.

Identifying the specific number of people with tinnitus who seek remedy from CAM is not straightforward. In an early and influential study, Andersson (1997) investigated prior management for a group of 69 consecutive patients in his Swedish psychology-based tinnitus clinic. The results revealed that the majority (65%) sought a variety of CAM approaches including acupuncture and relaxation therapy. Although the study was conducted approximately 25 years ago and was restricted to a particular national culture, there are some findings of note. Patients who had not undergone prior management attempts (35% of participants) showed greater response to conventional management strategies for tinnitus. This finding suggests that prior attempts to manage tinnitus, including CAM, might reduce an individual's responsiveness to psychologically based clinical management.

Bhatt et al. (2016) analyzed data from a large population study (2007 National Health Interview Survey), which was carried out in the United States. Responses indicated that a significant majority (84.8%) of patients with tinnitus had never tried any form of remedy. Only about half of those experiencing tinnitus (50.6%) had discussed their tinnitus with a physician. The most commonly discussed intervention for tinnitus management was medical therapy such as antidepressants, anticonvulsants, and intratympanic medication. Of those, approximately 8% were advised on nutritional supplements and 4% were advised on the use of alternative medicine. These figures are similar to those reported by Sindhusake et al. (2003), where only 37% had sought professional help, and only 6% of patients reporting tinnitus received any form of treatment.

A more recent study by Vayisoglu and Gur (2020) interviewed 102 individuals with chronic tinnitus using structured questionnaires. Results showed that 11.8% of respondents were using at least one CAM method, with 83.3% having used herbal products and 16.6% having tried acupuncture. The primary reasons for using CAM were medical treatment being ineffective, hopelessness, and despair. There were no differences between CAM users and non-CAM users based on age, sex, hearing level, tinnitus duration, or educational level. None of the patients using CAM experienced any beneficial effects of the treatments on tinnitus. The respondents commented that they would not recommend CAM usage to other tinnitus patients because of the lack of benefit. Furthermore, adverse events related to the use of CAM therapies were noted. For instance, one patient experienced a tympanic membrane perforation due to the use of Ecballium elaterium oil in the ear canal. Two patients experienced nausea and stomach pain due to oral ingestion of herbal products. All patients discontinued CAM usage either due to warnings about or actual experiences of the side effects of CAM. None of the patients informed their clinicians about their CAM usage.

Theoretical frameworks invariably shape the perspectives of tinnitus clinicians and researchers about CAM. In general, Western practitioners have a pejorative opinion about CAM. This negative attitude may be because the small sample sizes and methodological pitfalls of the majority of CAM studies make it difficult to endorse these strategies to patients (Khosravi et al., 2018). However, Crundwell and Baguley (2016) showed that 44% of clinicians in audiovestibular disciplines in the United Kingdom have personally used CAM, and 79% of these were satisfied with the outcomes. This finding suggests that the lack of evidence of safety and efficacy prevents clinicians from recommending CAM, rather than a simple rejection of it as a potential management alternative.

Recent Advances

Recent studies in the area of tinnitus and CAM are reviewed in this section, with particular emphasis on the benefits and risks of several CAM approaches.

Traditional Chinese Medicine

Traditional Chinese medicine (TCM) comprises many approaches, including acupuncture, exercise, and herbal remedies. TCM purports to maintain or promote health by maintaining balance of qi (energy). According to the theory underlying TCM, qi is believed to keep the body in balance, flowing along pathways known as meridians. Pain and ill health are considered a result of a blockage or imbalance of qi. Stimulating relevant points on the body with thin needles inserted into the skin (acupuncture) or applying manual pressure (acupressure/shiatsu) is believed to clear blockages and restore the flow of qi. These stimulation points are based on the patient's symptoms. TCM in tinnitus management generally focuses on areas in the ear, but it may include other points along the meridians. Liu et al. (2016) conducted a systematic review and meta-analysis on the use of acupuncture in the treatment of tinnitus. Results suggested acupuncture treatments provided some subjective benefit over conventional therapies; however, definitive conclusions were not possible. Liu et al. (2016) found the majority of Chinese studies reported positive results; however, most studies in English reported negative results. These differences may be explained by variations in acupuncture points and sessions between Chinese and English studies but may also potentially be related to methodological flaws and risk biases prevalent in the Chinese studies. Huang et al. (2020) conducted a systematic review and meta-analysis of randomized control trials assessing acupuncture for tinnitus. Results suggested that, when compared to control groups, acupuncture had no significant effect on visual analog scale (VAS) scores but showed positive effects as measured with Tinnitus Handicap Inventory (THI) (Newman et al., 1996) and Tinnitus Severity Index (TSI) (Meikle, 1992) scores. It is important to note that the low quality of evidence and small sample sizes of the included trials meant there was insufficient evidence to draw any definitive conclusions. Manz et al. (2021) performed a randomized controlled pilot study assessing acupuncture for acute tinnitus. A total of 48 individuals were recruited and randomized either to the control group that received usual care (n = 23) or to the intervention group that received four acupuncture treatments in a 4- to 6-week period in addition to usual care (n = 25). Tinnitus severity was assessed using a visual analog scale, the Tinnitus Functional Index (TFI) (Meikle et al., 2012), and the 12-item Mini Tinnitus Questionnaire (Mini TQ) (Hiller & Goebel, 2004) at baseline and

6 weeks after. In the intervention group, clinically significant differences were seen in all outcomes, except overall well-being, from baseline to end point. However, only the subjective change in tinnitus severity showed a significant group difference. No serious side effects were observed. While adverse events with acupuncture are uncommon, there is the potential risk of infection from unsterilized equipment (Xu et al., 2013).

TCM practitioners believe the flow of qi can be controlled with specific movements and postures. Tai chi is a form of Chinese martial arts that uses a sequence of postures and flowing movements to reduce stress and to improve balance and agility. We did not find any studies of tai chi for the management of tinnitus. Qigong is a mindfulness exercise that involves coordinated movement, breath, and awareness (Yang, 2013). Biesinger et al. (2010) assessed the use of qigong for tinnitus management in 80 patients who were randomly assigned to an intervention group consisting of 10 qigong training sessions in 5 weeks or a waiting-list control group. Results showed qigong to significantly reduce both the VAS and tinnitus questionnaire (Tinnitus Beeinträchtigungs Fragebogen TBF-12) (Greimel et al., 1999) scores. Current tinnitus management guidelines suggest the use of relaxation strategies to help manage tinnitus (Tunkel et al., 2014). Tai chi and qigong may contribute to improved relaxation of patients with bothersome tinnitus. The physical exercise of tai chi and qigong may also improve overall well-being and provide an active interest and hobby to enhance overall quality of life, which may also have a positive impact on tinnitus. However, well-designed studies are needed to accept or refute these hypotheses.

No research evidence supports the use of medication or supplements in the management of bothersome tinnitus. Nonetheless, the use of dietary supplements to manage tinnitus is common (Coelho et al., 2016). The American Academy of Otolaryngology—Head and Neck Surgery Foundation (AAO-HNSF) recommended against dietary supplementation, such as ginkgo biloba, melatonin, and zinc, given the preponderance of harm over clear benefit demonstrated in randomized clinical trials for any dietary supplementation (Tunkel et al., 2014). Ginkgo biloba extract is a popular herbal treatment that has been used in TCM for thousands of years. It forms an important component of traditional Chinese pharmacopoeia, a book that lists drugs and instructions for their use (Hilton et al., 2013; Sereda et al., 2019). Ginkgo biloba is used by patients for peripheral vascular disease and cerebral insufficiency (Hilton et al., 2013). Ginkgo has two key active chemical compounds: flavonoids (ginkgo-flavone glycoside) and terpenoids (ginkgolides A, B, C, J, and bilobalide). There are several mechanisms proposed for the action of gingko on tinnitus (Hilton et al., 2013; Kleijnen & Knipschild, 1992; Sereda et al., 2019), including:

- vasoregulator, increasing blood flow (Jung et al., 1990; Költringer et al., 1989; Shu et al., 2019);
- platelet-activating factor antagonist (Braquet & Hosford, 1991; DeFeudis, 1991; Nash & Shah, 2015);
- prevention of cell damage by free radicals (Pincemail et al., 1989; Smith et al., 2013); and
- changes in neuron metabolism (DeFeudis, 1991).

A Cochrane review by Hilton et al. (2013) found no evidence that ginkgo biloba was effective in patients with a primary complaint of tinnitus. Procházková et al. (2018) investigated the effects of ginkgo biloba extract EGb 761® versus pentoxifylline in chronic tinnitus using a randomized, double-blind, double-dummy clinical trial. For both treatment groups, significant improvements were observed for the mini-TQ and the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983) anxiety score. However, it should be noted that there was no true control group in this study, and out of 200 participants there were 20 adverse events in the EGb 761® group and 36 in the pentoxifylline group. Potential side effects of ginkgo biloba include:

- gastrointestinal disturbance,
- bleeding problems,
- interaction with anticoagulant medication, and
- seizures (Ernst, 2002).

Gushen pian is a traditional Chinese herbal medicine obtained from four different herbs: drynariafortunei, danshen, calcined ci shi, and glycyrrhiza (Mahmoudian-Sani, 2019).

Zhai et al. (2013) conducted a phase two randomized double-blind trial investigating the effect of gushen pian on tinnitus. One hundred and twenty patients were randomly assigned to one of three groups: double-blind treatment, open treatment, and control. The two treatment arms were given five gushen pian tablets every 8 hours for 4 weeks. Results suggested that gushen pian significantly improved tinnitus when compared to the control group. The total effective rate, defined as tinnitus not affecting work and sleep or changing from constant to occasional, was 89.2%. The total relief rate, without recurrence in 1 month, was 59.5% in the double-blind treatment group. It is important to note that this study did not include standardized outcome measures for assessment of tinnitus. These findings await further replication and confirmation.

Traditional Korean Medicine

Practitioners of traditional Korean medicine (TKM) theorize that tinnitus is mainly caused from irregularities in bowel and visceral (zang-fu) functioning. According to TKM, gallbladder deficiency associated with tinnitus is managed with banhabaekchulchonmatang (herbal preparation), whereas bojungikgitang (also an herbal preparation) is used to manage the pattern of qi deficiency (Khosravi et al., 2018). Kim et al. (2010) published a protocol for a randomized double-blind placebo-controlled study with three arms: bojungikgitang, *banhabaekchulchonmatang,* and placebo; however, study results using this protocol have not been published yet.

The root of the Korean red ginseng plant (KRG) (panax gingseng) has been used as an ingredient in Korean medicine for more than 2,000 years. Ginseng is reported to inhibit production of reactive oxygen species (Im et al., 2010). A common cause of tinnitus is inner ear hair cell damage. Kim et al. (2015) hypothesized that the antireactive oxygen species effects of KRG may treat chronic idiopathic tinnitus. Kim et al. (2015) conducted a randomized controlled trial investigating the effect of ginseng versus ginkgo biloba extract on quality of life in patients with chronic tinnitus. Over a 4-week study period, 61 individuals with tinnitus were randomized into one of three groups: control group (160mg/day ginkgo biloba extract), group 1 (1500mg/day KRG), and group 2 (3000mg/day KRG). Results showed a significant improvement between initial and post-treatment THI and Short Form-36 health survey (Ware & Sherbourne, 1992) scores in Group 2 participants. There was, however, no statistically significant difference between initial and post-treatment VAS scores in any group.

Traditional Japanese Medicine

Reiki is a Japanese technique for stress reduction and relaxation that involves placing hands on or near the body in different positions or near specific body parts. Practitioners believe this helps direct the flow of energy to facilitate the person's own healing response. However, we found no studies of reiki in the management of tinnitus.

Yoku-kan-san is a traditional Japanese herbal medication composed from seven plants: angelicae radix, atractylodis lanceae rhizoma, bupleuri radix, poria, glycyrrhizae radix, cnidii rhizoma, and uncariae uncis cum ramlus (Khosravi et al., 2018). Okamoto et al. (2005) presented a case study of a 44-year-old woman with undifferentiated somatoform disorder, insomnia, headaches, and bothersome tinnitus treated with yoku-kan-san. They reported that yoku-kan-san was effective for tinnitus; however, they did not provide details of how this improvement was quantified. The use of yoku-kan-san as a management tool for tinnitus has not been investigated with large-scale studies or randomized control trials.

Traditional Indian Medicine

Ayurveda, referring to knowledge of life, is an ancient Indian whole-body healing system. It relies on a holistic approach for mental and physical health. Practitioners of Ayurvedic medicine believe that disease is a result of an imbalance between body, mind, and spirit. The imbalance requires purification with products mainly derived from plants. The purification is followed by diet, herbal remedies, massage, yoga, and meditation. Yoga, originally developed in India, has gained a significant interest in the West in the past century. Postures (asanas), breathing techniques (pranayama), and meditation (dhyana) are performed to increase flexibility and relaxation and to reduce stress with the goal of creating a lasting sense of grounding. Some yoga positions are claimed to address common causes of tinnitus such as stress, neck stiffness, and low blood circulation; however, there is no peer-reviewed evidence to support such claims. A systematic review by Gunjawate and Ravi (2021) exploring the application of yoga and meditation for tinnitus found four studies using different types of yoga and pranayama for tinnitus. Three studies concluded there were positive effects of yoga on tinnitus. Köksoy et al. (2018) assessed the effect of yoga in 12 patients with chronic tinnitus. Participants attended yoga classes once a week and practiced yoga at home using a worksheet for 3 months. Results showed a reduction in stress using a stress symptom scale (Hovardaoğlu, 2004), tinnitus handicap using a 5-point grading scale (Yetiser et al., 2010), and tinnitus severity using a visual analog scale. It should, however, be noted that the study was conducted on a small sample of participants with no control groups. Niedziałek et al. (2019) reviewed the efficacy of a 12-week yoga program in 25 patients with chronic tinnitus. MRIs performed before and after training demonstrated stronger connections in the white matter of the motor cortex. Yoga is generally considered safe, but injuries such as sprains and strains can occur.

Homeopathy

Homeopathy is a treatment system based on the work of Samuel Hahnemann in the 1790s. Homeopathy employs plant-based remedies to promote self-healing. Contrary to modern pharmacology, the two principles of homeopathy are:

- **Like cures like:** Practitioners believe the body's defenses can be stimulated by small doses of substances that would be harmful if given in larger doses.
- **Minimum dose:** Practitioners believe that the more a substance is diluted, the greater its power to treat symptoms. Often homeopathic remedies have been diluted so many times there are almost no particles of the original substance.

Homeopathic products are often made as sugar pellets to be placed under the tongue. Homeopathic products may also be administered in other forms such as ointments, drops, or creams. Treatments are often tailored to each person, and it is common for different people with the same condition to receive different treatments (Tyler, 2008). Simpson et al. (1998) evaluated the homeopathic preparation "Tinnitus" in a double-blind, placebo-controlled clinical trial. Perceived intensity and intrusiveness of tinnitus were assessed using a VAS, questionnaires, and a battery of audiological measurements. It was concluded that the homeopathic medicine "Tinnitus" could not be shown to be more effective than the matched placebo. Goldstein et al. (2007) evaluated the impact of the homeopathic preparation "Clear Tinnitus" on tinnitus attributes. Fifteen patients whose clinical history, physical examination, and tympanometry indicated fluctuating middle ear pressure took the preparation for 3 months. Eleven patients completed the study, with seven reporting tinnitus relief and four not responding. Without the use of a control group and the lack of an adequate sample size, no clear conclusions can be drawn from this study.

While many homeopathic products are highly diluted, some products sold or labeled as homeopathic may contain substantial amounts of harmful ingredients such as heavy metals, which may have negative health effects (Tumir et al., 2010).

Other Management Approaches

Physical Manipulation

Signs of interactions between the auditory system and the somatosensory system include gaze-evoked tinnitus; cutaneous-evoked tinnitus; motor manipulation; or forceful muscle contractions of head, neck, and limbs that induce or suppress tinnitus or affect tinnitus loudness (Haider et al., 2017). Physical manipulation therapies such as chiropractic, osteopathy, and craniosacral therapy involve manual manipulation with the goal of reducing harmful tension in muscles of the head, jaw, and neck that may contribute to tinnitus. Craniosacral therapy in particular has adherents regarding tinnitus benefit (Hill, 2015), but the benefits are not supported by evidence from clinical trials.

Hypnosis or Hypnotherapy

Hypnosis (also called hypnotherapy) involves concentrating the mind to induce a state of deep relaxation, thus allowing the subconscious mind to be more open to selective and positive suggestions. Hypnosis has been shown to be effective in a number of clinical situations, such as irritable bowel syndrome. However, the evidence for hypnosis is poor for other health problems for which it is commonly employed, such as smoking cessation (Cope, 2008). Hypnosis may provide benefit in some tinnitus participants, but how this benefit compares to more mainstream approaches is not yet clear (Luetzenberg et al., 2020). Well-designed randomized controlled trials are needed to investigate the impact of hypnosis on tinnitus.

Melatonin

Melatonin is a hormone secreted by the pineal gland to regulate the sleep-wake cycle. Laboratory studies indicate melatonin protects against cochlear damage induced by acoustic trauma and ototoxic agents (Hosseinzadeh et al., 2019). Megwalu et al. (2006) found an improvement in both THI and Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) scores in participants with tinnitus who took 3 mg of melatonin per day for 4 weeks. The impact of melatonin on sleep was greatest among patients with the worst sleep quality, but its impact on tinnitus was not associated with the severity of the tinnitus. This study did not have a placebo control and the sustainability of the benefits was not determined. Neri et al. (2009) reported improvements in both tinnitus handicap and matched tinnitus loudness associated with the use of melatonin and sulodexide in patients with chronic tinnitus. The statistical analyses of the results in this study were not sufficiently robust for it to make a major contribution and the effects on sleep were not considered as a contributory variable. There is a need for well-designed studies to investigate the role of melatonin in individuals with bothersome tinnitus in whom sleep is disrupted (and who have not benefited from more conventional sleep management techniques). Hurtuk et al. (2011) assessed the efficacy of oral melatonin as treatment for chronic tinnitus in a double-blind crossover study, comparing 3 mg melatonin with a placebo for 30 days followed by a 1-month washout period. Tinnitus matching (TM), TSI, Self-Rated Tinnitus (SRT), PSQI, and Beck Depression Inventory (BDI) (Beck et al., 1961) were administered at baseline and every 30 days thereafter to assess the effects of each intervention. A significantly greater reduction in TM and SRT scores from baseline was observed after treatment with melatonin relative to the effect observed with placebo. Abtahi et al. (2017) compared the efficacy of melatonin and sertraline in treating tinnitus, using a double-blind protocol to assign 70 patients to either group 1 (3 mg melatonin once daily for 3 months) or group 2 (50 mg sertraline once daily for 3 months). THI scores in both groups decreased significantly, but the use of 3 mg melatonin once daily was more effective, with a greater reduction in THI scores. The lack of a control group in this study makes it difficult to draw meaningful conclusions from the data.

Future Directions

CAM is widely used across the globe for many conditions including tinnitus. It is clear that further rigorous and high-quality controlled studies with larger sample sizes should be conducted to confirm the efficacy of CAM. Until this evidence exists, CAM management strategies for tinnitus should be evaluated with care.

Clinical Implications

CAM is widespread in the attempted management of tinnitus patients, and indeed among audiovestibular clinicians (Crundwell & Baguley, 2016). As such, clinicians should take care not to be dismissive of CAM. However, the use of CAM is not without risk. Examples of risk include the interactions of St. John's wort with other medications, the possibility of burns with ear candling, and the possible inclusion of heavy metals in some supplements. Additionally, data indicate that exposure to multiple ineffective therapies can have negative psychological effects and preclude benefit from clinically proven interactions for tinnitus (Andersson, 1997). Where CAM is not reimbursed as part of conventional healthcare policies, there are monetary side effects. At present, there is no clear evidence that specific CAM approaches produce benefit for persons with bothersome tinnitus. Therefore, patients should be counseled to consider only evidence-based management options, as reviewed in other chapters of this book.

Key Messages

- The use of CAM is highly prevalent and may be driven by dissatisfaction with traditional medicine.
- There may be some benefits for people with tinnitus in the use of CAM from secondary effects upon well-being. However, there is no clinical trial evidence to definitively support the use of any CAM approach in tinnitus.
- Use of CAM in tinnitus management carries several risks. These may be financial, physical, and/or emotional. Disappointment from the use of CAM may reduce the efficacy of other evidence-based therapies.

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16 VALUES-LED CARE IN TINNITUS

Helen Pryce

Introduction

Over the last decade, there has been an increasing interest in values-led healthcare. These values are ethical principles of delivering healthcare that are respectful of patient autonomy, equitable, beneficial, and limit harm (Beauchamp, 2007). This chapter examines how clinicians can ensure their care for people with tinnitus respects and upholds these values and is sensitive to the patient's individual preferences.

A significant recent advancement in tinnitus management is increased awareness and knowledge of patient experience and perspective. For instance, studies on patient experience provide valuable new insight into the activities that promote autonomy and those that limit it (Pryce, Hall, Shaw, et al., 2018). This chapter examines the process of humanizing tinnitus care by positioning patients as experts in their own circumstances and needs, promoting the value of autonomy (Todres et al., 2007). We will describe how to negotiate with a patient and agree to the best management approach for each individual, given his or her circumstances.

In the United Kingdom, specific careers in hearing therapy have been commonplace since the early 1980s. In addition, some audiologists and physicians also provide tinnitus services but may lack specific training in psychotherapeutic approaches. Elsewhere, psychotherapists, psychologists with expertise in hearing, and audiologists with counseling and psychology training work in similar ways. For ease, this chapter addresses all these professionals as "clinicians." This is designed to encapsulate both the distinct professional group of hearing therapists as well as other professional groups who adopt a therapeutic approach to the care of people with tinnitus.

Background

How we live with a health condition can influence how we experience it (Granberg et al., 2014). The World Health Organization (WHO)'s International Classification of Function (ICF) (WHO, 2012) has described a shift in view in healthcare from a primarily biomedical model of health to a biopsychosocial model. The revised model emphasizes modifiable features in all health conditions, including psychological and social features. Modifiable features are those that can be modified to change the experience of the health condition without altering underlying pathology. There is a consensus that disadvantage from a health condition is not directly a result of the health condition alone but brought about through a combination of psychological and social factors (WHO, 2012).

Within this framework, we can view tinnitus as a symptom that may have little relationship with underlying pathophysiology, but that does have features that can be modified. In other words, people can perceive tinnitus less often and be less bothered by it with a psychological or social change rather than with a physiological change.

Recent Advances

Providing Benefit and Reducing Harm

Therapeutic approaches reduce suffering from tinnitus (Cima et al., 2019; Lewis et al., 2020; National Institute of Health and Care Excellence (NICE), 2020). The process of therapy has been described as "turning a full stop into a comma" (Orbach, 2018); that is, while therapy does not necessarily fix the problem, it provides the opportunity and space for the patient to explore their tinnitus. In doing so, it shifts perspective to the possibility of living with rather than suffering from tinnitus (Orbach, 2018). A therapeutic conversation considers the patterns of thinking and feeling that enhance distress. These patterns can be discussed openly and the patient can become more aware of the thoughts that maintain and enhance distress, as well as the thoughts that can reduce it (Dauman & Erlandsson, 2012; Pryce, Hall, Shaw, et al., 2018). Thoughts about tinnitus can be transformed through therapy and, in doing so, the perception about it can be dramatically altered (Dauman & Erlandsson, 2012; McKenna et al., 2014). This does not mean that simply talking about tinnitus is a panacea for all, but it is an important contribution to renewed and improved coping for many.

To illustrate how careful conversations can help patients, we have included some data excerpts from 41 in-depth qualitative interviews with people experiencing tinnitus. These interviews, part of a study of patient values and preferences for care, took place between January 2016 and June 2017 (see Pryce, Durand, et al., 2018; Pryce, Hall, Marks, et al., 2018; Pryce, Hall, Shaw, et al., 2018). The interviews were conducted by skilled qualitative researchers. The research participants were adults who had sought help via clinical services from hearing therapists, audiologists, and audiovestibular physicians. Their interviews took place at their homes and lasted approximately an hour. Interview data were transcribed and analyzed using cross-comparative grounded theory methods. These data illustrate the preferences participants hold for their management strategies.

Listening to patients with bothersome tinnitus is more important than instructing or giving information to them (Dauman et al., 2015; Pryce, Hall, Marks, et al., 2018). Careful questions can shape a conversation to enable a shift in perspective. Listening is vital to gaining a case history that contains not only medical information, but also the patient's values and preferences. The ability to listen to both directly and indirectly communicated information is key to understanding patient perspective. People, especially people in distress, do not necessarily communicate everything that is important to them verbally and directly. Instead, they pause, make throwaway comments, or communicate nonverbally through gesture or posture (Midwinter & Dickson, 2015). A skilled clinician can notice these shifts in communication.

> *Example: Patient describes what their tinnitus is like at present: "If I do this [gestures listening from both ears] it's OK. If I do this [gestures lying on a pillow blocking one ear] I'm totally screwed."*

In this example, the patient's language suggests an all-or-nothing perspective that equates hearing tinnitus to being "totally screwed." There is more meaning being communicated here than a literal description. There is a depth of feeling, a sense of hopelessness and passivity that is communicated in the choice of language. A skilled clinician notices both the literal meaning (if hearing is blocked, the tinnitus is perceived as worse) and the indirect meaning (if tinnitus is heard, it brings a sense of hopelessness and lack of control). Having opportunity to talk about these indirectly communicated thoughts and views can be very helpful. Patients themselves may not notice or think about their fears and thoughts about a tinnitus sound. They simply experience distress. A clinician can reflect their language back to the patient to enable them to hear it clearly and consciously. In this way, patients can share the acknowledgment of the impact of their experience. This acknowledgment is crucial to processing the emotion or distress that accompanies tinnitus. Once the emotions are named and defined, the real impact of the experience can be explored. By exploring impact in collaboration with a clinician, the patient is no longer alone in their management. They have support and validation.

Tinnitus can be quite distressing because it is a private experience. Without any social recognition of the perceived tinnitus sound, it can become a frightening experience. Perceiving tinnitus can even trigger a phobic reaction. Simply describing the experience to someone else and having them listen is enormously powerful, as these individuals describe (Cherian & Kahn, 2011; Dauman & Erlandsson, 2012; Dauman et al., 2015; Pryce, Hall, Shaw, et al., 2018, p. 788).

> *I think the discussion that she and I had was really helpful.*
>
> *Ultimately, it's very good to talk to someone who knows a lot . . . when you sit down one on one with someone who knows a good deal about it, then it's like, "Okay, it's not bad. It's not comfortable but there are things we can do to help and then we're going to do them."*
>
> *It helps so much to sit down and talk to other people and you're not alone.*

Patients are describing inexpensive and accessible aspects of care in these examples. Clinician attributes of compassion, caring, honesty, and kindness are helpful in these encounters. These qualities underpin values-led care (Halligan, 2008).

Insights From Sociological Perspectives of Health

Listening to patients helps validate their experience (Dauman et al., 2015; Pryce & Wainwright, 2008). Balint (1957) first described the implications of the Cartesian dualism that exists in healthcare where disorders of the body are separate from and afforded more status than disorders of the mind. Since then, sociologists have explored the social value systems around help seeking in healthcare. When a condition is not visible or easily quantifiable (such as tinnitus), it presents an immediate risk of patients' problems and experiences being deemed inferior to those with visible and measurable complaints. The cultural norms around illness and help seeking are ingrained in Western culture. Additionally, there are unspoken hierarchies in social value (Ferrari et al., 2006).

- Visible health conditions borne bravely: high social value.
- Visible health conditions borne with complaint: less social value.
- Nonobservable health conditions borne bravely: less social value.
- Psychologically based illnesses: lower social value.
- Malingering: lowest social value.

A visible acute condition, which fits medicalized models of health, is afforded more understanding and sympathy than a chronic nonobservable condition. Chronic conditions, which may be influenced by mental health and subject to stress reactions, receive less sympathy. The danger is that we apply a medicalized approach to our health management to attain a validity to the symptom set. Such conditions are increasingly common (Nimnuan et al., 2001). Nonspecific syndromic conditions (such as psychogenic seizures, chronic fatigue, chronic pain, irritable bowel syndrome and, more recently, the rise of food intolerances) illustrate a rise in real and distressing, but not necessarily medically based, symptoms. Some tests may not reveal the underlying pathophysiology of the condition but may help justify its realness for the patient. For instance, tinnitus pitch- and loudness-matching tests may serve to communicate a sense of validation of the experience the patient is describing. From the patient's perspective, it is important to be believed and to be taken seriously.

However, clinicians should remember that there is a risk of harm in these tests as well. It is important for clinicians to convey to their patients that chronic subjective tinnitus may not necessarily have a medical basis that can be cured following some form of treatment. If tests are not accompanied by detailed, evidence-based explanations, there is a risk of breakdown in the relationship and an increase in distress for the patient. In short, it can cause iatrogenic harm. In such circumstances, patients may lose faith in the clinician's ability to help them (Pryce & Wainwright, 2008) and may not believe the clinician (Balint, 1957; Pryce & Wainwright, 2008).

Hearing therapy approaches involve considerable information sharing and counseling, and this is increasingly being adopted by other audiological professionals (Pryce, Hall, Marks, et al., 2018). Clinicians communicate what is known about tinnitus thoroughly and clearly so that their patients become collaborators in understanding how the symptoms occur, how they are influenced, and how they are shaped by activity (Pryce, Hall, Marks, et al., 2018). This enables the patients to make predictions about how their actions will impact their perception.

The Case History Assessment

We have evidence from patients about what factors they value in clinical interactions (Pryce, Hall, Marks, et al., 2018). The most helpful interactions are those in which appointments are framed as shared exploration of tinnitus, factors that influence it, and the impact that tinnitus has on daily life. Open questioning is key to successful history taking because a lot of relevant information can be obtained via this approach. The way patients emphasize some parts of their history can reveal their thoughts, assumptions, and values. This information is needed to produce a rich case history. In chronic conditions, patients' views, values, and preferences provide important guidance for management. Compare the information gained in these two examples (Pryce, Hall, Marks, et al., 2018, p. 639):

> *Patient: What I understand now to be tinnitus, I've probably had for a long time. But it only became very noticeable in May of this year.*
>
> *Clinician: OK, so something happened in May this year?*
>
> *Patient: Something turned up the feedback and now I've got a whine on top of the whooshing.*
>
> *Clinician: OK, and how does the tinnitus affect you? So, the new noise, something shifted in May and how are you dealing with it?*
>
> *Patient: Initially I was pretty stressed.*
>
> --
>
> *Clinician: Did it start suddenly or gradually?*
>
> *Patient: Gradually.*
>
> *Clinician: Did anything trigger it?*
>
> *Patient: Er…I don't know.*
>
> *Clinician: Does it affect your sleep?*
>
> *Patient: Yes.*
>
> *Clinician: Can you continue with sports?*

Really listening to the patient's account provides a rich picture of the patient's experience. These responses tell the clinician about the coping profile of the individual patient and the values the patient holds. For instance, in the first excerpt, the patient revealed that the additional sound was a source of stress. So, helping the patient cope with changes in sound might be a target for therapy.

The second list of closed questions provide little novel insight for the clinician. How do they know what to prioritize? What's the most important issue? This is often the product of a service prioritizing consistency in information gathering over patient care. We must be wary of guidelines that constrain the way clinicians can care for their patients, requiring an algorithmic approach—for example, services that require their staff to behave in identical ways with different patients or to follow an identical sequence of inquiry. This approach may get in the way of noticing values and preferences in each individual patient.

The first and most important step clinicians take after gathering case history is to provide to the patient a clear explanation about tinnitus. This includes what we know about tinnitus *from research and experience*, and what we don't know *about this case*. The ability to tailor information that is relevant will vary—e.g., emphasis on link to hearing loss, description of the role of stress, and the relevance of otological history. Patients typically want targeted information when they seek help (see Pryce, Hall, Shaw, et al., 2018). Patients are heterogeneous by nature, with varying preferences.

> *I think the science is really important and, for me, understanding the science is important, even if the outcome is [that] there's nothing you can do about it. I want to understand as far as I can what's going on but equally, for me, the psychological approach is also really important. I mean, I'm not a medical person but I have a suspicion that health and well-being are very much tied up with psychological well-being and that,*

> *therefore, I suppose that's part of my strategy of denial, in a way, that actually, the longer I go on saying this isn't a problem and I'm going to ignore it, it seems to work.*
>
> *Well, what I most want to hear is a definitive answer—whether I'm stuck with this for life, or whether there's any real chance of an eventual recovery? Is this going to ever go away? That's what I want to know. That's all I want to know. Will I ever get my hearing back to normal?*

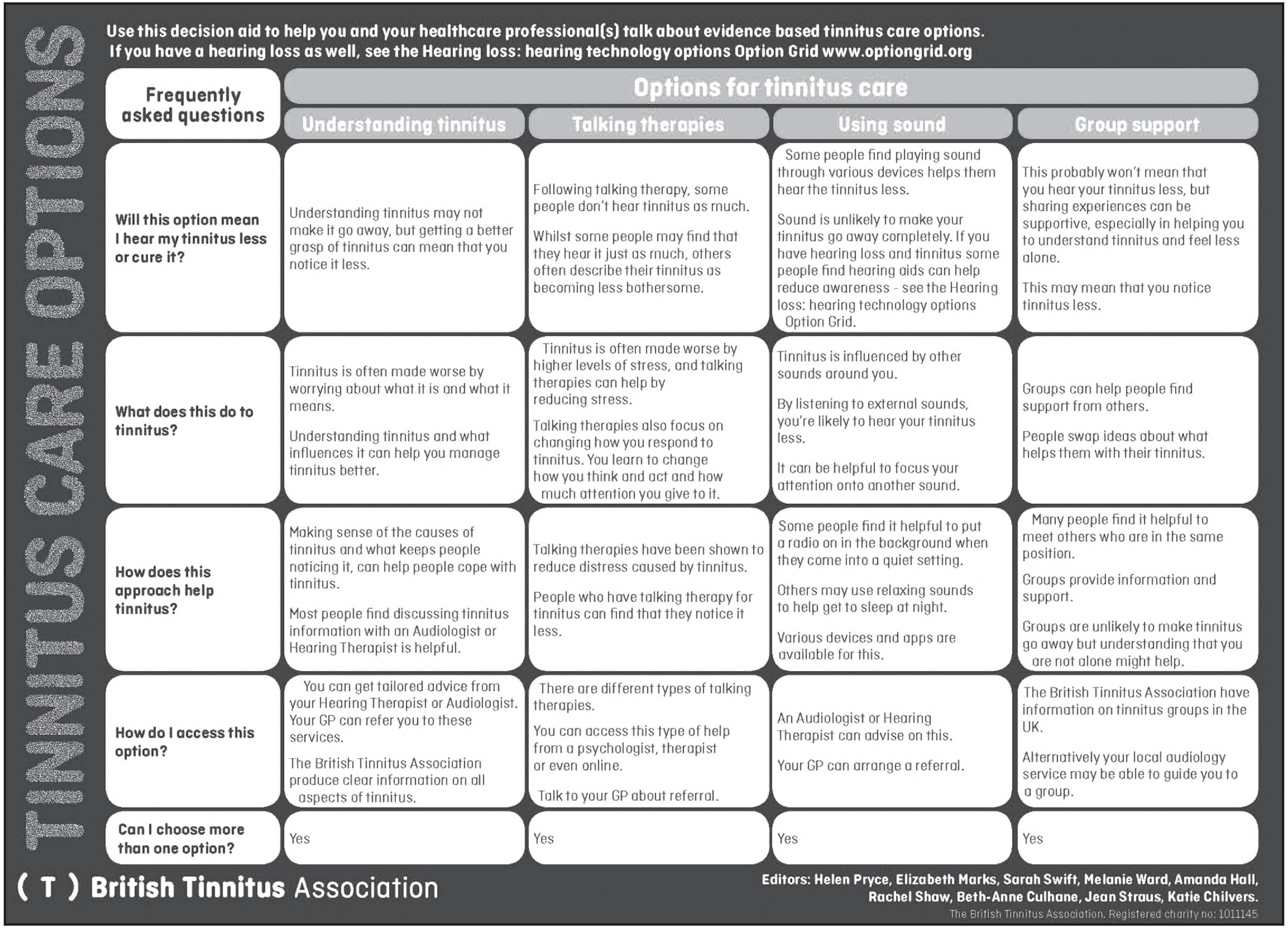
These examples illustrate the advantage of a conversation over the presence of information on the internet or from other sources. Patients appreciate a discussion that focuses on their individual profile. In particular, it helps the clinician to hear patient preferences for both management strategies and outcomes. These are often confused by both clinicians and patients but are important to clarify—stating that one wants to stop hearing tinnitus is not the same as agreeing to a course of action.

Promoting Autonomy and Equity Through Shared Decision Making

There is a global move to recognizing the importance of working with patient values and preferences in healthcare (Greenhalgh et al., 2014). This represents a shift in our understanding of evidence-based healthcare away from algorithmic prescription of care, based on effect size of various treatments, to an interpretive and values-based negotiation of care planning based on individual preferences (Djulbegoric & Guyatt, 2017). Shared decision making is a fundamental part of practicing evidence-based healthcare.

Currently, evidence-based management options for tinnitus involve psychological therapies such as cognitive behavioral therapy, mindfulness-based cognitive therapy, and acceptance and commitment therapy (please refer to Chapter 11 for additional details). There are also multiple acoustic interventions, including hearing aids and sound therapy options, which remain popular with both patients and clinicians, although research support is limited (Hoare & Hall, 2010) (please refer to Chapter 10 for additional details). Clinical options are only viable if they are offered in a way that the patient can readily access them. The consideration of all options is vital. Recent evaluations of clinical practice have shown that the use of decision aids enhanced communication and reduced patient decisional conflict (Pryce et al., 2021). Clinical care is an interpretative process that is best based on collaboration between patient and clinician through shared decision making. The first principle of shared decision making is that all possible options should be shared and considered. In practice, this means using decision aids to communicate existing options. Decision aids are tools that compare and contrast different management options to provide the patient and clinician with sufficient information to make a choice. The recent development of the U.K. decision aid for tinnitus (http://www.tinnitus.org.uk/decision-aid) is a clear example (Figure 16–1).

The decision aid was developed through a systematic process following internationally agreed-upon standards for development (Pryce, Durand, et al., 2018). Free-to-access videos are available describing its use and illustrating its application (http://www.tinnitus.org.uk/decision-aid). The challenge for the clinician is to acknowledge the autonomy of the patient to engage with this process and contribute to interpreting the available



TINNITUS CARE OPTIONS

Use this decision aid to help you and your healthcare professional(s) talk about evidence based tinnitus care options.
If you have a hearing loss as well, see the Hearing loss: hearing technology options Option Grid www.optiongrid.org

Frequently asked questions	Options for tinnitus care			
	Understanding tinnitus	Talking therapies	Using sound	Group support
Will this option mean I hear my tinnitus less or cure it?	Understanding tinnitus may not make it go away, but getting a better grasp of tinnitus can mean that you notice it less.	Following talking therapy, some people don't hear tinnitus as much. Whilst some people may find that they hear it just as much, others often describe their tinnitus as becoming less bothersome.	Some people find playing sound through various devices helps them hear the tinnitus less. Sound is unlikely to make your tinnitus go away completely. If you have hearing loss and tinnitus some people find hearing aids can help reduce awareness - see the Hearing loss: hearing technology options Option Grid.	This probably won't mean that you hear your tinnitus less, but sharing experiences can be supportive, especially in helping you to understand tinnitus and feel less alone. This may mean that you notice tinnitus less.
What does this do to tinnitus?	Tinnitus is often made worse by worrying about what it is and what it means. Understanding tinnitus and what influences it can help you manage tinnitus better.	Tinnitus is often made worse by higher levels of stress, and talking therapies can help by reducing stress. Talking therapies also focus on changing how you respond to tinnitus. You learn to change how you think and act and how much attention you give to it.	Tinnitus is influenced by other sounds around you. By listening to external sounds, you're likely to hear your tinnitus less. It can be helpful to focus your attention onto another sound.	Groups can help people find support from others. People swap ideas about what helps them with their tinnitus.
How does this approach help tinnitus?	Making sense of the causes of tinnitus and what keeps people noticing it, can help people cope with tinnitus. Most people find discussing tinnitus information with an Audiologist or Hearing Therapist is helpful.	Talking therapies have been shown to reduce distress caused by tinnitus. People who have talking therapy for tinnitus can find that they notice it less.	Some people find it helpful to put a radio on in the background when they come into a quiet setting. Others may use relaxing sounds to help get to sleep at night. Various devices and apps are available for this.	Many people find it helpful to meet others who are in the same position. Groups provide information and support. Groups are unlikely to make tinnitus go away but understanding that you are not alone might help.
How do I access this option?	You can get tailored advice from your Hearing Therapist or Audiologist. Your GP can refer you to these services. The British Tinnitus Association produce clear information on all aspects of tinnitus.	There are different types of talking therapies. You can access this type of help from a psychologist, therapist or even online. Talk to your GP about referral.	An Audiologist or Hearing Therapist can advise on this. Your GP can arrange a referral.	The British Tinnitus Association have information on tinnitus groups in the UK. Alternatively your local audiology service may be able to guide you to a group.
Can I choose more than one option?	Yes	Yes	Yes	Yes

(T) **British Tinnitus** Association

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The British Tinnitus Association. Registered charity no: 1011145

Figure 16–1. The international standard tinnitus care decision aid. Used with permission from the British Tinnitus Association.

options. Each option for tinnitus management has drawbacks that need to be considered carefully. For example, psychological management strategies require patient time and motivation to attend appointments and complete engagement, while managing devices may take time to use and practice. In most chronic conditions, the responsibility to manage the condition and engage with management options falls on the patient (Montori, 2017). Therefore, the pros and cons of interventions can only really be considered in the context of the burden it will place on the patient. So, a discussion of interventions needs to be accompanied by a discussion of the potential burdens.

Equitable Access to Deciding on a Management Strategy

Weighing the pros and cons of management options is a critical part of the therapeutic discussion. With this discussion, a first-choice intervention is determined and expectations of the interventions are clearly established. The process of shared decision making can contribute to improvements in patient uptake and use of services (O'Connor et al., 2003). Additionally, patients are more satisfied with management options delivered using this approach (Elwyn et al., 2012). Selecting a management strategy requires the clinician to pay close attention to patient preference of suggested options. It is unlikely that someone who does not value psychological therapies will benefit from a psychological therapy unless they can be persuaded of its merits. The clinician's job is to notice the response and to provide the information the patient may lack. This includes describing the mechanisms by which a management option for tinnitus can work, the likely effect size of the management option, and the practicalities of undertaking the management.

With a truly patient-centered approach, there is no conflict between the patient's and clinician's preferences. The patient has ultimate control over his or her situation, whereas the clinician's role is to support the patient's decision making by providing crucial information. The choice of intervention ultimately falls to the patient, who will have to live with the consequences of the choice.

A working alliance should be agreed upon between the patient and the clinician at the beginning of therapy sessions (Midwinter & Dickson, 2015). This discussion should include the number and frequency of sessions, the clinician's role, and the arrangements for ending the sessions. This working alliance is key to structuring the relationship safely and in a way that leaves both parties clear on what they can expect.

It is good practice to review the therapy goals midway through the appointments. It is important to convey to patients that they may be more aware of their tinnitus simply by seeking help and working to manage it. Clear indicators of success—which may vary for each individual—should be agreed upon in advance. These indicators could be behavioral (e.g., regular use of distracting sound when entering a quiet place), cognitive (e.g., forming challenges to negative intrusive thoughts), or lifestyle related (e.g., getting a better sleep routine or planning for nighttime waking).

Measuring the impact of tinnitus management on the patient is important. The typical way of evaluating a service is via a Patient Reported Outcome Measure (PROM) (Kingsley & Patel, 2017). Such measures can be structured validated questionnaires. One example is the Tinnitus Function Index (Meikle et al., 2012), which has been validated as a reliable way to measure impact of tinnitus on an individual (Fackrell et al., 2016; Meikle et al., 2012). Alternatively, a patient-generated measure can be helpful in targeting the changes that each individual prefers to make. The Client Orientated Scale of Improvement (COSI) is commonly used in the United Kingdom for this purpose (Dillon et al., 1997). It was revised to target tinnitus changes (Client Orientated Scale of Improvement in Tinnitus (COSIT) (Searchfield, 2019). With this measure, patients rate key changes they would like to make regarding tinnitus and then prioritize them. This is a helpful structure for therapeutic discussions and exploring what changes are required (Atkisson, 1982). There is also a need for patient reported experience measures (PREMs) to capture the burden of change and management for the individual with tinnitus (Kingsley & Patel, 2017). As yet, we do not have a targeted PREM for tinnitus care. Clinicians should endeavor to capture patient experience of management as part of the evaluation of their service provision.

Future Directions

The future direction for therapeutic care of people with tinnitus is increased engagement with patient preferences and values. This focus is on identifying what matters to a specific patient in specific circumstances. Explicit discussion of values and preferences is also helpful for the patient in examining their own responses and reactions to the tinnitus. Patterns of psychological adjustment to tinnitus indicate that preferences for management may shift as the patient lives successfully with their tinnitus (Pryce, Hall, Shaw, et al., 2018). Patients' core values influence their preferences in determining which management approach is right for them. Some people will find the sense of control that sound therapy or hearing aids provide helpful (Munir & Pryce, 2020). Others will appreciate the psychological adjustment that a psychological therapy can offer. A therapeutic approach will identify what matters most, what management will fit with the patient's preferences, what the patient's values are, and what will fit the patient's life. This approach promotes benefit over harm.

Clinical Implications

Values-led care is a means to an evidence-based healthcare tinnitus service. Clinicians offer values-led integration of what is known about a management strategy from evidence-based guidelines and research literature. Management requires careful communication skills designed to notice what works for each patient and to facilitate a clear discussion about hopes and fears for the tinnitus experience. The counseling and communication skills of clinicians are not a simple add-on to care. They are the heart of care. As Montori (2017) writes:

> *Evidence-based medicine cannot contribute to careful care without accounting for the unique situations patients face. The human ability to address these problems in conversation must be protected and enhanced.* (p. 127)

Skilled conversation is an opportunity to explore patient perspectives, values, and preferences (respecting autonomy). Shared decision making of management options is vital to ensure we judge the tradeoff of benefits and harms correctly (only the patient knows where this tipping point lies for them). Finally, by sharing information about options, we are sure to provide an equitable service where all have equal opportunity to self-determine benefit.

Key Messages

- Listening matters.
- Use questions carefully and selectively.
- Observe what the patient communicates indirectly.
- Patients seek help for validation, not just to get rid of tinnitus.
- We validate by listening and being congruent and honest in our communication.
- Beware of platitudes and reassurances—they can be interpreted as dismissive.
- Diagnose patient values and preferences both for the outcome of management and for the management itself.
- There are tradeoffs with every management approach.
- Weigh the pros and cons of each management strategy with your patient.
- Decision aids can help with communicating the pros and cons of different options.
- Measure both outcomes and patient experience to achieve these outcomes.
- Negotiate management choices.

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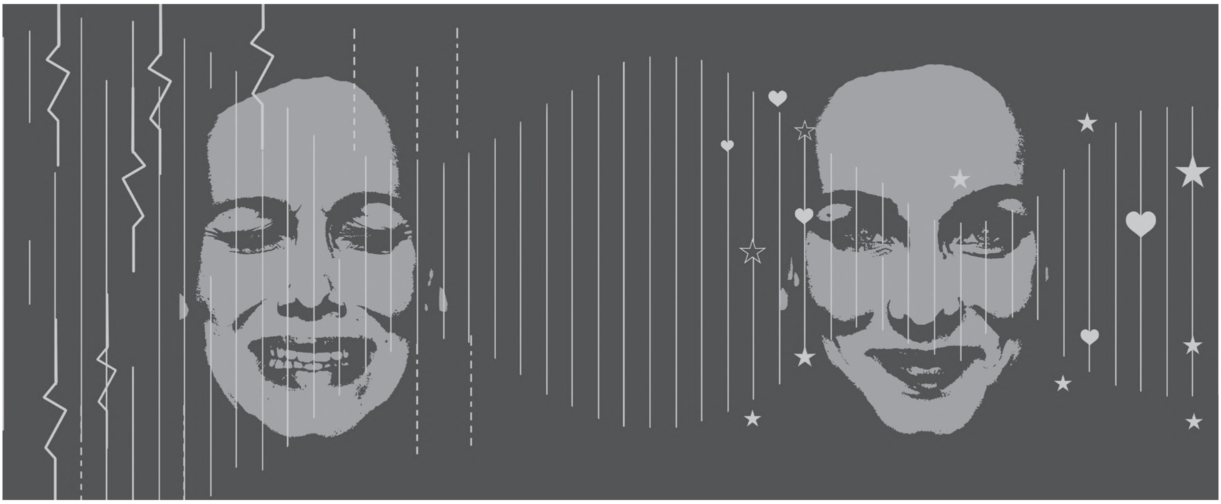
SECTION IV

HYPERACUSIS



17 HYPERACUSIS AND MISOPHONIA

Hashir Aazh

Introduction

There are several definitions of hyperacusis. One definition is intolerance of everyday sounds that causes significant distress and impairment in social, occupational, recreational, and other day-to-day activities (Aazh, Knipper, et al., 2018; Aazh et al., 2016). Another definition of hyperacusis is reduced tolerance to sounds that are perceived as normal by the majority of the population or were perceived as normal to the person before their onset of hyperacusis (Adams et al., 2021). The definition proposed by Aazh et al. (2016) suggests that hyperacusis can only be present if the sound intolerance leads to a significant distress. This is different from the definition proposed by Adams et al. (2021), which considers hyperacusis as present if the person experiences reduced tolerance to sound whether it causes distress or not.

In addition to the experience of discomfort when hearing certain loud sounds, individuals with hyperacusis often report physical symptoms such as headaches, balance problems, dysosmia (distortion of smells), and light sensitivity (Ke et al., 2020). More than 30% of people seeking help for their tinnitus and about 80% of patients with severe tinnitus handicap as measured via the Tinnitus Handicap Inventory (THI) (Newman et al., 1998) report hyperacusis (Aazh, Baguley, et al., 2019; Aazh & Moore, 2019; Cederroth et al., 2020).

In a review paper, Tyler et al. (2014) described four categories of hyperacusis based on the patient's reactions to sound, including: (a) loudness hyperacusis, (b) fear hyperacusis, (c) pain hyperacusis, and (d) annoyance hyperacusis. According to this taxonomy, patients experience loudness hyperacusis if moderately intense sounds are judged to be uncomfortable (Tyler et al., 2014). Patients with loudness hyperacusis often present with abnormally low uncomfortable loudness levels (ULLs), also known as loudness discomfort levels (LDLs) (Aazh & Moore, 2017b; Formby et al., 2007). This chapter uses the term ULL. Fear hyperacusis is defined as an aversive reaction to sounds that results in an anticipatory and avoidance behavior (Tyler et al., 2014). Pain hyperacusis is characterized by the perception of pain at sound levels that typical listeners would not perceive as painful. Several authors reported that ULLs can be as low as 30 dB HL in cases of severe hyperacusis (Aazh & Moore, 2018b; Sheldrake et al., 2015; Zaugg et al., 2016). Therefore, it is not surprising that, for patients with atypically low ULLs, a wide range of day-to-day environmental sounds might be perceived as uncomfortably loud or painful. Finally, annoyance hyperacusis is the experience of negative emotional reactions to particular sounds or groups of sounds, regardless of their loudness (Tyler et al., 2014). There is some overlap between annoyance hyperacusis and another disorder of decreased sound tolerance referred to as misophonia. Misophonia is defined as a high magnitude of emotional and behavioral reaction to repetitive and pattern-based auditory stimuli produced by human beings, such as eating sounds and breathing sounds (Erfanian et al., 2019; Jastreboff & Jastreboff, 2003). A recent study with Delphi design developed a consensus definition for misophonia as a disorder of decreased tolerance to specific sounds or stimuli associated with such sounds (Swedo et al., 2021). Some researchers classify misophonia as a psychiatric disorder (Jager et al., 2020; Schroder et al., 2013), whereas others suggest a possible neurological underlying mechanism (Cavanna & Seri, 2015; Kumar et al., 2017; Robinson et al., 2018). There are some similarities between hyperacusis and misophonia, as in both conditions the sufferers experience intolerance to certain sounds that causes significant distress and impairment in their social, occupational, recreational, and other day-to-day activities. However, there are significant differences in contextual and psychoacoustical properties of the sounds that the individuals with hyperacusis and misophonia find intolerable (Enzler, Fournier, et al., 2021; Enzler, Loriot, et al., 2021). Moreover, there are significant differences in cognitive, behavioral, and emotional reactions to sounds between the individuals with hyperacusis and misophonia (Aazh, Landgrebe, Danesh, & Moore, 2019). These findings mean that hyperacusis and misophonia are likely to be distinct disorders of sound intolerance (Kumar et al., 2021). The aims of this chapter are to review recent studies exploring: (a) prevalence of hyperacusis and misophonia in different populations and factors related to them, (b) neurobiological mechanisms of hyperacusis and misophonia, and (c) diagnostic methods and treatment strategies.

Background

Hyperacusis in Adults

The prevalence of hyperacusis in the general population is not well defined. A survey in Sweden using four questions related to sound intolerance reported that about 9% of 1,184 participants had hyperacusis (Andersson et al., 2002). Paulin et al. (2016) conducted another survey with 3,406 respondents (40% response rate) from the general population in Sweden. They used a single question to determine the presence of hyperacusis: "Do you have a hard time tolerating everyday sounds that you believe most other people can tolerate?" They reported that about 9% of the participants responded affirmatively to this question. This contrasts with the fact that only 1.9% of the participants reported having received a diagnosis of hyperacusis from a physician (Paulin et al., 2016). The discrepancy could reflect lack of awareness about hyperacusis among healthcare professionals leading to underdiagnosis of this condition. On the other hand, it may reflect that hyperacusis is not simply an oversensitivity to certain sounds. Many people are disturbed by certain sounds (e.g., deep or shrill motorbike noises or the sound of fingernails on a blackboard) but the bothersome sounds do not cause significant distress or interruption in their daily life. In fact, sensitivity to noise may be classified as a personality trait, not necessarily a disorder of sound intolerance (Gille et al., 2016; Shepherd et al., 2016; Weinstein, 1978). Only when the intolerance to certain sounds leads to distress and anxiety in everyday life may people be diagnosed with hyperacusis (Aazh et al., 2016). So, it is possible that these estimates might change if hyperacusis is identified with clinical interviews or validated hyperacusis questionnaires. A recent study that used a Turkish version of the Khalfa Hyperacusis Questionnaire (HQ) (Khalfa et al., 2002) reported that only 3.2% of the 529 participants recruited from an online forum in a medical university in Turkey had hyperacusis (Erinc & Derinsu, 2020).

Hyperacusis in Children

A systematic review noted that the prevalence of hyperacusis in children and adolescents reported in different studies varied from 3.2% to 17.1% (Rosing et al., 2016). Hall et al. (2015) reported that 3.7% of a sample of 7,097 11-year-old children in the U.K. responded affirmatively to a single question about whether they “ever experience oversensitivity or distress to particular sounds.” It is also known that hyperacusis is more prevalent among children with autistic spectrum disorder than the general pediatric population (Danesh et al., 2015; Ralli et al., 2020). Aazh, McFerran, and Moore (2018) assessed the incidence of hyperacusis as measured via a ULL-based criterion among 62 children and adolescents seen at an audiology outpatient tinnitus and hyperacusis service. Ten patients (16%) were referred because they had tinnitus with no sound intolerance complaint, 33 (53%) had sound intolerance complaints without tinnitus, and 19 (31%) had a combination of tinnitus and sound intolerance complaints. Hyperacusis was defined by an average ULL at 0.25, 0.5, 1, 2, 4, and 8 kHz for the ear with the lower average ULL (which is denoted as ULLmin) of ≤ 77 dB HL (Aazh & Moore, 2017b). The ULLmin diagnostic criteria differentiates hyperacusis from loudness recruitment. Loudness recruitment is a consequence of sensorineural hearing loss in which loudness perception grows rapidly at intensity levels just above the threshold of hearing (Stach, 1997). In cases of loudness recruitment, ULLmin is likely to be more than 77 dB HL, mainly due to the presence of moderate or severe hearing loss (Aazh & Moore, 2017b; Moore & Glasberg, 2004). Severe hyperacusis was categorized by a ULL of 30 dB HL or less for at least one of the measured frequencies for at least one ear (Aazh & Moore, 2018b). Results showed that 85% of the children/adolescents met the criteria for hyperacusis and 17% met criteria for severe hyperacusis. The high prevalence of hyperacusis in this study can be explained by the characteristics of the sample—50 out of the 62 patients were referred because of sound intolerance problems, either alone or in combination with tinnitus. A recent cross-sectional study with Danish children aged 10 to 16 years suggested that 14.6% of the participants reported symptoms of hyperacusis. The odds of having hyperacusis symptoms were approximately five times higher among those with tinnitus compared to those without tinnitus (Nemholt et al., 2020).

Hyperacusis and Mental Health

The relationship between hyperacusis and mental illness has been highlighted in audiology literature by several authors (Aazh & Moore, 2017d; Blaesing & Kroener-Herwig, 2012; Fackrell et al., 2015; Greenberg & Carlos, 2018, 2019). However, there has been little research on the impact of adverse childhood experiences as a risk factor for being affected by hyperacusis in adulthood. Adverse childhood experiences are defined as exposures to different forms of abuse (e.g., physical, emotional, or sexual) and family dysfunction (e.g., substance abuse, mental illness, mother treated violently, incarcerated household member, or parental separation) (Felitti et al., 1998). There is a strong relationship between childhood exposure to abuse and household dysfunction and self-reported disability in adulthood (Schussler-Fiorenza Rose et al., 2014). The relationship remains strong and statistically significant even after adjusting for physical and mental health conditions (Schussler-Fiorenza Rose et al., 2014). Parental separation and parental poor mental health are important forms of adverse childhood experiences with prevalence of 23.3% and 19.4%, respectively. In the past 5 years, there has been a series of studies aiming to assess the relationship between the severity of hyperacusis handicap and history of parental mental illness and parental separation in childhood (Aazh, Danesh, & Moore, 2019; Aazh, Landgrebe, & Danesh, 2019; Aazh, Langguth, & Danesh, 2018; H. Aazh et al., 2020). These studies indicated that children whose parents suffered from a mental illness were at higher risk of developing greater hyperacusis handicap as adults (as measured via HQ) compared with those without a childhood history of parental mental illness (adjusted odds ratio was 6.7, $p = 0.011$) (Aazh, Langguth, & Danesh, 2018). This finding is consistent with studies suggesting that childhood adversities can have an influence on children's development and may affect the way individuals respond to stress later in life (De Bellis & Zisk, 2014).

Prevalence of and Factors Related to Misophonia

There are conflicting results about the prevalence of misophonia in adults (Naylor et al., 2021; Siepsiak, Sobczak, et al., 2020; Wu et al., 2014). A study using an online questionnaire with 483 undergraduate university students in the United States showed that nearly 20% of the participants reported significant misophonia symptoms as measured with the Misophonia Questionnaire (MQ) (Wu et al., 2014). Their results showed that the MQ score among undergraduate university students was correlated with general sensory sensitivities, obsessive-compulsive, anxiety, and depressive symptoms (Wu et al., 2014). Naylor et al. (2021) conducted an online survey completed by medical students in a single university in the U.K. They found that 49.1% of 336 respondents had misophonia as measured by the Amsterdam Misophonia Scale (A-MISO-S) (Schroder et al., 2013). The discrepancy between the results of these two studies may be related to factors such as: (a) the differences in the questionnaires used, MO versus A-MISO-S, and (b) the differences in study populations, undergraduate students in the United States versus medical students in the United Kingdom. There are some studies that suggest medical students are a distinct group from general undergraduate population and have lower emotional intelligence and higher rates of anxiety and stress (Meena & Santre, 2019).

In a small-scale study, Siepsiak, Sobczak, et al. (2020) assessed the prevalence of misophonia among 94 inpatients diagnosed with depression. Diagnosis of misophonia was based on the MisoQuest questionnaire (Siepsiak, Śliwerski, et al., 2020) administered in a face-to-face interview. The interviewer had the opportunity to clarify the questions and make sure the patient did not misunderstand them. Their results showed that 11 out of 94 (12%) participants were diagnosed with misophonia based on their MisoQuest score. The much lower prevalence of misophonia reported in this study compared to the studies discussed earlier (Naylor et al., 2021; Wu et al., 2014) can be related to the differences in study populations, sampling procedures, and the method in which the questionnaires were administered. For example, university students who chose to take part in a survey about misophonia are more likely to have experienced symptoms of misophonia compared to the general population. This highlights the possibility of selection bias (Pannucci & Wilkins, 2010). In contrast, patients staying in a psychiatric ward for depression treatment often complete various questionnaires during their stay in the hospital, many of which are directly linked with their standard care. Therefore, inpatients with diagnosis of depression who chose to take part in the interviews conducted by Siepsiak, Sobczak, et al. (2020) were less likely to have been motivated because they had experienced symptoms of misophonia. The discrepancy between these studies may also indicate a low specificity for the misophonia self-report questionnaire when completed without assistance from a clinician. It is possible that the use of self-report questionnaires in an online format led to high levels of false positive results and overestimation of prevalence of misophonia in the studies conducted by Wu et al. (2014) and Naylor et al. (2021). Future research should assess whether the performance of self-report questionnaires differ based on the method that they are used (e.g., assessing participants' responses when questionnaires are administered by a clinician in a face-to-face session versus being completed without the help of a clinician).

Rouw and Erfanian (2018) assessed factors related to misophonia in an online survey of 301 individuals with misophonia, mainly recruited from online patient support groups and forums. The study showed that 50% of the participants did not report any comorbid mental illnesses. However, post-traumatic stress disorder (PTSD) was related to the severity of misophonia (Rouw & Erfanian, 2018). Jager et al. (2020) evaluated psychiatric disorders among 575 participants with a diagnosis of misophonia. Their results showed that 6.8% of the patients with misophonia had major depressive disorder, 2.8% had obsessive-compulsive disorder (OCD), 5% had attention deficit hyperactivity disorder (ADHD), 3% had autistic spectrum disorder (ASD), and 26% had obsessive-compulsive personality traits (Jager et al., 2020).

Recent Advances

Mechanisms

There are several theories about the underlying mechanisms of hyperacusis. Some studies suggest a genetic component to hyperacusis and noise sensitivity in general (Heinonen-Guzejev et al., 2005; Matsumoto et al., 2011; Mercati et al., 2017; Sosanya et al., 2017). A study on twins in Finland showed that noise sensitivity aggregated in families, and their genetic model provided an estimate of heritability of 40% (95% CI = .24–.54) (Heinonen-Guzejev et al., 2005). However, sometimes heritability is conditional to environmental exposure, which is known as gene-environment interaction (Boomsma et al., 2002). More studies with larger samples are needed to further examine genetic components of noise sensitivity and to assess if its heritability is different between populations with high and low noise exposures (Heinonen-Guzejev et al., 2005). In another genetic study, Mercati et al. (2017) studied individuals with ASD and symptoms of severe hyperacusis. Prevalence of hyperacusis in ASD is about 41% (Williams et al., 2021). Findings of the study by Mercati et al. (2017) suggested that abnormal gene dosage of CNTN5 or CNTN6 might represent a risk factor for the auditory problems in this population. Contactin genes CNTN5 and CNTN6 are expressed exclusively in the nervous system and code for neuronal cell adhesion molecules that promote formation and maintenance of the nervous system and sensory-motor neuronal pathways (Shimoda & Watanabe, 2009). There are some case studies that report possible genetic predisposition to misophonia (Brout et al., 2018; Cavanna, 2014; Danesh & Aazh, 2020; Sanchez & Silva, 2018). In a small-scale study, Edelstein et al. (2013) interviewed 11 individuals with misophonia and their results showed that 55% of the participants reported that misophonia ran in their family.

Other theories emphasize the role of stress in the development of hyperacusis (Hasson et al., 2013). There is long-standing evidence that stress, anxiety, and fear can make it difficult for some people to discriminate between safe and unsafe stimuli (Beck, 1976; Lader et al., 1967). If a sound is interpreted as unsafe, it produces a false alarm leading to further anxiety (Beck, 1976; Lader et al., 1967). One hyperacusis theory postulates that sound-induced anxiety heightens spontaneous neuronal activities within the auditory system. Consequently, neurons that normally respond at higher sound levels begin to respond to lower sounds levels, leading to the perception of increased loudness (Aazh, Knipper, et al., 2018).

Other theories link hyperacusis and tinnitus, with increased neural synchrony and reorganization of the tonotopic map in the auditory cortex. Several investigations report changes in the brain of animals with salicylate-induced or noise-induced hearing loss (Eggermont, 2012; Eggermont & Roberts, 2004; Noreña et al., 2002; Roberts et al., 2010; Sun et al., 2012; Sun et al., 2008). Recent studies using the blood oxygen level-dependent (BOLD) signal of the functional magnetic resonance imaging (fMRI) have shown that salicylate-induced hearing loss impacts various sections of the auditory pathway as well as nonauditory regions of the brain—regions responsible for emotion, arousal, memory, and motor planning (Salvi et al., 2021). A combination of sound-evoked hyperactivity within the auditory and nonauditory regions of the brain can lead to the experience of hyperacusis, and possibly tinnitus.

A recent study with veterans suggests a link between blast exposure and development of hyperacusis (Theodoroff et al., 2019). Exposure to explosions in combat situations is known to cause hearing damage combined with psychological trauma (Gallun et al., 2012). Hyperactivity within the auditory system as the result of the noise damage, combined with hyperactivity in the nonauditory regions of the brain due to psychological impact of the blast, could explain why veterans exposed to blasts might be more likely to experience hyperacusis (Gallun et al., 2012).

The interactions between the auditory and nonauditory regions of the brain and their role in the development of hyperacusis and tinnitus have also been highlighted in research about responsiveness of the brain to peripheral auditory damage (Hofmeier et al., 2018; Ruttiger et al., 2013; Ruttiger et al., 2017; Singer et al., 2013). These studies suggest that hyperacusis and tinnitus are not primarily linked to an elevation of hearing thresholds. Rather, hyperacusis and tinnitus are related to the differences in the brain's responsiveness to auditory damage that, in turn, depends on memory, stress, and other nonauditory factors (Singer et al., 2013).

Hwang et al. (2009) compared brain activation in response to sound in three patients with hyperacusis and three healthy participants with no hyperacusis, using fMRI. They observed that the brain activity in patients with no hyperacusis was mainly clustered in the right superior temporal gyrus and the primary auditory cortex. However, in patients with hyperacusis, brain activation was increased and extended beyond the auditory areas to the frontal lobes (superior, middle, or inferior frontal gyri) and occipital lobes (precuneus, cuneus, superior occipital gyrus, lingual gyrus, or fusiform gyrus). More recently, Koops and van Dijk (2021) investigated sound-evoked brain activities using fMRI in 35 participants with hearing loss and tinnitus, with and without hyperacusis as indicated by a cutoff score of 22 on the HQ. This cutoff score was chosen based on the study conducted by Aazh and Moore (2017b) suggesting that 95% of patients with an HQ score of ≥22 meet the ULL-based criterion for hyperacusis of ULLmin ≤77 dB HL, and vice versa. Koops and van Dijk (2021) reported that sound-evoked activity in cortical and subcortical auditory structures was higher in the group with HQ score of 22 or more. They also assessed the fMRI results with a different cutoff score of 16 on HQ, as proposed by Fioretti et al. (2015). Analysis showed that the HQ cutoff score of 16 did not reflect a significant increase in brain activities.

Hyperactivity of the auditory and nonauditory regions of the brain has also been highlighted in individuals with misophonia, as reported at the Misophonia Symposium during the 4th International Conference on Hyperacusis in London (Aazh, Knipper, et al., 2018). In a study conducted by Kumar et al. (2017), fMRI data were acquired in 20 patients with misophonia and 22 control participants while they listened to misophonia trigger sounds (e.g., eating, breathing sounds). Results showed that compared to the control group, the trigger sounds elicited an exaggerated brain activity in individuals with misophonia in the anterior insular cortex (AIC) as well as abnormal functional connectivity of AIC with other areas of the brain. AIC is responsible for subjective sense of the inner body and negative emotional experiences and is a key component of the salience network. The salience network is an interconnected pattern of neurons in the brain that plays a role in detecting and orienting attention toward stimuli that are significant for an individual (Seeley et al., 2007). Consistent with the results reported by Kumar et al. (2017), a more recent study using fMRI in individuals with misophonia showed that audio-visual misophonic cues (e.g., video clips of a person making typical misophonia trigger sounds by eating a carrot, eating a grapefruit, typing, and heavy breathing) can lead to hyperactivity in the insula, anterior cingulate cortex (ACC), and right superior temporal cortex (Schroder et al., 2019). To sum up, the fMRI studies have shown that individuals with hyperacusis and misophonia exhibit hyperactivity of the auditory and nonauditory regions of the brain when listening to certain sounds.

Assessment

In some patients, hyperacusis is a symptom of an underlying medical condition; therefore, a medical examination is required. The medical conditions associated with hyperacusis have other complications too, which are often detected by a physician prior to a patient being referred for hyperacusis assessment and management. For example, hyperacusis has been reported in patients with Bell's palsy (De Seta et al., 2014; Gilchrist, 2009), fibromyalgia and regional pain syndrome (de Klaver et al., 2007), migraines (Paulin et al., 2016), ASD (Williams et al., 2021), Lyme disease (Nields et al., 1999), and depression (Aazh & Moore, 2017a). Misophonia can also be related to some underlying medical conditions, comprising Tourette's syndrome (Cavanna & Seri, 2013; Neal & Cavanna, 2013), PTSD (Rouw & Erfanian, 2018), major depressive disorder, ADHD, ASD, obsessive-compulsive personality traits (Jager et al., 2020), and personality disorders (Cassiello-Robbins et al., 2020). Medical assessment of comorbid pathologies with hyperacusis and misophonia is outside the scope of this chapter. Rather, the focus is on the assessment of the severity of symptoms and the impact of hyperacusis and misophonia on the patient's life.

Hyperacusis and its impact on the individual can be assessed with the use of psychometric instruments. The most commonly used questionnaires for this purpose are the HQ (Khalfa et al. 2002), the Multiple Activity Scale for Hyperacusis (MASH) (Dauman & Bouscau-Faure, 2005), Geräuschüberempfindlichkeit (GÜF) (Nelting et al., 2002), and the Inventory of Hyperacusis Symptoms (IHS) (Greenberg & Carlos, 2018). Typically used questionnaires for misophonia are the Misophonia Activation Scale (MAS-1) (Dozier, 2015; Fitzmaurice, 2010), the Amsterdam Misophonia Scale (A-MISO-S) (Schroder et al., 2013), the Misophonia Assessment Questionnaire (MAQ) (Johnson, 2014), the Misophonia Questionnaire (MQ) (Wu et al., 2014), the Misophonia Physical Response Scale (MPRS) (Bauman, 2015), the Selective Sound Sensitivity Syndrome Scale (S-Five) (Vitoratou, 2018), and the MisoQuest (Siepsiak, Śliwerski, et al., 2020).

Audiologists often use ULLs to determine the lowest level at which sounds are perceived to be too loud. For individuals with normal hearing, the average ULL across the audiometric frequencies is about 100 dB HL (Sherlock & Formby, 2005). People with hyperacusis often have lower-than-normal ULLs in one or both ears (Tyler et al., 2014). ULLs contribute to the diagnosis of hyperacusis and assess the extent of hyperacusis. Aazh and Moore (2017b) showed that a diagnosis of hyperacusis based on HQ scores is consistent with a diagnosis based on ULLs if the following cutoff scores are adopted for a positive diagnosis: the average ULLs at 0.25, 0.5, 1, 2, 4, and 8 kHz for the ear with the lower average ULL, ULLmin, should be ≤77 dB HL and the HQ score should be ≥22. With these cutoff values, 95% of patients with HQ scores meeting the criterion for hyperacusis will also meet the hyperacusis criterion based on ULLs, and vice versa.

Enzler, Fournier, et al. (2021) proposed a novel approach of hyperacusis assessment by using psychoacoustic ratings of natural sounds. They tested 26 participants with hyperacusis and 23 control participants. Hyperacusis was diagnosed based on meeting two out of three criteria: (a) ULLmin ≤77 dB HL, (b) HQ score ≥22, and (c) self-reported complaint of sound intolerance. Participants were presented with different natural sounds in a controlled environment at four sound levels (60, 70, 80, and 90 dB SPL). They were asked to rate the sounds on a pleasant to unpleasant visual analog scale. Results showed that unpleasant sounds (e.g., fire alarm, train brakes, squeaking balloons, fork scratching on a plate) were rated as unpleasant by both groups, but pleasant sounds (e.g., fountain, laugh, harp, ocean, underwater, piano, and birds) led to a larger difference in ratings between participants with and without hyperacusis. Therefore, they suggested that pleasant natural sounds show a higher discriminant power than unpleasant natural sounds to diagnose hyperacusis. Their analysis showed that the accuracy of this new psychoacoustic method in diagnosing hyperacusis was comparable to that of the ULLmin and the HQ criteria proposed by Aazh and Moore (2017b).

Finally, it is important to highlight that depending on the procedure used for measurement of ULLs, the test can cause discomfort for some patients. Aazh and Moore (2017c) reported that in 24% of 362 consecutive patients who sought help for tinnitus and/or hyperacusis from an audiology department in the United Kingdom, the starting presentation level of 60 dB HL as recommended by the British Society of Audiology (BSA, 2011) for determination of ULLs exceeded the patient's ULL for at least 1 frequency. Therefore, certain modifications are required in performing the ULL test to minimize the risk of discomfort for patients. See the study by Aazh and Moore (2017c) for detailed information on the recommended procedure for ULLs among patients with tinnitus and hyperacusis.

Management

In the last decade, various medical and nonmedical strategies have been employed for management of hyperacusis such as middle ear tendon resection (Kim et al., 2017); round window reinforcement (Silverstein et al., 2020; Silverstein et al., 2015); cochlear implantation (Ramos Macias et al., 2018); medication (Abouzari et al., 2020; Attri & Nagarkar, 2010); counseling, education, and sound therapy (Formby et al., 2017; Jastreboff & Jastreboff, 2014; Pienkowski, 2019; Tyler et al., 2015); and CBT delivered by audiologists or psychologists (Aazh, 2020a; Aazh, 2020b; Juris et al., 2014).

Medical Management

Kim et al. (2017) assessed the effects of middle ear tendon resection on middle ear myoclonic tinnitus in 37 patients. Their results showed that compared to the preoperation, the average ULLs at 0.25, 0.5, 1, 2, 3, 4, and 6 kHz increased significantly after the surgery (average follow-up period was 16 months) ($p = 0.013$). There was no statistically significant change in hearing thresholds. Subjective complain of hyperacusis was recorded in 22 out of 37 patients preoperation, which reduced to two out of 37 postoperation ($p < 0.001$). Although the average ULLs increased compared to preoperation, the preoperation ULLs in most patients were over 90 dB HL, which is much higher (better) compared to average ULLs of less than 80 dB HL typically reported among patients with hyperacusis (Aazh & Moore, 2017b; Fioretti et al., 2016). The authors suggested that the discrepancy in preoperation ULL thresholds with typical hyperacusis samples could indicate possible differences in characteristics of hyperacusis among patients with middle ear myoclonic tinnitus. Limitations of this study were the lack of a control group and lack of validated instruments for assessment of hyperacusis.

Silverstein et al. (2020) assessed the effect of oval and round window reinforcement surgery on hyperacusis in 40 patients. Their results showed that mean HQ scores reduced from 30.7 to 15.9 ($p < 0.001$) and average ULLs increased (improved) from 70.8 dB HL to 84.1 dB HL 1 month after the operation ($p < 0.001$). The mean preoperative air-conduction pure-tone average (PTA) was 25.3 dB HL, which increased to 31.6 dB HL postoperatively. Although the change in hearing thresholds did not reach statistical significance ($p = 0.19$), it might explain the changes in ULLs following the operation. Hearing loss would lead to reduced loudness for most sounds, thereby increasing the ULLs. There are several studies that report a positive correlation between across-frequency average ULLs and average hearing thresholds (Aazh & Moore, 2017b; Sheldrake et al., 2015). However, past studies suggest that the scores on self-report hyperacusis questionnaires do not seem to be related to hearing thresholds (Aazh et al., 2021). Therefore, the average of 6-dB HL increase in hearing thresholds postoperation does not explain the significant improvements in HQ score observed in this study. This study shows promising results for oval and round window reinforcement surgery, but future studies with control groups are needed.

Ramos Macias et al. (2018) compared hyperacusis symptoms as measured via the Sound Hypersensitivity Questionnaire (SHQ) (Herraiz et al., 2006) on 16 cochlear implant recipients. Patients had unilateral hearing loss, with one ear fulfilling cochlear implantation criteria, and an additional severe tinnitus handicap. They reported a statistically significant change in total score of SHQ 12 months after the implantation as a secondary benefit of the treatment ($t = -3.61$, $p = 0.0026$). This study had a very small sample size and no control group. Authors suggested that future studies should include control groups evaluating alternative treatment options such as bone-anchored hearing aids (BAHA) or contralateral routing of signal (CROS) hearing aids.

Abouzari et al. (2020) reported a retrospective analysis on 25 patients with hyperacusis who were treated with medications used for migraines (e.g., nortriptyline, verapamil, topiramate) as well as lifestyle and dietary modifications. The follow-up assessment was carried out 6 months after the initial treatment visit. Results showed that the mean total HQ score improved significantly from 32.2 (standard deviation [SD] = 3.6) pretreatment to 22.0 (SD = 5.7) post-treatment ($p < .001$). The mean of ULLs increased from 81.3 dB (SD = 3.2) to 86.4 dB (SD = 2.6) dB ($p < .001$). Authors suggested that the small sample size and lack of a control group were among the limitations of this study.

Overall, these preliminary studies on surgical operations and medical treatments show promising results. Future studies with randomized controlled trial (RCT) design are needed to assess the efficacy of these procedures (Pocock, 1983).

Counseling and Audiological Management

With regard to sound therapy and education, Formby et al. (2015) conducted an RCT on 36 patients with bilateral sensorineural hearing loss and complaints of sound intolerance. Participants were assigned randomly to one of four treatment groups: (a) educational counseling plus sound therapy implemented with binaural sound generators (full treatment); (b) counseling and placebo sound generators (PSGs); (c) binaural sound generators alone; and (d) neutral control treatment implemented with the PSGs alone. Results showed that patients who received the full treatment improved significantly more than the other groups based on comparison of the pre- and post-treatment values of categorical loudness judgments measured at 0.5, 2, and 4 kHz. These study results are quite promising, and future trials with larger sample sizes are needed.

There are several studies assessing the clinical effectiveness of CBT in the management of hyperacusis and misophonia (Aazh et al., 2020; Aazh, Landgrebe, Danesh, & Moore, 2019; Aazh & Moore, 2018; Juris et al., 2014; Nolan et al., 2020; Schroder et al., 2017). Juris et al. (2014) conducted an RCT on the effect of CBT for patients who reported hyperacusis as their main problem. They randomly assigned 30 patients to the CBT group and 32 patients to a passive waiting-list control group. Patients in the CBT group received six sessions of CBT, while patients in the waiting-list group received no intervention. The difference (improvement) in pre- and post-treatment scores on the HQ was 8.3 (SD = 7) for the CBT group and 4.1 (SD = 6) for the waiting-list group. In some studies that assessed the effect of audiologist-guided internet-based CBT on tinnitus distress, the outcome for hyperacusis was also reported. (Beukes, Andersson, et al., 2018; Beukes, Baguley, et al., 2018). Beukes, Andersson, et al. (2018) reported the change in HQ score in patients who received 8 weeks of audiologist-guided internet-based CBT compared to patients in the control group, who received two to three face-to-face sessions of education and counseling. The change in HQ scores following treatment did not differ significantly between the two groups. The effect size was 0.16 (95% CI, −0.26 to 0.57). In other words, the two interventions were equally effective in reducing hyperacusis handicap. In another RCT, Beukes, Baguley, et al. (2018) randomly assigned participants to receive 8 weeks of audiologist-guided internet-based CBT (intervention group) or 8 weeks of monitoring (control group). Sixty-three out of the 73 patients who were randomized to the intervention group completed the treatment and all patients randomized to the control group ($n = 72$) completed the control assessments. The audiologist-guided internet-based CBT led to greater improvement in HQ scores than for the control group (effect size = 0.3; 95% CI = 0.0 to 0.7).

Aazh and Moore (2018) conducted a retrospective study comparing hyperacusis-related distress before and after CBT delivered by audiologists trained in the delivery of CBT ($n = 68$). For the subgroup of patients with a diagnosis of hyperacusis based on an HQ score ≥22 (Aazh & Moore, 2017b) who completed the course of CBT ($n = 14$), the mean pre-CBT HQ score was 29.5 (SD = 4.4) and the mean post-CBT score was 20.8 (SD = 6.7), an 8.7-point improvement ($p = 0.0003$). In another study, Aazh et al. (2020) reported that among 31 patients who completed audiologist-delivered CBT for tinnitus and/or hyperacusis, 97% rated the acceptability of audiologist-delivered CBT as 7/10 or above; the median of patients' responses to this question was 10/10. The responses to the question about the acceptability of receiving CBT for tinnitus and/or hyperacusis from a specialist audiologist were not statistically different between patients with and without hyperacusis.

In comparison to hyperacusis, research on misophonia is relatively limited (Porcaro et al., 2019; Potgieter et al., 2019). Several authors have reported promising results from case studies using CBT to help patients with misophonia (Bernstein et al., 2013; McGuire et al., 2015; Schroder et al., 2017). Schroder et al. (2017) reported the results of CBT for 90 patients with misophonia (mean age = 36 years, SD = 12 years). The CBT sessions were given weekly for 7 to 8 weeks in a group setting and were delivered by clinical psychologists with extensive experience in CBT for OCD. The A-MISO-S was administered by a trained psychiatry resident at three time points, comprising: T0 (initial assessment); T1 (prior to the start of the CBT), which was on average 29 weeks (SD = 16 weeks) after the initial assessment; and T2 (end of the treatment). All patients were added to a waiting list after the initial assessment, which led to the time lapse between T0 and T1. The mean A-MISO-S score was 13.6 (SD = 2.9) at T0 and remained unchanged at T1. The mean A-MISO-S score was reduced (improved) by 4.5 points (SD = 3.5) at T2 ($p < 0.001$). This suggests that CBT delivered in a group setting is helpful for patients with misophonia. Some authors suggested that dialectical behavior therapy (DBT) may also be suitable for patients with misophonia as it focuses on acceptance of one's emotional reaction rather than reducing it through exposure and cognitive restructuring tasks (Kamody & Del Conte, 2017). DBT can be particularly useful if individuals with misophonia find it hard to utilize certain CBT techniques when exposed to the trigger sounds due to the intensity of their emotional and behavioral reactions. Consistent with this observation, a recent study suggested that individuals with misophonia may find it hard to perform certain cognitive tasks when exposed to the trigger sounds (Daniels et al., 2020). Daniels et al. (2020) assessed cognitive control function while listening to misophonia trigger sounds in 79 participants. The cognitive control was measured via a Stroop color naming task, which is a neurophysiological test assessing the individual's ability to inhibit interfering distractions when completing certain cognitive tasks (Scarpina & Tagini, 2017). Their results showed that after controlling for the personality trait of neuroticism, cognitive control was significantly reduced in people with misophonia symptoms when they were exposed to trigger sounds. If future studies prove that this finding is generalizable to clinical populations, then this lack of cognitive control in patients with misophonia when exposed to the trigger sounds could hamper their ability to undertake certain cognitive techniques of the CBT.

Future Directions

Phenomenological studies are required in the future to reach better definitions for hyperacusis and misophonia (Green & Thorogood, 2009). Although defining these conditions can be challenging as their exact underlying mechanisms are not fully understood, more accurate definitions can help in designing psychometric instruments that can be used to estimate the prevalence of hyperacusis and misophonia in the general population. Conflicting results with regard to the prevalence of hyperacusis and misophonia also suggest the need for more research in diagnostic criteria and designing appropriate psychometric measures. It is also important to investigate whether the performance of self-report questionnaires for hyperacusis and misophonia differ based on the method used to administer them (e.g., online versus face-to-face clinical sessions). Future research should compare neurobiological, audiological and psychological aspects of misophonia and hyperacusis. Research on the genetic basis of these conditions is still in its infancy, but it has great potential to help us understand and treat these conditions in the future (Amanat et al., 2021; Cederroth et al., 2019; Maas et al., 2017; Szczepek et al., 2019). Questions about various treatment methods for hyperacusis are among the research priorities in this discipline (Baguley & Hoare, 2018; Fackrell et al., 2019). Clinical trials on different treatment modalities for hyperacusis and misophonia are likely to help us understand these conditions better. It is important that future studies use an RCT design to assess the efficacy of medical and nonmedical interventions (Pocock, 1983). Finally, developing evidence-based educational materials (hard copy or online) about hyperacusis and misophonia to communicate research findings with patients and clinicians is needed in the future (Aazh & Danesh, 2021; Smith et al., 2020).

Clinical Implications

When assessing patients with hyperacusis and misophonia in audiology clinics, it is important to screen for underlying psychological disorders and refer to appropriate mental health professionals for further investigation and treatment (when needed). There are a wide range of screening questionnaires recommended for evaluation of psychological problems in clinical audiology settings (Aazh & Moore, 2017d). Based on the literature search presented in this chapter, there seems to be a discrepancy between the questionnaire-based diagnosis of hyperacusis and misophonia and the outcome of clinical interviews. Therefore, clinicians should not rely solely on self-report questionnaires when assessing the impact of hyperacusis or misophonia on a patient's life. A multidisciplinary approach is needed to establish whether the patient's symptoms are related to hyperacusis and misophonia or to other underlying psychological or medical factors.

Key Messages

- There is some overlap between the definitions of hyperacusis and misophonia (Aazh, Knipper, et al., 2018).
- Prevalence of hyperacusis varies from 2% to 9% in the adult population and from 3.7% to 17% in children (Fagelson & Baguley, 2018).
- Estimates of the prevalence of misophonia vary between 8.5% in a population of inpatients with depression (Siepsiak, Sobczak, et al., 2020) to about 50% among a sample of medical students in a U.K. university (Naylor et al., 2021).
- Hyperacusis is not simply an oversensitivity to certain sounds. The diagnosis of hyperacusis refers to the experience of intolerance to certain sounds that causes significant distress and impairment in day-to-day life (Aazh et al., 2016).
- fMRI studies have shown that individuals with hyperacusis and misophonia exhibit hyperactivity of the auditory and nonauditory regions of the brain when listening to certain sounds (Koops & van Dijk, 2021; Kumar et al., 2017).
- Although the severity of hyperacusis and misophonia is strongly correlated with certain anxiety and mood disorders, research has shown that about half of the individuals with hyperacusis and misophonia do not present with any other diagnosable mental illness (Aazh & Moore, 2017d; Rouw & Erfanian, 2018).

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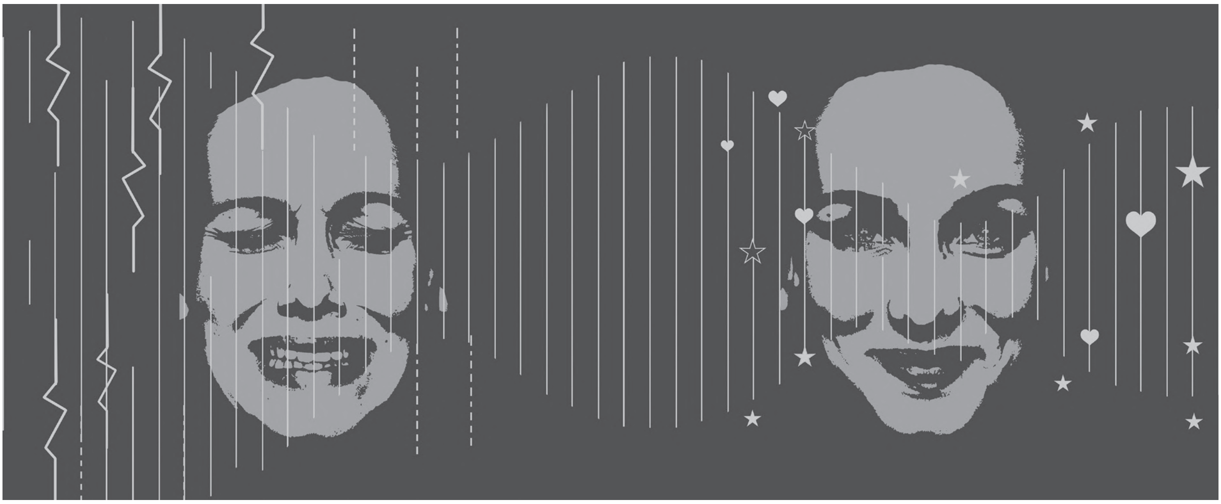
SECTION V

RECENT DEVELOPMENTS



18

THE ROLE OF SOCIAL MEDIA IN TINNITUS AND HYPERACUSIS

Colleen A. O'Brien-Russo and Aniruddha K. Deshpande

Introduction

Online social media platforms like Facebook, Twitter, YouTube, and Instagram are deeply ingrained in our society and culture, and it is no surprise that a growing portion of the population turns to social media platforms to learn about various health conditions, including tinnitus (Deshpande et al., 2018). Tinnitus is a complex condition that is often misunderstood and warrants substantial counseling (Manchaiah et al., 2019). As a result, social media is an abundant source of information and advice. Unfortunately, not all of the content found online is valid, and can often conflict with evidence-based research about tinnitus (O'Brien et al., 2019). It is critical that members of the tinnitus community—individuals with bothersome tinnitus, as well as their family and friends—are educated about the condition and its peer-reviewed management techniques. The aim of this chapter is to provide an overview of tinnitus-related information found online and on social media platforms. Stakeholders can use this information to educate themselves and to minimize the potential spread of online misinformation about tinnitus. Clinicians can also use this information for effective counseling of tinnitus patients by helping them detect, disregard, and even challenge false claims they may encounter online.

Background

Consumption of Health-Related Information on Social Media Platforms

Social media is a collective term for the assortment of internet-based platforms that permit users to communicate, exchange ideas, and share messages instantly (Ventola, 2014). Currently, approximately three-quarters of American adults are active on at least one social media platform, and the same is true for a staggering 93% of adolescents and young adults in the United States (Rideout & Fox, 2018). This increased use of social media is not unique to the United States; global surveys estimate that 53.6% of the world's population utilizes social media, with nearly 80% of Northern and Western Europeans, 72% of South Americans, and 66% of Eastern Asians using online social platforms (Chaffey, 2021).

Furthermore, an increasing number of people seeking medical information turn to the internet and social media platforms for guidance (Sugawara et al., 2012). This increased use of online resources has revolutionized how healthcare data are spread and exchanged (Finn, 2019). The internet is now the primary source of health information in the United States (Basch et al., 2018), with an estimated 80% of adults over the age of 18 (Ventola, 2014) and 87% of Americans between the ages of 14 and 22 years (Rideout & Fox, 2018) using online platforms to search for medical information. In addition to seeking data related to health, many social media users also use these platforms to share their own experiences and concerns regarding personal medical conditions (Manchaiah et al., 2018). While the seemingly unlimited amount of information existing on the internet is advantageous, medical and research communities should share information that is evidence based, accurate, free of jargon, and easily understandable to the average reader (Manchaiah et al., 2019). At the same time, it is critical that information shared online is not oversimplified and thus misunderstood.

Validity of Health-Related Information on Social Media Platforms

Presently, there are no drug treatments effective in mitigating tinnitus (McFerran et al., 2019), but an increasing number of investigations show the benefits of informational counseling and cognitive behavioral therapy (CBT) in helping tinnitus sufferers mediate their reactions to the condition (Jun & Park, 2013; Manchaiah et al., 2019; Ni et al., 2020) (please see Chapter 11 for additional details on CBT). This increased emphasis on self-management can help minimize negative emotional reactions to tinnitus, ultimately guiding tinnitus patients to cope with their chronic condition (Manchaiah et al., 2018; McFerran et al., 2019). Unfortunately, there are a relatively limited number of professionals trained in providing CBT and counseling to the tinnitus population (Baguley et al., 2013). Due to the current lack of evidence-based management options (Ni et al., 2020), those suffering from tinnitus may feel inclined to seek guidance online and thus risk exposure to misinformation related to the condition (Baguley et al., 2013).

In this chapter, the term *misinformation* refers to any statement or claim that is either known to be incorrect or lacks rigorous scientific evidence. Misinformation exists in nearly all disciplines on social media platforms (Shin et al., 2018) including health conditions. For instance, investigations have revealed that health-related misinformation is prevalent on YouTube (Basch et al., 2018) and Twitter (Suarez-Lledo & Alvarez-Galvez, 2021). A recent analysis of tinnitus-related information on social media platforms revealed high prevalence of misinformation (Deshpande et al., 2018). As an increasing number of individuals turn to social media platforms to collect health-related information, it is critical that scientific communities understand and attempt to overcome this ever-growing threat of online misinformation (Shin et al., 2018).

Recent Advances

Individuals with tinnitus actively use social media platforms to share their experiences, learn more about their condition, and build self-efficacy. However, the possibility of these individuals obtaining poor quality information and being financially exploited by invalid tinnitus “cures” cannot be overlooked. Social media platforms can have a significant impact on the tinnitus community, and it is imperative that audiologists, otolaryngologists (ENTs), and other relevant clinicians are aware of the current online climate.

Benefits of Social Media Platforms

Popular social media platforms—such as Facebook, Twitter, YouTube, Instagram, LinkedIn, and TikTok—have their own distinct uses and utilization patterns. These platforms are advantageous to both the general population and the tinnitus community due to their effectiveness in transmitting information instantly (Choudhury et al., 2017) and at no cost. Further, their ubiquitous availability and affordability make them ideal communication channels for both patients and clinicians alike (Patel et al., 2015).

Social media platforms can be effective means of increasing self-efficacy and enhancing health awareness for individuals with various health conditions, including hearing loss (Manchaiah et al., 2021) and tinnitus (Ni et al., 2020). These platforms are interactive and engaging, often creating a welcoming virtual environment to share and exchange ideas (Choudhury et al., 2017). Patel et al. (2015) determined that for individuals with chronic diseases, social media platforms can improve outcomes by offering “social, emotional, or experiential support” (p. 1335). Further, these online platforms present a unique opportunity for users to express themselves and personalize their online presence. This can lead to increased self-efficacy, feelings of empowerment, and desire to take control of their conditions (Finn, 2019; Sugawara et al., 2012).

Healthcare providers and clinicians can also utilize online tools and social media platforms as powerful instruments for education and advocacy (Ventola, 2014). Clinicians and researchers can use social media platforms to share recent advances in healthcare, network with other professionals, advocate for and spread awareness about relevant healthcare topics, and even interact with and educate patients or participants who have questions or concerns. Healthcare organizations and research institutions can also have a significant presence on social media platforms through advertising, marketing, fundraising, sharing relevant news, and offering online support. Investigations have also found improvements in patient outcomes, education levels, and adherence to protocols when individuals with chronic diseases shared electronic comunication with their healthcare providers (Ventola, 2014).

Several recent investigations have revealed that a plethora of tinnitus-related information exists on social media platforms such as Facebook, Twitter, and YouTube. Deshpande et al. (2018) tracked, categorized, and analyzed social media information related to tinnitus, and found that Facebook pages related to tinnitus consist of a high proportion of service providers such as audiologists, otolaryngologists, other physicians, and nonprofit organizations, as depicted in Figure 18–1. These providers often promote their businesses and share information about services offered to diagnose and manage tinnitus. On the other hand, Facebook groups primarily function as online support groups where users ask questions and receive responses from others in the community. Manchaiah et al. (2018) performed a similar analysis of Facebook pages and determined that the tinnitus community uses the platform to acquire information about symptoms and diagnosis,

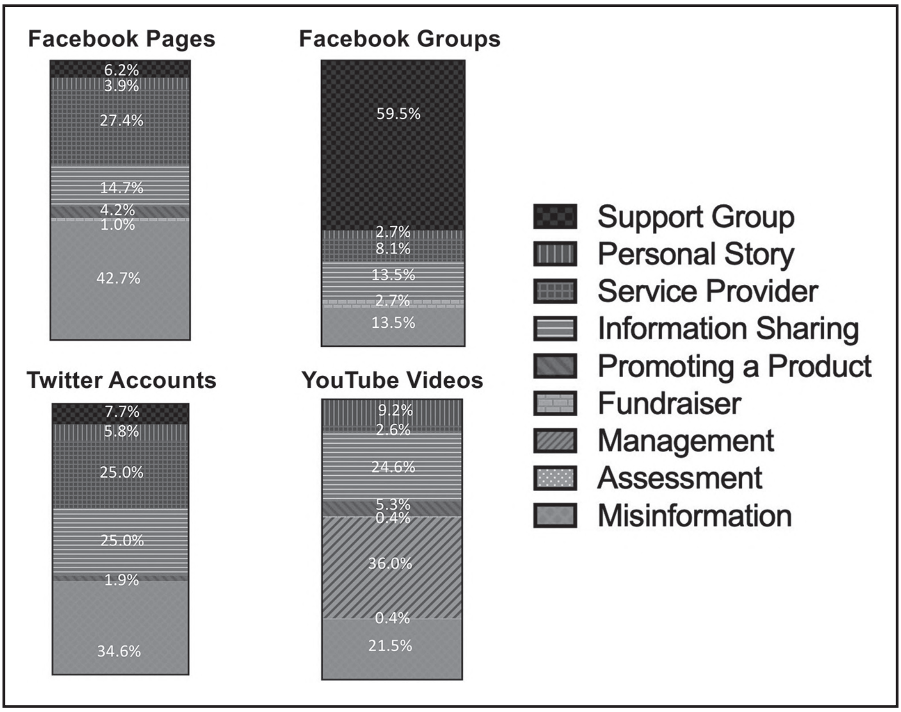


Figure 18–1. Breakdown and categorization of tinnitus-related information portrayed on four social media platforms: Facebook pages, Facebook groups, Twitter accounts, and YouTube videos (Deshpande et al., 2018).

gain social support, cope with the condition, learn about research updates, and practice self-reflection.

Twitter use by the tinnitus community has been similarly investigated. Ni et al. (2020) performed an in-depth analysis of Twitter usage related to the condition and found that the platform was dominated by commercial user accounts whose primary purposes were advocacy and education. The authors concluded that Twitter can "unify the tinnitus community in advocacy and outreach efforts" (p. 213), especially since it is currently the most popular social media platform used for the purpose of healthcare communication (Pershad et al., 2018). Sugawara et al. (2012) found that for individuals with the medical diagnosis of cancer, Twitter can serve as a powerful tool that connects them to a larger network of other cancer patients. It was also found to be a source of psychological support that created feelings of interconnectedness. Individuals with tinnitus may use Twitter in a comparable manner and also experience these benefits. In addition, Pershad et al. (2018) concluded that the ability of healthcare workers to instantly share information with countless individuals via Twitter "has the potential to revolutionize public health efforts" (p. 4). These benefits can be translated to audiologists and otolaryngologists who use Twitter as a platform for disseminating tinnitus information.

YouTube is another social media platform that hosts tinnitus-related content. A majority of the videos analyzed in the Deshpande et al. (2018) study offered self-help options and do-it-yourself techniques for managing tinnitus, such as videos playing several hours of masking noise, as well as individuals sharing their experiences with tinnitus. The three most-viewed videos pertaining to tinnitus at the time of the investigation amassed nearly 15 million combined views. Basch et al. (2018) conducted a similar analysis of the portrayal of tinnitus on YouTube and found that most videos were created by social media consumers from the general public. Compared to videos uploaded by healthcare professionals or media sources, videos uploaded by nonprofessional social media users were more than four times more likely to be focused on an individual's own experience with tinnitus. These vlog-style videos allowed individuals to freely discuss their experiences related to tinnitus. Not surprisingly, videos uploaded by media sources were more engaging and visually pleasing than those shared by professionals.

Shortcomings of Social Media Platforms

The value of social media platforms must be weighed against their potential shortcomings. Manchaiah et al. (2019) provide a thorough analysis of the readability of online tinnitus-related information as determined by reading grade level (RGL)—the number of years of education in the United States that would be necessary to comprehend text. In the United States, the average adult has a RGL of 7. It is recommended that public health information be shared at or below a RGL of 6 (Weiss, 2007). Manchaiah et al. (2019) determined that, unfortunately, "the vast majority of tinnitus-related websites are well above the recommended readability levels" (p. 37). The readability of the investigated online tinnitus information required an average of 10 to 12 years of education to comprehend, and the recommended RGL was consistently exceeded. Additionally, tinnitus websites with lower readability contained higher-quality information, leaving accurate content inaccessible to the average reader. On the other hand, some online tinnitus information, such as Tweets of less than 280 characters, may be oversimplified and thus misinterpreted (Pershad et al., 2018).

Additionally, critical regulations and enforcements of the type of information that can be shared on social media platforms are not adequate (Vraga & Bode, 2018). Powerful and sensitive claims related to tinnitus can be posted by social media users, and there is no regulatory body monitoring shared content (Ni et al., 2020). The absence of gate-keeping mechanisms has led to inappropriate, untrue, and potentially harmful information about tinnitus being spread online (O'Brien et al., 2019). As Pershad et al. (2018) explain, social media platforms are unique in that they utilize crowdsourcing as a means of information sharing and fact checking. As a result, it is common for poorly informed individuals or entities to share opinions and unfounded claims as facts, making it difficult for other social media users to identify unbiased claims.

Perhaps the most significant limitation of obtaining health information on social media platforms is the ubiquity of misinformation (Ventola, 2014), resulting in difficulty validating the reliability of sources (Pershad et al., 2018). The recent analysis of social media use within the tinnitus community conducted by Deshpande et al. (2018) found surprisingly high degrees of incorrect information being shared on social media platforms, with misinformation being one of the three most-common categories on almost every platform analyzed. Misinformation was found in 44% of

Facebook groups, 43% of Facebook pages, 35% of Twitter accounts, and 22% of YouTube videos (note that only the first 300 of 350,000+ resulting YouTube videos were analyzed). Some examples of the misinformation commonly shared pertained to illegitimate remedies (e.g., onion juice, garlic oil, ginkgo biloba, dietary supplements) and unfounded treatments (e.g., flicking the back of the skull, participating in religious practices). Similarly, the investigation of online tinnitus-related information by Manchaiah et al. (2019) found "the quality of information . . . to be significantly lacking" (p. 36). Inaccurate information and poor readability were found throughout their investigation. Many of the websites analyzed existed to sell a product yet lacked accurate information and failed to disclose risks. This surplus of misinformation related to tinnitus is thought to be explained by a combination of factors, including its high prevalence, bothersome nature, and lack of a treatment (i.e., cure) (Manchaiah, 2019; Blakley, 2016). This increase in online tinnitus misinformation is particularly dangerous for individuals who self-diagnose their tinnitus and fail to seek medical evaluations to rule out potential pathologies associated with tinnitus.

While not all misinformation found online is shared intentionally or maliciously, it is clear that social media platforms are appealing for those trying to take advantage of desperate individuals seeking guidance for their tinnitus. Some commercial industries sell unsubstantiated products marketed as tinnitus cures, which has created a multibillion-dollar online industry (Blakley, 2016). Advertised "cures" found throughout social media platforms range from subtly misleading assertions to senseless, unsubstantiated claims. DiSogra (2015) reported a thorough evaluation of over-the-counter (OTC) tinnitus products in the United States. Because these products are classified by the Food and Drug Administration (FDA) as dietary supplements rather than pharmaceuticals, the assertions about product effectiveness are not monitored. The majority of advertised products and supplements remain uninvestigated clinically, and many are believed to provide no remedy beyond a placebo effect. Alarmingly, according to DiSogra, only one in 10 of the ingredients identified was supported by peer-reviewed research, and some were actually known to cause tinnitus or have deadly interactions with other drugs. The variety of "curative" products advertised on social media platforms can be a danger to many unknowing individuals. Claims regarding their efficacy should be viewed as anecdotal and not evidence based. The reader is referred to Chapter 14 for a review of the use of supplements for tinnitus.

Finally, Basch et al. (2018) further articulate that the public can be grossly misled by information they find on social media platforms, especially information that is shared by uninformed laypeople. These researchers explain that social media platforms tend to focus on anecdotal evidence and personal experiences of tinnitus rather than evidence-based findings. For example, of the 100 most-viewed YouTube videos they investigated, only one-quarter were uploaded by professionals, and these videos were not as popular as those uploaded by consumers or media organizations. Other investigations also determined that much of the information about tinnitus found online is inherently biased, focused on sharing individual stories of success related to tinnitus management rather than impartial, generalizable findings (Manchaiah, 2019). Individuals exposed to a significant amount of contradictory and unfounded medical claims may become overwhelmed with information and ultimately make harmful decisions (Finn, 2019). It is interesting to note that although the effectiveness of CBT in mitigating tinnitus is supported with research evidence, there is a substantial lack of information about CBT on social media platforms. This may explain why there is still relatively little knowledge and interest in CBT among the online tinnitus community (Manchaiah, 2018).

Portrayal of Hyperacusis on Social Media Platforms

Although tinnitus and hyperacusis often co-occur, Google Trends suggest that "tinnitus" is more frequently searched than "hyperacusis" or even "hearing loss" (Manchaiah, 2019). Deshpande et al. (2019) performed an analysis of hyperacusis on social media platforms and found that these platforms played a similar role in helping individuals learn about the condition and share their experiences with hyperacusis. However, fewer search results emerged about hyperacusis (273 results) compared to tinnitus (1,459 results). In addition, there was significantly less misinformation about hyperacusis (5.1% of Facebook pages, compared to 42.7% for tinnitus) (Figure 18–2). These findings confirm that tinnitus is a particular target for online misinformation.

Future Directions

It is clear that greater culpability and accuracy of tinnitus-related information on social media platforms is desperately needed at this time (Manchaiah et al., 2019). While

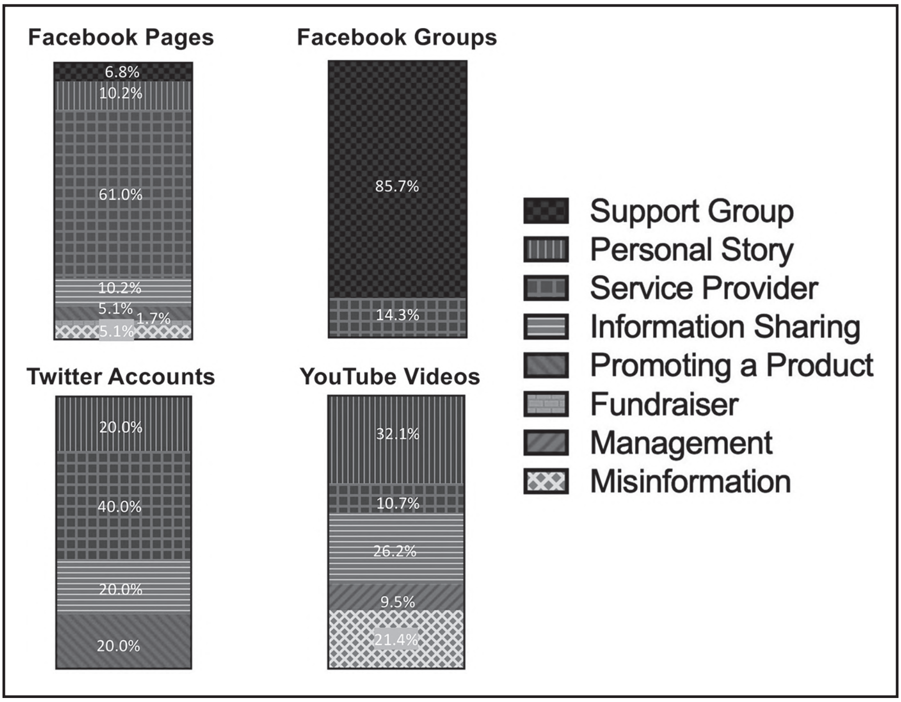


Figure 18–2. Breakdown and categorization of hyperacusis-related information portrayed on four social media platforms: Facebook pages, Facebook groups, Twitter accounts, and YouTube videos (Deshpande et al., 2019).

it is critical for social media users to effectively distinguish between accurate claims and misinformation, it is nearly impossible to expect the eradication of all online misinformation. As Shin et al. (2018) describe, misinformation is cyclical in nature. It tends to reemerge on social media platforms, expanding its control as more individuals continue to share and repeat it. Despite these challenges, there are several actions that can be taken to begin mitigating these difficulties related to inaccurate tinnitus information on social media platforms.

It is critical that stakeholders in the academic and medical communities share information that is accessible to the average reader. Manchaiah et al. (2019) underscore the importance of lowering readability levels of online tinnitus information to maximize patient outcomes. This is no small task given the complexity of tinnitus and its management, but it is critical to develop user-friendly websites about tinnitus that are easily understood by individuals with low literacy. Academic and medical communities can follow the lead of the World Health Organization (WHO, 2020), which created a COVID-19 "Mythbuster" page to combat misinformation by providing information on the gravity of the disease, risks of self-medicating with unverified medications, importance of mask use, and irrelevance of 5G mobile networks in the spread of the virus (Sharma et al., 2020). Additionally, Basch et al. (2018) wisely suggest that professional healthcare organizations consider involving social media trailblazers, like celebrities, in discussing tinnitus and helping initiate campaigns to spread more reliable information.

Discussing the existence of misinformation related to tinnitus on social media platforms is both timely and relevant. Sharma et al. (2020) note that the field of healthcare misinformation on social media platforms warrants additional investigations, as it is rapidly expanding and currently understudied. Audiologists, physicians, and relevant stakeholders in the academic, medical, and public health communities must work together to create a factual yet engaging environment on social media platforms where individuals can access high quality information while also feeling comfortable asking questions and creating dialogues. Professional organizations can follow the lead of other engaging online health campaigns, like the ALS "Ice Bucket Challenge" and Instagram's #HereForYou mental health campaign. After analyzing tinnitus videos on YouTube, Basch et al. (2018) concluded that the most enticing and attractive videos were those uploaded from media sources, not healthcare professionals. Relevant clinicians and researchers should take the initiative to create and share captivating educational tinnitus campaigns. Stakeholders can also create a "Tinnitus Mythbuster" page like the WHO did with the COVID-19 page to increase transparency and availability of accurate information.

Existing social media resources can be used in novel tinnitus management protocols. For instance, Deshpande et al. (2021) used a virtual reality (VR) paradigm to present a 360^0 YouTube video in conjunction with sound therapy to individuals with tinnitus. This randomized controlled trial found that the VR-sound therapy setup reduced tinnitus loudness and tinnitus functional index (TFI; Meikle et al., 2012) scores significantly in tinnitus participants.

Educating individuals with tinnitus is both an imperative and effective method to combat the abundance of tinnitus misinformation found throughout social media. A recent preliminary investigation analyzed how individuals with tinnitus respond to videos discussing the condition, with the purpose of determining their susceptibility to online misinformation (O'Brien & Deshpande, 2019). Participants were shown 10 YouTube videos currently circulating on the internet related to tinnitus. Five videos were accurate and five contained misinformation. Participants rated the videos on perceived authenticity. Researchers then provided a brief educational intervention in which the definition, prevalence, and management of tinnitus were discussed. Participants rewatched and rerated the same 10 videos in a random order so that researchers could assess whether the counseling session was effective in helping participants flag misinformation. Interestingly, a highly significant difference in accuracy detection was found before and after the educational counseling session. The results of this study suggest that participants had a greatly improved ability to detect misinformation and distinguish facts after learning about evidence-based information related to the condition. These findings underscore the value of providing educational counseling to the tinnitus community by audiologists, otolaryngologists, general practitioners, and other relevant clinicians.

Finally, increased social media gatekeeping related to medical misinformation is critically warranted. In May 2020, Twitter began implementing new labels and warning statements on messages that contained dubious or misleading claims related to COVID-19. Similarly, Facebook began removing several pages and groups condoning misinformation, like an "anti-mask" group with more than 10,000 members (Klepper, 2020). These are excellent first steps to minimize misinformation and to prioritize public health. It is also noteworthy that although rumors are spread by repetition, the same is true for accurate information. If accurate claims about tinnitus are continually repeated online, they become more familiar to the public, and thus more credible and accepted (Shin et al., 2018).

Clinical Implications

The ubiquity of online misinformation and false claims related to tinnitus can have long-lasting implications on the field of audiology. It is critical that clinicians themselves are aware of the current state of online (mis) information so they can help their patients avoid confusion or harm resulting from inaccuracies seen online (Deshpande et al., 2018). Manchaiah et al. (2018) also emphasize the importance of healthcare providers being aware that patients may have erroneous preexisting beliefs that they developed from social media platforms. Similarly, DiSogra (2015) advises audiologists to further educate themselves and appropriately counsel patients about evidence-based tinnitus management techniques. Finn (2019) mentions the importance of discussing the advantages and pitfalls of social media with current students in disciplines related to tinnitus. Most of these students have grown up using social media platforms, and as future clinicians they must be prepared to confront invalid claims on social media platforms.

Clinicians and students simply being aware of this situation is not enough to overcome the "pandemic" of tinnitus misinformation. They must be cognizant that patients who have been exposed to online misinformation may enter clinical encounters with skepticism and mistrust. Finn (2019) warns that social media misinformation can cause "unwarranted skepticism about medical guidelines" (p. 225), leading patients to doubt their providers about certain medical conditions or practices (i.e., vaccination). O'Brien and Deshpande (2019) explain that if patients are bombarded with misinformation online, they may question the credibility and knowledge of their audiologists or physicians, thus weakening the patient–provider relationship. For instance, if a patient thinks that tinnitus can be cured by dietary supplements or other oversimplified solutions, they will likely be frustrated (and possibly embarrassed) when their clinician explains the inaccuracies of these beliefs (Pershad et al., 2018).

Audiologists, otolaryngologists, and other relevant clinicians should be actively prepared to guide patients toward valid information online and re-educate those with inaccurate understanding of tinnitus in a nonjudgmental manner (Deshpande et al., 2018). The notion that there is nothing to be done for individuals experiencing tinnitus is a grossly flawed and obsolete mindset. Clinicians can advise patients on the benefits of amplification, sound therapy, CBT, and tinnitus management regimens. They must also be prepared to make appropriate referrals when necessary (O'Brien & Deshpande, 2019). Additionally, clinicians can offer patients advice on how to obtain accurate information from peer-reviewed online sources, like suggesting they follow the American Tinnitus Association on Twitter rather than join a Facebook group advertising miracle tinnitus pills. As DiSogra (2015) articulates, it is critical for clinicians to discuss OTC tinnitus supplements with patients so that they are aware that none are FDA approved or have scientific evidence of efficacy at this time, and that some can actually be harmful. Additionally, clinicians can explain that if an instant cure for tinnitus were developed, it would be breaking news in the medical community. We must warn our patients to steer away from tinnitus claims that seem too good to be true.

We are in the midst of a potentially precarious shift in the way individuals obtain healthcare information and make medical decisions. Social media platforms are often the first outlets that patients use to learn about health conditions like tinnitus. The benefits of these digital platforms cannot be understated—patients can gain peer-reviewed information; learn ways to manage their tinnitus; and find support, empathy, and advice from others in the community. However, we cannot overlook the serious risks of social media use for the tinnitus community. As Klepper (2020) articulates, there is "no antidote in sight for the burgeoning outbreak" of online healthcare misinformation. Clinicians must be equipped to combat the negative impact of online misinformation related to tinnitus, while also offering constructive ways for them to promote self-management of their often-frustrating condition.

Key Messages

- Most adults in the United States utilize social media regularly, and these internet platforms have become the primary resource for obtaining health information about conditions like tinnitus.
- Individuals with tinnitus actively use social media platforms to share their experiences, learn more about their condition, garner social support, build self-efficacy, and enhance awareness of the condition.
- Due to tinnitus's high prevalence, lack of evidence-based management options, and bothersome nature, tinnitus sufferers may feel inclined to seek guidance on social media, but much of the content found online is unregulated, has low readability, and/or conflicts with evidence-based research about tinnitus.
- This increase in online tinnitus misinformation is particularly dangerous for individuals who self-diagnose tinnitus and fail to seek medical evaluations to rule out potential pathologies associated with tinnitus.

- Scientific communities and relevant clinicians must effectively counsel tinnitus patients to minimize the potential spread of online misinformation about tinnitus and help them be prepared to detect, disregard, and even challenge false claims they may encounter online.

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19

IMPLICATIONS OF THE COVID-19 PANDEMIC FOR TINNITUS

Eldré W. Beukes and Vinaya Manchaiah

Introduction

The start of the year 2020 was like most others—plans were made and goals were set. Little did people know that the year would transform the world and be forever remembered in history. A previously unknown virus started an epidemic, rapidly spreading as a Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) and leading to the COVID-19 outbreak and global health emergency. On March 11, 2020, within weeks of discovering this virus, the World Health Organization (WHO) declared the COVID-19 outbreak as a global pandemic due to the alarming spread and severity of the consequences (Sohrabi et al., 2020).

Due to the human-to-human transmission of SARS-CoV-2 (Chan et al., 2020), most countries introduced regional lockdowns to reduce social interactions, advising people to stay at home when possible (Lewnard & Lo, 2020). This resulted in extraordinary disruption to day-to-day living as many venues, including schools, offices, and recreational spaces, were closed. Although such measures reduced the spread of the virus and saved lives, accumulating evidence indicates that the restrictive measures imposed by global lockdowns resulting in the loss of freedom of movement, separation from family and friends, and great uncertainty had a negative impact on well-being (Vindegaard & Benros, 2020). Numerous systematic reviews confirm reduced well-being, increased insomnia, and increased mental health difficulties such as anxiety and depression due to COVID-19 in the general population (Cénat et al., 2020, Kocevska et al., 2020; Vindegaard & Benros, 2020; Xiong et al., 2020). People at greater risk for these effects included those with higher perceived stress loads, less family support, unsteady family income, low self-reported health, and poor sleep quality (Vindegaard & Benros, 2020).

Further, restrictions on professional gatherings and changes in work patterns were introduced for many employees. For some people, there was a loss of income, leading to financial uncertainties (Wright et al., 2020). The combination of these factors resulted in additional stress for a large portion of the population. Stress is a known risk factor for various psychological disorders and illnesses including heart disease, depression, and anxiety. It can change metabolic and immune activity and alter neuronal networks involved in the regulation of emotion and cognition (Bottaccioli et al., 2019).

Identifying individuals at greatest risk for emotional distress, anxiety, depression, and insomnia during disaster events is important to create appropriate support mechanisms. As a result of the relationship between psychosocial difficulties and tinnitus (Durai & Searchfield, 2016; Malouff et al., 2011; Mazurek et al., 2019), the additional stress and anxiety associated with the pandemic could increase tinnitus severity for some individuals as anxiety and insomnia are strong predictors of tinnitus severity (Beukes, Manchaiah, et al., 2020). A bidirectional relationship between stress and tinnitus has also been identified, perhaps associated with changes in neuronal networks (Pattyn et al., 2018). Tinnitus may be initiated or exacerbated during stressful periods (Mazurek et al., 2019). Both tinnitus and stress also affect cognitive functioning, making it more difficult for an affected person to face challenges (Clarke et al., 2020).

Tinnitus affects people differently, and reactions to tinnitus differ widely. Perception of tinnitus causes no concern for some people, whereas for others it causes great distress (Beukes, Manchaiah, et al., 2020). People with bothersome tinnitus may limit their daily activities, further worsening their tinnitus (Manchaiah et al., 2018). Although the COVID-19 pandemic is associated with many devastating effects, it has provided the opportunity to increase understanding of the effects of viral infections on tinnitus as well as internal and external factors on tinnitus experiences. In this chapter, we review the emerging research regarding the effects of the COVID-19 pandemic on tinnitus. This information is preliminary, as research on this topic is evolving.

Background

Initial reports about COVID-19 symptoms included respiratory failure, fever, headaches, and loss of taste and smell. Some symptoms, such as loss of smell (Hopkins et al., 2020), persisted even after recovery from SARS-CoV-2. Initial media reports and case studies noted tinnitus initiation after contracting COVID-19 as an unexpected finding (e.g., Chirakkal et al., 2020; Degen et al., 2020; Fidan, 2020; Lamounier et al., 2020; Maharaj et al., 2020; Sun et al., 2020) and further exploration indicated that this finding was plausible.

A number of viral infections directly damage inner ear structures; induce inflammatory responses; increase susceptibility to bacterial or fungal infections; or result in hearing loss (reduced hearing in one or both ears), tinnitus (a sound that is heard in the ears or head, not related to any external sound source), and vestibular and/or balance disorders (e.g., imbalance, a spinning sensation, and different forms of dizziness) (Cohen et al., 2014). Recovery from hearing loss and related disorders can be spontaneous or aided by treatment. However, some viruses such as the cytomegalovirus, rubella, and measles may result in permanent auditory damage

Larger studies conducted to identify the presence of tinnitus and other audiological symptoms in patients with confirmed COVID-19 are summarized in Table 19–1. The number of participants with COVID-19 included in these studies varied greatly between 6 and 1,420. Most studies were conducted in China or Europe. Although the publications did not always specify whether tinnitus was a preexisting or new symptom, the proportion of participants with tinnitus ranged from 0.4% to 23% for the larger studies (sample size of at least 20 participants).

Table 19–1. Studies Investigating Audiological Symptoms in Individuals With Confirmed COVID-19. Reports of Tinnitus Findings Presented.

Study and Location	***Number of Participants With Confirmed COVID-19***	***Demographic Details***	***Proportion of Participants Reporting Tinnitus***
Lechien et al. (2020); Europe	*n* = 1,420	Mean age: 39.17 (SD: 12.09) years Female: *n* = 962 (67.7%) Male: *n* = 458 (32.3%)	*n* = 5 (0.4%)
Viola et al. (2020); Italy	*n* = 185 Patients from 15 Italian hospitals	Mean age: 52.15 (SD: 13) years Female: *n* = 86 (47%) Male: *n* = 99 (53%)	*n* = 43 (23%) 73% had continuous and 37% had intermittent tinnitus
Elibol (2020); Turkey	*n* = 155	Mean age: 36.3 (SD: 8.1) years Female: *n* = 91 (58%) Male: *n* = 64 (42%)	*n* = 2 (1%)
Munro et al. (2020); U.K.	*n* = 121	Of the 16 reporting changes in hearing and/or tinnitus, the median age was 64 years. Female: *n* = 2 (12%) Male: *n* = 14 (88%)	*n* = 8 (7%) *n* = 1 was unilateral, *n* = 1 tinnitus resolved
Korkmaz et al. (2020); Turkey	*n* = 116	Mean age: 57.24 (SD: 14.32) years; range: 19–83 years Female: *n* = 58 (50%) Male: *n* = 58 (50%)	*n* = 13 (11%)
Liang et al. (2020); China	*n* = 86	Median age: 35.5 years; range: 6–57 years Female: *n* = 42 (49%) Male: *n* = 44 (51%)	*n* = 3 (4%)
Freni et al. (2020); Italy	*n* = 50	Mean age: 37.7 (SD: 17.9) years; range: 18–65 years Female: *n* =20 (40%) Male: *n* = 30 (60%)	Tinnitus appeared or worsened in *n* = 10 (20%) during the active phase of COVID-19. Tinnitus was still persistent in *n* = 5 (10%) 15 days after a negative test was obtained.
Cui et al. (2020); China	*n* = 20	Median age: 63 years; range: 32–72 years Female: *n* = 9 (45%) Male: *n* = 11 (55%) In severe or critical condition: *n* = 19 (95%)	*n* = 1 (5%) (52-year-old male)

continues

Table 19–1. *continued*

Study and Location	***Number of Participants With Confirmed COVID-19***	***Demographic Details***	***Proportion of Participants Reporting Tinnitus***
Karimi-Galougahi et al. (2020); Iran	*n* = 6, of which 3 had confirmed COVID-19 and 3 had COVID-19 symptoms (of which 2 had negative tests, and 1 test result was pending	Age range: 22–40 years; no comorbidities or ototoxic drug use reported Female: *n* = 4 (67%) Male: *n* = 2 (33%)	*n* = 4 (67%)

Results need to be interpreted with caution, as not all studies included patients who had confirmed SARS-CoV-2 and it was not clear if participants were symptomatic or asymptomatic. Munro et al. (2020) investigated the presence of tinnitus and hearing loss in 138 adults with confirmed SARS-CoV-2 after discharge from a hospital in the United Kingdom. Of those, 7% reported tinnitus and 7% reported a deterioration in hearing. Among participants with hearing loss, 88% were males. Viola et al. (2020) reported that 23% of 185 hospitalized COVID-19 patients in Italy reported tinnitus. In this study, 67% of the participants were males. Gender differences in the prevalence of tinnitus in COVID-19 patients require further exploration. In the Italian study, tinnitus was described as recurrent for 40%, occasional for 23%, continuous with varying intensity for 16%, persistent for 9%, pulsatile for 7%, and continuous with the same intensity making it difficult to sleep for 4% of the patients (Viola et al., 2020).

A study focusing on the impact of the pandemic on preexisting tinnitus reported that 8% of respondents had experienced COVID-19 symptoms (Beukes, Baguley, et al., 2020). Although participants with preexisting tinnitus were recruited, seven respondents developed tinnitus and four developed hearing loss after contracting COVID-19. Of those participants with preexisting tinnitus who contracted COVID-19, 40% reported that their tinnitus became more bothersome using a Likert Scale rating, 54% reported no changes to their tinnitus, and 6% reported improved tinnitus. Those participants reporting an improvement mentioned that their tinnitus was not as big a concern as fighting to survive COVID-19. Some participants reported a worsening of tinnitus. However, it was not clear whether the reported changes were directly related to the virus. Other factors may have played a role; for instance, participants taking medications or dietary supplements to boost their immune response reported a significant increase in their tinnitus.

These initial exploratory studies have provided a foundation for further robust and systematic research. It is not known if tinnitus and hearing loss are directly related to the COVID-19 virus or whether the auditory disorders are related to other factors, such as the impact of critical care that includes ototoxic medications (Ciorba et al., 2020). Tinnitus and hearing loss may also result from local or systemic infections, or from vascular or autoimmune disorders. Factors contributing to tinnitus may also include stress associated with being hospitalized or communication difficulties during hospital stays due to the use of personal protective equipment (e.g., face masks).

Initial systematic reviews have indicated diverse audiovestibular symptoms following COVID-19, including hearing loss, tinnitus, vertigo, otitis externa, and undefined ear pain (Almufarrij et al., 2020, Beukes, Ulep et al., 2021; Jafari et al., 2021; Maharaj et al., 2020). Of these symptoms, tinnitus has been the most prevalent, although the exact incidence is not clear as different studies were included in each review. The reported incidence of tinnitus in those affected by SARS-CoV-2 was 4.5% (Confidence Interval [CI]: 1.2 to 15.3) by Jafari et al. (2021), which included six studies; 8% (CI: 5 to 13) by Beukes et al. (2021), which included 18 cross-sectional studies, and 14.8% (CI: 6 to 26) by Almufarrij and Munro (2021), which included 12 studies. It is possible that some of the individuals in these studies may have experienced tinnitus due to causes not related to the SARS-CoV-2 virus or as a side effect of vaccination for the virus. As the existing research has generally not included well-controlled studies, more robust research is required to explore such causal relationships.

Recent Advances

The pandemic impacted not only individuals who contracted the COVID-19 virus, but also non-COVID-19 adults with preexisting tinnitus due to the various lifestyle changes and social distancing restrictions imposed. During the pandemic, insomnia was more frequent in the general population (Kocevska et al., 2020). Of the participants, 67% reported lower sleep quality, which is known to affect tinnitus negatively. Hearing difficulties were aggravated due to the mandatory use of masks. Loss of visual cues and reduced acoustic transmission made speech perception more difficult (Brooks, 2020).

Several healthcare centers in Italy (Anzivino et al., 2020) and China (Xia et al., 2020) reported an influx of patients with bothersome tinnitus after the first wave of COVID-19 cases. The grade of tinnitus severity on the Tinnitus Handicap Inventory (THI) (Newman et al., 1996) increased (i.e., worsened) by one level for a small sample (12 out of 16 patients) tested in Italy (Anzivino et al., 2020). Xia et al. (2020) reported that the effect of anxiety associated with the impact of the pandemic appeared to contribute to elevated tinnitus awareness based on THI and Self-Rating Anxiety Scale (SAS) (Vigil-Colet et al., 2008) data for 89 tinnitus patients before and 99 patients during the pandemic. In contrast, Schlee et al. (2020) found increases in stress levels from a clinical population in Germany (*n* = 122), but no significant differences in tinnitus severity prior to and during the pandemic.

To study the impact of the pandemic on a geographically diverse tinnitus population, Beukes, Baguley, et al. (2020) undertook a mixed-methods exploratory cross-sectional investigation of 3,103 individuals with tinnitus from 48 countries. Although the survey was translated into six languages, obtaining a truly representative sample proved difficult. Most of the respondents were from North America (49%) and Europe (47%), with only a minority representing other world regions (4%). At the time of the survey (May–June 2020), the majority (67%)

of participants reported that the pandemic had not altered their tinnitus, 31% reported that the tinnitus was exacerbated during the pandemic, and 2% reported that their tinnitus was better.

Beukes, Baguley, et al. (2020) also explored the impact of mediating factors such as health concerns, lifestyle changes, social distancing restrictions, and emotional factors on tinnitus experiences during the COVID-19 pandemic. Results of the study are summarized in Table 19–2. Most of the respondents (58%) reported being lonely, and 84% desired more social interactions. The majority (67%) indicated waking up earlier or having less-restful sleep, and 46% reported a lower sleep quality. Most of the respondents (51%) reported no financial worries, 41% were somewhat worried, and 8% were very worried about the impact of COVID-19 on finances. Of the respondents, 34% reported being more anxious, 20% were more depressed, 15% were more irritable, and 31% reported no change in their emotional state.

In the Beukes, Baguley, et al. (2020) study, preexisting tinnitus was significantly exacerbated for those self-isolating, experiencing loneliness, or sleeping poorly. Preexisting tinnitus was also exacerbated for participants reporting reduced exercise compared to prepandemic levels. Increased depression, anxiety, irritability, and financial worries also significantly contributed to more bothersome tinnitus during the pandemic. Moreover, females and younger adults were more likely to report bothersome tinnitus. Beukes, Baguley, et al. (2020) suspected this may be due to the pandemic having a greater impact on work and lifestyle changes for these individuals.

Interestingly, in the same study (Beukes, Baguley, et al., 2020), the impact of COVID-19 restrictions varied significantly between countries. Overall, the impact was greatest for those in the United Kingdom. This may be due to the timing of the survey (May–June 2020) during the peak period of the virus in the United Kingdom or due to the stringency of restrictions compared to the United States or other countries.

Future Directions

Findings from these initial studies indicate that more research is needed to study the relationship between COVID-19 and tinnitus. One potential avenue is to gain insight into how people managed their tinnitus during the pandemic. Many people with preexisting tinnitus reported that their tinnitus remained unchanged, and some even reported an improvement (Beukes, Baguley, et al., 2020). It is plausible that individuals who reported no change in tinnitus during the pandemic were using active and positive coping strategies. These strategies are associated with less problematic tinnitus, anxiety, and depression as compared to passive coping mechanisms (Beukes, Manchaiah, Andersson, et al., 2017). Some persons may have even derived positive experiences related to living with tinnitus during the pandemic (Beukes, Manchaiah, Valien, et al., 2017).

To understand how people coped with tinnitus during the pandemic, Beukes, Onozuka et al. (2021) questioned 1,522 respondents living in North America about resources that helped them cope with their tinnitus during the pandemic. The most frequently utilized resources were family and friends (65%), spending time outdoors or in nature (57%), and relaxing (46%) (Figure 19–1). Other reported activities for coping included arts and crafts, woodworking, cooking, reading, online courses, pet therapy, music, prayer, movies, gardening, house or yard maintenance, and other projects.

Table 19–2. Mediating Factors Associated With the Wider Pandemic Effects of Tinnitus

	Health-Related Factors	***Social Distancing Restrictions***	***Lifestyle Changes***	***Emotional State***
Tinnitus exacerbated (31%)	• Health concerns • Family health concerns • Concerned about contracting the virus • Effects of having the virus • Future healthcare • Difficulty accessing healthcare • Reduced ability to access hearing healthcare • Medication/ vitamins taken • Fluctuations in the tinnitus sounds heard	• Rigorously following social distancing advice • Fewer engagements • Fewer social interactions • Housebound • Loneliness • Listening difficulties	• Less exercise • Noisier at home • Too quiet • Increased alcohol consumption • Increased caffeine intake • Diet less healthy than prior to the pandemic • Higher workload (work, schooling, household) • Busier • Decreased activity levels • Poor sleep	• Frustrations • Relationship problems • Stress, worrying, and anxiety • More depressed • More irritable • Financial worries • Lack of relaxation time • Being furloughed/laid off from work
Tinnitus better (2%)	• Reframing problems • Fighting the virus	• Reduced listening • Frustration	• Healthier than prior to the pandemic • Increased relaxation • Sleeping better • More peaceful lifestyle • Quieter • More time in nature • More exercise • Better diet	• Working from home
Tinnitus stable (67%)	• No additional health concerns • Tinnitus not severe • Had not had virus • Family healthy	• Acceptance of new routine • Not self-isolating • Continuing social interactions	• Access to outdoor spaces • Diet unchanged	• No additional mental health concerns • No financial changes • Similar work patterns

From Beukes, E. W., Baguley, D. M., Jacquemin, L., Lourenco, M. P. C. G., Allen, P. M., Onozuka, J., Stockdale, D., Kaldo, V., Andersson, G., & Manchaiah, V. (2020). Changes in tinnitus experiences during the COVID-19 pandemic. *Frontiers in Public Health*, *8*, 681. https://doi:10.3389/fpubh.2020.592878. Republished by Creative Commons Attribution License (CC BY).

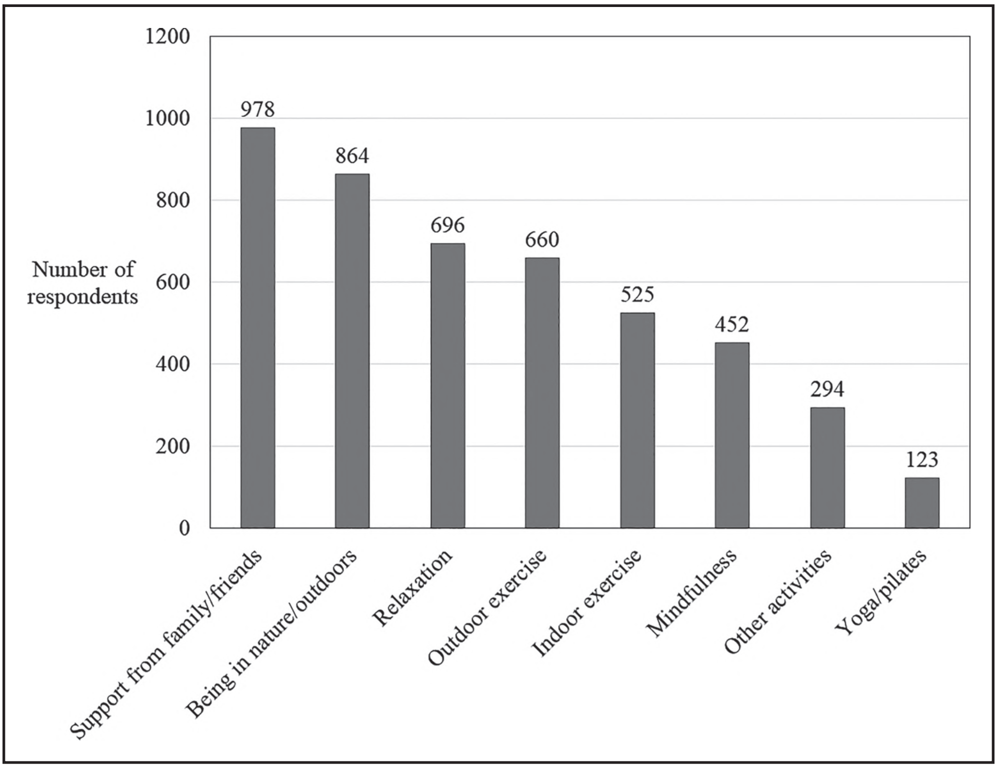

Figure 19–1. Coping resources utilized during the pandemic from 1,522 adults living in North America.

Some respondents also reported that the calmer lifestyle helped them as they had more time for sleep, healthy meals, meditation, and yoga.

When comparing the coping mechanisms used by individuals with different levels of tinnitus severity measured on the Tinnitus Handicap Inventory Screening (THI-S) (Newman et al., 1996), tinnitus distress was significantly less for those who used relaxation, exercised, and spent time outdoors (Beukes, Onozuka, et al., 2021). These findings illustrate the importance of social contact, relaxation, and enjoyable life activities that underpin and improve quality-of-life experiences and can help people cope with tinnitus.

Clinical Implications

During the pandemic, many healthcare services (including audiological services) were severely limited as they sought safer means of delivery. Individuals with tinnitus may have found it more difficult accessing help during this time. To investigate help seeking, Beukes, Onozuka et al. (2021) compared help seeking for tinnitus before and during the pandemic in North America. The findings revealed that significantly less support was sought during the pandemic compared to the prepandemic period. Specifically, the support included professional healthcare providers (8%), self-help resources (7%), the American Tinnitus Association (3%), and internet interventions (2%). The decrease in help seeking was partly attributed to concerns about the risk of unnecessary exposure to the virus during clinical appointments. Some respondents also indicated that they were unsure where to access services, as many audiological practices were not operating during the pandemic. Also, some respondents reported concerns about the availability of professional help for their tinnitus, hearing aid fitting, and other health and mental health conditions. Beukes, Onozuka, et al. (2021) found that tinnitus distress was significantly less for those persons who sought help via their usual audiology clinic and for those who had ongoing or remote support. These findings highlight the importance of accessible support for persons with tinnitus distress.

Beukes, Onozuka et al. (2021) surveyed 1,522 adults in the United States and Beukes, Lourenco, et al. (2021) surveyed 710 individuals in Europe to explore what type of support would be helpful for individuals with tinnitus during the pandemic. The results revealed that respondents desired tinnitus support, hearing support, social support, and pandemic-related support (Table 19–3). Respondents with tinnitus indicated a need for professionals who were more understanding regarding the impact of tinnitus on their life. They expressed a need to be treated by multidisciplinary tinnitus experts if their tinnitus was related to other difficulties; e.g., neck or jaw problems. The respondents also expressed a need for more patient-centered, evidence-based therapies and greater intervention options. In addition, respondents had a great desire for reliable tinnitus information provided online by experts (Beukes et al., 2019). Many respondents also reported hearing difficulties. However, some respondents were unable to afford hearing aids or custom hearing protection. Respondents also expressed a desire for greater public awareness about tinnitus difficulties to create more social and peer support. Lastly, respondents desired additional support during the pandemic to help them cope with insomnia, loneliness, and anxiety.

Tinnitus support and clinical service providers might consider the aforementioned gaps in service provision to more effectively shape patient-centric tinnitus care. Overall, the authors' observations suggest that the COVID-19 pandemic has clearly highlighted the need for accessible evidence-based tinnitus interventions and, especially, remote care models to ensure that the service delivery continues despite external factors. Moreover, these surveys suggest a clear and immediate need to develop adequate social support mechanisms, such as tinnitus support groups.

Key Messages

- The associations between tinnitus and the SARS-CoV-2 virus/COVID-19 pandemic are unclear, as research in this area is still emerging.
- Health professionals who may be involved in the care of COVID-19 patients should be mindful that contracting the SARS-CoV-2 virus may lead to tinnitus, hearing loss, and other audiovestibular difficulties, and that such individuals should be directed to appropriate care.
- Individuals with tinnitus expressed a need for services to be more readily and safely available despite the pandemic. Accessible smartphone application- and

Table 19–3. Support Desired by Individuals With Tinnitus During the COVID-19 Pandemic

Theme	***Subtheme***
Tinnitus support	Access to multidisciplinary tinnitus experts who understood the problems associated with tinnitus A greater range of evidence-based therapies and resources for tinnitus Remote patient-centered tinnitus interventions Access to reliable online information about tinnitus Making tinnitus research a greater priority Finding a cure for tinnitus
Hearing support	Help with hearing difficulties, particularly as facial clues were lacking during the mandatory use of masks Availability of affordable hearing aids, as high cost prevented purchase of these devices More support for obtaining custom-made affordable hearing protection Hearing loss prevention
Social support	Helping the general public understand the impact of tinnitus More understanding from relatives Tinnitus peer-support groups Being able to speak to someone about tinnitus experiences; e.g., via help lines
Pandemic support	Support for solitude Help with the resulting sleep difficulties Ways to manage the resulting anxiety Ideas to cope with the stress related to the pandemic and ways to stay positive

Beukes et al. (2021a and 2021b).

internet-based tinnitus interventions should be promoted (e.g., Beukes et al., 2019; Beukes, Fagelson, et al., 2020; Kaldo et al., 2013; Manchaiah et al., 2020; Nagaraj & Prabhu, 2020)

- Additional support should be offered to individuals in whom tinnitus severity has increased due to health, social, and/or emotional effects of the COVID-19 pandemic. These individuals may include those experiencing loneliness, those having fewer social interactions, and those who are more anxious or worried.
- The need for greater awareness of the toll of tinnitus on patients is paramount within the healthcare community. Patient organizations and professionals should be encouraged to work together to provide improved outlets for tinnitus care.
- Further studies are required to collate implications of COVID-19 on tinnitus, and service provision should be structured accordingly.

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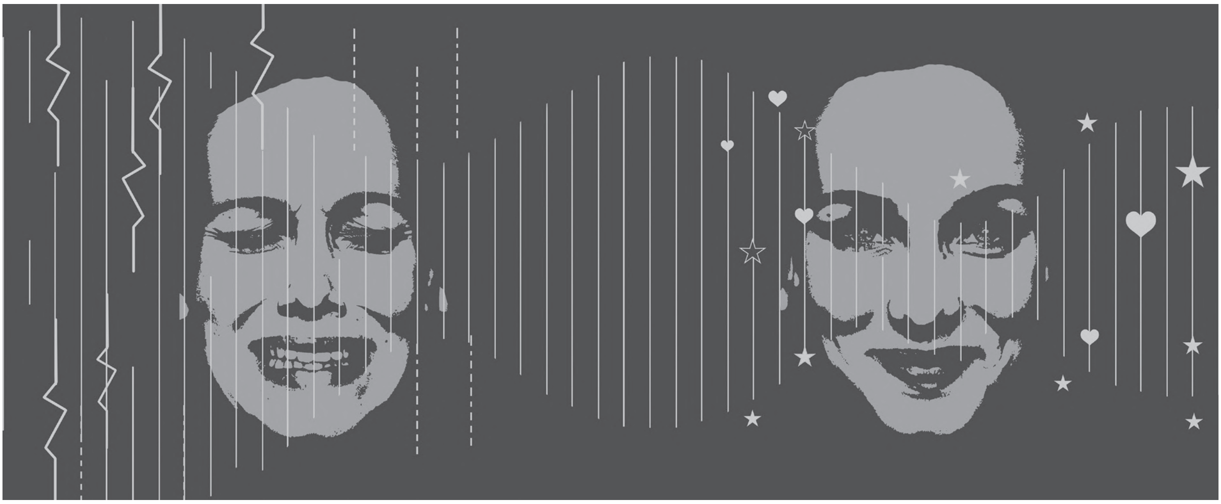
SECTION VI

ILLUSTRATIVE CLINICAL SCENARIOS



Section VI depicts interesting real-life clinical scenarios involving patients with tinnitus. Each case study describes the clinical history of a patient, followed by a detailed diagnostic evaluation of the patient, including audiological evaluation (pure-tone audiometry, speech audiometry, and tympanometry), tinnitus evaluation (loudness matching, pitch matching, minimum masking levels, and questionnaire responses), and medical/neuroimaging evaluation where applicable. Next, the diagnosis and treatment recommendations are described, followed by management outcomes. Finally, the case study is summarized via key messages for clinicians.

The aim of these case studies is to demonstrate how clinicians could approach complex cases in the light of knowledge gained on tinnitus prevention, assessment, and management from the preceding sections.

20 CASE STUDY 1: ASYMMETRICAL SENSORINEURAL HEARING LOSS AND TINNITUS

Aniruddha K. Deshpande and Lisa Mener

Clinical History and Description

B. B., a 70-year-old male retired engineer, initially presented to an otolaryngology clinic with the complaint of sudden hearing loss accompanied by fluctuating tinnitus in the left ear that began a month prior. B. B. reported noticing a drastic worsening in his hearing after being exposed to reverberation occurring from an open rear car window while he was driving. Soon after this event, B. B. noticed a sharp pain and a clogged sensation in the left ear. B. B. described the experience as follows: "I noticed external sounds became amplitude modulated; there was a very noticeable attenuation in my hearing that was coincident with my heartbeat."

Prior to the event described above, B. B.'s medical history consisted of occasional ear infections during childhood; he reportedly became more susceptible to otitis externa after swimming 25 feet deep in a mineral spring at approximately 20 years of age. At that time, he also noticed increased sensitivity, discomfort, and a squeaking sound in the left ear. B. B. reported to have always noticed a very subtle high-pitched tinnitus, that was easy to ignore and perceived as evenly balanced between ears, when in a quiet environment. However, he denied prior hearing loss and/or bothersome tinnitus. Further pertinent medical history was otherwise unremarkable.

At his initial consult with the otolaryngologist, B. B. reported that he could no longer understand soft speech and that loud sounds produced discomfort and sometimes pain. He now avoided crowded places and listening to music; even moderately loud music sounded distorted and was more bothersome than enjoyable. In addition, he began to utilize closed captioning while watching television and often requested repetition from others. Prior to the perceived decline in hearing, B. B. felt that he could comprehend auditory input more easily from his left ear compared to his right ear. For this reason, B. B. preferred to utilize his left ear when speaking on the phone; however, he was now no longer able to utilize his left ear in this manner. From his spouse's point of view, B. B. became much more irritable with the onset of hearing loss and tinnitus. She reported that B. B. could no longer engage in conversations among crowds, no longer enjoyed listening to music at venues, or to the radio in the car—"nothing was fun for him."

Diagnostic Evaluation

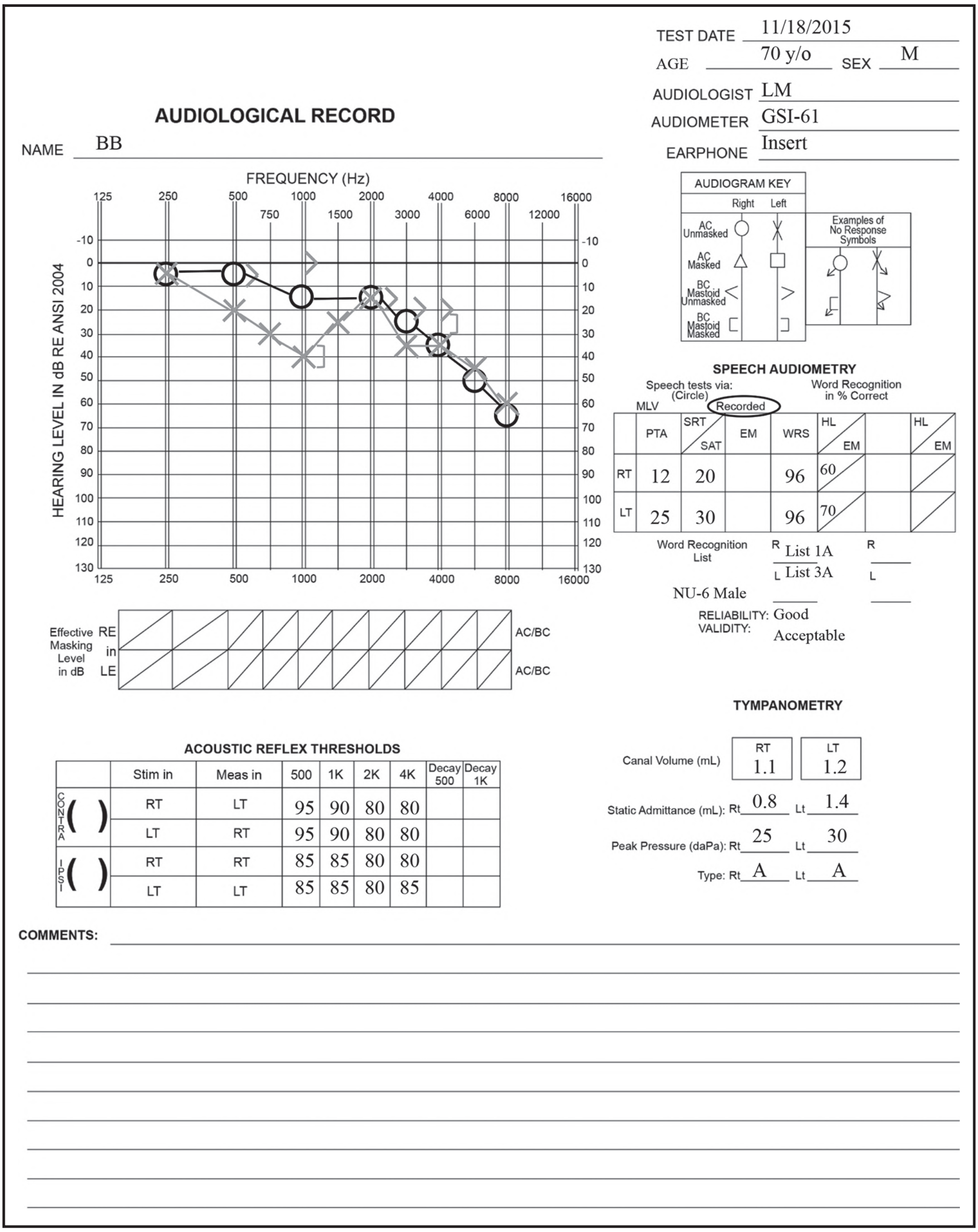
Audiological Evaluation

B. B.'s initial audiological evaluation revealed hearing within normal limits (WNL) at low frequencies, sloping to moderate sensorineural hearing loss (SNHL) in the left ear, and mild to moderately severe SNHL in the right ear at high frequencies. An asymmetry was noted at 500 and 1000 Hz, with the left ear thresholds being 15 and 25 dB poorer than the right ear, respectively (Durakovic et al., 2019). A normal speech recognition score (SRS) of 96% was obtained bilaterally. Immittance measures indicated a normal Type A tympanogram bilaterally. Ipsilateral (ipsi) and contralateral (contra) acoustic reflex thresholds (ARTs) were present at all frequencies tested, although thresholds were obtained at reduced sensation levels for left ipsi/contra at 1000 Hz and for all modalities at 4000 Hz, consistent with cochlear hearing loss (Figure 20–1).

The second audiological evaluation, conducted approximately 2 months after the initial evaluation, indicated a decrease in hearing in the left ear across all frequencies tested. Hearing loss in the left ear was now consistent with mild to moderately severe mixed hearing loss, with the right ear essentially unchanged since the initial evaluation (right ear thresholds within 10 dBHL according to the initial audiogram). Results now indicated an asymmetry in thresholds between the ears (Durakovic et al., 2019) at all frequencies tested except 8000 Hz, ranging from 15 to 50 dB, with the left ear being worse. Left ear SRS decreased to 84%, consistent with slight difficulty in word recognition. The right ear SRS remained within the normal range. Left ear ipsilateral ARTs were obtained at reduced sensation levels while those for the right ear were obtained at normal sensation levels (Figure 20–2). Hypermobile, Type Ad tympanogram was obtained in the left ear with normal Type A tympanogram in the right ear.

As a result of B. B.'s decline in hearing, an intratympanic (IT) steroid injection in the left ear was recommended by the otolaryngologist as it has been shown to be beneficial for patients with idiopathic sudden SNHL (Bear & Mikulec, 2014). B. B.'s hearing was reevaluated in the left ear only, 3 months post-initial audiological evaluation (3 weeks following IT injection). Results indicated no change in hearing in the left ear except for a slight reduction in SRS (78%). He also underwent a course of oral steroids and amino acid supplements at the recommendation of his otolaryngologist; treatments did not result in any recovery of hearing or change in tinnitus perception.

B. B.'s hearing continued to be monitored both routinely and whenever a change in hearing was suspected. His left ear hearing thresholds and word recognition scores gradually deteriorated over time. B. B.'s most recent audiological evaluation, conducted approximately 5 years post-initial audiological evaluation, revealed a profound SNHL from 250 to 8000 Hz in the left ear. Hearing in the right ear was WNL from 250 to 1000 Hz, sloping from mild to moderately



AUDIOLOGICAL RECORD

NAME BB

TEST DATE 11/18/2015

AGE 70 y/o SEX M

AUDIOLOGIST LM

AUDIOMETER GSI-61

EARPHONE Insert

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	12	20		96	60		
LT	25	30		96	70		

Word Recognition List R List 1A L List 3A R ___ L ___

NU-6 Male

RELIABILITY: Good

VALIDITY: Acceptable

Effective Masking Level in dB												
RE												AC/BC
LE												AC/BC

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	95	90	80	80		
	LT	RT	95	90	80	80		
IPSI ( )	RT	RT	85	85	80	80		
	LT	LT	85	85	80	85		

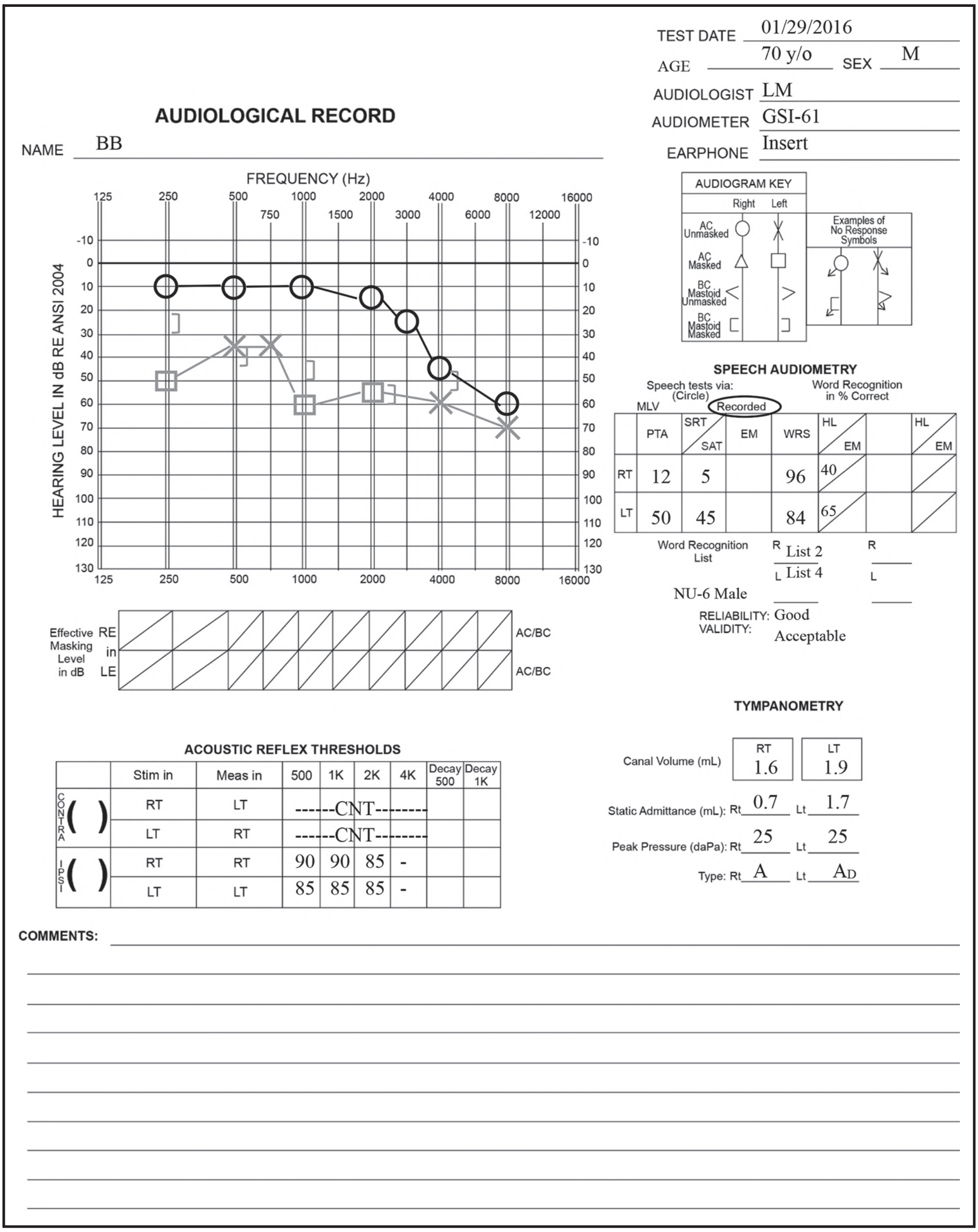
TYMPANOMETRY

	RT	LT
Canal Volume (mL)	1.1	1.2
Static Admittance (mL)	0.8	1.4
Peak Pressure (daPa)	25	30
Type	A	A

COMMENTS:

Figure 20–1. Initial audiological evaluation; approximately 1 month post-onset of symptoms.

severe SNHL at higher frequencies. Speech detection threshold (SDT) and SRS could not be obtained in the left ear. The SRS in the right ear was 96%. Immittance measures indicated normal Type A tympanogram in the right ear, and hypermobile Type Ad tympanogram in the left ear; ARTs were not evaluated at that time (Figure 20–3).



TEST DATE 01/29/2016

AGE 70 y/o SEX M

AUDIOLOGIST LM

AUDIOMETER GSI-61

EARPHONE Insert

AUDIOLOGICAL RECORD

NAME BB

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	12	5		96	40		
LT	50	45		84	65		

Word Recognition List R List 2 L List 4 R L

NU-6 Male

RELIABILITY: Good

VALIDITY: Acceptable

Effective Masking Level in dB											
RE											AC/BC
in											
LE											AC/BC

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	------CNT--------					
	LT	RT	------CNT--------					
IPSI ( )	RT	RT	90	90	85	-		
	LT	LT	85	85	85	-		

TYMPANOMETRY

	RT	LT
Canal Volume (mL)	1.6	1.9

Static Admittance (mL): Rt 0.7 Lt 1.7

Peak Pressure (daPa): Rt 25 Lt 25

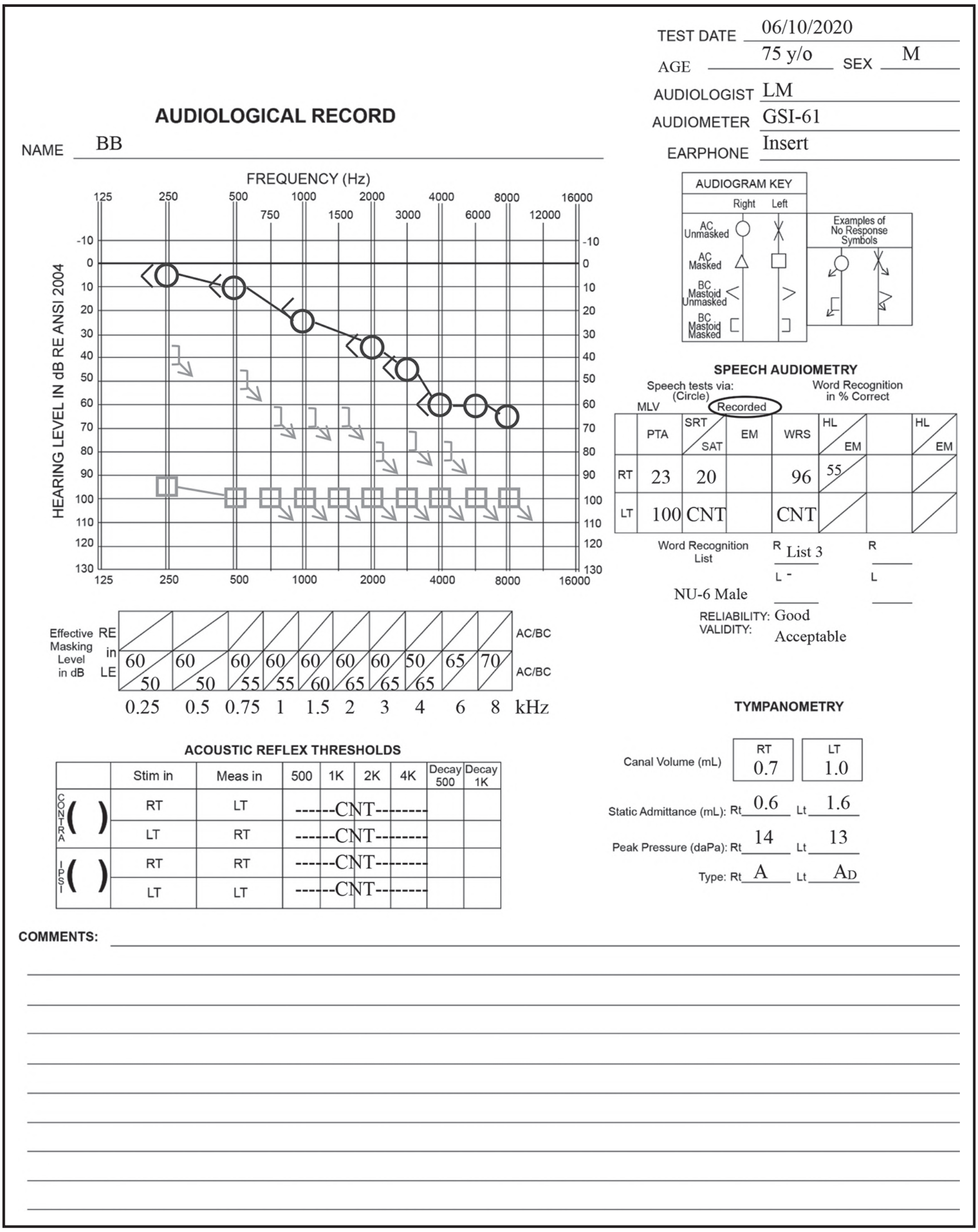
Type: Rt A Lt AD

COMMENTS:

Figure 20–2. Audiological evaluation approximately 2 months post-initial audiological evaluation; change in hearing of left ear displayed.

Neuroimaging Evaluation

In light of asymmetrical hearing loss and report of left-sided tinnitus, B. B. underwent serial magnetic resonance imaging (MRI), magnetic resonance angiography (MRA) and computerized tomography (CT) scan (Bear & Mikulec, 2014). Significant findings are described here: B. B. underwent his first MRI approximately 2 days fol-



AUDIOLOGICAL RECORD

TEST DATE 06/10/2020
AGE 75 y/o SEX M
AUDIOLOGIST LM
AUDIOMETER GSI-61
EARPHONE Insert
NAME BB

Effective Masking Level in dB

		0.25	0.5	0.75	1	1.5	2	3	4	6	8 kHz	
RE	in											AC/BC
LE		60 50	60 50	60 55	60 55	60 60	60 65	60 65	50 65	65	70	AC/BC

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]
Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	23	20		96	55		
LT	100	CNT		CNT			

Word Recognition List NU-6 Male
R List 3 R
L - L
RELIABILITY: Good
VALIDITY: Acceptable

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	------CNT--------					
	LT	RT	------CNT--------					
IPSI ( )	RT	RT	------CNT--------					
	LT	LT	------CNT--------					

TYMPANOMETRY

	RT	LT
Canal Volume (mL)	0.7	1.0

Static Admittance (mL): Rt 0.6 Lt 1.6
Peak Pressure (daPa): Rt 14 Lt 13
Type: Rt A Lt A_D

COMMENTS:

Figure 20–3. Audiological evaluation approximately 5 years post-initial audiological evaluation; displays complete deterioration of hearing on the left side.

lowing initial audiological evaluation. The report indicated that there was no evidence of vestibular schwannoma and no abnormal enhancement involving the left seventh cranial nerve/VII complex. Report from a subsequent MRI conducted approximately 2 years post-initial audiological evaluation, however, indicated a "3mm linear focus of enhancement involving the middle turn of the left cochlea. In retrospect, there was a punctate enhancement involving the left cochlea on the prior brain MRI." Findings were indicative of an intracochlear vestibular schwannoma. An additional MRI conducted approximately 3 years post-initial audiological evaluation, revealed a "stable enhancement within the basal turn of the left cochlea consistent with a 3mm vestibular schwannoma." The most recent MRI, conducted approximately 5 years post-initial audiological evaluation, indicated an "enhancement within the middle turn of the left cochlea, which appeared slightly more prominent than the previous one and was consistent with intracanicular cochlear schwannoma." The area of enhancement during the third MRI measured 1.7 × 4.0 mm as compared with 1.3 × 4.0 mm during the second visit. The presence of an intracochlear schwannoma (ICS) can be seen in Figure 20–4. MRA and CT scan results were unremarkable.

Detection of ICS is challenging due to the tumor's small size, position, and variable clinical/imaging features. Presenting symptoms are often shared with other otologic diseases, such as Meniere's disease and labyrinthitis, causing diagnosis to be delayed. High-resolution MRI with gadolinium enhancement is considered the gold standard for schwannoma diagnosis. The addition of gadolinium allows these tumors to become strongly enhanced and more sharply defined on T1-weighted images. Differential diagnosis of ICS from other diseases, such as labyrinthitis ossificans, can be achieved by patient history and temporal CT scan to detect bony growths on the membranous labyrinth. Small intralabyrinthine lesions, such as ICS, may be difficult to visualize on MRI and may only be detected in retrospect. For this reason, detection of ICS depends upon an appropriate MR imaging protocol

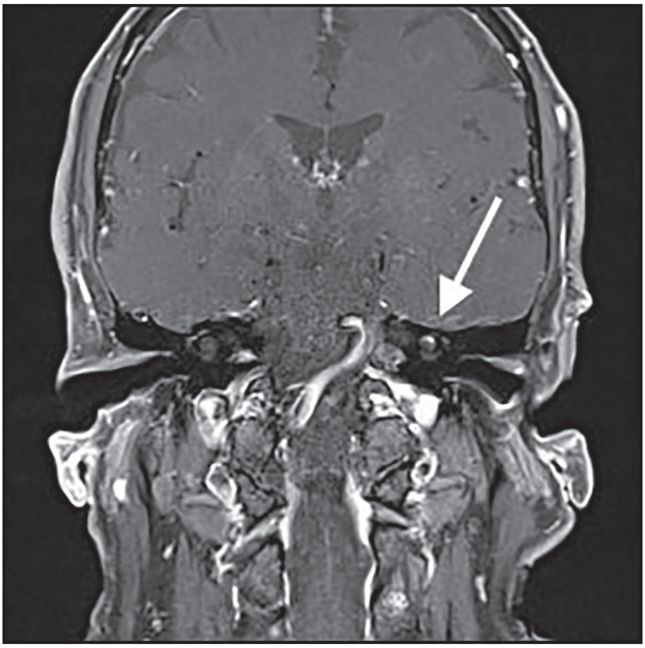


Figure 20–4. MRI scan displaying presence of left intracochlear schwannoma.

as well as the radiologist's awareness of these tumors (Magliulo et al., 2009; Miller et al., 2010; Salzman et al., 2011).

Tinnitus Evaluation

Unilateral hearing loss and tinnitus are two of the most common symptoms among patients with ICS. Patients with ICS typically present with progressive sensorineural hearing loss, accompanied by poor speech understanding. A mixed type of hearing loss may also occur, likely due to increased intracochlear impedance, which may account for the occasional mixed hearing loss displayed on B. B.'s audiograms (Alves et al., 2014). As his hearing changed over time, B. B. reported his tinnitus to fluctuate in pitch, loudness, and type of sound experienced.

B. B.'s tinnitus was evaluated via a detailed patient report, pitch matching, and the Tinnitus Handicap Inventory (THI) (Newman et al., 1996). B. B. described his tinnitus as "almost a pure tone, mixed with warbling and clicks." He perceived his tinnitus to be pulsatile and changing from being unilateral to bilateral at different times. He also reported hearing additional sounds such as "banjo music" when extremely exhausted or under stress. He reported noticing a change in tinnitus loudness, pitch, and quality when he moved his head from looking down to looking upward, "as in a quick nod."

Most descriptions about the quality of tinnitus come from patients' self-reports; however, self-reports may be problematic as patients may not utilize the same words to describe the same sounding tinnitus (McFadden, 1982). To better portray his auditory perceptions, B. B. created sound samples from the year of tinnitus onset to approximately 5 years later. Detailed auditory descriptions of B. B.'s tinnitus, created by himself, can be accessed on the companion website.

To assess B. B.'s tinnitus pitch, a modified forced-choice pitch-matching procedure (Korth et al., 2020; Penner & Bilger, 1992) was conducted by an audiologist approximately 2 years post-B. B.'s initial audiological evaluation. A pure tone was presented to the patient in each ear separately, while the patient was tasked with comparing the tone with the tinnitus heard in the contralateral ear. Based on the patient's responses, the audiologist adjusted the tone to best match the tinnitus perceived by the patient. In the left ear, B. B.'s tinnitus was pulsatile in nature and pitch-matched to a 3 kHz pure tone, while in the right ear, it was perceived as a constant tone and pitch-matched to an 8 kHz pure tone.

The THI is a reliable questionnaire utilized to quantify the impact of tinnitus on daily living. The THI was administered prior to B. B.'s management of tinnitus and revealed a score of 78 out of a possible 100 points, placing him in Grade 5: Catastrophic. Grade 5 is consistent with tinnitus that is constantly heard, disrupts sleep, and can interfere with the ability to carry out daily activities (McCombe et al., 2001).

Diagnosis and Recommended Management

B. B. began wearing hearing aids approximately 2 years following his initial audiological evaluation. He was fit with bilateral Widex Beyond 440 receiver-in-the-canal hearing aids with the Widex Zen program for tinnitus management. Widex Zen therapy allows for an individualized tinnitus management program by combining components of management strategies that have been found to provide tinnitus relief, such as tinnitus retraining therapy (TRT) (Jastreboff & Jastreboff, 2000), cognitive behavioral therapy (CBT) (Jun & Park, 2013), counseling, amplification, fractal tones, relaxation strategies, and sleep management (Seetow & Jeppesen, 2012; Tyler et al., 2017). B. B. was a participant in the beta testing of the Widex Zen app for the iPhone while he still had binaural hearing. He reported the Widex Zen program to be somewhat helpful in reducing the perceived loudness of his tinnitus. B. B. reported noticing less benefit from the fractal sounds as his hearing in the left ear worsened but found certain sounds to be more appropriate as his hearing and tinnitus changed. Once B. B. no longer perceived benefit from the left hearing aid (due to the degree of hearing loss), he discontinued use of the left hearing aid but continued to utilize the hearing aid on the right ear (the left hearing aid was reprogrammed as a back-up aid for the right ear). In addition, B. B. found his own noise generators, with sounds of his choice, to be beneficial in the management of his tinnitus (Henry et al., 2008).

At the recommendation of his otolaryngologist, B. B. underwent an evaluation for the possibility of left cochlear implantation with removal of the schwannoma. Not only would a cochlear implant address B. B.'s hearing loss and localization difficulties, but there is also evidence that cochlear implants can help reduce tinnitus and the tinnitus handicap (Kloostra et al., 2018; Tyler et al., 2015). A cochlear implant evaluation was conducted approximately 3.5 years post-initial audiological evaluation, but B. B. did not meet audiological candidacy criteria for cochlear implantation at that time. Since B. B.'s evaluation, cochlear implant candidacy criteria have expanded; cochlear implantation for individuals 5 years and older with single-sided deafness (defined as profound SNHL in one ear and normal hearing or mild SNHL hearing loss in the other ear) or asymmetric hearing loss (defined as profound SNHL in one ear and mild to moderately severe SNHL in the other ear, with at least a 15-dB difference in pure-tone average between ears) has been approved by the U.S. Food and Drug Administration (FDA) (Kornak, 2019). Therefore, B. B. may now meet the audiological candidacy criteria for a cochlear implant as described by the new guidelines; however, per B. B.'s otolaryngologist, review of neuroimaging films with the medical team indicates a midturn cochlear schwannoma that is unable to be removed. For this reason, a cochlear implant was not pursued and a trial of bilateral microphones with contralateral routing of signal (BiCROS) was recommended as the next step in B. B.'s hearing loss management by the otolaryngology and audiology team. In addition, due to the mild growth of the schwannoma displayed on imaging, B. B. was referred by otolaryngology to the neurosurgery team for possible stereotactic radiation treatment (Alves et al., 2014).

As recommended, B. B. underwent an evaluation for a BiCROS system. Aided testing, with the Oticon CROS, was conducted under a number of conditions and compared to his performance with his right hearing aid alone. Although his performance with the BiCROS was not significantly better than his performance in the monaurally aided condition, B. B. was still interested in the possible improvement he may perceive from simply having access to sound on his left side. After a trial with a loaner BiCROS system for approximately 1 week, B. B. felt the delay in sound he heard to be bothersome and did not perceive enough benefit to be willing to pursue this option.

Outcome

B. B. continues to utilize a Widex Beyond 440 receiver-in-the-canal hearing aid in his right ear as well as compensatory strategies to aid in communication. Such strategies include strategic seating arrangements to ensure his better ear is facing toward the speaker and ensuring a clear view of the speaker's face for visual cues. B. B. reports localization to be extremely difficult and utilizes additional visual indicators to assist in this task, such as enabling a flashing light on his cell phone when it rings.

In managing his tinnitus, B. B. finds CBT and mindfulness to be the most effective management (Jun & Park, 2013). He reports that meditation and mindfulness allow him to keep calm and to become accepting of his tinnitus; he reports to now approach his tinnitus with the thought that "these are just the sounds of my life," rather than engaging in past feelings of despair and frustration. Although the loudness of his tinnitus has not decreased much, this new mindset has allowed B. B. to feel better, emotionally, in the presence of his tinnitus.

An audiologist re-administered the THI 5 years after the initial audiological evaluation, after B. B. had learned and engaged in the tinnitus management that he found to be the most effective. The THI revealed a score of 28 out of a possible 100 points—a reduction of 50 points compared to the initial assessment—indicating significant improvement in tinnitus handicap. B. B. was now placed in Grade 2: Mild; this grade is consistent with tinnitus that may be easily masked by environmental sounds and easily forgotten with activities (McCombe et al., 2001).

At this time, B. B. has not yet consulted with neurosurgery and remains unsure of how he will proceed in managing his left intracochlear schwannoma. However, he will continue to be monitored by the otolaryngology and audiology team, who will keep him apprised of management options and technological advances that may provide him with further hearing and tinnitus management and an improved quality of life.

In summary, this case portrayed worsening asymmetrical hearing loss over time in the presence of an intracochlear schwannoma, as well as perceived changes in tinnitus. Despite treatment with oral and intratympanic steroids, the patient did not experience improvement in hearing. This case study described the patient's journey through audiological and otologic monitoring, hearing loss management, as well as learning how to manage an ever-changing tinnitus through CBT and meditation.

Key Messages

- Unilateral hearing loss and tinnitus are the most prevalent presenting symptoms among patients with intracochlear schwannomas.
- Tinnitus is often not strictly tonal in quality; it can be perceived in many variations with respect to its temporal and spectral characteristics, and may change frequently.
- Tinnitus apps and noise generators can provide relief from tinnitus.
- Cognitive behavioral therapy, acceptance therapy, and mindfulness can be effective management tools to reduce the tinnitus handicap.

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21

CASE STUDY 2: SUDDEN SENSORINEURAL HEARING LOSS AND TINNITUS

Aniruddha K. Deshpande and Diana Callesano

Clinical History and Description

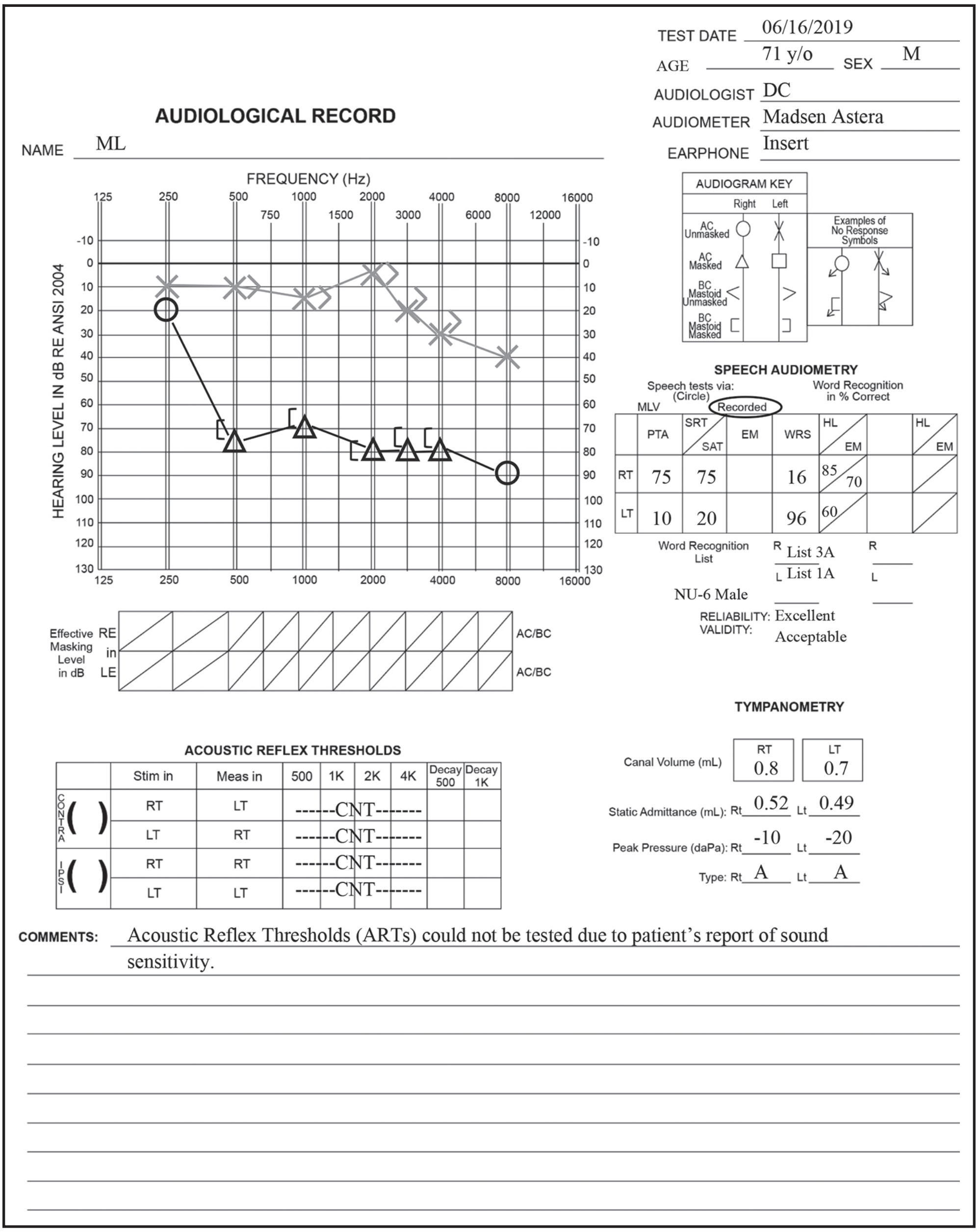
M. L., a 71-year-old male psychologist, presented to the audiology clinic with a complaint of sudden hearing loss in his right ear that started 1 day ago. He reported that, when he awoke that morning, he experienced a sensation of fullness in his right ear coinciding with tinnitus. He described the tinnitus as "low but noticeable." It was not until he lifted his left ear off the pillow that he realized there was quite a difference in hearing between his two ears. Additional symptoms included sensitivity to sound, difficulty concentrating, and trouble sleeping due to his tinnitus.

M. L. reported that he worked as a psychologist and saw about 10 patients per week for 45-minute sessions in a quiet setting. M. L. expressed concern regarding his ability to hear his patients. He had to ask his patients to repeat themselves frequently, which he felt made it appear as though he was not listening. He reported being distracted by his tinnitus, which was intensified by the quiet surroundings in his office. M. L.'s symptoms also made it difficult for him to enjoy social gatherings. He either avoided attending them or left early due to difficulty hearing people and sensitivity to sound. He reported that certain noises (such as his grandchildren yelling in the pool) made his tinnitus worse.

Diagnostic Evaluation

Audiological Evaluation

Pure-tone audiometry revealed hearing within normal limits from 250 to 3000 Hz, sloping to a mild presumable sensorineural hearing loss (SNHL) through 8000 Hz in the left ear. The right ear demonstrated normal hearing at 250 Hz, precipitously sloping to a severe to profound SNHL from 500 to 8000 Hz (Figure 21–1). Speech-recognition thresholds (SRTs) were in good agreement with the three-frequency pure-tone average (PTA) bilaterally. Word recognition score (WRS) for the left ear was obtained at 40 dB sensation level (dBSL; ref: SRT) using Northwestern University's NU-6 Word List



TEST DATE 06/16/2019

AGE 71 y/o SEX M

AUDIOLOGIST DC

AUDIOMETER Madsen Astera

EARPHONE Insert

AUDIOLOGICAL RECORD

NAME ML

Effective Masking Level in dB RE in LE: RE AC/BC; LE AC/BC

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	75	75		16	85 / 70		
LT	10	20		96	60		

Word Recognition List R List 3A L List 1A R L

NU-6 Male

RELIABILITY: Excellent

VALIDITY: Acceptable

TYMPANOMETRY

	RT	LT
Canal Volume (mL)	0.8	0.7

Static Admittance (mL): Rt 0.52 Lt 0.49

Peak Pressure (daPa): Rt -10 Lt -20

Type: Rt A Lt A

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	------CNT-------					
	LT	RT	------CNT-------					
IPSI ( )	RT	RT	------CNT-------					
	LT	LT	------CNT-------					

COMMENTS: Acoustic Reflex Thresholds (ARTs) could not be tested due to patient's report of sound sensitivity.

Figure 21–1. M. L.'s audiogram at the initial visit.

(Tillman & Carhart, 1966) 1A via monitored live voice. This protocol could not be applied to M. L.'s right ear due to loudness discomfort. Instead, WRS was obtained at 10 dB SL (ref: SRT) in the right ear. M. L.'s WRS was 96% and 16% in the left and right ears, respectively. Tympanometry revealed normal ear canal volume, static admittance, and middle ear pressure (Type A) in both ears. Acoustic reflex thresholds (ARTs) could not be tested due to the patient's report of sound sensitivity.

Tinnitus Evaluation

Tinnitus Pitch Match

M. L. perceived tinnitus in his right ear. All tinnitus measurements were performed in M. L.'s contralateral (i.e., left) ear to minimize confusion (Henry et al., 1999) and due to concerns of sound sensitivity in the right ear. First, various auditory stimuli (pure tone, narrowband noise, broadband noise) were presented to M. L. to help him broadly define the perception of his tinnitus. M. L. described his tinnitus to match closely with tonal stimuli. Next, a two-alternative forced-choice bracketing procedure was used to identify the pitch of his tinnitus (Kim et al., 2017). He matched his tinnitus to an 8000-Hz pure tone.

Tinnitus Loudness Match

A tinnitus loudness match was performed in M. L.'s left ear at his tinnitus pitch (i.e., 8 kHz pure tone) using a 1-dB step size involving ascending runs. The starting point for this procedure was 40 dB HL—his threshold at 8 kHz in the left ear. M. L. matched the loudness of his tinnitus at 49 dB HL (or 9 dBSL; ref: 8 kHz).

Minimum Masking Level

Broadband noise (BBN) was presented in M. L.'s left ear in an ascending manner beginning at his BBN threshold of 5 dB HL. The patient was asked to signal a "stop" hand gesture when he no longer perceived his tinnitus. M. L. achieved a minimum masking level (MML) at 15 dB HL (or 10 dB SL; ref: his BBN threshold).

Loudness Discomfort Level

Loudness discomfort level (LDL) measurement was not attempted with M. L. as he expressed concerns about sound sensitivity.

Residual Inhibition

The residual inhibition (RI) test was performed to observe whether the patient experienced brief suppression of his tinnitus following presentation of noise. White noise was presented at 10 dBSL (ref: MML) in the left ear for 1 minute. Prior to the residual inhibition task, M. L. rated his tinnitus loudness to be 6 out of 10 on a numerical rating scale (*1* = very soft, *10* = very loud). After cessation of the white noise, he rated his tinnitus at 3 out of 10. This suggests that he experienced partial tinnitus suppression after the noise presentation.

Questionnaires

M. L.'s initial score on the Tinnitus Handicap Inventory (THI) (Newman et al., 1996) was 46, consistent with a moderate degree of self-perceived tinnitus impact. M. L.'s score on the Hyperacusis Questionnaire (Khalfa et al., 2002) was 32, consistent with a mild degree of impact from sound sensitivity.

Diagnosis and Recommended Management

Following his initial appointment at the audiology clinic, M. L. immediately scheduled a consultation with a local otolaryngologist, where he was diagnosed with sudden sensorineural hearing loss and tinnitus. M. L. was initially placed on an oral steroid taper regimen for 1 week. At the same time, he was also referred for magnetic resonance imaging (MRI) of the internal auditory canals (IACs) with and without contrast. The results of the MRI scans were unremarkable. Since the oral steroids did not yield any significant improvement in his hearing loss or tinnitus, M. L. then received three intratympanic (IT) steroid injections over the next 4 weeks. The IT injections did not result in any change in his hearing.

After all medical intervention options had been exhausted, M. L. reported back to the audiology clinic approximately 5 weeks after his initial appointment. At this appointment, M. L. reported that he had already been fitted with binaural Oticon OPN S3 miniRITE hearing aids at his otolaryngologist's office and that the otolaryngologist referred him to the audiology clinic for tinnitus management. The combination of symptoms he was experiencing and their effects on quality of life were discussed with M. L. to help him better understand the management options available to him. M. L. stated that he was less concerned about his hearing loss than the disruption caused by his tinnitus.

Comprehensive informational counseling was provided to M. L. at the initial visit and at subsequent follow-up appointments. This counseling included a functional review of the peripheral and central auditory system and the role of the autonomic nervous system in tinnitus perception. An emphasis was placed on the latter, as M. L. had a professional understanding of the limbic system and its role in conditioned responses to negative stimuli. The tenets of tinnitus retraining therapy (TRT) (Jastreboff & Jastreboff, 2020) were discussed to reinforce neurophysiologic understanding of tinnitus and hyperacusis. M. L. was counseled extensively on the process of habituation to tinnitus. Given his professional training in psychology, M. L. had an exceptional understanding of this process. It was further explained that when tinnitus was assigned a "neutral signal" status, it would no longer be perceived as dangerous or threatening (Jastreboff & Jastreboff, 2000).

In conjunction with his audiology visits, it was also recommended that he consult with a psychologist.

Outcome

M. L.'s hearing aids had been programmed with an open dome and mild high-frequency gain in the left ear. He used an 8 mm double-vented bass dome in the right ear. Real-ear measurements using NAL-NL2 (Keidser et al., 2011) targets for soft (50 dB SPL), average (65 dB SPL), and loud (80 dB SPL) inputs revealed that his settings did not meet target gain levels in the right ear. Therefore, his dome was changed to an 8 mm power dome, adaptation was set to Level 3 from Level 1, and gain was increased by 7 to 9 dB from 1000 to 4000 Hz. Follow-up real-ear measurements yielded an improvement in target gain for the aforementioned inputs; however, due to the degree of hearing loss in the right ear, he was still underfit in the mid and high frequencies. Additional gain adjustments were made to approximate targets within the confines of the hearing aid limits.

M. L.'s hearing aids were programmed with four settings. The first setting—called "everyday"—provided amplification only. Three tinnitus programs were established using various steady-state sounds including white, red, and pink noise. M. L. listened to his tinnitus programs for about 2 hours per day as a passive listening task. He reported that the white noise program was the most helpful in reducing the loudness of his tinnitus.

Weekly psychology sessions focused on the use of hypnotherapy to manage M. L.'s reaction to tinnitus. M. L. stated that once he was in a trancelike state, he was asked to envision his tinnitus as a dimmer switch. A dimming of the lights corresponded to a dimming of his tinnitus volume. M. L. reported a reduction in the intrusiveness of his tinnitus following the sessions.

M. L. also used meditation to manage his stress and anxiety. He applied a combination of mindfulness meditation and transcendental meditation for about 10 minutes each day. He played nature sounds in the background to reduce the intrusion from the tinnitus during his meditation. M. L. reported that the meditation made him feel calm and at ease. He also stated that meditation helped him reduce negative thoughts surrounding his tinnitus.

M. L. followed up for audiological appointments three times over the next 6 months. At his 3-month audiology follow-up appointment, M. L.'s pure-tone thresholds remained stable. He was able to participate in LDL measurements at this appointment (Table 21–1). M. L.'s score reduced to 20 on the THI and to 0 on the Hyperacusis Questionnaire, suggesting significant improvement in his tinnitus distress and sound sensitivity issues.

M. L. continued to demonstrate improvement at his 6-month follow-up visit with a THI score of 10. He was not asked to complete the Hyperacusis Questionnaire due to the previous score of 0. M. L. still felt that his tinnitus was disruptive at times, but the combination of amplification, sound therapy, hypnotherapy, and meditation had allowed him to achieve a level of acceptance and control that helped him minimize the impact of tinnitus on his daily activities.

Table 21–1. M. L.'s LDLs

	500	*1000*	*2000*	*4000*
Right	89	90	90	89
Left	90	91	90	92

Key Messages

- Sudden hearing loss with tinnitus can be disruptive.
- Comprehensive otolaryngological and audiological evaluation is recommended in such cases.
- Patients may explore various interventions to help promote habituation to tinnitus including amplification, sound therapy, and TRT.
- Clinicians should note that some patients may try experimental interventions for tinnitus (such as hypnotherapy); however, it should be emphasized that the evidence for such interventions is weak.

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22 CASE STUDY 3: PULSATILE TINNITUS

Adwight Risbud, Mehdi Abouzari, and Hamid R. Djalilian

Clinical History and Description

K. T., a 41-year-old woman, presented to the otolaryngology clinic complaining of bilateral pulsatile tinnitus for the past 3 years. She reported that the tinnitus was worse on the right side. The tinnitus was intermittent, occurring approximately four times per month and lasting for 1 hour at a time. Additionally, the patient described aural fullness and muffled hearing associated with her tinnitus. She stated that her symptoms were worsened by stress, anxiety, and poor sleep. K. T. denied hearing loss or ear pain, but reported a personal history of migraine headaches, mental fogginess, neck stiffness, and both light and smell sensitivity. Her family history was significant for migraines in both her mother and brother.

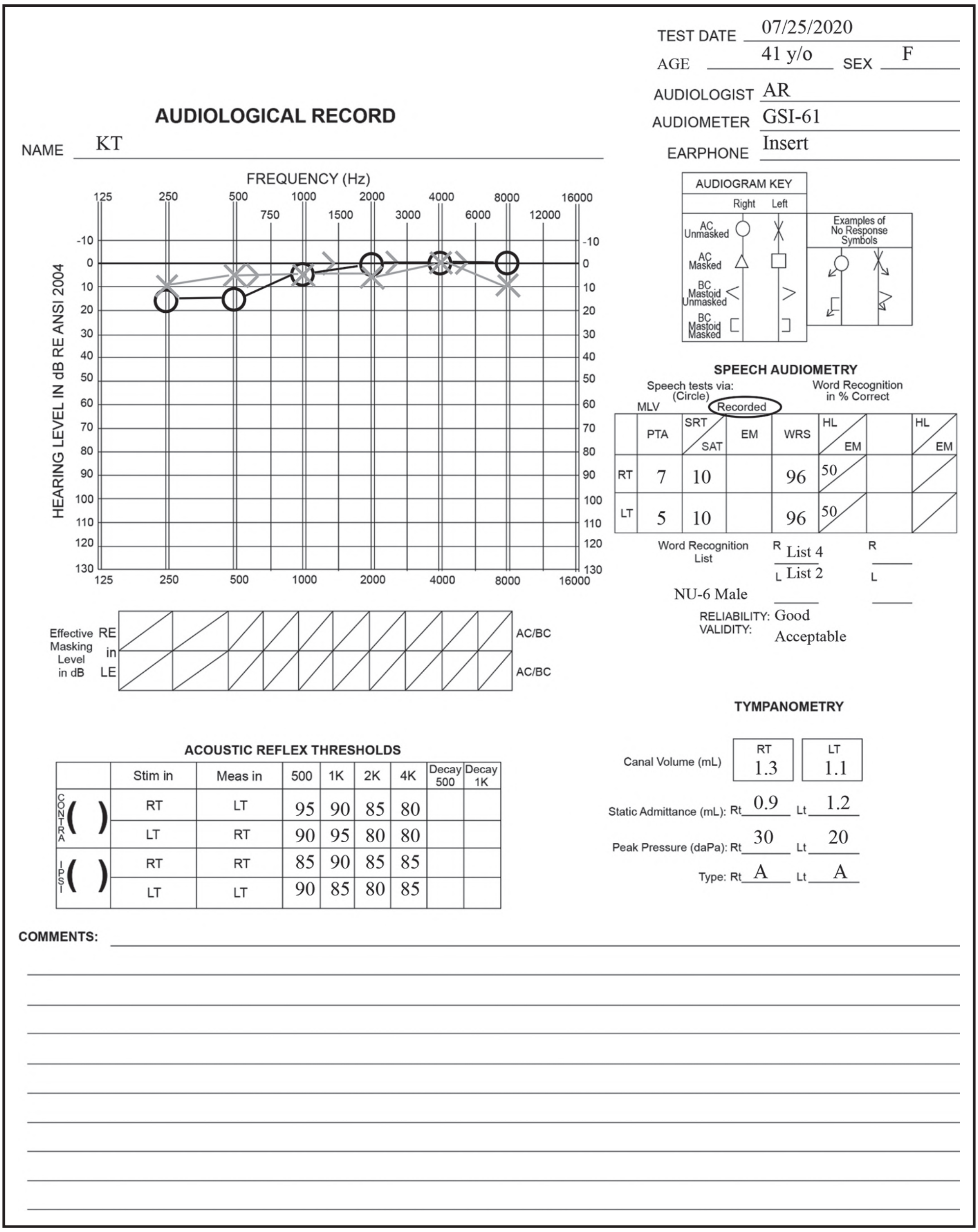
Diagnostic Evaluation

Audiological Evaluation

Audiological testing was performed on K. T. using pure-tone audiometry (PTA), speech-reception threshold (SRT) testing, and word recoginition testing. Results of these tests showed normal hearing (<25 dB HL at all frequencies) and normal word recognition (WRS = 96%) in both ears (Figure 22–1). Audiological assessment is performed when evaluating any patient presenting with pulsatile tinnitus, mainly to identify conductive hearing loss or enhanced bone-conduction thresholds due to third-window abnormalities (e.g., superior semicircular canal dehiscence). Third-window abnormalities provide low-resistance alternative pathways for sound waves. Such anomalies can create an air-bone gap by increasing sensitivity to bone conduction while simultaneously decreasing sensitivity to air-conducted sound, thereby resulting in a conductive hearing loss.

Tinnitus Evaluation

As part of obtaining patient history, K. T. was asked to complete a custom migraine questionnaire. This questionnaire included a comprehensive list of questions regarding migraine-related symptoms and clinical features reported in the literature (Dodick, 2018; Moshtaghi et al., 2018). K. T.'s responses to the questionnaire revealed several features suggestive of migraine such as unilateral headache, neck stiffness,



TEST DATE 07/25/2020
AGE 41 y/o SEX F
AUDIOLOGIST AR
AUDIOMETER GSI-61
EARPHONE Insert

AUDIOLOGICAL RECORD

NAME KT

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	7	10		96	50		
LT	5	10		96	50		

Word Recognition List R List 4 L List 2 R ____ L ____
NU-6 Male
RELIABILITY: Good
VALIDITY: Acceptable

Effective Masking Level in dB RE in LE AC/BC AC/BC

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	95	90	85	80		
	LT	RT	90	95	80	80		
IPSI ( )	RT	RT	85	90	85	85		
	LT	LT	90	85	80	85		

TYMPANOMETRY

	RT	LT
Canal Volume (mL)	1.3	1.1

Static Admittance (mL): Rt 0.9 Lt 1.2
Peak Pressure (daPa): Rt 30 Lt 20
Type: Rt A Lt A

COMMENTS:

Figure 22–1. K. T.'s audiogram showing normal hearing bilaterally.

light and sound sensitivity, and aural fullness. K. T. was also asked to complete the Tinnitus Functional Index (TFI) (Meikle et al., 2012), a standardized questionnaire used for assessing tinnitus severity and treatment responsiveness. Her TFI score (80) indicated that it was a "very big problem" and was "severe enough to qualify for more aggressive intervention" (Henry et al., 2016, p. 64).

Medical/Neuroimaging Evaluation

K. T. was asked if her tinnitus could be suppressed with pressure on the side of the neck or by turning the neck. If the pulsatile tinnitus can be extinguished with those maneuvers, then the cause can be assumed to be venous in nature, as the flow in the carotid or vertebral arteries cannot be stopped with those maneuvers. Physical examination was then performed on K. T., beginning with inspection and auscultation of her neck, mastoids, and orbits. Auscultation of the neck and mastoids was normal. Additionally, microscopic ear examination showed no abnormalities. Findings of the physical examination typically direct an imaging workup. An ophthalmological evaluation may also be considered to investigate signs of increased intracranial pressure; if suspected, lumbar puncture may be subsequently performed to measure cerebrospinal fluid (CSF) pressure and establish a diagnosis.

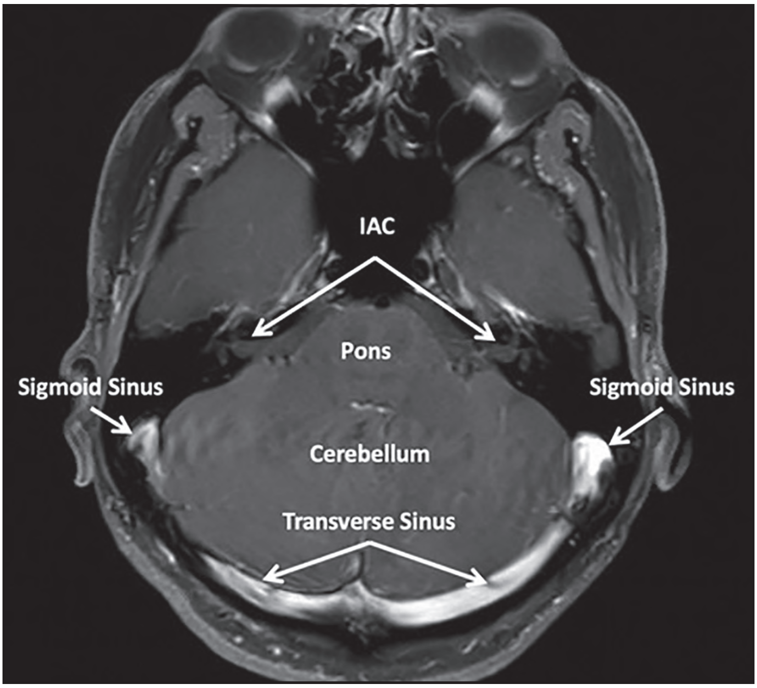
To rule out a vascular mass as the cause of K. T.'s symptoms, neuroimaging was performed using magnetic resonance imaging (MRI) of the brain with attention to the internal auditory canals with gadolinium. Venous pulsatile tinnitus that stops with neck pressure or turning requires a magnetic resonance venography (MRV) for work up. Magnetic resonance angiography (MRA) should be obtained in cases of audible bruits or if the patient cannot extinguish the pulsatile tinnitus with neck pressure or head turning. MRI of K. T.'s brain showed no abnormalities (Figure 22–2).

If MRI results are negative or inconclusive, a temporal-bone computerized tomography (CT) scan may be additionally considered to identify abnormalities not seen on MRI (e.g., sigmoid sinus diverticulum or dehiscence, jugular bulb dehiscence, tegmen defects, or third-window abnormalities) (Pegge et al., 2017). After K. T.'s MRI showed no abnormalities, a CT scan was performed and was also normal.

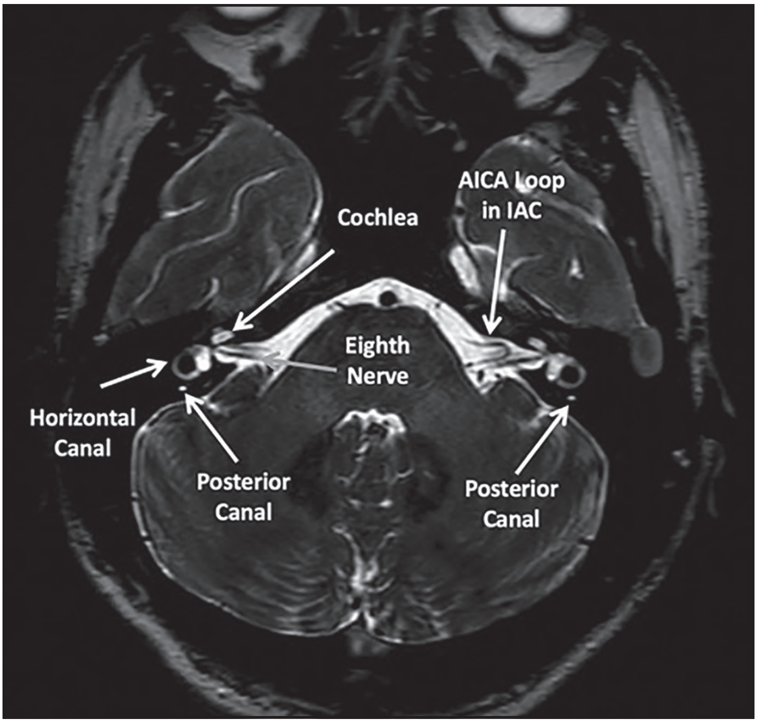
Diagnosis and Recommended Management

Pulsatile tinnitus is a frequently encountered complaint in otolaryngology practices, with a variety of causes and clinical presentations. Patients with pulsatile tinnitus often describe their tinnitus as a whooshing sound that is synchronized with their heartbeat. In most cases, imaging workup does not reveal a vascular cause such as a neoplasm or venous or arterial malformation. Acquired vascular abnormalities such as sigmoid sinus diverticulum and jugular bulb dehiscence can also lead to pulsatile tinnitus. Other causes include idiopathic intracranial hypertension, third-window abnormalities including semicircular canal and carotid cochlear dehiscence, and disorders that cause a conductive hearing loss (Liyanage et al., 2006). Important causes of pulsatile tinnitus are listed in Table 22–1.

Recently, migraine has been studied as another possible etiology of pulsatile tinnitus (Weinreich & Carey, 2016). Migraine is one of the most prevalent and disabling conditions in the United States, affecting more than 20% of the population (Lin et al., 2011). While the exact mechanism remains unclear, one theory regarding the pathophysiology of migraine involves brain hyperexcitability and activation of the trigeminal system by excitatory neurotransmitters and chemical mediators (Malholtra, 2016; Tajti et al., 2015). These mediators also exert downstream effects including pain transmission and vasodilation, possibly explaining the development of pulsatile

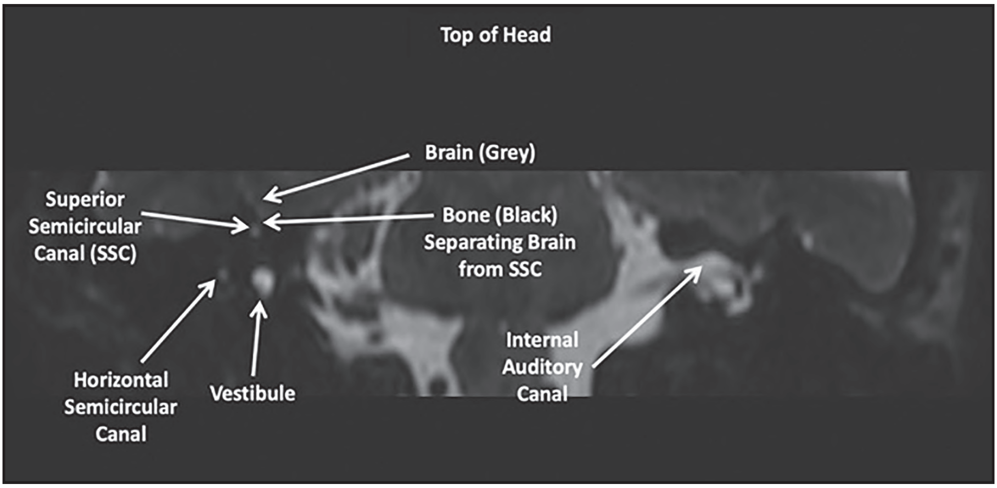


A



B

Figure 22–2. A. Post-contrast MRI showing no IAC tumor (*axial view*). IAC = internal auditory canal. **B.** MRI showing no posterior semicircular canal dehiscence (*axial view*). AICA = anterior inferior cerebellar artery. *continues*



C

Figure 22–2. *continued* **C.** MRI showing no superior semicircular canal dehiscence (*coronal view*).

Table 22–1. List of Important Causes of Pulsatile Tinnitus

Arterial	***Venous***	***Temporal or Skull-Based***	***Other***
Atherosclerosis	Idiopathic intracranial	Glomus tumor	Anemia
AV fistula	Hypertension	Meningioma	Thyroid disease
AV malformation	Dural venous sinus stenosis	Cholesterol granuloma	Pregnancy
Carotid artery dissection	Venous hum	Paget's disease	Semicircular canal dehiscence
Fibromuscular dysplasia	Jugular bulb dehiscence		Carotid cochlear dehiscence
Intracranial aneurysm	Sigmoid sinus diverticulum		Otosclerosis
Vascular compression of CN VIII	Sigmoid sinus dehiscence		Meniere's disease
			Migraine

AV = Arteriovenous; CN = Cranial Nerve.

tinnitus in migraine patients (Weinreich & Carey, 2016). The hypersensitivity of the brain (similar to hyperacusis) can cause amplification of internally audible sounds such as blood flow in the sigmoid sinus, jugular bulb, and carotid artery (Abouzari et al., 2020).

In the absence of abnormal physical examination and imaging findings, components of the patient's history may point to an underlying migraine disorder as the source of his or her symptoms. Examples of these features include a personal or family history of migraine diagnosis; headache that is unilateral and pulsating; nausea and/or vomiting; motion, light, and/or sound sensitivity; food and stress triggers; and otalgia or aural fullness. K. T. reported multiple migraine features including unilateral headache, neck stiffness, both light and sound sensitivity, aural fullness, and family history of migraine.

For patients receiving a diagnosis of migraine-related pulsatile tinnitus, both conservative and medical management may be considered. Management decisions depend on the severity of the symptoms, prior response to medications, and patient preference. Conservative options include avoidance of symptom triggers, including specific foods and physical activities, in addition to stress management and adherence to a regular diet and sleep schedule. Empiric treatment with traditional migraine medications such as nortriptyline, verapamil, topiramate, magnesium, and vitamin B2 have demonstrated relative efficacy in treating both pulsatile tinnitus and migraine symptoms in these patients (Weinreich & Carey, 2016). K. T. was counseled on stress-reduction strategies and proper sleep hygiene and was prescribed nortriptyline (10 mg) in addition to vitamin B2 and magnesium supplementation. She was also advised to follow a migraine diet and to keep a diary of her symptoms to identify any alleviating or exacerbating factors (certain foods, activities, or other triggers).

Outcome

At the 3-month follow-up, K. T. was asked to complete the same TFI and custom migraine questionnaires administered at her initial visit. Responses to these questionnaires revealed reduction in both the frequency and severity of her tinnitus (post-treatment TFI = 30) as well as improvement in other migraine symptoms, particularly decreased aural fullness and neck stiffness. She reported compliance with the recommended lifestyle and dietary changes, and continues to take daily supplements and migraine medication.

Key Messages

- A comprehensive evaluation with history, physical exam, and imaging should be performed in patients with pulsatile tinnitus to rule out important and potentially serious causes (such as tumors or vascular abnormalities).
- Migraine disorder represents another possible etiology of pulsatile tinnitus and may be revealed in the patient through a detailed assessment of migraine symptoms and family history.
- Treatment with migraine lifestyle, diet, and prophylactic medications may be beneficial in reducing the frequency and severity of symptoms for patients with migraine-related pulsatile tinnitus.

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23

CASE STUDY 4: MANAGING DEBILITATING TINNITUS IN A PATIENT WITH COMPLEX COMORBIDITIES

Tricia L. Scaglione, Lori Zitelli, and David P. Jedlicka

Clinical History and Description: Initial Visit

Sam (pseudonym), a 48-year-old adult male, initially presented to the otolaryngology clinic at a university medical center for evaluation of dizziness and vertigo. Sam reported that he had experienced a cardiac event as well as a stroke approximately 6 months prior. A review of his outside medical records demonstrated that he had undergone extensive diagnostic workup including computerized tomography (CT) scan of the head, magnetic resonance imaging (MRI) of the brain, magnetic resonance angiography (MRA) of the head and neck, MRI of the cervical spine, CT of the chest, carotid ultrasound, 24-hour Holter monitoring, 2D echocardiogram, electrocardiogram (EKG), exercise/nuclear Single Photon Emission Computed Tomography (SPECT) stress test, and hypercoagulable workup. Findings supported a right-sided posterior parietal stroke in addition to cardiomyopathy. Sam's care was managed collaboratively by a cardiologist, a neurologist, and an otolaryngologist.

At the initial otolaryngology appointment, Sam reported that he experienced vertigo. The vertigo was triggered when he rolled over onto his right side and when he moved his head while showering. Additionally, Sam described fatigue, presyncope, and a rushing sensation in his head and neck during these episodes. He also reported severe headaches, unilateral nonpulsatile high-pitched tinnitus in his right ear, and a history of left middle ear problems. A re-view of Sam's medical records confirmed a prior tympanoplasty in the left ear.

Diagnostic Evaluation: Initial Visit

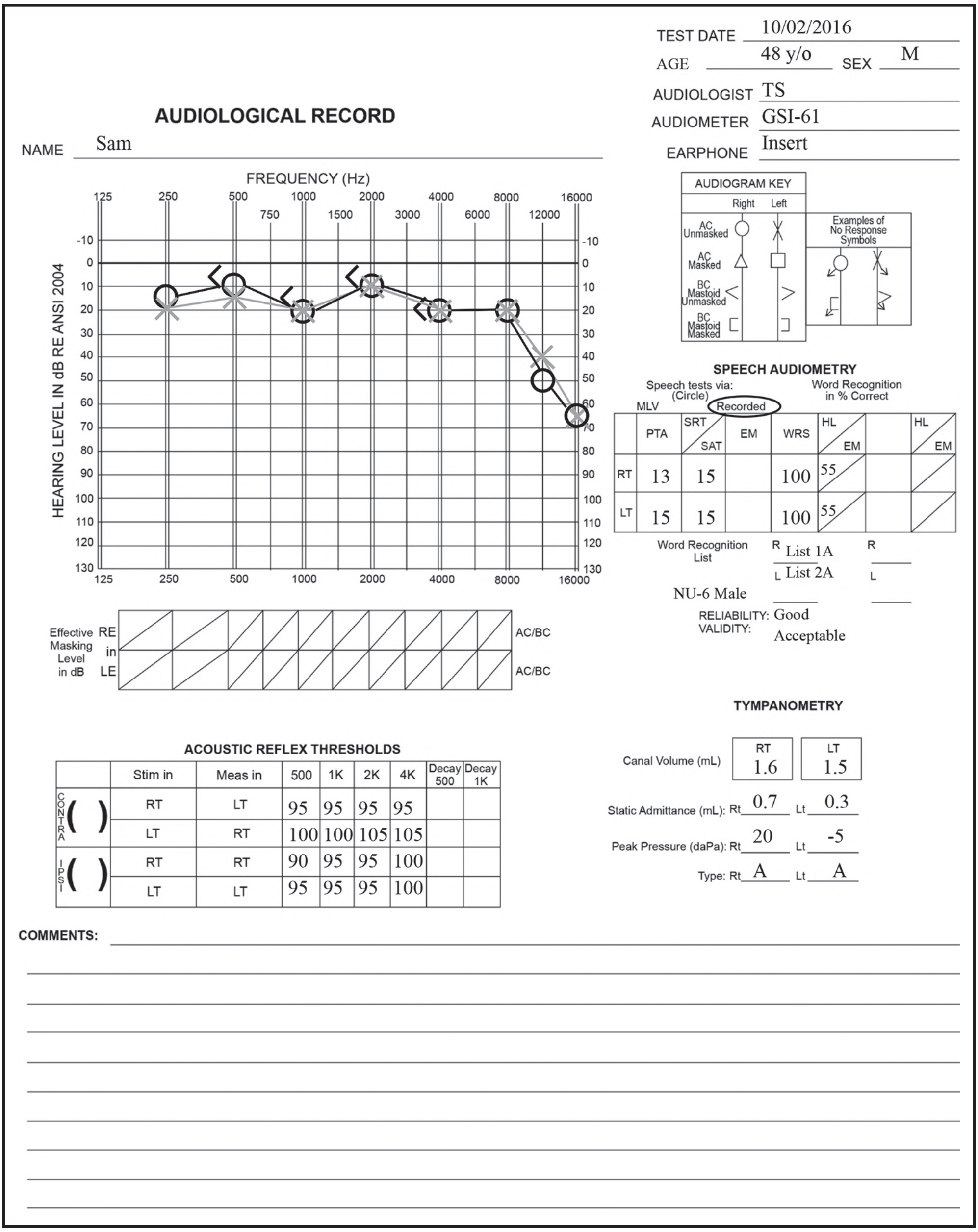
Audiological Evaluation

Sam's initial audiometric testing revealed essentially normal hearing sensitivity (defined as pure-tone thresholds less than 25 dB HL) with 100% word recognition in quiet at conversational levels bilaterally. Tinnitus is often a symptom of damage to the auditory system; therefore, given Sam's report of unilateral, high-pitched tinnitus in the absence of hearing loss in the standard audiometric frequencies, ultrahigh-frequency audiometry was performed (Henry et al., 2020; Savastano, 2008). Results revealed a moderate notched hearing loss centered around 14,000 Hz with recovery to normal sensitivity at 20,000 Hz bilaterally, with an asymmetry (left worse than right) noted from 9000 to 11,200 Hz (Figure 23–1) and from 18,000 to 20,000 Hz. Additionally, aural immittance testing demonstrated normal function of the right tympanic membrane, borderline reduced mobility of the left tympanic membrane consistent with previous surgical history, and normal ipsilateral and contralateral acoustic reflexes bilaterally, defined as reflex thresholds recorded at 70 to 90 dB SL (Metz, 1952).

Diagnosis and Recommended Management Initial Visit

The otolaryngologist, suspecting vestibular migraines, referred Sam for a comprehensive vestibular evaluation that included vestibular evoked myogenic potentials (VEMP), rotational chair, computerized dynamic posturography (CDP), and video-nystagmography (VNG) testing. Tympanometry was performed immediately prior to the vestibular evaluation and demonstrated normal middle ear function of the right ear and compromised middle ear function of the left ear (ref: 0.1 mL static compliance). Despite left tympanometric findings, VEMP testing was attempted with results demonstrating an absent left response for both ocular and cervical VEMP. As conductive components may reduce or falsely obliterate responses, VEMP results were ultimately deemed inconclusive (Wang & Lee, 2007). Rotational chair testing demonstrated a faint right beat nystagmus during spontaneous testing, decreased gain, phase lead, and normal symmetry in sinusoidal harmonic rotations, normal time constants in rotational trapezoidal testing (100.0 deg/sec), leftward trending deviations in static subjective visual vertical testing, and abnormal deviations with left activation and center position in dynamic subjective visual vertical testing. CDP included sensory organization testing and motor control testing, which yielded normal findings, as did the VNG battery including oculomotors, high-frequency head shaking, positioning, and positional testing. Bithermal calorics were deferred due to left compromised middle ear status (Lee et al., 2009). Overall, these results were consistent with a partially compensated peripheral vestibulopathy that included utricular dysfunction.

Vestibular rehabilitation therapy (VRT) is frequently recommended for patients who are suffering from vestibular disorders. The goal of this type of treatment is to help patients achieve compensation more quickly to improve their daily function. It is indicated for individuals suffering from stable vestibular lesions, central lesions or mixed central/peripheral lesions, head injuries, psychogenic vertigo, vertigo with uncertain etiology, and residual dizziness following treatment of benign paroxysmal positional vertigo (BPPV) (Telian & Shepard, 1996). As such, Sam was referred for VRT and was encouraged to consult with a neurologist.



TEST DATE 10/02/2016

AGE 48 y/o SEX M

AUDIOLOGIST TS

AUDIOMETER GSI-61

EARPHONE Insert

AUDIOLOGICAL RECORD

NAME Sam

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	13	15		100	55		
LT	15	15		100	55		

Word Recognition List R List 1A L List 2A R ____ L ____

NU-6 Male

RELIABILITY: Good

VALIDITY: Acceptable

Effective Masking Level in dB RE in LE AC/BC AC/BC

TYMPANOMETRY

Canal Volume (mL): RT 1.6 LT 1.5

Static Admittance (mL): Rt 0.7 Lt 0.3

Peak Pressure (daPa): Rt 20 Lt -5

Type: Rt A Lt A

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	95	95	95	95		
	LT	RT	100	100	105	105		
IPSI ( )	RT	RT	90	95	95	100		
	LT	LT	95	95	95	100		

COMMENTS:

Figure 23–1. Audiometry (including high frequencies) results at the initial otolaryngology appointment.

Outcome: Initial Visit

After establishing care with the otolaryngologist, Sam was followed by his neurologist for several years. Due to an increase in severity of headaches described as “an explosion in the back of the head,” the neurologist requested to have an MRI of the brain repeated. Results did not yield any change when compared to the previous year’s MRI. Management included trials with numerous medications and a series of Botox injection procedures intended to alleviate his migraines (Andreou et al., 2018). Reportedly, Sam’s headaches improved significantly from a 10/10 severity to a 4/10 severity (using a visual analog scale, with *0* denoting no pain and *10* denoting extreme pain). Sam underwent 2 years of VRT with a physical therapist to address his persistent vestibular issues. He reported limited subjective benefit. At the recommendation of his physical therapist, Sam also pursued a neuro-ophthalmologic consult due to strabismus.

Sam continued to receive cardiovascular care that included a prescription for a portable defibrillator. He was also followed closely by his primary care physician (PCP) to manage issues related to high blood pressure, high cholesterol, and gout.

Clinical History and Description: Follow-Up Visit

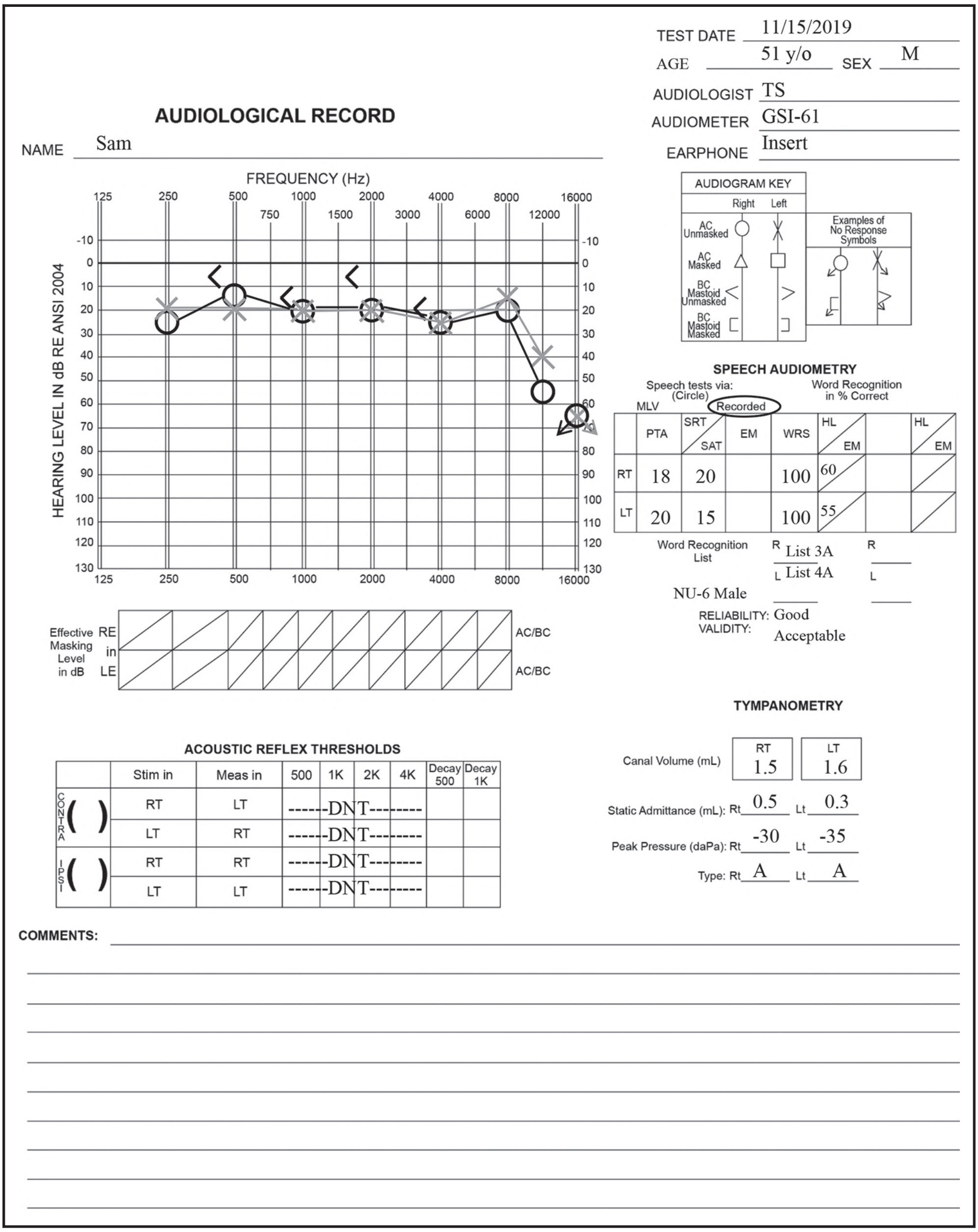
Three years after his initial otolaryngology consult, Sam, accompanied by his wife, returned to the audiology clinic complaining of debilitating tinnitus in his right ear. Sam clarified that while his tinnitus was present at the initial visit with the otolaryngologist, his vestibular symptoms were the primary concern at that time. As his vestibular symptoms lessened in severity, the perception of his tinnitus distress increased. Sam reported that the tinnitus was constant, fluctuated in loudness, and impacted all aspects of his life. Sam became tearful as he described how the tinnitus and accompanying health issues impacted his life and drove him toward suicidal ideation. Sam reported that he was no longer able to work, drive, or attend medical appointments independently, adding that he felt like a burden to his family. Sam reported that his marriage was strained due to his chronic health issues and due to financial concerns related to both his inability to work and the cost incurred from necessary medical interventions. In addition, Sam reported that his sleep was significantly disturbed. He was frequently woken up by the vestibular disorder and headaches triggered by rolling motions. His tinnitus prevented him from falling back asleep after he had been awoken.

Diagnostic Evaluation: Follow-Up Visit

Audiological Evaluation

Updated audiometric testing revealed that Sam’s hearing remained largely stable when compared to his previous audiogram 3 years prior, with the exception of the high-frequency thresholds. High-frequency audiometry revealed a decrease in right ear thresholds from 9000 to 14,000 Hz (Figure 23–2) and no responses at equipment intensity limits from 16,000 through 20,000 Hz bilaterally.

Distortion product otoacoustic emission (DPOAE) measurements were com-



TEST DATE 11/15/2019

AGE 51 y/o SEX M

AUDIOLOGIST TS

AUDIOMETER GSI-61

EARPHONE Insert

AUDIOLOGICAL RECORD

NAME Sam

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	18	20		100	60		
LT	20	15		100	55		

Word Recognition List R List 3A L List 4A R L

NU-6 Male

RELIABILITY: Good

VALIDITY: Acceptable

TYMPANOMETRY

Canal Volume (mL) RT 1.5 LT 1.6

Static Admittance (mL): Rt 0.5 Lt 0.3

Peak Pressure (daPa): Rt -30 Lt -35

Type: Rt A Lt A

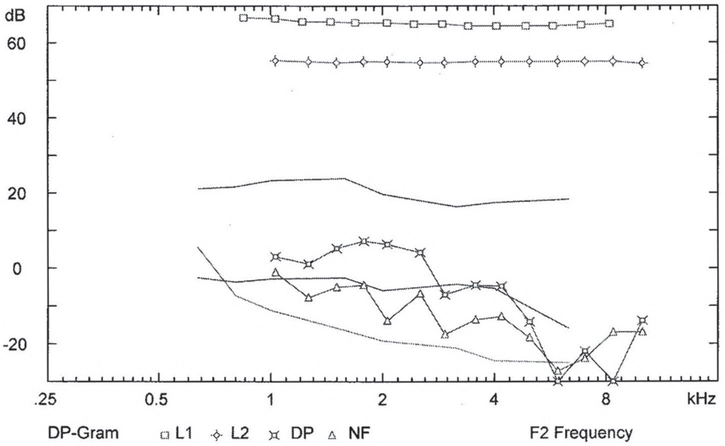
ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	------DNT--------					
	LT	RT	------DNT--------					
IPSI ( )	RT	RT	------DNT--------					
	LT	LT	------DNT--------					

COMMENTS:

Figure 23–2. Audiometry (including high frequencies) results at the follow-up appointment.

pleted for test frequencies from 1000 to 10,000 Hz bilaterally (Figure 23–3). DPOAE amplitudes for the right ear were normal at all frequencies evaluated, consistent with audiometric thresholds. As DPOAEs are expected to be present with normal hearing sensitivity to mild sensorineural hearing loss, the left ear results



Left: 22-Jul-19: -: UM 1000-10000 Hz Diagnostic 12 Freq: 19G22D01.OAE

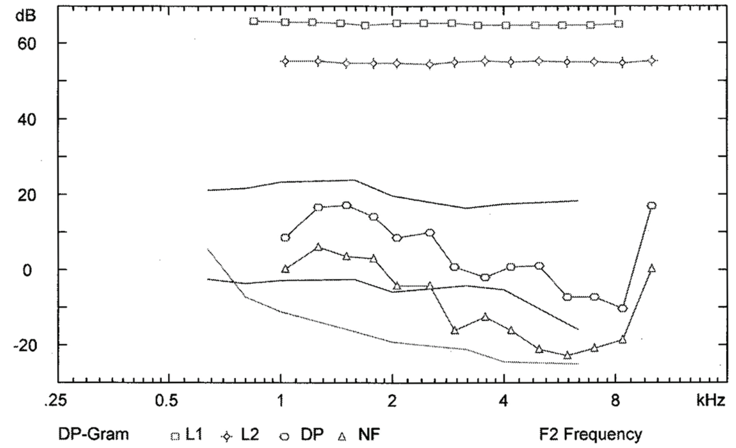
L1(dB)	L2(dB)	F1(Hz)	F2(Hz)	GM(Hz)	DP(dB)	NF(dB)	DP-NF(dB)
65.1	54.6	8203	10031	9071	-14.0	-17.0	3.0
65.0	55.0	6891	8391	7604	-30.4	-17.1	-13.3
64.7	55.2	5766	7031	6367	-22.0	-24.1	2.1
64.6	55.0	4875	5953	5387	-31.6	-27.4	-4.2
64.5	55.1	4078	4969	4501	-14.4	-18.5	4.1
64.6	55.0	3422	4172	3778	-4.8	-13.0	8.2
65.1	55.2	2906	3563	3218	-4.5	-13.7	9.2
65.3	54.8	2438	2953	2683	-7.1	-17.6	10.5
65.4	54.9	2063	2531	2285	4.0	-6.8	10.8
65.4	55.2	1688	2063	1866	6.3	-14.0	20.3
65.6	55.1	1453	1781	1609	7.1	-4.6	11.7
65.6	54.9	1219	1500	1352	5.2	-5.1	10.3
66.5	55.1	1031	1266	1142	1.1	-7.8	8.9
66.7	55.4	844	1031	933	3.1	-1.3	4.4

Figure 23–3. Sam's Distortion Product Otoacoustic Emission results. *continues*

were inconsistent with audiometric thresholds in the 4500 to 10,000 Hz range. The decreased left ear DPOAE amplitudes in this high-frequency test range are consistent with Sam's history of middle ear reconstruction. Compromised integrity of the middle ear may result in inefficient energy transfer and/or an inability to accurately measure the DPOAEs (Lieberum et al., 1996).

Tinnitus Evaluation

Sam participated in an informational counseling session for his tinnitus. He was counseled about the anatomy and physiology of the auditory system and how it relates to tinnitus. Counseling included explanation of his hearing test results and realistic expectations for management, as well as coping and management options for



Right: 22-Jul-19: -: UM 1000-10000 Hz Diagnostic 12 Freq: 19G22D00.OAE

L1(dB)	L2(dB)	F1(Hz)	F2(Hz)	GM(Hz)	DP(dB)	NF(dB)	DP-NF(dB)
65.1	55.4	8203	10031	9071	16.8	0.1	16.7
65.0	54.8	6891	8391	7604	-10.5	-18.7	8.2
64.8	55.1	5766	7031	6367	-7.4	-20.9	13.5
64.7	55.2	4875	5953	5387	-7.2	-22.8	15.6
64.7	55.2	4078	4969	4501	1.1	-21.1	22.2
64.8	55.2	3422	4172	3778	0.9	-16.2	17.1
65.3	55.3	2906	3563	3218	-1.9	-12.5	10.6
65.3	55.1	2438	2953	2683	0.9	-16.2	17.1
65.3	54.7	2063	2531	2285	10.0	-4.1	14.1
65.0	54.9	1688	2063	1866	8.6	-4.3	12.9
65.4	54.9	1453	1781	1609	14.1	3.1	11.0
65.6	54.8	1219	1500	1352	17.1	3.6	13.5
65.8	55.3	1031	1266	1142	16.6	6.0	10.6
66.0	55.3	844	1031	933	8.5	0.3	8.2

Figure 23–3. *continued*

tinnitus. The audiologist emphasized that his complex medical history contributed to and exacerbated his tinnitus. In addition, long-term collaborative care of a multidisciplinary team would be critical to management of his symptoms. Following the counseling session, Sam was scheduled to return for psychoacoustic tinnitus measurements.

Tests were performed to identify the pitch, loudness, and spectral content of Sam's perceived tinnitus. Sam perceived tinnitus in his right ear; however, pitch and loudness matching were performed in the left ear (i.e., contralaterally) to reduce confusion (Henry et al., 1999). Sam matched his tinnitus to a 12,500 Hz pure-tone stimulus at 14 dB SL (ref: left ear threshold of 40 dB HL at 12,500 Hz). Minimum masking level (MML) was assessed in the right ear and revealed that a broadband noise (BBN) of

6 dB SL (ref: BBN threshold of 8 dB HL in the right ear) was necessary to provide total masking of tinnitus. Residual inhibition testing assessed using a BBN stimulus at a presentation level of +10 dB SL (re: MML) bilaterally for 1 minute produced a partial reduction of tinnitus loudness that lasted for a duration of approximately 3 minutes (Henry, 2016). Loudness discomfort levels (LDLs) were obtained bilaterally to rule out decreased sound tolerance. Sam's LDL responses were assessed using a 2-dB step size. Results of 90 dB HL or greater across all frequencies evaluated indicated normal sound tolerance levels bilaterally (Sherlock & Formby, 2005). Table 23–1 summarizes Sam's tinnitus evaluation outcomes.

Two validated inventories were used to assess Sam's self-perceived tinnitus-related handicap and other aspects of his life impacted by tinnitus. Sam's overall score of 96.8 out of a possible score of 100 on the Tinnitus Functional Index (TFI) (Meikle et al., 2012) indicated that aggressive intervention was warranted. A review of the TFI subscale results confirmed that Sam's tinnitus distress spanned across all domains of his life. Sam's score of 95 out of a possible 104 on the Tinnitus Reaction Questionnaire (TRQ) (Wilson et al., 1991) confirmed his subjective perception of severe tinnitus distress. Further, Sam reported frequent thoughts of suicidal ideation secondary to the catastrophic impact of tinnitus on his life.

Table 23–1. Sam's Psychoacoustic Tinnitus Evaluation

Measurement	***Outcome***
Laterality	Right ear
Pitch match (left ear)	12,500 Hz pure tone
Loudness match (left ear)	54 dB HL (14 dB SL)
Broadband noise threshold (right ear)	8 dB HL
Minimum masking level (right ear)	14 dB HL (6 dB SL)
Residual inhibition (bilateral)	Partial
Loudness discomfort levels (right ear)	500 Hz = 98 dB HL 1000 Hz = 102 dB HL 4000 Hz = 98 dB HL 12,500 Hz = 90 dB HL
Loudness discomfort levels (left ear)	500 Hz = 98 dB HL 1000 Hz = 100 dB HL 4000 Hz = 102 dB HL 12,500 Hz > 92 dB HL (limit of equipment)

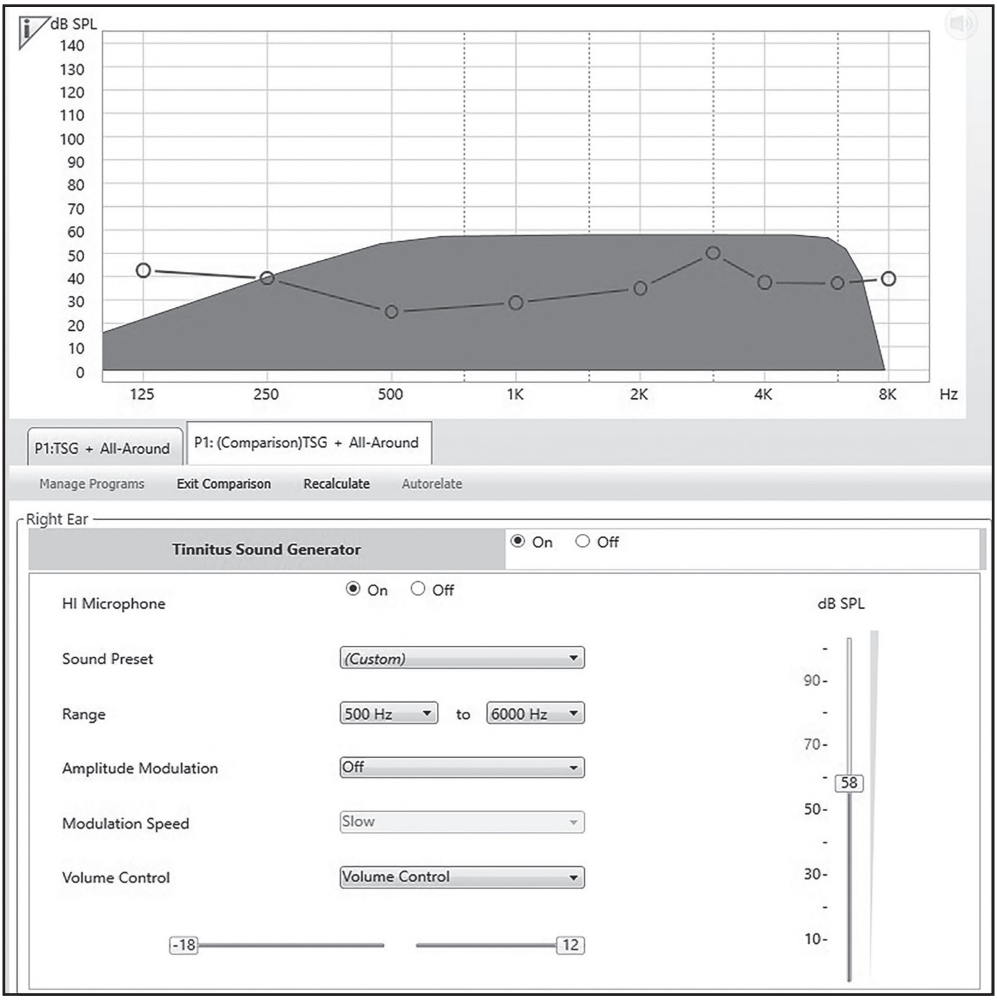
In view of Sam's emotional reaction to tinnitus, he was also screened for comorbid mental health issues using the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983). This scale is a reliable and valid screening tool for identifying symptoms of depression and anxiety in outpatient settings (Bhatt et al., 2017; Bjelland et al., 2002; Pattyn et al., 2016; Reavis et al., 2020). Sam's overall scores on the HADS suggested the presence of both anxiety and depression at the time of administration (Snaith, 2003).

Diagnosis and Recommended Management: Follow-Up Visit

Sam and his wife were counseled extensively regarding the need to address Sam's comorbid mental health issues to reduce his negative reaction to the tinnitus. It was emphasized that untreated mental health issues were likely to impact Sam's ability to cope with his tinnitus (Karaaslan et al., 2020). Sam indicated that while he was motivated and open to seeking help, his previous attempts to secure a mental health provider were unsuccessful due to insurance restrictions and provider capacity limitations for taking on new patients. Sam's managing audiologist continued to employ a multidisciplinary approach and contacted a social worker, who secured him an appointment with a mental health provider.

Sam's audiologist counseled him about the importance of proper sleep hygiene, as unmanaged sleep issues can contribute to increased tinnitus disturbance levels (Crönlein et al., 2007). To address his chronic sleep issues, Sam's audiologist referred him to a sleep medicine specialist, who recommended positional therapy strategies (de Vries et al., 2015) to improve his sleep—for instance, inserting a tennis ball under his shirt or using a weighted band to keep him from rolling on his right side. Additional testing by the sleep medicine specialist revealed a positive diagnosis of obstructive sleep apnea. Sam was fit with a continuous positive air pressure (CPAP) device. Sam's audiologist recommended additional strategies such as breathing exercises, relaxation exercises, and environmental sound enrichment to reduce the intrusiveness of the tinnitus perception (Kreuzer et al., 2012). The sound enrichment was recommended for instances when Sam was not using his CPAP device or when the device did not produce sufficient ambient noise.

Some tinnitus management strategies employ sound therapy (Henry et al., 2008). Sam's audiologist recommended that Sam wear two ear-level sound devices (Folmer & Carroll, 2006). Ear-level sound devices can support multiple functions including amplification for hearing loss, a sound generator for tinnitus management, or a combination of both. Ear-level sound devices were utilized as tinnitus sound generators alone since Sam's audiometric thresholds were within normal limits. Microphones were enabled to allow Sam access to normal environmental sounds. The devices were set with an active volume control that allowed Sam to adjust the volume of the sound generators to his preferred setting based on perceived tinnitus loudness and environmental acoustics. Sam was instructed to set the volume using a mixing point level where both the tinnitus and the tinnitus sound generator stimulus were audible (Jastreboff, 2011). Figure 23–4 shows Sam's preferred device settings. He was counseled to utilize his devices daily, only removing them to sleep or shower. Sam was also encouraged to introduce sound enrichment (e.g., television, radio, or fan) in his environment



Tinnitus Sound Generator ● On ○ Off

HI Microphone ● On ○ Off

Sound Preset (Custom)

Range 500 Hz to 6000 Hz

Amplitude Modulation Off

Modulation Speed Slow

Volume Control Volume Control

-18 12

58

Figure 23–4. Sam's preferred Tinnitus Sound Generator settings.

when he was not wearing the sound generators to aid in contrast reduction (Henry et al., 2008). Following a trial with bilateral devices, Sam reported that cost was a limiting factor in purchasing two devices; so, he decided to purchase one GN ReSound Enya 361 device for the right ear. Although there are limitations to utilizing a monaural ear-level device, individuals may benefit from unilateral tinnitus sound generator management (Oishi et al., 2012).

Outcome: Follow-Up Visit

It is common for patients to report an immediate sense of improvement (i.e., reduction) in their tinnitus loudness levels when acoustic stimulation is introduced via ear-level devices (Folmer et al., 2006). Sam's immediate relief from the activated tinnitus sound generator manifested as tears of joy. At his 2-month follow-up appointment, Sam's TFI questionnaire score improved from an initial score of 96.8 to 71.2—a 25.6-point reduction. Psychometric data obtained during TFI development indicated that a change of 13 points or more can be interpreted as a significant improvement in self-perceived tinnitus-related handicap (Meikle et al., 2012). Researchers suggest a minimum of 20% to 40% improvement on the TRQ to quantify clinically significant improvement (Hazell, 1999; Hiller & Haerkötter, 2005; Jastreboff, 1996). Sam's audiologist documented a 37% reduction of his TRQ scores from an initial score of 95 to a follow-up score of 60, suggesting a clinically significant improvement.

One year later, Sam reported that he was managing his tinnitus well. He wore the tinnitus sound generator daily on his right ear, only taking it off when going to bed. When compared to the initial questionnaire responses, Sam demonstrated a significant 95-point decrease on the TFI, with improvement from an initial score of 96.8 to a final score of 3.6, and a 96% decrease on the TRQ with improvement from an initial score of 95 to a final score of 4. Additionally, Sam's responses on the HADS (*1* for anxiety, *3* for depression) were now within the normal range of 0 to 7 points. Sam reported that he was receiving treatment from a psychiatrist (Citalopram and Aripiprazole) as well as a psychologist. This professional mental health management helped him improve his ability to cope with his chronic health conditions, including tinnitus. Sam was also able to reduce negative reactions to tinnitus through psychotherapy (also referred to as talk therapy) and cognitive behavioral therapy (CBT) (Lambert & Vermeersch, 2002). Sam was able to find mental health providers close to his residence. As a result, he was able to utilize public transit options. The use of public transit provided him with a sense of independence and did not require his wife to continually request time off from work. Sam was also able to obtain disability status, which provided a source of financial support for his family. He continues to attend vestibular physical therapy for the management of his vestibular disturbances, in addition to his routine visits with cardiology, family medicine, neurology, and otolaryngology.

Key Messages

- A patient must be motivated to seek care for his or her tinnitus and related comorbidities to successfully manage tinnitus.
- Developing a multidisciplinary team is required for the management of tinnitus and related comorbidities.
- Ease of access to members of the multidisciplinary care team may be a barrier to those seeking tinnitus management outside of a comprehensive medical center.
- Most tinnitus management options (such as tinnitus retraining therapy or neuromonics) require 6 or more months of daily sound therapy, in addition to routine counseling and follow-up appointments (Henry et al., 2009; Herraiz et al., 2005, Vieira et al., 2011). The patient must remain committed to the tinnitus management through the entire duration of the program to achieve maximum benefit.
- Treatment of comorbidities that may exacerbate a patient's tinnitus, along with an appropriate tinnitus management program, may lead to the best patient outcomes.

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24 CASE STUDY 5: SOMATOSENSORY TINNITUS

Maja Svrakic

Clinical History and Description

J. M., a 40-year-old male clinical coordinator working at on office desk, presented to an outpatient otolaryngology subspecialty clinic at an academic tertiary referral center with bilateral tinnitus. He reported that he first noticed tinnitus approximately 3 weeks earlier after waking up one morning. J. M. described the tinnitus as whooshing, constant, and nonpulsatile. He reported noticing the tinnitus more in quiet environments. J. M. characterized his tinnitus as moderately bothersome, but said that it did not interfere with his sleep. The patient had a history of bruxism, diagnosed by another clinician at an outside hospital. He reported trying two different over-the-counter mouth guards to minimize the condition. Despite wearing these mouth guards, the patient's tinnitus became more noticeable. It was unclear if his bruxism intensified or the over-the-counter mouth guards caused the tinnitus to become more noticeable. J. M. took over-the-counter ibuprofen to relieve temporal and dental discomfort. He reported an increase in anxiety in the past month with several panic attacks, for which he took Alprazolam, that was prescribed to him by another clinician on several occasions. He reported no hearing loss, known sound exposure, or head trauma. His history revealed hypertension, high cholesterol levels, prediabetic condition, and gout (for which he took Candesartan, Metformin, and Allopurinol). These medical conditions and prescription medications were managed by another clinician at an outside hospital.

Diagnostic Evaluation

On physical exam, the patient was an overweight man in no apparent distress. His head and neck examination revealed tenderness to bimanual palpation of temporomandibular joints bilaterally without any step-offs or clicks. He reported subjective changes in the pitch and loudness of his tinnitus with pressure at the joints. Cranial nerve function was symmetrical and normal.

Pain at the temporomandibular joint confirmed with palpation is always pathologic. It may indicate clenching, grinding (bruxism), dental misalignment, poorly fit dentures, repetitive chewing (e.g., gum, apple eating), and strain and sprain of the joint brought on by prolonged periods of mouth opening, such as in dental procedures or during intubation for surgery. In addition, it is recommended that patient history include questions about clenching associated with stress and anxiety (Israel & Davila, 2014; Manfredini et al., 2004; Pavaci et al., 2019; Shedden Mora et al., 2012).

Audiological Evaluation

An otomicroscopic exam revealed normal appearing ear canals, tympanic membranes, and middle ear landmarks. The Rinne test performed with a 512-Hz tuning fork was positive; i.e., longer duration of audibility via air conduction than bone conduction bilaterally. The Weber test performed with the tuning fork placed at the center of the forehead did not lateralize to either ear. These results are consistent with J. M.'s audiogram.

J. M. underwent a complete audiological evaluation, including pure-tone audiometry at octave frequencies from 250 to 8000 Hz, speech audiometry including speech-recognition threshold (SRT) and word-recognition score (WRS) tests, tympanometry, acoustic reflex testing (Figure 24–1), and a transient evoked otoacoustic emission (TEOAE) screening, all of which were within normal range. The results of the audiological assessment were consistent with normal hearing sensitivity.

A clinical vestibular examination conducted in the otolaryngologist's office was normal, with no nystagmus, no lag on head impulse testing, negative Dix-Hallpike, and negative Romberg and Fukuda step tests.

Tinnitus Evaluation

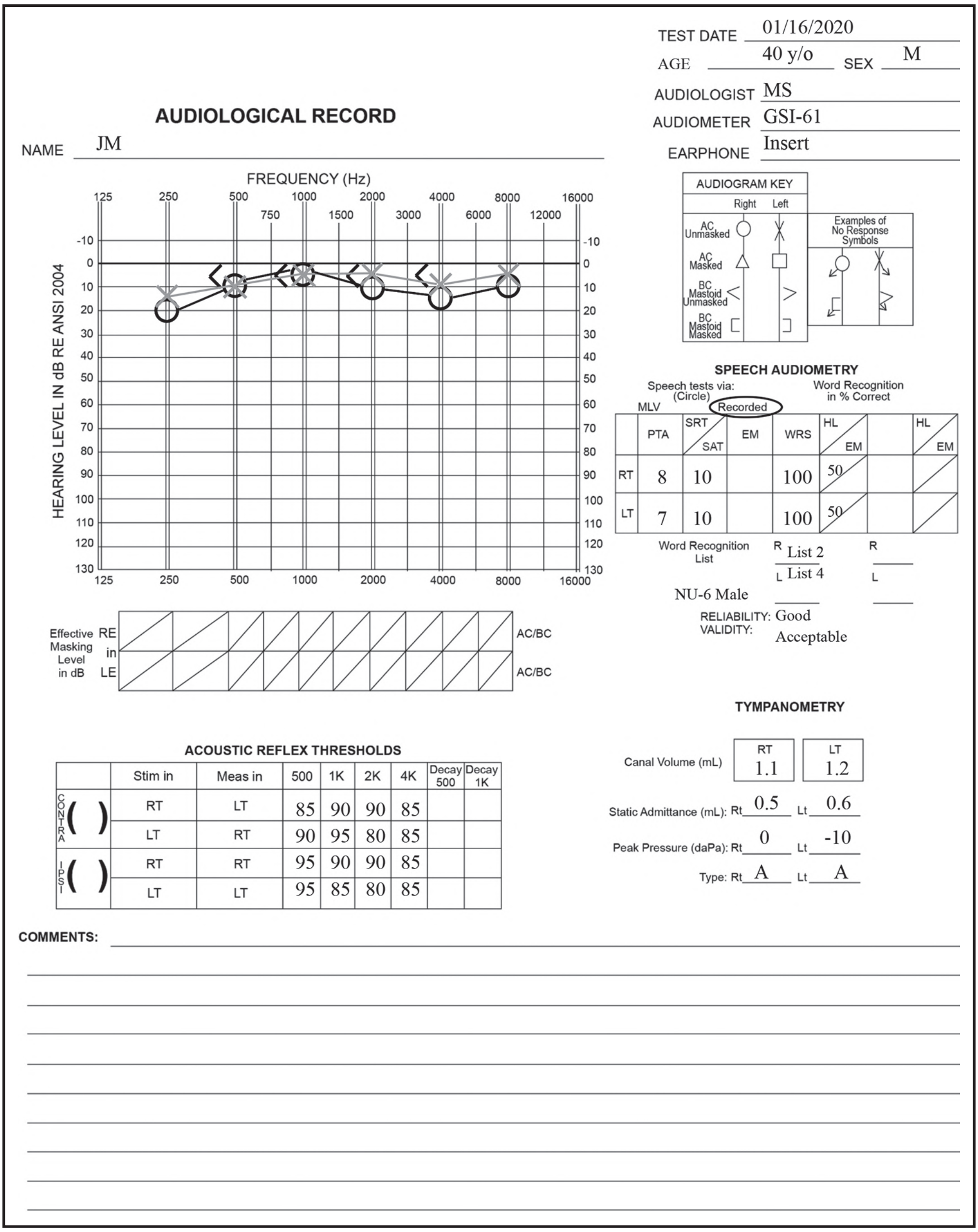
Tinnitus pitch matching was attempted, but J. M. was unable to identify a stimulus that matched the pitch of his tinnitus. Minimum masking level (MML), performed with a broadband noise in the right ear, was obtained at 30 dBHL. J. M. also completed the Tinnitus Handicap Inventory (THI) (Newman et al., 1996) and received a score of 22 out of a possible 100. According to the THI, a score of 22 indicates "mild tinnitus, easily masked by environmental sounds and easily forgotten with activities; may occasionally interfere with sleep but not daily activities" (Newman et al., 2008).

Medical/Neuroimaging Evaluation

The patient did not undergo any neuroimaging evaluation as there was no asymmetry in his hearing loss or tinnitus, nor were there any neurological signs and symptoms that would warrant such tests. Magnetic resonance imaging (MRI) is not recommended for workup of symmetric tinnitus. Asymmetric hearing loss or tinnitus can warrant imaging of the internal auditory canals and cerebellopontine angle. If warranted, contrast should be used to highlight pathologies such as inflammatory or neoplastic disorders, which are very rare even in asymmetric hearing loss (less than 1% of such studies ordered) (Tunkel et al., 2014).

Diagnosis and Recommended Management

The patient was diagnosed with somatosensory tinnitus related to temporomandibular joint dysfunction. This diagnosis was based on recent anxiety and panic attacks, bruxism, the use of a mouth guard, and a physical examination significant for both tenderness at the temporomandibular



AUDIOLOGICAL RECORD

NAME JM

TEST DATE 01/16/2020

AGE 40 y/o SEX M

AUDIOLOGIST MS

AUDIOMETER GSI-61

EARPHONE Insert

Effective Masking Level in dB											
RE in											AC/BC
LE											AC/BC

SPEECH AUDIOMETRY

Speech tests via: (Circle) MLV [✓ Recorded]

Word Recognition in % Correct

	PTA	SRT / SAT	EM	WRS	HL / EM		HL / EM
RT	8	10		100	50		
LT	7	10		100	50		

Word Recognition List: R List 2, L List 4; R ____, L ____

NU-6 Male

RELIABILITY: Good

VALIDITY: Acceptable

ACOUSTIC REFLEX THRESHOLDS

	Stim in	Meas in	500	1K	2K	4K	Decay 500	Decay 1K
CONTRA ( )	RT	LT	85	90	90	85		
	LT	RT	90	95	80	85		
IPSI ( )	RT	RT	95	90	90	85		
	LT	LT	95	85	80	85		

TYMPANOMETRY

	RT	LT
Canal Volume (mL)	1.1	1.2

Static Admittance (mL): Rt 0.5 Lt 0.6

Peak Pressure (daPa): Rt 0 Lt -10

Type: Rt A Lt A

COMMENTS:

Figure 24–1. J. M.'s complete audiological evaluation.

joints and reported changes in tinnitus pitch and loudness with pressure on the joint, in combination with normal audiological findings. Other causes of somatosensory tinnitus include neck injury secondary to motor vehicle accidents or chronic poor sleep positioning, neck disease, neck muscle sprain and strain, prolonged bed rest, and prolonged surgery with improper neck positioning and poor neck support (Haider et al., 2017; Michiels et al., 2018). Somatosensory tinnitus can be unilateral or bilateral. Although this was not possible with J. M., some patients with somatosensory tinnitus can identify a tone that matches the pitch of their tinnitus (Haider et al., 2017; Michiels et al., 2018; Pavaci et al., 2019). Matching tinnitus to a specific tone can help create a customized notched sound therapy (Okamoto et al., 2010; Stein et al., 2016).

J. M.'s treatment consisted of a dental evaluation of muscular attachments of the temporomandibular joints, a custom-fitted mouth guard, and myofascial release therapy. Disease of the temporomandibular joint can be treated with jaw rest (e.g., minimizing chewing and mouth opening), custom-fitted mouth guards versus an over-the-counter mouth guard that may cause more strain, warm compresses, anti-inflammatory medications, and physical therapy (Israel & Davila, 2014).

While there are few published studies of myofascial release therapy for treatment of tinnitus (Rocha & Sanchez, 2012), this is a recognized therapy for treatment of TMJ dysfunction and pain (Calixtre et al., 2015; Morell, 2016; Nahian et al., 2021). This type of manual therapy requires stretching and flexing the soft tissues surrounding the TMJ and is performed by a physical therapist.

Management of anxiety contributing to chronic clenching depends on the patient's history and compliance with recommendations. Examples of lower-level modalities include identifying stressors and avoiding them, meditation and mindfulness, physical exercise, massage therapy, music therapy, and engagement in hobbies and activities that are gratifying and relaxing. Behavioral therapy and medications should be considered in cases where the lifestyle modifications are not sufficient at reducing anxiety. J. M.'s anxiety that contributed to teeth grinding and clenching was addressed with recommendations for engaging in physical exercise, mindfulness training from a trained psychologist, and regularizing the sleep cycle.

J. M.'s medical care for his chronic conditions of hypertension, hypercholesterolemia, prediabetes, and gout continued without any alteration.

Outcome

At a clinic visit 6 weeks later, J. M. expressed less anxiety and no longer reported discomfort of his temporomandibular joint. He was coping better with his daily stressors that caused anxiety and had instituted an exercise regimen. J. M. was using a custom-fitted mouth guard and had undergone physical therapy. He had no reported hearing changes. His tinnitus was subjectively less noticeable and his follow-up THI score was 18 (down from 22).

Key Messages

- Somatosensory tinnitus is frequently associated with temporomandibular joint or neck injury—either acute or chronic. Patients typically report a change in the pitch of tinnitus when the points of injury are palpated.
- Tinnitus pitch matching may help create a customized notched sound therapy, one of the management modalities of somatosensory tinnitus.
- Physical therapy, such as myofascial release therapy, can be used to treat the temporomandibular joint and/or the neck, depending on the site of strain.
- Comorbid anxiety can contribute to chronic tension in the muscles of the

head and neck and thus exacerbate somatosensory tinnitus. Anxiety also lowers the patient's ability to cope with tinnitus. Therefore, anxiety and chronic stress should be assessed and managed.

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INDEX

Note: Page numbers in **bold** reference non-text material.

30 Bruel and Kjaer Noise Sentinel stationary sensors, 79
3-hydroxy-3-methylglutargyl coenzyme A (HMG-CoA) reductase inhibitors, 44

A

AAOHNS (American Academy of Otorhinolaryngology-Head and Neck Surgery), 103, 116, 124
ABR wave-I amplitudes, 9, 10
Accelerometers, 47, **48**
Acceptance and commitment therapy (ACT), 193, 212, 215
Acetaminophen, 44–45, 51
Acetylcholine, 233
Acoustic reflex measurement/testing, 114–115, 382
Acoustic reflex thresholds (ARTs), 342–343, 354–355
Acquired vascular abnormalities, 361
Acupressure/shiatsu, 263. *See also* Traditional Chinese medicine (TCM)
Acupuncture, 11, 193, 262–264
ADHD (attention deficit hyperactivity disorder), 229, 293, 296
Adolescents, **48**
  episodic tinnitus in, 41–42
  hyperacusis in, 291
  using social media platform, 313
Adoptees, tinnitus in, 28
Advances in tinnitus treatment modalities, 221–239
  background, 222–223
  clinical implications, 237–238
  future directions, 233–237
  introduction, 221–222
  recent advances, 223, 226–233
Adverse childhood experiences and hyperacusis, 291–292
Advocacy, online platforms for, 315–316
African Americans, tinnitus in, 46
Age and online healthcare interventions, 172
Aggression and cognitive behavioral therapy, 196
Agriculture Improvement Act, 250
Air-bone gap, 119–120
Airway irritation, 254
Albums, tinnitus, 169
Alcohol, 50
Allergies, 115, 254
Alzheimer's dementia, 123
American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS), 58
American Tinnitus Association (ATA), 214
Aminoglycoside antibiotics, 45, 58
Amplification and tinnitus management, 179–186
  background, 179–182
  clinical implications, 185–186
  future directions, 183–185
  introduction, 179
  recent advances, 182–183
Amsterdam Misophonia Scale (A-MISO-S), 292, 296, 299
Amygdala, 7, 35
Analgesics, 44, 45, **53**
Anemia and tinnitus, **363**
Angelicae radix (herbal medication), 266
Anger, 108, 196
Angiotensin-converting enzyme inhibitors, 44
Animal models of tinnitus, 8, 10, 51, 235, 237

Annoyance hyperacusis, 289–290
Anterior cingulate cortex (ACC), 153, 230
Anterior insular cortex (AIC), 295
Antibiotics, 44, 45, 58, 254
Antithrombotic drugs, 44
Anxiety, 13, 46, 159, 254
  about the assessment process, 115
  cognitive behavioral therapy for treating, 194–197, **199**, **203**
  in German patients, tinnitus-related, 57
  onset of tinnitus and, 107, 109–110
  reduction, **167**
  somatosensory tinnitus and, 384
  sound-induced, 294
Anxiety Screening Tool, 110
Apps
  for cognitive behavioral therapy (CBT), 73
  Computer Science Laboratory (CSL), 72
  hearing aids for tinnitus management and, 172–173
  hearing assessment, 135
  Mindshift, 173
  mobile apps for audiometric testing, 140
  myNoise, 173
  NoiseTube, 72
  Oticon Tinnitus Sound, 173
  for pitch, 134, 136
  for pitch matching, 135
  Relax Melodies—Sleep Sounds, 173
  relaxation, 214
  for self-help, 134, 140
  SimplyNoise, 173
  Tinnitus Therapy Lite, 173
  Track Your Tinnitus, 135
  White Noise Free, 173
  Woebot, 173
  Wysa, 173
App-based questionnaires, 137–138
App-based tinnitus assessment, 133–141
  background, 133–134
  clinical implications, 140
  future directions, 140
  introduction, 133
  recent advances, 134–140
App-based tinnitus skills education, 214–215. *See also* Books; Education
Appetite, fluctuating, 254
Aripiprazole, 377
Aromatherapy, 253
Aspirin, 10, 44–45, 58
At-home options. *See* Self-directed tinnitus therapy
Atherosclerosis and tinnitus, **363**
Atractylodis lanceae (herbal medication), 266
Attend, react, explain, adapt (AREA) model, 166, 168
Attention retraining, 168
Audibility and mask use, 57
Audio Notch app, 173
Audiogram matching, 150
Audiological assessment of tinnitus, 101–129, 139–140, 165–166, **167**, 168
  guiding principles, 102
  introduction, 101–102
  protocol for assessment of patients with bothersome tinnitus, 102–103, 106–111, 114–124
Audiological management for hyperacusis, 298–300
Audiologist-delivered cognitive behavioral therapy for tinnitus. *See* Cognitive behavioral therapy (CBT) and tinnitus, audiologist-delivered
Audiometric phenotypes, 36
Audiometric testing, mobile apps for, 140
Audiometry, 139, 185–186. *See also* Pure-tone audiometry (PTA); Speech audiometry
Audiovestibular symptoms, 56, 329
Auditory brainstem response (ABR), 8–9, **114**, 116–117, 147, 149–150
Auditory cortex (AC), 9, 147, 152, **224**, 227, 230–232
Auditory damage/disorders, 294, 326, 328–329
Auditory evoked responses, 116–117
Auditory hair cell regeneration, 235–237
Auditory memory cells, 227
Auditory-related networks, 154
Auditory side effects, 45, 57
Auditory steady-state response (ASSR), 147
Auditory thalamus, 9
Aural immittance, **112**, 114–115, 368
Autistic spectrum disorder (ASD), 291, 293, 295, 296

Automated Method for Testing Auditory Sensitivity (AMTAS) software, 120
Autonomy and equity through shared decision making, 280, 282
AV fistula and tinnitus, **363**
AV malformation and tinnitus, **363**
Avicenna, 253
Ayurveda, 247–248
Azithromycin, 57

B

Balance disorders, 57, 326
Banhabaekchulchonmatang (herbal preparation), 265
Bbb—Big cities, big noise, big data, 79
Beaver Dam Offspring Study (BOSS), 43
Beck Depression Inventory (BDI), **92**, 110, 268
Behavioral therapy, 165, 168, 194, 384
Bell's palsy and hyperacusis, 295
Benign paroxysmal positional vertigo (BPPV), 368
Beta-blockers, 44
Bilateral microphones with contralateral routing of signal (BiCROS), 348–349
Bimodal stimulation, 8, 13, 235
Binaural Oticon OPN S3 miniRITE hearing aids, 356
Biobank, U.K., 42, **52**, **54**
Biochemistry of DNA and tinnitus, 23–24, **25**, 26
Biomarkers, 26
  genetic, 37, 234
  neuronal, 233–234
  physiological, 35, 36
Biotin, 249
Blacks, prevalence of tinnitus in, 42
Blast exposure and development of hyperacusis, 294
Blood oxygen level-dependent (BOLD) signal, 294
Bojungikgitang (herbal preparation), 265
Bone-anchored hearing aids (BAHA), 298
Bone-conduction (BC)
  pure tone audiometry, 115
  pure-tone hearing testing, 213
  thresholds, mobile apps for, 140
Books, 161, **162**, 164–165
Boothroyd's model of rehabilitation, 166
Brain
  networks, 151–153
  rhythms, 150–151
Brain-derived neurotrophic factor (BDNF), 29, **31**, 234, 237
Breathing techniques (pranayama), 266
British Society of Audiology (2016) guidelines, 114, 116
British Tinnitus Association (BTA), 163, 214
Broadband noise (BBN), 128–129, 355, 373–374
Brochures, 161, **162**
Brodmann areas (BA), 148
Brown bread, 51
Bupleuri radix (herbal medication), 266
Burst stimulation, **224**, 226, 232

C

C2 dermatome, 229
Caffeine and tinnitus, 47–48, **49**, 50, 59
Calcined ci shi (herb), 265
Calcium, 51
Calcium channel blockers, 44
Cannabidiol (CBD) oils
  adverse reactions to, 254
  advertised for tinnitus relief, 253–254
  cannabis-derived products and, 249–251
Cannabis, 50
Canon of Medicine (Avicenna), 253
Cardiovascular health and tinnitus, 43–47
  confounding factors, 46
  diabetes mellitus, 45
  hypertension, 43–44
  interaction among factors, 46–47
  medications, 44–45
  smoking, 46
Care. *See also* Self-directed tinnitus therapy/self management; Values-led care in tinnitus
  clinical, 23, 171, 200, 280
  government healthcare websites, 162
  healthcare providers, 96
  online healthcare interventions, 172
  options, **281**
  person-centered, 159–160
  values-led, 283

Carotid artery dissection and tinnitus, **363**
Carotid cochlear dehiscence and tinnitus, **363**
Case-control study designs, 29
Case history assessment, 278–280. *See also* Patient history, importance of
Case studies
  asymmetrical sensorineural hearing loss and tinnitus, 341–349
  debilitating tinnitus in a patient with complex comorbidities, 367–377
  pulsatile tinnitus, 359–364
  somatosensory tinnitus, 381–384
  sudden sensorineural hearing loss and tinnitus, 353–357
CBT for Tinnitus, 203. *See also* Cognitive behavioral therapy (CBT) and tinnitus
Central auditory system (CAS), 6, 7–8, 10
Central gain theory, 10, 222
Cerebral insufficiency, 264
Cerebrospinal fluid (CSF) pressure, 360
Chemotherapy- induced nausea and cannabidiol (CBD) products, 250
Children
  hyperacusis in, 291–292
  self-reported tinnitus after childhood cancer, 45
  tinnitus in, 46
China, bothersome tinnitus after COVID-19, 57, 329
Chloroquine, 57, 252
Chocolate, 51, **54**
Cholesteatoma, 103
Cholesterol granuloma and tinnitus, **363**
Chrome, PnS sensor software on, 75
Chronic pain and tinnitus, 195, 229, 232, 278
Cingulate gyrus, 35
Cisplatin-induced tinnitus, 45
Citalopram, 377
Citygram-Sound project, 71–76, 78–80
  art-driven, 76, 78–79
  data-driven, 73–76
  piloting Citygram, 79–80
Client Orientated Scale of Improvement (COSI), 283
Client Orientated Scale of Improvement in Tinnitus (COSIT), **94**, 161, 283
Clinical care, 23, 171, 200, 280
Clinical interviews, 291, 301
Cnidii rhizoma (herbal medication), 266
Cocaine, 50–51
Cochlear damage/dysfunction, 116
  age and, 8
  determining, 184
  hearing loss triggers and, 180, 222
  melatonin and, 268
  noise exposure and, 10
  tinnitus and, 5, 35, 180
  vitamins and, 252
Cochlear function, 111, 137
Cochlear outer hair cells (OHCs), 5–8, 148
Cochlear progenitor cells, 236
Cochrane review, 182, 264–265
Cognitive behavioral therapy (CBT) and tinnitus
  apps for, 73
  books on, 164–165
  CBT-based coping skills, 211
  CBT-based self-help treatment, 138, **168**
  information on social media, 319
  internet-based cognitive behavioral therapy (ICBT) programs, 165–166
  in the management of hyperacusis and misophonia, 298–300
  psychology referral for, 108
  role in tinnitus management, 58, 183, 210, 235, 280, 314, 348, 377
Cognitive behavioral therapy (CBT) and tinnitus, audiologist-delivered, 193–204
  advantages, 204
  clinical outcomes, **203**, 204
  delivery mechanisms, 196
  evidence, 197–200
  future directions, 203–204
  introduction, 193
  research evidence, 195–196
  resources, 200–201, 203
  scope, principles, and components, 194–195
  step-by-step guide, **202**
  tinnitus intervention studies, **198–199**
Cognitive impairment and peripheral hearing loss, 123
Cognitive restructuring, 211
Communication, **167**
  channels, 315
  skills of clinicians, 283
  stress, 181

Complementary and alternative medicine and tinnitus, 261–269
  background, 261–263
  clinical implications, 268–269
  future directions, 268
  introduction, 261
  recent advances, 263–268
Computer Access to Research on Dietary Supplements (CARDS) database, 255
Computer Science Laboratory (CSL) app, 72
Computerized dynamic posturography (CDP), 368
Computerized tomography (CT), 344
Concentration and tinnitus, **95**
Consultation-based therapy, 159
Consumer Ear Disease Risk Assessment (CEDRA), 102–103
Contactin genes, 294
Continuous positive air pressure (CPAP) device, 375
Contralateral routing of signal (CROS) hearing aids, 298
Coordinated reset (CRR) neuromodulation, 136
Coping
  resources, **332**
  skills, 7, 135, 140, 161, **167**, 193, 210–211, 214, 276, 330, 372
Cortical auditory evoked potentials (CAEPs), 147, 150
Cortical oscillations, aberrant, 9–10
Cortical tonotopic maps, 181
Cough, 56
Counseling, 136
  for hyperacusis, 298–300
  self-directed tinnitus therapy and, 165–166
  telehealth, 212
COVID-19 pandemic, implications for tinnitus, 56–57, 325–334
  app-based tinnitus intervention and, 215
  audiological symptoms in individuals with confirmed COVID-19, **327–328**
  background, 326, 328–329
  clinical implications, 332–333
  coping resources, **332**
  future directions, 330, 332
  introduction, 325–326
  mediating factors, **331**
  online communication and, 172
  recent advances, 329–330
  support desired by individuals with tinnitus, **334**
  telehealth-based solutions, 213
Cranial nerve (CN) VIII, 6, **363**
Craniosacral therapy, 267
CRISPR/Cas9 gene-editing tool, 237
Cultural norms around illness, 278
Cyanocobalamin, 249
Cytomegalovirus and auditory damage, 326

D

Daily Stress Inventory (DSI), 50
Danish children, hyperacusis in, 291
Danshen (herb), 265
Day-night average sound level (DNL), 79
Debilitating tinnitus in a patient with complex comorbidities, case study, 367–377
  clinical history and description: follow-up visit, 370
  clinical history and description: initial visit, 367
  diagnosis and recommended management: follow-up visit, 375–376
  diagnosis and recommended management: initial visit, 368
  diagnostic evaluation: follow-up visit, 370–375
  diagnostic evaluation: initial visit, 367–368
  outcome: follow-up visit, 376–377
  outcome: initial visit, 370
Decision making, 159, 160–161, 163, 186, 280, 282–284
Deep brain stimulation (DBS), 230, **231**, 232–233
Default-mode network (DMN), 152, 153
Dementia, 43, 53, 57, 123
Deoxyribonucleic acid (DNA), biochemistry of, 23–24, 26
Depression. *See also* Mental health and tinnitus
  in adults aged 70 to 85 years, 55
  Client-Oriented Scale of Improvement in Tinnitus (COSIT), 161

Depression *(continued)*
  cognitive behavioral therapy for treating, 194–197, **199**, 203
  hyperacusis and, 295–296
  onset of tinnitus and, 7, 107, 109–110
  oral morphine and patients with, 51
  patient's negative reaction and, 110
  psychopharmacological treatments for, 57–58
  post-traumatic stress disorder (PTSD) and, 56
  questionnaires for, 91, **92**, **93**, **106**, 124
  self-directed care plan for, **167**
  tinnitus-related distress and, 35, 46
Depression, Anxiety, and Stress Scales (DASS), **49**, 50, **92**
Device calibration, 139–140. *See also* Audiological assessment of tinnitus
Diabetes mellitus, 35, 45, 51
Dialectical behavior therapy (DBT) for misophonia, 299–300
Diarrhea, 254
Diet and tinnitus, 42, 51, **52–54**, 55, **167**
Dietary Caffeine and Health Study Questionnaire, 48, 50
Dietary Supplement Health and Education Act of 1994 (DSHEA), 248
Dietary supplements, 248–249
  adverse reactions to, 254
  advertised for tinnitus relief, 251–252, 264
Diffusion tensor imaging (DTI), 151
Discordant dysfunction theory, 5–8
Distortion product otoacoustic emissions (DPOAEs), **113**, 115–116, 128, 370–372
Distress, tinnitus
  associated with hearing loss, 7, 10–13
  cognitive behavioral therapy for tinnitus, 197, 200, 204, 213, 299
  COVID-19 pandemic and, 57
  Internet-Based Cognitive Behavioral Therapy (ICBT) Programs, 165
  neural correlates for, 7
  provision of information for, 161
  psychological factors and, 35
  quality of life and, 214
  questionnaires for, 90, **94**, 374
  reduction, 215, **224**, 227, 332, 333
  stimulation of the distress network, 232
Diuretics, 44, 58
DIY sound therapies, 172–173
Dizygotic twins, 28
Dizziness, 56, 103, 254
Do-it-yourself (DIY) options, 169, 317
Dorsal anterior cingulate cortex (dACC), 232
Dorsal attention network (DAN), 152
Dorsal cochlear nucleus (DCN), 5, 6–7, 8, 13, 147, 229
Dorsal lateral prefrontal cortex (DLPFC), 148, **224**, 227–228, 230, 233
Dorsal root ganglion (DRG) cells, 237
Double-blind treatment group, 265
DPOAEs. *See* Distortion product otoacoustic emissions (DPOAEs)
Drowsiness, 254
Drynariafortunei (herb), 265
Dural venous sinus stenosis and tinnitus, **363**
Dyspnea, 56
Dystonia, 232, 244

E

Ear disease and dizziness, 103
Ear-level sound devices, 375
Ear pain after COVID-19, 329
Ear pounding, 45
Ecological momentary assessment (EMA), 135, 138–139
Edge computing, 74
Education. *See also* Books
  educational materials, 214
  online platforms for, 315–316
  through provision of information for patients, 161
EGb 761^{R}, 265
Electro- or magnetoencephalography (EEG/MEG), 73, 148, 229
Electroencephalography, 148
Electronic maskers, 169
Electrophysiological estimation, 116
Emotion and tinnitus, 10–11, **95**
Employment and responsibilities, **167**
Endolymph potassium, 237
Envelope following responses (EFRs), 150

Environmental factors of tinnitus, 26–28, 37, 237, 293
Environmental noise, 71, 72, 73–74, 78, 80
Epidemiology of Hearing Loss Study (EHLS), 43– 45
Epilepsy, 229, 254
Equilibrium disorders, 57
Essential oils, 249, 253
European Food Safety Authority (EFSA), 248
Eustachian tube dysfunction, 4
Evidence-based management options for tinnitus, 280, 282
Evidence-based support, 159
Exercise and tinnitus, 47, **48**, 58, **162**, 164, **167**, 173, 248, 254, 263–264, 330, **331**, 332, 337, 375, 384
Exposure therapy, 194–195

F

Face-to-face
  interview, 292, 293, 299, 300
  sessions in cognitive behavioral therapy, 196, 197, **198**, 200, 204
  therapy, 171
Facebook, 315, 318, 319, 321, 322
Fat, 51
Fatigue, **167**, 181, 254, 278, 367
Fear hyperacusis, 289
Females
  auditory brainstem responses in, 149
  COVID-19 symptoms in, 58
  prevalence of tinnitus in, 42, 43, 44, 330
  self-reported hearing problems in, 44–45
Fibromuscular dysplasia and tinnitus, **363**
Fibromyalgia and hyperacusis, 295
Fish, 51
"*FlatCat 5*" sticker mic prototype, 75
Flavonoids, 251, 264
Folate, 249
Food-frequency questionnaire, **53**, **54**
Forced-choice bracketing procedure, 355
Free-to-access videos, 280
Frequency lowering, 182
Frontal gyri, 35
Fruit, 51
Functional imaging with positron emission tomography (PET), 148
Functional magnetic resonance imaging (fMRI), 6, 9, 13, 148, 226, 294, 295

G

Gadolinium, 346, 360
Gallbladder deficiency associated with tinnitus, 265
Gastric side effects, 45
Gaze-evoked tinnitus, 267
Gene
  candidate gene approach, 24, 29
  dosage of CNTN5 or CNTN6, 293–294
  gene-editing tool, 237
  gene-environment interaction, 293
  polymorphisms, 234
Generalized anxiety disorder questionnaire (GAD-7), **203**
Generally regarded as safe (GRAS), 249
Genetic basis of tinnitus, 23–37
  background, 23–24, 26–28
  clinical implications, 37
  introduction, 23
  nonexhaustive list of studies investigating, **30–34**
  recent advances, 28–29, 35–37
Genetic biomarkers, 37, 234
Genetic variability, 24, 26
Genome, 24–26, 28, 29, **33**, **34**, 45
Genomewide association studies (GWAS), 28–29, 45
Genotype-phenotype associations for tinnitus, 28–29
Gerauschuberempfindlichkeit (GUF) questionnaire, 296
Germany, stress levels from a clinical population in, 329
Ginkgo biloba, 58, 264
  versus ginseng, 265
  side effects of, 254, 265
  as tinnitus supplement, 251–252
Ginseng *versus* ginkgo biloba, 265
Glaucoma and cannabidiol (CBD) products, 250
Glial cell line-derived neurotrophic factor (GDNF) treatments, 237
Glomus tumor and tinnitus, **363**
Glycyrrhiza (herb), 265

Glycyrrhizae radix (herbal medication), 266
GN ReSound Enya, 376
Godin Leisure-Time Exercise questionnaire, 48, **48**
Government healthcare websites, 162
Group sessions, 55, 196, 210
GSI AudioStar Pro device, 120
Guided self-help, 159
Gushen pian, 265

H

Habituation, 12, **162**, 180, 181, 356
Hallucinogens, 50–51, 222
Harvestworks, 79
Head injury and hearing loss, 103
Headphones for prototyping therapies, 169
Health determinants and modifiable risk factors, 26, 41–59
  background, 41–43
  clinical implications, 59
  future directions, 58–59
  recent advances, 43–48, 50–51, 55–58
Health Professionals Follow-Up Study, 43, 44
Health-related information on social media platforms, 313–314
Hearing, **95**, 276
  assessment apps, 135
  disorders, 35
  healthcare providers, 96
  protection, 11, 12
  sensitivity, 116
  therapy approaches, 278
Hearing aids for tinnitus management, 170, **181**
  apps and, 172–173
  background, 179–180
  close monitoring and follow-up, 186
  cochlear damage measurement, 184
  contralateral routing of signal (CROS), 298
  degree of hearing loss and, 182
  fitting and information from patients, 186
  gain adaptation, 180
  gain/ output for tinnitus relief, 183–184
  habituation, 181
  hearing aid-based tinnitus suppression, 234
  in-depth assessment, 185–186
  masking, 180–181
  neuromodulation, 181–182
  noise-reduction algorithms in, 181
  optimization of hearing aid gain/ output for tinnitus relief, 183–184
  other intervention strategies and, 185
  outcome measures, 183
  recent advances, 182
  reduced communication stress, 181
  research design, 183
  selection of, 161
  tinnitus pitch, 184
  via Bluetooth, 173
Hearing loss. *See also* Noise-induced hearing loss (NIHL); Sensorineural hearing loss (SNHL) and tinnitus, asymmetrical, case study; Sensorineural hearing loss (SNHL)
  after COVID-19, 329
  cognitive impairment and peripheral, 123
  degree of, and hearing aids, 182
  due to hazardous occupational noise exposure, 11
  due to outer hair cells (OHCs) loss, 7–8
  head injury and, 103
  hyperactivity of subcortical and cortical areas and, 9
  idiopathic sensorineural, 103
  middle ear dysfunction and, 121
  in musicians, 5
  noise-induced, 26
  peripheral, 6, 123
  reversible, 51
  salicylate-induced, 294
  sensorineural, 119
  sudden onset, 119
  triggers and cochlear damage/dysfunction, 180, 222
HEI, **53**
Hemp, 249
Herbal remedies, 55
Herb–drug interactions, 55
Heritability, 23, 28, 29, 293
Heroin, 50–51
Heschl's gyrus, 154
High-definition (HD) tDCS, 150, **224**
Hippocampus, 35, 234, 235
Homeopathy, 266–267

Homework for counseling sessions, 168
Hospital Anxiety and Depression Scale (HADS), **92**, 265, 375
Household dysfunction and hyperacusis, 292
Human Genome Project (HGP), 23
Hydrocodone (VicodinR), 51
Hydroxychloroquine, 57
Hyperactivity within the auditory system, 294–295
Hyperacusis, 159, 211
  in adults, 290–291
  app for questionnaires about, 138
  assesement, 295–297
  in children, 291–292
  clinical implications, 300–301
  cognitive behavioral therapy for treating, **199**
  future directions, 300
  introduction, 289
  management, 297–300
  mechanisms, 293–295
  mental health and, 291–292
  portrayal on social media platforms, 319
  prevalence in ASD, 293
  tinnitus supplements and, 251
  types, 289–290
  visual analog scales for, 138
Hyperacusis Questionnaire (HQ), **203**, 291, 296, 299, 357
Hypertension and tinnitus, 35, 42, 43–44, 51, **363**
Hypnosis, 267–268
Hypnotherapy, 267–268

I

Ibuprofen, 44, 381
Idiopathic intracranial and tinnitus, **363**
Idiopathic sensorineural hearing loss, 103
Idiopathic tinnitus, 6, 265, **363**
Illegitimate remedies, 318
Illness Perception Questionnaire-Revised (IPQ-R), 50
Impact noise type, 4
Impulse noise type, 4
IMS Institute for Healthcare Informatics, 133
Inferior colliculus (IC), 7
Information-based self-help, **162**
Information for patients and education, 161
Informed decisions, 102, 160. *See also* Decision making
Inhalants, 50–51
Inner hair cell (IHC)-driven activity, 5
Insomnia
  cannabidiol (CBD) products and, 251
  cognitive behavioral therapy for treating, 194–196, **199**, **203**
  during pandemic, 329
Insomnia severity index (ISI), **93**, **203**
Insular cortex, 154, 295
Interferon, 57
Internal auditory canals (IACs), 356, **362**
Internet-based cognitive behavioral therapy (ICBT), 165, 196, **198**, 199, 200, 213
Intracochlear impedance, 347
Intracochlear schwannoma (ICS), 346, 349
Intracochlear vestibular schwannoma, 346
Intracranial aneurysm and tinnitus, **363**
Intratympanic (IT) steroid injections, 342, 356
Invasive neuromodulation for tinnitus, 230–233
  auditory cortex stimulation, 230–232
  deep brain stimulation (DBS), 232–233
  stimulation of the distress network, 232
  vagus nerve stimulation (VNS), 233
Inventory of Hyperacusis Symptoms (IHS) questionnaires, 296
Ircam, 79
Iron, 51
Italy, bothersome tinnitus after COVID-19, 329
Ivermectin, 57

J

Jackson Heart Study, 46
Jugular bulb dehiscence, 361, **363**

K

Kidney disease and tinnitus, 45
Korean NHANES, 42, 46, **54**
Korean red ginseng plant (KRG) (panax gingseng), 265
Kurtosis, 4

L

Labyrinthitis, 346
Left temporoparietal area (LTA), 185, **224**, 227
Lidocaine, 148, 149
Lifestyle recommendations, 165–166, **167**, 168
Likeness rating scales, 137
Likert scale, **93**, 328
Limbic system structures, 7
Lipoflavonoids in tinnitus supplement, 251
Lockdown-related stress, 57
Loop diuretics, 44, 58
Lopinavir-ritonavir, 57
Loudness, 229, 232, 347
  matching, 13, 118, 124, 128, 134–137, 186, 278, 340, 373
  perception, 6, 291
  recruitment, 129, 291
Loudness discomfort levels (LDLs), **114**, 117, 129, 186, 289, 355, 374
Lung injuries and cannabidiol (CBD) products, 250
Lyme disease and hyperacusis, 295

M

Magnesium in tinnitus supplement, 251, 364
Magnetic resonance angiography (MRA), 344, 361
Magnetic resonance imaging (MRI), 6, 117, 151, 344, 355–356, 360, 382
Magnetic resonance venography (MRV), 361
Magnetoencephalography, 148
Major depressive disorder and misophonia, 296
Maladaptive plasticity, 9
Malaria, 57
Males, prevalence of tinnitus in, 42
Marijuana, 50–51, 249
Mask use and audibility, 57
Masking of tinnitus, 12, 128–129, 169, 180–181
Meaning of Life questionnaire, **94**
Measles and auditory damage, 326
Medical Outcomes Study 36-item short form (SF-36), 47
Medications, **167**, 298, 364, 384. *See also* Remedies
  cardiovascular health and tinnitus, 44–45
  herbal, 266
  migraine, 298
  nonsteroidal anti-inflammatory (NSAID), 43, 44, 45
  ototoxic, 26, 37, 45, 58
  self-medication, 50, 255–256
Meditation (dhyana), 266
Melatonin, 58, 251, 264, 268
Meniere's disease, 103, 119, 346, **363**
Meningioma and tinnitus, **363**
Mental health and tinnitus, 55–58
  COVID-19, 56–57
  dementia, 57
  pharmacotherapy, 57–58
  post-traumatic stress disorder (PTSD), 56
Mental illness and hyperacusis, 291–292
Mesenchymal stem cells, 237
Methadone, 51
Methamphetamines, 50–51
mHealth, 133
Micro-Electro-Mechanical System (MEMS), 72–73
Middle ear function/dysfunction, 111, 114–115, 119–120
Middle East Respiratory Syndrome (MERS), 56
Midturn cochlear schwannoma, 348
Migraine, 361, 363, **363**. *See also* Pulsatile tinnitus, case study
  hyperacusis and, 295
  medications, 298, 364
  questionnaire, 359–360
Mindfulness, 349
  meditation, 357
  mindfulness-based cognitive therapy, 280
  mindfulness-based stress reduction (MBSR), 193
  training, 384
Mindshift app, 173
Mini Tinnitus Questionnaire (mini-TQ), 137, 263–264
Minimum masking level (MML), 13, 355, 373–374, 382
Misinformation, 314, 317–318, 320–321

Misophonia
  assessment, 295–297
  clinical implications, 300–301
  defined, 290
  dialectical behavior therapy (DBT) for, 299–300
  factors related to, 292–293
  future directions, 300
  genetic predisposition to, 294
  management, 297–300
  mechanisms, 293–295
  prevalence of, 292–293
  underlying medical conditions, 296
Misophonia Assessment Questionnaire (MAQ), 296
Misophonia Physical Response Scale (MPRS), 296
Misophonia Questionnaire (MQ), 296
MisoQuest questionnaire, 292, 296
Mobile App Rating Scale (MARS), 140
Mobile apps for audiometric testing, 140
Monozygotic twins, 28
Mood, app-based questionnaires for, 137–138
Morphine, 51
MP3 players for prototyping therapies, 169
Multiple Activity Scale for Hyperacusis (MASH), 296
Multivitamin-multimineral therapy, 55
Music for lateral inhibition, 170
Music Hackathon at NYC Spotify, 79
Music-induced tinnitus, 4–5. *See also* Noise-and music-induced tinnitus
Music therapy, 169
Musical hallucinations, 222
Musicians, hearing protection in, 12
MyNoise app, 173
Myofascial release therapy, 384

N

NAL-NL2, 356
Narrowband noise (NBN), 127, 135, 232, 355
National Center for Rehabilitative Auditory Research (NCRAR), 7
National Health Service Choices website, 163
National Institute for Health and Care Excellence (NICE), 108, 114, 116, 124, 160, 185
Naturecare Tinnitus Sound Relaxer, 169
Negative beliefs/emotions, 161–162, 168, 221, 290, 295, 314
Neural auditory dysfunction, 115, 116
Neural degeneration, 236
Neural hyperpolarization, 226
Neural progenitor cells, 237
Neural synchrony, 9, 294
Neurofeedback, **225**, 228–229
Neuroimaging techniques, 115, 148–149
Neuromodulation, 136, 180, 181–182, 222. *See also* Noninvasive neuromodulation for tinnitus
Neuronal biomarkers, 233–234
Neuropathic pain and cannabidiol products, 251
Neurostimulation techniques, 8, 13, 135, 222, 235
New Jersey Poison Center records (ToxiCALLR), 51
New York University, 79
NHANES (National Health and Nutrition Examination Survey), 41, 42, 45, 46, 47, **48**, 50, **53**–**54**, 55
NHS I and II, 44
Niacin, 249, 252
NIH ODS, 249
Noise-and music-induced tinnitus, 3–5
  background, 5–7
  clinical implications, 11–12
  future directions, 12–13
  introduction, 3–5
  management, 12
  prevention, 11–12
  recent advances, 7–11
Noise energy, 4
Noise exposure, 8, 9, 27, **32**, **53**, **90**, 103, 150, 293
  annoyance and, 79
  duration and intensity, 4
  environmental, 72
  of individuals with chronic, acute, subacute, and no tinnitus, **27**
  leading to noise-induced hearing loss (NIHL), 10
  occupational, 4, 11, 29, **33**, 42, 88
  personal, 72
  recreational, 4–5, 42–43, 45

Noise exposure *(continued)*
  reduction in, **167**
Noise-induced hearing loss (NIHL), 10, 26, 73, 139–140
Noise Outcomes in Service Members Epidemiology (NOISE), 56
Noise-reduction algorithms in hearing aids, 181
Noise sensitivity and heritability, 293
Noisegate Festival, 79
NoiseTube app, 72
NOISY project, 79
Non-Hispanic Whites, prevalence of tinnitus in, 42
Nonauditory injuries, 6
Noninvasive neuromodulation for tinnitus, 223, **224–225**, 226–230
  neurofeedback, 228–229
  transcranial alternating current stimulation (tACS), 227–228
  transcranial direct current stimulation (tDCS), 226–227
  transcranial magnetic stimulation (TMS), 223, 226
  transcranial random noise stimulation (tRNS), 228
  transcutaneous electrical nerve stimulation (TENS), 229–230
  transcutaneous vagus nerve stimulation (tVNS), 230
Nonpsychoactive cannabidiol oil, 249
Nonsteroidal anti-inflammatory (NSAID) medications, 43, 44, 45
Nontinnitus ears (NTE), 150
Norepinephrine, 233
Nortriptyline, 298, 364
Notch filter amplification, 182
Notch signaling pathways, 236
Notched sound therapy, 169–170
Nucleus accumbens (NAc), 153
Nurses' Health Study II, 47

O

Obesity and tinnitus, 46
Objective diagnosis of tinnitus, 147–154
  background, 148–149
  clinical implications, 154
  future directions, 154
  introduction, 147–148
  recent advances, 149–153
Obsessive compulsive disorder (OCD) and misophonia, 293, 296
Occupational noise exposure, 4, 11, 29, **33**, 42, 88
Occupational Safety and Health Administration (OSHA) regulations, 4, 11
Odds ratio (OR), 29, 43
Older adults, prevalence of tinnitus in, 42
Olive oil, 249
Online clinics for self-directed tinnitus management, 170–171
Online sound therapies, 169–171
Online support, 163–164, 214
Online tinnitus information/therapies, 162–163, 171–172, **173**
Operculum, 154
Orbitofrontal cortex (OFC), 153
Oticon CROS, 348
Oticon Tinnitus Sound app, 173
Otitis externa after COVID-19, 329
Otoacoustic emissions (OAEs), **113**, 115–116
Otolaryngological side effects and COVID-19, 56
Otologic diseases, 103, 347
Otoprotection, 45
Otosclerosis and tinnitus, **90**, 103, **363**
Otoscopy, 111, **112**, 115
Ototoxic drugs, 58, 103
Ototoxic medications, 26, 37, 45, 58, 329
Ototoxicity, 35, 45, 51, 57, 101, 139–140
Ototoxins, 44
Outer hair cells (OHCs), 5–7, 148
Over-the-counter (OTC)
  substances, 103
  tinnitus relief products, 252, 318
  tinnitus supplements, 55, 251, 322
Oxford Web-Q, **54**
Oxycodone, 51
Oxymorphone, 51

P

Paget's disease and tinnitus, **363**
Pain
  chronic pain and tinnitus, 195, 229, 232, 278

  ear pain after COVID-19, 329
  hyperacusis, 289
  neuropathic pain and cannabidiol products, 251
  regional pain syndrome and hyperacusis, 295
Pantothenic acid, 249
Parahippocampus, 147, 153, 233
Parasympathetic nervous system, 11, 13
Parietal cortices, 35
Parkinson's disease, **231**, 232, 251
Patient-centered approach, 282
Patient health questionnaire (PHQ-9), **93**, **203**
Patient history, importance of, 87–96
  background, 88, 90–91
  examples of key questions, **89–90**
  future directions, 95–96
  introduction, 87
  questionnaires, 90–91, **92–95**
  recent advances, 91, 93, 95
Patient reported experience measures (PREMs), 283
Patient Reported Outcome Measure (PROM), 282
Pentoxifylline, 265
Perception of tinnitus
  anxiety and/or depression and, 110
  apps and, 138–139
  audiological assessment of patients and, 101
  bilateral cochlear dysfunction and/or hearing loss and, 116
  environmental sound and, 115
  gamma oscillations and, 223
  hearing aids and, 180, 182, 183
  lidocaine-related changes and, 149
  limbic structures and, 7
  loss of OHCs and, 5
  loudness, 6
  medication and general health history and, 58, 59
  natural sounds disrupting, 168–169
  online content and, 170
  otoscopy and, **112**
  patients' case history and, 88
  reduction in, 12, 13
  short-term, 184
  as tinnitus phenotype, 26, 35
  transcranial direct current stimulation (tDCS) on, 185
Peripheral auditory system, 5, 8, 59
Peripheral hearing loss, 6, 123
Permanent threshold shifts (PTS), 8
Person-centered care, 159–160
Personal digital assistant (PDA), 138
Personal listening devices (PLDs), 12
Personality disorders and misophonia, 296
Petersen Schmidt Rosito, 47–48
Phantom percept. *See* Perception of tinnitus
Pharmacotherapy, 57–58, 234
Phenotyping, 26, 35–37
Phonetically balanced (PB) words, 122
Photosensitivity, 254
Physical activity, **48**, **89**, **90**. *See also* Exercise and tinnitus
Physical manipulation therapies, 267
Physiological biomarkers, 35
Picture-in-picture (PIP) visualization, 75–76
Pink noise, 12, 356
Pitch, 184
  amplification and, 184
  apps for, 134, 136–137, 140
  decreased gain and, 182, 184
  DPOAE measurement and, 115
  estimator, 135
  hearing loss at, 151
  notched sound therapy and, 169
  pure tone audiometry and, 113, 128
  residual inhibition and, 129
  test frequencies and, 115
Pitch matching, 127–128, 382
  apps for, 135, 136, 137
  to frequencies where hearing is impaired, 180
  match using self-assessment online, 170
  psychoacoustic tinnitus assessment and, 114
  tests, 278
Pittsburgh Sleep Quality Index (PSQI), **92**, 268
Placebo sound generators (PSGs), 298
Plant oils, 249, 253
Planum polare, 154
Planum temporale, 154
Platinum-based neoplastics, 58
Plug-and-sense (PnS) sensor system design, 75

Polygenic risk score (PRS), 37
Poria (herbal medication), 266
Positron emission tomography (PET), 6, 148
Post-traumatic stress disorder (PTSD)
  cannabidiol (CBD) products and, 251
  cognitive behavioral therapy for treating, 194
  depression and, 56
  misophonia and, 293, 296
Postures (asanas), 266
Practice Guidance for Tinnitus in Adults, 124
Precision Sound Therapy™, 171
Precuneus, 35, 148, 153–154, 295
Prefrontal cortex (PFC), 13, 148, **152**, 153, 228, 234
Pregnancy and tinnitus, **363**
Prepubertal gynecomastia, 254
Prescription opioids, 51
Primary auditory cortex (A1), 7, 149, 227, 231, 295
Progressive Tinnitus Management (PTM) program, 7, 210–211
Protein, 24, 26, 51, **54**
Protocol for assessment of patients with bothersome tinnitus, 102–103, 106–111, 114–124
  components of the diagnostic protocol, **112–114**
  objective auditory procedures, 111, 114–117
  otoscopy, 111
  patient history, 102–103
  pure-tone audiometry, 117–121
  speech audiometry, 121–124
  tinnitus questionnaires, 103, **104–106**, 107
  validated tinnitus inventories, 107–111
Psychoacoustic tinnitus assessment, **114**, 124–125, 127–129, 136, 186
  loudness discomfort levels (LDLs), 129
  loudness matching, 128
  masking of tinnitus, 128–129
  overview, 124–125
  pitch matching, 127–128
  residual inhibition, 129
  threshold for white (broadband) noise, 127
Psychological management strategies, **164**, 282
Psychometric properties, 36
Psychopharmacological interventions, 58
Psychosocial effects, 55, 108, 151, 182, 193, 275, 326
Psychotherapy, 58, **167**, 196, 377
Pulsatile tinnitus, case study, 359–364
  clinical history and description, 359
  diagnosis and recommended management, 361, 363–364
  diagnostic evaluation, 359–361
  important causes of, **363**
Pure-tone audiometry (PTA), 45, **113**, 115, 116, 297, 353, 359
  air-conduction, 117–118
  bone-conduction, 118–121
Purpose-designed desktop sound generators, 169

Q

Qi (energy), 263, 265. *See also* Traditional Chinese medicine (TCM)
Qigong, 264
Quality of life (QOL), 13, 91, 107–108
Questionnaires, 88–91, **92–93**, 103, **104–106**, 107, 355. *See also* Patient history, importance of
  Amsterdam Misophonia Scale (A-MISO-S), 296
  app-based, 137–138
  for assessment of reaction to tinnitus, 137–138
  for ecological momentary assessment of tinnitus, 138–139
  Gerauschuberempfindlichkeit (GUF), 296
  hyperacusis, 291
  Inventory of Hyperacusis Symptoms (IHS), 296
  migraine, 359–360
  Misophonia Activation Scale (MAS-1), 296
  Misophonia Assessment Questionnaire (MAQ), 296
  Misophonia Physical Response Scale (MPRS), 296
  Misophonia Questionnaire (MQ), 292, 296

  - MisoQuest, 296
  - Multiple Activity Scale for Hyperacusis (MASH), 296
  - outcomes of tinnitus management and, 183
  - quality of life (QOL), 13
  - Selective Sound Sensitivity Syndrome Scale (S-Five), 296
  - Sound Hypersensitivity Questionnaire (SHQ), 298
- Quinine, 44, 58, 252

R

- Randomized controlled trials (RCTs), 183, 211–212, 263, 264, 268, 298, 320
- Reading grade level (RGL), 317
- Real-ear measurements, 356
- Recorded therapy sounds, 162
- Recreational noise exposure, 3, 4, 42–43, 45
- Regional pain syndrome and hyperacusis, 295
- Regulatory oversight
  - cannabidiol oil and, 250
  - sale of dietary supplements and, 248–249
- Relax Melodies—Sleep Sounds app, 173
- Relaxation
  - app, 214, 173
  - guide, **201**
  - lack of, **331**
  - strategies, **89–90**, **162**, **164**, 165, **167**, 169, 170, 173, 195, 200, 210, 348
  - therapy, 262
  - through hypnosis, 267
  - through Traditional Japanese Medicine, 266
- Remedies. *See also* Medications
  - herbal, 55
  - illegitimate, 318
- Residual inhibition (RI), 129, 355
- ReSound Relief app, 173
- “Rest and digest” response, 11
- Resting-state functional connectivity (rsFC), 153
- Resting-state networks (RSNs), 153
- Reversible hearing loss, 51
- Rhizoma (herbal medication), 266
- Ribavirin, 57
- Riboflavin, 249
- Rinne test, 382
- Rubella and auditory damage, 326

S

- Salicylate-induced hearing loss, 294
- Satisfaction With Life Scale (SWLS), 47
- Schizophrenia and cannabidiol (CBD) products, 250
- SDSN Music, 79
- Secondary auditory cortex (A2), 7, 231, 232, 233
- Seizure disorders in children and cannabidiol (CBD) products, 251
- Selection bias, 293
- Selective Sound Sensitivity Syndrome Scale (S-Five), 296
- Self-assessment online, 170
- Self-directed tinnitus therapy/self management, 107, 159–174, 204, 314, 322
  - background, 160–161
  - clinical implications, 171–173
  - evolution of support and recent advances, 161–166, 168–171
  - future directions, 171
  - introduction, 159–160
- Self-efficacy, 160, 163, 212, 314–315
- Self-healing, 266
- Self-help, 159–160
  - apps for, 134, 140
  - assisted, 196
  - associations, 55
  - books, 161
  - cognitive behavioral therapy and, 138, 196–197, 205
  - method, 172
  - online/information-based, **162**, 170, 172
  - programs, 165, 169
  - websites, **162**
  - on YouTube, 316–317
- Self-medication, 50, 255–256, 320
- Self-Rated Tinnitus (SRT), 268
- Self-Rating Anxiety Scale (SAS), 329
- Self-reported disability in adulthood and hyperacusis, 292
- Self-Test for Anxiety, 110

Semicircular canal dehiscence and tinnitus, **363**
Sensor networks, 73, 74, 76
Sensorineural etiologies, 119
Sensorineural hearing loss (SNHL), 115, 119, 348
Sensorineural hearing loss (SNHL) and tinnitus, asymmetrical, case study, 341–349
  clinical history and description, 341–342
  diagnosis and recommended management, 347–349
  diagnostic evaluation, 342–347
  outcome, 349
Sensorineural hearing loss (SNHL) and tinnitus, case study, 353–357
  clinical history and description, 353
  diagnosis and recommended management, 355–356
  diagnostic evaluation, 353–355
  outcome, 356–357
Sensory-motor neuronal pathways, 294
S(e)oul Sound(e) scapes, 79
Sertraline, 268
Service delivery gap, 160
Shared decision making in evidence-based healthcare, 280, 282–284
Sigmoid sinus diverticulum and tinnitus, 361, **363**
SimplyNoise app, 173
Sin(e)escapes, 79
Single-nucleotide polymorphisms (SNPs), 24, **25**, 26, 28
Sinus infections, 115
Skin irritation, 254
Sleep, **95**
  apnea and cannabidiol (CBD) products, 251
  difficulties/disorder, 51, 137–138
  hygiene, 107, 210, 364, 375
  impact of melatonin on, 268
  improvement, **167**
  quality during pandemic, 329
Smokers, former, and tinnitus, 42
Smoking, 26, 36, 42
  cessation, 267
  as risk factor for hearing loss, 43–44, 46–47, **89**, 101, 107
Social distancing and audibility, 57
Social isolation and tinnitus, 163
Social media in tinnitus and hyperacusis, 313–329
  background, 313–314
  clinical implications, 321–322
  future directions, 319–321
  introduction, 313
  recent advances, 314–319
Social recognition of perceived tinnitus sound, 277. *See also* Perception of tinnitus
Social value, hierarchies in, 278
Socialization, **167**
Sociological perspectives of health, 277–278
Somatosensory stimulation, 13, 235
Somatosensory tinnitus, case study, 381–384
  clinical history and description, 381
  diagnosis and recommended management, 382–384
  diagnostic evaluation, 381–382
  outcome, 384
Somatosounds, 4
Sound
  amplification. *See* Amplification and tinnitus management
  conditioners, 169
  enrichment, 197, **201**, 375
  files, 170
  generators, 12, 127, 169, 170, 210, 298, 375–376
  pillow speakers, 169
  sensitivity, **203**, 204, 355, 357, 360, 364
  sound-evoked hyperactivity, 294
  sound-induced anxiety, 294
  tolerance, 56, **114**, 115, 117, 129, 186, **201**, 211, 290, 374
Sound Hypersensitivity Questionnaire (SHQ), 298
Sound maps in tinnitus research, 71–81
  background, 72–73
  clinical implications and future directions, 80–81
  introduction, 71–72
  recent advances, 73–76, 78–79
Sound therapy, 12, 96, **167**, 168–171
  applications, 213–214
  for tinnitus management, 210

Sounds of New York City (SONYC, n.d.), 72–73
Spatiotemporal noise measurements, 80
Speech audiometry, **113**, 116
  speech perception in noise, 122–124
  speech recognition (reception) threshold, 121–122
  word recognition in quiet, 122
Speech detection threshold (SDT), 343
Speech-in-noise ratio (SNR), **52**
Speech perception, **113**, 118, 122–124, 329
Speech recognition score (SRS), 342–343
Speech-recognition thresholds (SRTs), 121–122, 353, 359, 382
Spontaneous otoacoustic emissions (SOAEs), 5
St. John's wort, 269
State-Trait Anxiety Inventory, **92**
Stem-cell differentiation, 236
Stimulation of the distress network, 232
Stress, 46, 325–326
  app-based questionnaires for, 137–138
  of being hospitalized, 329
  hyperacusis and, 294
  lockdown-related, 57
  reduction, 170
  stress symptom scale, 266
  visual analog scales for, 137–138
Stroop color naming task, 300
Stroop test, 13
Structural brain changes, 151
Substance use and tinnitus
  alcohol, 50
  cannabis, 50
  cocaine, 50–51
  cognitive behavioral therapy for treating, 195–196
  hallucinogens, 50–51
  heroin, 50–51
  inhalants, 50–51
  prescription opioids, 51
Suicidal ideation, 55, 91, 212, 370, 374
Sulodexide, 268
Sunflower oil, 249
Superior canal dehiscence syndrome (SCDS), 120
Superior temporal gyrus, 154, 295
Swedish Tinnitus Outreach Project, 36
Sympathetic nervous system activity, 11, 13
Synaptopathic noise-induced tinnitus, 8–9
Synaptopathy, 8–9, 35, 150
Synthetic Sentence Identification (SSI) test, 123–124
Systemic diseases, 26–27, **33**, 35, 101

T

Tai chi, 264
Tailor-made notched music training (TMNMT), 234
Talk therapy, 377
Tele-PTM, 210–212
Teleaudiology and clinical management of tinnitus, 171, 209–215
  background, 210–211
  clinical implications, 215
  future directions, 214–215
  introduction, 209
  recent advances, 211–214
Temporal interference (TI), 235
Temporomandibular joint (TMJ) problems, 4, 35, **225**, 229, 381, 382, 384
Terpenoids, 264
Test battery approach, 102, **113**, 114–115, 121, 123, 124, 186, 201
Testicular cancer, self-reported tinnitus after, 45
Delta-9-tetrahydrocannabinol (THC), 249, 250, 253
Thalamocortical dysrhythmia (TCD), 9–10, 223
Thalamus, 7, 9, 153
Therapy-resistant neurological disorders, 232
Thiamine, 249
ThinkCoffee, 79
"3D" sound mapping approach, 72
Thyroid disease and tinnitus, **363**
Time-of-day-dependence of tinnitus, 139
Tinnitracks tinnitus therapy, 170
Tinnitus
  apps, 73, 135, 138, 139, 173
  assessment of reaction to, 137–138
  audiological assessment related to, 139–140
  brain networks, 151–153

Tinnitus *(continued)*
  as a central nervous system phenomenon, 6–7
  chronic, 26–28
  clinical manifestation of, 35
  as a cochlear phenomenon, 5–6
  comorbidities, 36
  diagnosis and management of, 26
  ecological momentary assessment of, 138–139
  incidence of, 43, 46
  inventory, **112**
  limbic system and, 10–11
  management of, 58–59
  objective, 4
  prevalence rates of, 5, 43
  primary characteristics assessment, 135–137
  psychological factors of, 35, 36
  as a psychological phenomenon, 7
  subjective, 4
  symptom severity, 134, 137, 138, 139
  tinnitus-related phenotypic features, 28
  types of, 4
  validated tinnitus inventories, 107–111
Tinnitus and Hearing Survey (THS), 211
Tinnitus E-program, 165, 171–172
Tinnitus ears (TE), 150
Tinnitus Functional Index (TFI), 13, 45, 47, **94**, 107–108, 111, 137, 150, 168, 173, 186, **198**, **203**, 263, 282–283, 320, 360, 374, 377
Tinnitus Handicap Inventory Screening (THI-S), 137, 138, **332**
Tinnitus Handicap Inventory (THI), 45, 46, 93, **94**, 107, 108, **109–110**, 111, 137, 186, **198**, 263, 265, 268, 289, 329, 347, 349, 355, 382
Tinnitus Handicap Questionnaire (THQ), **94**, 153, 186
Tinnitus Handicap Scale (THS), 48
Tinnitus Holistic Simplified Classification, 35–36
Tinnitus matching (TM), 36, 58, 135, 268
Tinnitus Primary Functions Questionnaire, 93, **94**
Tinnitus Questionnaire (TQ), 48, **94**, 108
Tinnitus Reaction Questionnaire (TRQ), **94**, 107, 111, 186, 374
Tinnitus Research Initiative website, 88
Tinnitus Research Screening Questionnaire (ESIT-SQ), 88
Tinnitus retraining therapy (TRT), 81, 135, 348, 356
Tinnitus Sample Case History Questionnaire, 88, 186
Tinnitus Severity Index (TSI), **94**, 108, 186, 263, 268
Tinnitus Tester, 137
Tinnitus Therapy Lite app, 173
Tinnitus Today publication, 214
Tinnitus Tunes, 170
Tones, 11, 118, 128, 136, 150, 230, 233, 348
Tonic stimulation, 226, 231–232
Tonotopic maps models, 181, 222
Tonotopic organization, 10
Topiramate, 298, 364
Tourette's syndrome, 296
Track Your Tinnitus app, 135, 138, 139
Traditional Chinese medicine (TCM), 247, 263–265
Traditional Indian medicine, 266
Traditional Japanese medicine, 266
Traditional Korean medicine (TKM), 265
Tramadol, 51
Transcranial alternating current stimulation (tACS), **224**, 227–228
Transcranial direct current stimulation (tDCS), 185, **224**, 226–227, 234
Transcranial magnetic stimulation (TMS), 8, 13, 223, **224**, 226
Transcranial random noise stimulation (tRNS), **225**, 228
Transcutaneous electrical nerve stimulation (TENS), **225**, 229–230
Transcutaneous vagus nerve stimulation (tVNS), **225**, 230
Transient evoked otoacoustic emissions (TEOAE), 116, 382
Tremors, 232
Trigeminal nerves, 11
Turkey, patients in
  audiological symptoms in individuals, **327**
  hyperacusis in, 291
  otolaryngological side effects in, 56
Twin studies, 28
Twitter, 314, 315, 316, 318, **319**, 321, 322
Two-alternative forced choice (2AFC) approaches, 127

Tympanometry, 111, **112**, 114, 115, 120, 354, 368, 382
Type A tympanogram, 42, 342–343

U

Uncariae uncis cum ramlus (herbal medication), 266
Uncomfortable loudness levels (ULLs), 150, 289, 296, 297–298
  criterion for hyperacusis, 295
  ULLmin, 291
United Kingdom, impact of restrictions in, 330
United Nations Global Arts Initiative, 79
Unix-based Raspberry Pi (RPi) single-board computer, 75
Urban noise, 71–73
U.S. Pharmacopeia (USP), 248

V

VA Video Connect (VVC), 212
Vagus nerve stimulation (VNS), 230, **231**, 233. *See also* Transcutaneous vagus nerve stimulation (tVNS)
Vagus nerves, 10, 11, 13, **225**
Vall66Met polymorphism, 234
Values-led care in tinnitus, 275–284
  background, 275–276
  clinical implications, 283–284
  future directions, 283
  introduction, 275
  recent advances, 276–280, 282–283
Vascular compression of CN VIII and tinnitus, **363**
Vasoregulator, ginko as, 264
Vegetables, 51
Venous hum and tinnitus, **363**
Verapamil, 298, 364
Vertigo after COVID-19, 329
Vestibular evoked myogenic potentials (VEMP), 368
Vestibular rehabilitation therapy (VRT), 368
Vestibular schwannoma, 103
Veterans with tinnitus, 56
Video-nystagmography (VNG) testing, 368
Video otoscopy, 111, **112**
Virtual reality (VR) paradigm, 320
Visual analog scale (VAS), 48, 135–136, 186
  acupuncture and, 263
  for assessment of reaction to tinnitus, 137–138
  for ecological momentary assessment of tinnitus, 138–139
  for hyperacusis, 138
  scores, 50, 265
  for stress, 137–138
  for tinnitus severity, 266
Visual cortex, **152**, 153
Visual cues, 329, 349
Vitamins, 249
  adverse reactions to, 254
  advertised for tinnitus relief, 252–253
  vitamin B_2, 51, 364
  vitamin B_3, 252–253
  vitamin B_{12}, 51, **54**, 251, 252
Vlog-style videos, 317
Voxel-based morphometry (VBM), 151
VR-sound therapy, 320

W

Waist circumference, 43, 46
Weber test, 382
Websites, 107, 163, 170, 172, 214, 317, 318, 320, 347
  advertising essential oils, 253
  British Tinnitus Association (BTA), 163
  government healthcare, 162
  National Health Service Choices website, 163
  self-help, **162**
  Tinnitus Research Initiative, 88
White (broadband) noise, 11, **114**, 127, 169–170, 173, 231, 232, 355, 356
White matter (WM), 151, 154, 266
White Noise Free app, 173
Wholemeal/wholegrain bread, 51
Wide-Noise, 72
Widex Zen program, 347–349
Wireless headphones, 170
Wnt signaling pathways, 236
Woebot app, 173
Women. *See* Females
Word recognition
  in hearing assessment, **113**
  in quiet, 122
  testing, 359

Word recognition score (WRS), 353–354
  asymmetry in, 103
  tests, 382
Work-related illness, 11
Wysa app, 173

Y

Yoga, 266, **332**
Yoku-kan-san, 266
Young adults
  bothersome tinnitus in, 330
  prevalence of tinnitus in, 42
YouTube, 314, 315, 316–317, 318, **319**, 320, 321

Z

Zen therapy, 185
Zinc in tinnitus supplement, 58, 251–252, 264